Reimagining Ride Sharing: Efficient, Equitable, Sustainable Public Microtransit

Eleni Bardaka, Leila Hajibabai, Munindar P. Singh
North Carolina State University

Abstract
This article approaches ride sharing from the perspectives of equity and sustainability. A lack of transportation access exacerbates the challenges faced by transportation-disadvantaged individuals and communities, reducing opportunities for employment and civic engagement. This article presents a vision for public microtransit geared toward addressing today's disparities in transportation access. Through a methodology focused on user requirements and values, a user experience promoting cooperation, and an equity-based optimal resource allocation, it shows how cooperative ride sharing can realize an efficient, equitable, and sustainable public microtransit system.

Introduction

Internet Ethics concerns the ethical ramifications of Internet applications. Whereas a lot of the work on machine learning or algorithm ethics concerns the outputs of a computational mechanism, when we think of applications, we can incorporate the entirety of the sociotechnical system in which the application is deployed.

This article concerns an Internet application focused on a transportation problem with the objective of achieving equity in the provision of transit services to diverse communities. In suburban and rural communities across the US, public transportation services, if they exist at all, are sparse, infrequent, and inefficient[1]. This service profile disproportionately affects those disadvantaged due to socioeconomic status, age, and physical or mental disability. A lack of adequate transportation forecloses access to opportunities and critical destinations.

Microtransit is a shared demand-responsive transit model that provides flexible routes and on-demand scheduling[2]. Publicly owned microtransit has emerged as a promising solution for connecting suburban and rural populations to employment and important services, directly or through first-mile and last-mile connections to fixed-route transit. Private companies such as Uber and Lyft, which offer similar services, are inherently drawn to concentrate on densely populated areas, where revenue is higher. Consequently, they have been attracting trips from more sustainable transport modes and dramatically increasing vehicle-miles traveled[2].

Public microtransit has seen limited application in the US. Assessment of the few US pilots has shown that a lack of understanding of community needs and inadequate local engagement hinders their success. The objective of equity suggests that public microtransit services be first made available to transportation-disadvantaged populations. However, existing equity planning studies on microtransit have been limited to low-cost rides and support for technologically challenged groups.

Routing and scheduling algorithms and technologies typically disregard user restrictions and special needs, while current approaches to sharing do not engender user flexibility except through pricing[3]. Crucially, equity has been omitted from ex-post evaluations of user and trip empirical data[4].

Accordingly, we describe a new approach to enable *equitable access to* and *equitable use of* microtransit services that places user-adaptivity at the heart of a public microtransit system. Here, *access* means the system is available and visible to transportation-disadvantaged populations and *use* means the system prioritizes transportation-disadvantaged users and critical trips. Specifically, first, this approach is based on an understanding of a transportation-disadvantaged population's needs and barriers to adoption. Second, it incorporates cooperative ride sharing in which prosocial decision-making by users can improve system-wide outcomes, especially efficiency (reducing wait times for service), equity (ensuring improved access and service for vulnerable groups), and sustainability (reducing vehicle-miles and energy consumption, and leveraging the existing transit infrastructure such as buses). Third, it moves away from traditional pricing incentives, which may be inequitable when some users are economically disadvantaged and applies persuasion principles to promote prosocial behavior in cooperative ride sharing.

Scenario

To understand the depth of the problems faced by transportation disadvantaged populations, consider the rural parts of Orange County, NC, located on the west of the North Carolina Triangle Region. The Triangle Region has a total population of 2.2 million. Housing in the Triangle's major employment centers (Chapel Hill, Durham, and Raleigh) has become unaffordable due to high demand, gentrification, and redevelopment around the three Tier 1 universities located there. Orange County is 87% rural; about two-thirds of its employed low-income residents work outside of the county[5].

Fixed-route bus service provides limited connectivity within Orange County but connections to nearby job centers remain almost nonexistent. Not being able to work or paying a high overhead in time has downstream effects on income, time spent with children, civic engagement, participation in voting, and so on, which pushes transportation-disadvantaged communities further down. It is perhaps surprising how the decentralization of poverty, the mismatch between the location of affordable housing and pertinent job opportunities, and transportation inequity arise so close to a major technology center. The situation in other parts of the world is no less dire.

