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Pricing for a Last-Mile Transportation System

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ABSTRACT

The Last-Mile Problem refers to the provision of travel service from the nearest public transportation node to a home or other destination. Last-Mile Transportation System (LMTS), which has recently emerged, provide on-demand shared transportation. We consider an LMTS with multiple passenger types—adults, senior citizens, children, and students. The LMTS designer determines the price for the passengers, last-mile service vehicle capacity, and service fleet size (number of vehicles) for each last-mile region to maximize the social welfare generated by the LMTS. The level of last-mile service (in terms of passenger waiting time) is approximated by using a batch arrival, batch service, multi-server queueing model. The LMTS designer's optimal decisions and optimal social welfare are obtained by solving a constrained nonlinear optimization problem. Our model is implemented in numerical experiments by using real data from Singapore. We show the optimal annual social welfare gained is large. We also analyze a counterpart LMTS in which the LMTS designer sets an identical price for all passenger types. We find that in the absence of price discounts for special groups of passengers, social welfare undergoes almost no change, but the consumer surplus of passengers in special groups suffers significantly.

1. Background and literature survey

The Last-Mile Problem (LMP)—that is, the design and provision of travel service from a public transportation node to a passenger's final destination—has attracted growing attention in recent years, for several reasons. First, the lack of last-mile service is the main deterrent to use of public transportation services. At the same time, with population rapidly increasing in many cities, how to motivate people to use public transport, and in turn reduce road congestion and air pollution, is challenging. Second, the impaired mobility of certain demographic groups, such as senior citizens, children and students traveling alone with safety concerns, and people with physical disabilities, increases demand for last-mile service and may even be required by law if they use a public transportation mode.[1] Third, with more business models and services arising from the sharing economy, last-mile service, which offers on-demand transportation that utilizes a shared resource (i.e., a shared vehicle fleet), serves as an important testbed and breaks ground for generic on-demand shared services.

A specific last-mile region in a *Last-Mile Transportation System* (LMTS) is illustrated schematically in Fig. 1. LMTS serves a public transportation node, such as a rapid transit metro station at which trains discharge passengers. Passengers' final destinations (homes, workplaces, public institutions, etc.) are spatially distributed in the urban area served by the node, and

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[1] In Singapore, many people in these groups prefer a public transportation mode because it is much cheaper than personalized travel services. One key reason they sometimes cannot take public transportation (and must therefore rely on personalized travel services) is the lack of an LMTS.

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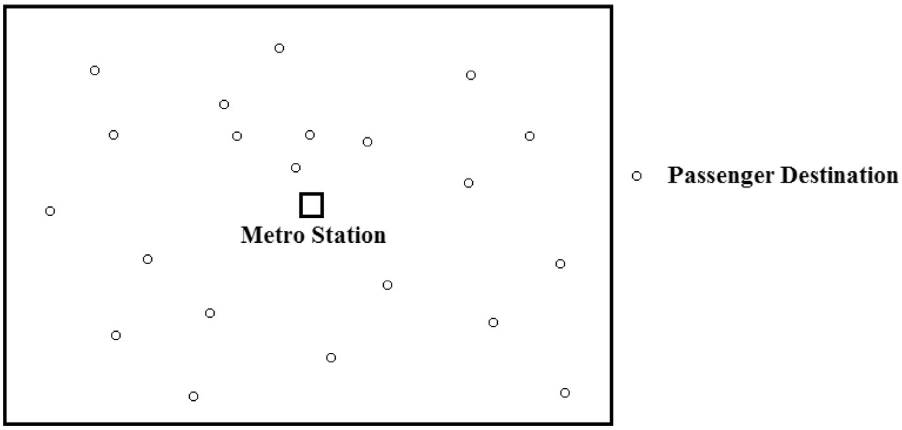

Fig. 1. Schematic of a last-mile region around a metro station.

a fleet of vehicles is available to transport each passenger to her final destination. The routes and schedules of LMTS vehicles are flexible, and can adjust to specific last-mile service requests.

Any passenger needing last-mile service is required to provide advance notice to the LMTS of her impending arrival at the alighting station and her specific final destination. Once this information is received, the LMTS assigns her to one of the vehicles in the LMTS fleet, plans the vehicle's route so that it includes a stop at her destination, estimates the vehicle's departure time, and notifies her accordingly. Once all of the passengers assigned to a vehicle are on board, the vehicle executes a delivery route with stops at each passenger's destination and returns to the station to pick up passengers for its next delivery tour. Detailed LMTS settings for the area around the last-mile region of one metro station can be found in Wang and Odoni (2014).

Many papers address various models and case studies of the LMP and LMTS. With the high penetration of services such as Uber worldwide, most people are aware of the benefits of on-demand transportation services and request even more specialized forms, including last-mile service. Several case studies analyze LMTS in different contexts, including Liu et al. (2012) study of a bicycle-sharing program for an LMTS in Beijing. Many studies have also examined the design and operation of an LMTS. Wang and Odoni (2014) address the planning side by focusing on LMTS from a stochastic and planning perspective and provide closed-form approximations for the performance of an LMTS as a function of the system's fundamental design parameters. Addressing the operational side, Wang (2017) focuses on LMTS from an operational perspective and provides efficient strategies for passenger assignment, vehicle routing and scheduling based on a set of last-mile demand information. Personal rapid transit (PRT), which refers to a variety of transportation systems with characteristics that are similar, in some ways, to LMTS, has also attracted significant attention in recent years, such as Anderson (1998), Bly and Teychenne (2005), Lees-Miller et al. (2009), Berger et al. (2011), and Mueller and Sgouridis (2011).

The pricing problem of urban transportation systems has been studied in diverse contexts. The relevant literature mainly focuses on dynamic pricing and congestion pricing in transportation network. The most influential papers in this area include Yang & Bell (1997), Yang & Huang (1998, 2005), Yang & Meng (2000), Lindsney & Verhoef (2001), Mookherjee & Friesz (2008), Lu et al. (2008), Lou et al. (2010), de Palma & Lindsey (2011), Wu et al. (2011), Lawphongpanich & Yin (2012), Do Chung et al. (2012), and Wang et al. (2016). None of these papers addresses LMTS pricing, which is the subject of this paper.

We study LMTS pricing with multi-type passengers—adults, senior citizens, children, and students. Given each type's last-mile service demand in each last-mile region, the geometric route configuration, discounts for specific passenger types, and the vehicle operating cost, we solve a constrained nonlinear optimization problem to determine the price for the passengers, the vehicle capacity, and the service fleet size (number of vehicles) in each last-mile region to maximize the social welfare generated by LMTS.

The main body of the paper is organized as follows: In Section 2, we propose a constrained nonlinear optimization model for LMTS pricing. Section 3 implements the model in a set of numerical experiments by using real data from Singapore; we also discuss our results and insights. Section 4 contains summary and concluding remarks.

2. Model

We now present the main model for the LMTS pricing. We first introduce the settings and notation in Section 2.1. We then describe two important measures—passenger waiting time and passenger utility—in Section 2.2 and Section 2.3, respectively. We propose the LMTS designer's problem—a constrained nonlinear optimization model in Section 2.4, and finally discuss how to solve it in Section 2.5.