A general traffic equilibrium framework with ride-hailing services that considers flow-dependent waiting time and public transit

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Project Objective

The objective of this research is to capture the deadheading miles incurred by the emerging ride-hailing services such as Uber and Lyft and quantify the corresponding waiting cost of customers accurately in order to better assist transportation planners in understanding the impact of these emerging transportation services on congestion and mobility.

Problem Statement

In spite of the proliferation of ride-hailing services, recent evidence shows that their expansion deteriorates traffic conditions in some major cities, e.g., the growth of ride-hailing contributed to the 47% increase in vehicle miles traveled (VMT) in San Francisco from 2010 to 2016. One important reason that ride-hailing may cause more traffic congestion is that drivers need to pick up customers, which leads to deadhead miles (i.e., empty miles). Empirical studies show that the deadheading miles could significantly contribute to the overall VMT in a city. Large deadhead miles could cause long waiting for customers, as shown by recent evidence in metropolitan areas such as Los Angeles, Boston, and Washington DC.

An important feature of the waiting costs in the ride-hailing market is that they change with the flow of drivers and choice of customers, due to various reasons such as change of supply and demand or different traffic conditions. In turn, the waiting cost influences the decision of customers. If the waiting cost is too large, a customer may cancel the trip or stick with traditional transportation modes such as solo driving or public transit. As an alternative mode choice, ride-hailing makes the behavior of travelers much more complicated to estimate due to its interactions with the supply of drivers and the corresponding waiting.

With the significance of the deadheading miles and customer waiting caused by ride-hailing services, it is important for transportation planners to capture the deadheading miles and quantify the corresponding waiting cost of customers to estimate the impact of these services on total system VMT.

Research Methodology

In this research project, we develop a general traffic equilibrium framework with ride-hailing services and customer waiting, which includes three interacting modules:

(1) Transportation Netwok Company (TNC) choice module: each TNC decides the dispatching flow of ride-hailing vehicles to maximize its own profit;

(2) Traveler choice module: each traveler decides the mode (ride-hailing, solo driving, or public transit) that minimizes the travel cost;

(3) Customer waiting module: the dynamics of ride-hailing customers' waiting cost in terms of ride-hailing vehicles' dispatching flows and travelers' choice flows.

The TNC choice module and the traveler choice module together form a generalized Nash equilibrium, coupled with a customer waiting module formulated as a queueing system. We show there exists a solution for the proposed general traffic equilibrium framework with ride-hailing services and customer waiting.

Results

Our proposed model is validated using the well-studied Sioux-Falls network. The method of Ban et al. (2019) and a linear waiting cost function are used to compare with our model. The main results are summarized in Table 1. As we can observe from the table, the numerical results show that without modeling the waiting cost explicitly, Ban et al. (2019) underestimates the waiting cost, and as a result, overestimates the mode share of ride-hailing travelers and VMT in the system. For example, Ban et al. (2019) overestimates VMT by 63.8% compared with our model. Similarly, if we use a linear waiting cost function, it will underestimate the waiting cost by 29.9% compared with our method. Consequently, a linear waiting cost function would output 50% more mode share of ride-hailing travelers and overestimate the VMT by 40.7%. With our proposed general modeling framework, transportation planners can better understand ride-hailing customers' waiting costs and deadheading miles induced by ride-hailing vehicles. This could help policymakers develop appropriate incentives that capture the features of ride-hailing services to reduce congestion in the transportation system.

Table 1. Comparison between the different models in the Sioux-Falls network.

	VMT	Deadheading Miles	Avg. Waiting Cost	% of Ride-hailing
Ban et al. (2019)	54000	25200	65	100%
Linear Waiting Cost	46390	17590	573	65%
Our Model	32963	4163	817	15%