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Modeling taxi driver anticipatory behavior

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ABSTRACT

As part of a wider behavioral agent-based model that simulates taxi drivers' dynamic passenger-finding behavior under uncertainty, we present a model of strategic behavior of taxi drivers in anticipation of substantial time varying demand at locations such as airports and major train stations. The model assumes that, considering a particular decision horizon, a taxi driver decides to transfer to such a destination based on a reward function. The dynamic uncertainty of demand is captured by a time dependent pick-up probability, which is a cumulative distribution function of waiting time. The model allows for information learning by which taxi drivers update their beliefs from past experiences. A simulation on a real road network, applied to test the model, indicates that the formulated model dynamically improves passenger-finding strategies at the airport. Taxi drivers learn when to transfer to the airport in anticipation of the time-varying demand at the airport to minimize their waiting time.

1. Introduction

In many cities in the world, particularly in developing countries, taxis represent a substantial share of the volume of traffic. Consequently, successfully modeling taxi flows should be an integral part of any traffic forecasting model that is applied in such cities (e.g. Castro, Zhang, & Telecom, 2013; Ferreira, Poco, Vo, Freire, & Silva, 2013; Huang, Zhu, Li, Li, & Wu, 2010; Li et al., 2012; Liu, Andris, & Ratti, 2010; Ma, Zheng, & Wolfson, 2013; Tang et al., 2016). At the microscopic level, taxi drivers need to decide which strategy to follow in search of their next passenger: Should they cruise the city? Should they wait at a taxi stand? Which search pattern should they follow?

In this paper, we focus on a particular kind of strategy: going to locations, which have a high, but temporally strongly fluctuating, demand. Examples are airports and major train stations. Modeling this behavior is interesting because it has some challenging properties. The success of taxi drivers' behavior is highly sensitive to their anticipatory behavior. The high demand locations, such as airports, are usually located outside the city. Consequently, taking passengers from airports to the city tends to involve long distance taxi rides that bring in much revenue. Rides from the airport are therefore popular among taxi drivers. The attractiveness of these rides from the airport results in considerable competition, which in turn may lead to queues and waiting times when the number of taxis going to the airport exceeds the demand at that moment in time.

Thus, the strategic decision to go to the airport is a risky decision. It is not only risky due to the uncertain competition of other taxi drivers, but also because of specific demand conditions. Unless a driver can bring a passenger to the airport, the trip to the airport does not bring in any revenue. Moreover, because airports are popular among many taxi drivers, if a driver arrives too late at the airport the queue may already be quite long. Queues represent unproductive times. To make matters potentially worse, if the airport is a hub, incoming and outgoing airplanes come in waves. Consequently, there is the risk that a taxi driver needs to wait until the next wave of flights arrives.

To cope with this risk, taxi drivers need to develop effective anticipatory behavior. Anticipatory behavior refers to forward looking forward actions. Taxi drivers need to think in advance, foresee a future outcome, and take effective action prior to the future event (Butz, Sigaud, & Gerard, 2009). Specifically, they need to leave for the airport at the right time, such that their waiting time is kept to a minimum. Because the true demand at the airport is unknown, the adequacy of taxi drivers' anticipatory behavior depends on the accuracy of their subjective expectations or beliefs about the future demand and competition at the targeted destination. Different from searching along streets, which may involve a relatively high degree of randomness, the success of a taxi drivers' anticipatory behavior is based on the correctness of their beliefs about future demand and supply at the airport, which implies going to the airport at the right time such that the waiting time to pick up a passenger is minimal.

The problem how to model such behavior is academically challenging and practically relevant. The challenge is to formulate behavioral mechanisms that reflect pro-active, anticipatory behavior of taxi drivers that capture their adaptive behavior in case their current behavior has

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failed. If taxi drivers leave for the airport too early, they run the risk of facing unproductive, waiting times until the next wave of flights arrives. If they leave too late, many other taxi drivers may have arrived at the airport sooner, resulting in long queues. Practically, understanding taxi drivers decisions underlying observed taxi movement patterns may provide guidance for improved taxi supply services and taxi regulation policy. Anticipatory behavior is one of these decisions that needs investigation.

An examination of the literature on taxi movements indicates that this particular problem has not been addressed in the literature. Taxi movements have been mainly modeled according to two main approaches. The first approach assumes a taxi driver makes a single choice about a location zone. Each time, a taxi driver chooses a zone, and then stays at that zone until picking up a passenger. It defines destination choice behavior. A taxi can directly move to any targeted zone. Generally, no distinction is made between different types of zones. Zones are typically considered as destinations or choice alternatives, with certain attributes. The choice of a zone is based on the (dis)utility of the zone, for example, on the shortest travel time to that zone and the time staying at that zone to pick up a passenger (Yang & Wong, 1998). Several models followed the single choice assumption (Wong, Wong, & Yang, 2001; Wong, Wong, Yang, & Tong, 2003; Wong, Wong, Yang, & Wu, 2008; Yang, Wong, & Wong, 2002; Yang, Ye, Tang, & Wong, 2005a, 2005b) and included monetary costs and revenues into the utility function. Later, individual choice models such as the multinomial model have been used (Szeto, Wong, Wong, & Yang, 2013). The decision utility associated with choosing a zone is the time-dependent profit rate, which equals the expected profit (collected fare minus cost) divided by search time.

Although these models are interesting and relevant, from a behavioral perspective, they do not capture the notion that time costs are also opportunity costs in taxi driver passenger-finding behavior. As alternative locations have different travel times, it is problematic to compare them across different time horizons. It makes it even more difficult to compare different strategies, which probably have different time horizons, e.g. search and going to a destination.

