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Transportation Systems with Autonomous Vehicles: models and algorithms for equilibrium assignment

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Abstract

Technologies for connected, automated or autonomous vehicles (AVs) are fast developing, so that they seem ready for substituting in the near future privately owned non-autonomous traditional vehicles (TVs) and further supporting the spread of shared vehicles both for person and good transportation. On the other hand, it may easily be anticipated that the time needed to turn the existing stock of TVs into AVs will last several years during which mixed traffic is expected. A change so great may be not technology-driven only, but also requires a carefully analysis of its several impact through well designed enhancements of tools already available to the transportation systems modelers and planners. Such enhanced tools may be casted in the general framework of multi-user class assignment to transportation networks, concerning: (i) transportation network analysis, through level-of-service models distinguishing between non-autonomous vs. autonomous vehicles, presumably sharing same infrastructure; (ii) travel demand analysis, through behavioral choice modeling paradigms, including choice between AVs vs. TVs, owned vs. shared, as well as route choice behavior; (iii) steady-state equilibrium assignment. This paper describes models and algorithms to deal with steady-state equilibrium assignment; they are used to show to which extent existing methods can still be applied as well as which issues remain still open and worth of further research efforts.

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Keywords: Autonomous vehicles, Transportation systems, Equilibrium assignment.

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1. Introduction

Technologies for connected, automated or autonomous vehicles (AVs) are fast developing, so that they seem ready for substituting in the near future privately owned non-autonomous traditional vehicles (TVs) and further supporting the spread of shared vehicles both for person and good transportation. On the other hand, it may easily be anticipated that the time needed to turn the existing stock of TVs into AVs will last several years during which mixed traffic is expected. A change so great may be not technology-driven only, but also requires a carefully analysis of its several impact through well designed enhancements of tools of Traffic and Transportation Theory (TTT) already available to the transportation systems modelers and planners.

TTT studies the interactions between the level of service provided by transportation systems and the results of several types of user choice behavior, which may regard in a hierarchical order:

- driving, concerning interactions between users travelling on the same facility and their effects on travel time, ... ;
- routing, concerning connections between origin and destination of the journey, possibly departing time, … ;
- travelling, concerning transportation mode, time-of-day, destination, frequency, … ;
- mobility, concerning car ownership, driving license acquisition, … .

On top of the above hierarchy there are the kinds of user behavior addressed by land-use/transport interaction theories.

Tools of the Traffic and Transportation Theory have reached a very advanced and sophisticated level, and large-scale applications are current practice (a wide presentation with commented references in Cascetta, 2009). Most of these tools are based on explicitly behavioral modeling approaches, which grant clear interpretation of parameters, and may be referred to two main classes:

- traffic analysis and control [traditionally called traffic engineering], these methods include modeling user driving behavior only;
- transportation systems analysis and design, these methods include modeling of routing user choice behavior, and possibly other choice dimensions as mentioned above.

[Methods based on so-called data-driven (also referred to as soft computing or machine learning, or …) approaches are mainly used for specific tasks, such short-term traffic forecasting, incident detection, … and will not be discussed in this paper.]

Main tools for transportation systems analysis (following a macroscopic approach) are based on methods for *travel demand assignment to a transportation network*, or just *assignment* for short, commonly used to support transportation project assessment and evaluation.

In the following we will discuss to which extent existing methods based can still be applied as such or with straightforward enhancements for the analysis transportation systems with AVs. For brevity's sake kinds of choice behavior others than routing and driving will be not be explicitly considered. Moreover we will assume steady state equilibrium conditions and will not discussed advanced methods aiming at dealing with within-day or day-to-day dynamics.

In this paper we will mainly focus on mathematical features of models and solution algorithms for steady-state equilibrium assignment. Main emphasis is on private road transportation systems for travelers.

The paper is structured as follows: section 2 discusses main assumptions, definitions, notations and equations for modeling a transportation system with AVs; section 3 presents fixed-point models and solution algorithms based on materials in section 2; some concluding remarks and research perspectives are discussed in section 4.