How can Internet Computing help better serve low-income and vulnerable populations? County administration has purchased five minivans to launch a microtransit pilot in collaboration with Ford Mobility-Transloc. Such resources are valuable but how can we use them efficiently and equitably to achieve the greatest welfare for the community they serve?

Challenges and Approach

An effective approach to realizing efficient, equitable, and sustainable public microtransit must take four main concerns into account, as shown schematically in Figure 1 below.

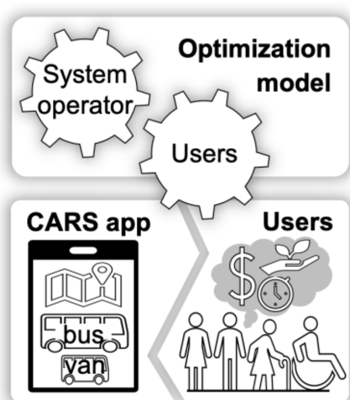

Figure 1. A schematic of the proposed user-adaptive ride sharing approach.

First, we must understand users, their requirements, and their values. Second, we must provide a user experience that provides transparency into and builds trust in the microtransit system and simultaneously guides the users toward prosocial, i.e., cooperative, attitudes such that they elect to accommodate each other, thereby improving the three system outcomes of efficiency, equity, and sustainability. The user experience is reflected in the CARS app. Third, we must develop a microtransit optimization model that allocates resources (here, rides) in accordance with those requirements and values. Fourth, in addition to the above operational concerns, to enable continual improvement and keeping with user needs, there is a need for monitoring and assessment of outcomes to determine how well the components and the entirety of the microtransit system perform. We think of these as circumscribing the operational concerns.

Understanding users and their needs

The first step is to identify and prioritize transportation-disadvantaged groups. Engage with the users and representative civic organizations to identify important destinations (e.g., employment locations, medical facilities, and grocery stores). Perform spatial cluster[6] and accessibility[7] analysis of spatial data from the Census (e.g., American community survey, longitudinal employer-household dynamics) and fixed-route transit feeds to create descriptive typologies and identify (i) transportation-disadvantaged neighborhoods, e.g., based on poverty rate, race, underrepresented ethnicities, single-parent status, linguistic isolation, vehicle ownership, and senior status by age[1]; (ii) underserved areas with a high proportion of transportation-disadvantaged groups; and (iii) origin-destination pairs inadequately connected by public transportation. It is also important to identify (i) *critical* destinations, such as employment and health care facilities; (ii) criteria for selecting and prioritizing users such as age and income; and (iii) mechanisms to identify transportation-disadvantaged individuals for service prioritization.

Equity-driven, adaptive, prosocial user experience

To explain the desired user experience, we envision a new app, named *Cooperative Adaptive Ride Sharing or CARS*. Figure 2 shows one of the screens of CARS as seen by a user, Redd, who is making a ride request (shown in dark red). Redd has panned the map to show the region of interest and is requesting a ride from her home (red dotted ellipse) to the bottom right (red solid ellipse). These ellipses capture a user's flexibility: the larger the region the more flexible the user is in terms of pickup and dropoff.