The second approach assumes a taxi driver makes a series of sequential choices. A taxi driver chooses a series of locations, which defines search behavior. Under the assumption of the first approach, a driver can choose any location. It implies that a driver may choose a disjacent location. It violates the principle that search behavior continuously involves visiting adjacent locations. In contrast, the second approach defines search behavior by restricting drivers to visit adjacent locations only. For example, a Markov chain approach has been proposed to model this sequential search behavior (Wong, Wong, Bell, & Yang, 2005). A taxi is only allowed to move to an adjacent node. The decision of choosing a node is independent of previous decisions. A taxi driver chooses a series of nodes until meeting a passenger. The utility of choosing a node consists of pick-up probability and profitability. Ryan, Szeto, and Wong (2015) estimated a sequential logit model, which allowed a driver to decide on future actions. A driver makes a series of sequential decisions about the next zone to search customers, and the probability of choosing a final destination is the cumulative probability of the choice probabilities across all zones on a search route. Wong, Szeto, and Wong (2014) divided urban space into small spatial cells. A driver makes sequential decisions about which adjacent cell to choose in search of customers. The utility of a cell is the cumulative pick-up probability of the cell and the cumulative pick-up probabilities of the cells departing from that cell. Since the utility functions of zonal and local choices differ, to incorporate them into the framework, a two-stage model was proposed (Wong, Szeto, & Wong, 2015). The first stage is to choose district zones and the second stage is to choose a series of cells inside a district zone.

These models generally capture taxi behavior in terms of going to a zone and local search. However, anticipatory behavior is not explicitly modeled. Destinations such as airports differ from typical district zones. Passenger demand highly depends on real-time arrivals of flights. Therefore, the decision to go to such a destination cannot be simply modeled by replacing district zones by nodes in a choice set. Moreover, existing models do not have a mechanism that represents the looking forward (anticipatory) behavior of taxi drivers. In an uncertain environment, taxi drivers hold imperfect knowledge. They need to experience the outcome of their decisions and update their subjective beliefs about the passenger finding process. With an information updating mechanism, taxi drivers are able to react to dynamic environments.

With these considerations in mind, this article focuses on modeling taxi drivers' anticipatory behavior. We develop a model that simulates the behavior of taxi drivers in this context. Adequate models should satisfy at least two requirements. First, they should have a valid mechanism that captures taxi drivers anticipatory behavior to arrive on time at the airport. Second, they need a mechanism that captures how taxi drivers learn from their previous decisions and adjust their behavior to better cope with the uncertain demand and behavior of other taxi drivers. This model is part of a more comprehensive model system that also incorporates the other mentioned strategies such as searching for passengers along streets. In this article, we limit the discussion to anticipatory behavior related to high, strongly fluctuation demand locations and test the model focusing on the airport.

In the following sections, we will first present a decision making model under uncertainty and introduce a model of information updating. Then, to test the basic performance of the model, we develop a simulation and discuss its results. Finally, we draw conclusions.

2. The model

2.1. Notation

A road network is a realistic representation of taxis' movement environment. Assume a road network consisting of nodes and links $\mathbb{Z} = (\mathbb{N}, \mathbb{L}, \mathbf{X}^N, \mathbf{X}^L)$, where $\mathbb{N} = \{n \mid n \in \mathbb{N}\}$ is a finite set of nodes, $\mathbb{L} = \{l \mid l \in \mathbb{L}\}$ is the finite set of links. Two adjacent nodes are connected by a link. Passengers are assumed to get on and off at nodes. Taxis move along links, and pick up passengers at nodes of the network. A node covers a range of urban space. A driver's travel route/trip is denoted by r. A finite set of nodes $\mathbb{N}_r = \{n \mid n \in \mathbb{N}_r\}$ comprises trip r. Route r from origin node n to destination node $n'(n, n' \in \mathbb{N})$ involves a sequence of nodes $(n, n_1), (n_1, n_2), \ldots, (n_q, n_{q+1}), \ldots, (n_{N_r}, n')$ in which no node appears more than once. The number of nodes on trip r is denoted by N_r. A link l_q connects two adjacent nodes (n_q, n_{q+1}). A trip r comprises a set of links $\mathbb{L}_r = \{l \mid l \in \mathbb{L}_r\} = \{l_1, l_2, \ldots, l_{N_r-1}\}$. Note this is a general representation; airports are specific destination nodes (Fig. 1).

Urban-transportation systems are highly dynamic. A day consists of 24 h and therefore, potentially, taxi drivers base their decisions of the

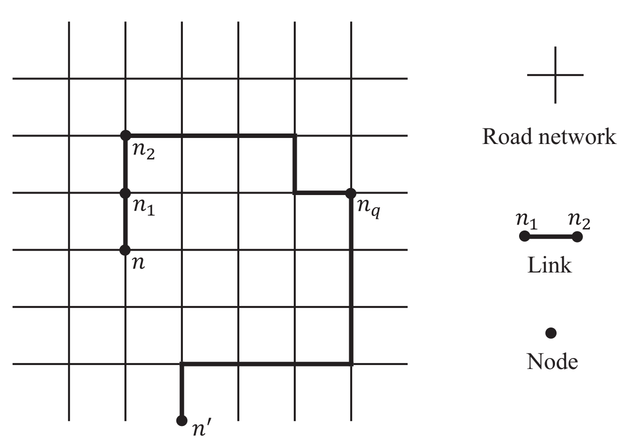

Fig. 1. Road network, link and node.