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Framework for automated taxi operation: The family model

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Abstract

Replacement of conventional taxis by automated vehicles will challenge taxi operation in many ways. Decisions made by taxi drivers will be substituted by an integrated scheduling system that also manages the non-revenue generating activities such as vehicle pre-allocation, recharging and service trips. In order to tackle this challenge, this study introduces a theoretical framework for autonomous vehicles based on the model of a family. The family model decomposes the complexity of scheduling for automated vehicle fleets. It allows vehicles to negotiate among them in a decentralized fashion and at the same time it allows the fleet manager to set fleet priorities and to pre-allocate vehicles in locations of expected future demand. Furthermore, it proposes a transparent framework for communication with service providers. Moreover, this study discusses selected opportunities and challenges of automated vehicle fleets.

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Keywords: Automated vehicles; Scheduling; Theoretical framework; Fleet management; Taxi

1. Introduction

Automated taxi vehicle fleets will reshape urban public transport systems. In the automated era, the scheduling responsibility of the driver will be replaced by algorithms, since the vehicles are driverless. In particular, removing

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taxi drivers and their decision making will trigger a comprehensive reconsideration of the whole taxi system and will lay the foundation for the future connected, data-rich and fully automated system.

The objective of this paper is to propose a theoretical framework for the fully autonomous fleet management. This study aims to consider not only replacing conventional taxis with autonomous vehicles but on creating new operation ecosystems. This paper also focuses on challenges and opportunities of autonomous fleet management. However, one definitive solution for the scheduling is not presented in this paper. This study specially considers high demand automated taxi systems in megacities, in which the demand for taxis as well as related services often exceed the supply.

2. Taxi operation in the literature

The ultimate question for taxi dispatching is which taxi should be allocated to which passenger booking request. The following paragraphs provide an overview of taxi dispatching research and taxi passenger-searching strategies and general fleet manager considerations.

2.1. Sequential and simultaneous dispatching of taxi to immediate bookings

Historically, most of the taxi dispatching research focused on the rule-based sequential assignment of taxis to immediate booking requests. According to the rule-based sequential assignment, booking requests are assigned as they come on the first-come, first-come principle to the nearest available taxi.

One of the first taxi dispatching studies by Bailey, Jr & Clark (1987) investigated efficiency of basic dispatch rules to assign booking requests either to: (1) closest free taxi, (2) closest occupied taxi or (3) the taxi which is vacant for the longest time. Later, they investigated whether after delivering a passenger to the destination, should the taxi: (1) return to a centralized base, (2) remain at the delivery location, or (3) relocate to another optimal location based on some relocation algorithm. (Bailey and Clark, 1992)

Subsequent research investigated details and incremental improvement potential of these rule-based dispatching strategies. For example, Lee et al. (2004) and Lee & Wu (2013) concluded that a time-based assignment is superior to a Euclidean distance assignment. Indeed, there are many situations in which the nearest vehicle is on the opposite side of the street, but cannot turn around or cross the street or is delayed at traffic lights.

Most recently Maciejewski and Bischoff (2015) studied various dispatching rules in under- supply and over-supply context in a realistic, large-scale and detailed simulation in Berlin and Barcelona. They concluded that it is beneficial to change dispatching strategies depending on the supply-demand ratio.

However, none of these incremental improvements were able to overcome a fundamental drawback of the sequential rule-based dispatching strategy, which is that once confirmed, booking request remain assigned to the same taxi. That may reduce taxi operation performance over time. As a result, taxi drivers' costs rise and passengers wait longer or may not get a taxi at all. In order to suppress the drawbacks of sequential assignment of taxis to booking requests, researchers suggested to slightly delay assignment of new booking requests in order to buffer them and assign them simultaneously (concurrently). Buffering increases the number of assignments possibilities and thereby chance of finding more optimal assignment.

Ngo (2004)studied simultaneous dispatching of taxis to immediate booking requests. He proposed a fuzzy linear framework to softly model the dispatching rules and their combinations (including taxi distance, utilization, time ratio and costs) and translate them to assignment of taxis to passengers.

Seow et al. (2010) proposed a taxi dispatch architecture to support concurrent assignments of immediate bookings using a decentralized agent group negotiation approach that attempts to minimize the total customer pickup time of taxis. In every dispatch cycle, taxi agents negotiate on behalf of real taxi on how to assigns new requests, which were buffered in the last dispatch cycle. Seow et al. (2010) allow the taxi drivers to accept or reject the new assignment. All pending requests rejected by the drivers are forwarded to the next dispatch cycle. Moreover, Seow et al. (2010) extended taxi availability to include soon-to-be-available taxis, in order to allow a larger pool of taxis to be matched.

Zhan et al. (2014) proposed a system for bipartite matching of trips to passengers in New York. They studied a system wide recommendation mechanism that matches taxis and immediate booking requests for the purpose of minimizing taxi costs, taxi fleet size or combination of both. Passenger bookings are first buffered and then centrally