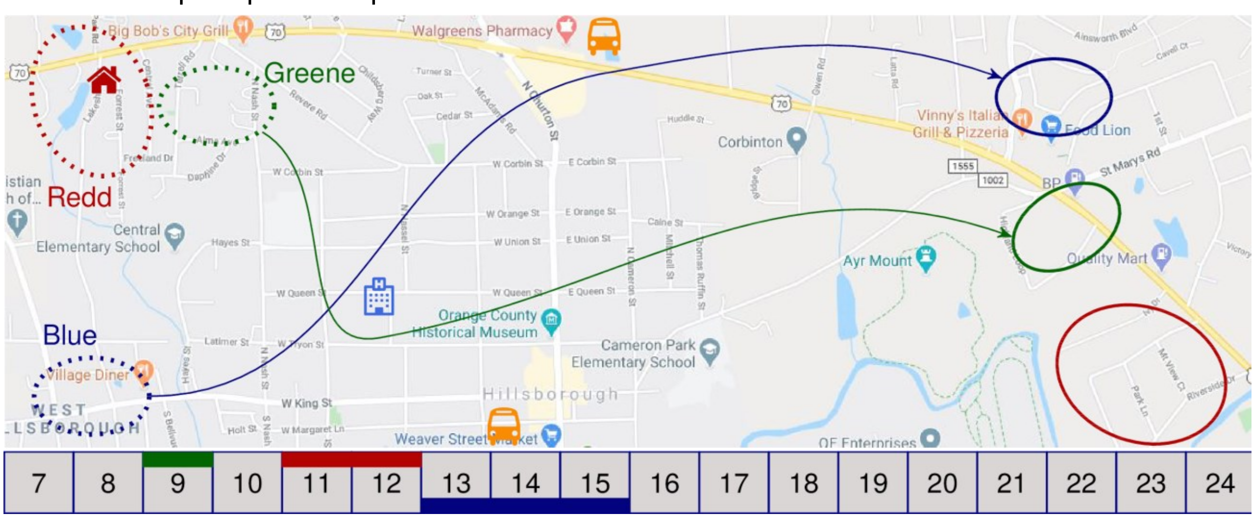

Figure 2 An illustration of the CARS app demonstrating transparency to users and encouraging prosocial requests.

The app shows two other rides (by users Blue and Greene, respectively). These rides are determined to be relevant to Redd since they pass close enough to Redd's origin or destination and are within a couple of hours of Redd's request. The sizes of the ellipses for Blue and Greene are set mainly as a privacy guard, so that Redd cannot see another user's pickup and dropoff addresses but only the surrounding regions. The lines indicate the trajectories produced by the route optimizer. Blue's trajectory passes close to a bus station and Greene's to the county clinic.

CARS is designed for equitable service to transportation-disadvantaged individuals and neighborhoods. For instance, the optimizer will choose routes that pass through critical destinations or transportation-disadvantaged neighborhoods provided doing so doesn't hurt objectives such as delay or cost excessively. Such routes would improve access to microtransit in an equitable manner. CARS would not only present such routes but would explain their selection to boost user confidence and cooperative spirit.

The bottom of the screen shows times as hours. A user can request a ride for anytime during a specified interval: the longer the interval the more flexible the request. Here, we see that Redd is considering requesting a ride for 11AM or 12PM, whereas Greene and Blue already placed their requests for 8AM and 1-3PM, respectively.

Since system efficiency improves if rides can be combined, CARS encourages cooperation between users to combine their rides if feasible. We assume users are motivated to share rides for improving sustainability, efficiency (timeliness), equity, or social interaction. The CARS app enables riders to disclose personal information, such as their transportation-disadvantaged status, purpose for a ride, and timing constraints. For example, Redd could be headed to visit a friend in a hospice and Greene may be a transportation-disadvantaged user going to work. When users learn such information, they would concede to each other in terms of the timings of their requested rides and how far from their ideal location they can accept a pickup or dropoff. For example, Redd may decide to switch her visit to earlier and share her ride with Greene, since it is not feasible for Greene to change his work schedule.

The efficacy of the CARS app rests on users not only participating in it but cooperating with each other to improve system outcomes. Prosocial behavior, whereby individuals use actions involving sharing or donating resources to promote the well-being of others[8], can be promoted through empathy-building messaging strategies. Some principles established in the study of persuasion[9] can be naturally adapted to this end. Specifically, we include social proof (following an established practice in one's peer group), homophily (doing what others similar to oneself do), commitment (contributing as one committed to), and reciprocity (returning a favor and rewarding those who are good). For instance, a user may be willing to change her pickup time to later in the day to accommodate a critical trip by another user and might be more receptive to doing so if the CARS app indicates that the other user had previously accommodated other people in similar situations.

Equity-driven optimization

The CARS app is undergirded by an optimizer that produces appropriate ride routes and based on the requirements of (i) the system operator, e.g., the Orange County administration and (ii) individual users.

A bi-level mathematical optimization program[10] is promising. The upper-level problem concerns resource allocation for vehicle routing that aims to minimize the operator costs and maximize its revenue subject to a set of operational and feasibility constraints and user-specific criteria. These costs include capital investments, e.g., purchasing minivans, and operational costs, e.g., on fuel. The revenue comprises passenger-mile rates over time with incentives for serving rides based on their priorities for transportation-disadvantaged status and trip criticality. Clearly, market pricing, much less surge pricing, are inapplicable here since the purpose is to improve equity despite socioeconomic status. Riders would be highly subsidized and may be allowed a fixed number of rides per month. Charges can be based on transportation-disadvantaged status and trip criticality. The optimizer is pushed toward providing access to transportation-disadvantaged neighborhoods and critical destinations by setting the upper-level objective function accordingly.

The lower-level model minimizes users' costs including travel time, service cost, wait time to get served, and walking distance to and from a ride. An adaptive dynamic programming representation[11] captures system dynamics over time periods at which the decisions of the operator and users are made.

The bi-level formulation represents a game-theoretic model where the operator plays the leader and users are the followers while each seeks to maximize its own benefits. A solution is the equilibrium condition in the bi-level optimization program that satisfies the objectives of both levels. The proposed bi-level model can be reformulated as an equivalent single-level program using Karush-Kuhn-Tucker conditions with the lower-level user-specific objective function as complementary equations[10].

If the user criteria are over-constrained, the optimizer would find solutions that may not be efficient or sustainable. However, if users are flexible, the optimizer can produce multiple acceptable options. For instance, if a wider origin and destination region is chosen by a user, the optimizer can find options that connect the vehicle to an existing transit route, such as a bus, yielding improvements in efficiency and sustainability. When some users are necessarily constrained (such as being wheelchair-bound), if other users are flexible, the outcomes can be acceptable overall.

Ex-post analysis

To continually improve the microtransit system, the CARS app will collect data on requests (timestamp, seats requested, wheelchair accessibility, pickup and dropoff times and locations); trips (estimates of pickup and dropoff time provided to users, actual pickup and dropoff timestamp, pickup and dropoff locations, number of passengers in the vehicle during the trip, user's age, and trip route); microtransit vehicles (vehicle speed, location, routes, and number of passengers on board); and user experience (user satisfaction, trust in other users, and perceptions of system transparency and equity).

Efficiency and sustainability are estimated from aggregate measures[12] including total number of passengers and probability density distributions of journey distance, duration, waiting time, number of passengers in the vehicle. Equity is analyzed based on spatiotemporal measures such as distribution of trip requests, waiting time, delayed arrivals to see how the service is used and experienced across different geographies and neighborhoods. Vertical equity[13] quantifies the distribution of impacts between users of different social groups (e.g., % trips by low-income users), not apparent from the spatiotemporal measures. Analyzing vertical equity requires linking user survey records with trip data. Geographically weighted regression models[14] is a promising approach to understand the spatial heterogeneity of socioeconomic determinants of microtransit demand from a neighborhood.

Conclusions

It's difficult in general to produce successful sociotechnical systems that accommodate not only efficiency but also equity and sustainability. Economics-centered approaches, for example, can achieve efficiency but at the cost of equity. This article motivates an equity-centered, cooperative, and adaptive approach to sociotechnical systems based on the new paradigm of promoting prosocial behavior among users and system transparency as a basis for optimizing resource allocation. By reimagining familiar ideas of ride sharing as a public resource to be shared in this way, it argues how we can achieve efficient, equitable, and sustainable microtransit.

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Eleni Bardaka is an Assistant Professor in Civil, Construction, and Environmental Engineering at NC State University, Raleigh, NC, USA. She received a Ph.D. degree in Civil Engineering and an MS degree in Economics from Purdue University. Her research focuses on topics of transportation equity including transportation accessibility and impacts of transportation investments on neighborhoods and businesses. She is the high-volume review coordinator of the Community Resources and Impacts committee of the Transportation Research Board. Contact her at ebardak@ncsu.edu

Leila Hajibabai is an Assistant Professor in Industrial and Systems Engineering at NC State University, Raleigh, NC, USA. She received a Ph.D. degree in Civil Engineering from The University of Illinois at Urbana-Champaign, IL, USA. Her research interests include operations research, systems analytics and optimization, and supply chain logistics. She is a member of INFORMS and is active in the Transportation Network Modeling committee of the Transportation Research Board and Transportation Science and Logistics group of INFORMS. Contact her at lhajiba@ncsu.edu.

Munindar P. Singh is currently a Professor in Computer Science and a Co-Director of the Science of Security Lablet at NC State University, Raleigh, NC, USA. He received a Ph.D. degree in computer sciences from The University of Texas at Austin, Austin, TX, USA. His research interests include the engineering and governance of sociotechnical systems, and AI ethics. He is an IEEE Fellow, a AAAI Fellow, and a former Editor-in-Chief of IEEE Internet Computing and ACM Transactions on Internet Technology. Contact him at m.singh@ieee.org.