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Planning of truck platoons: A literature review and directions for future research

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ABSTRACT

A truck platoon is a set of virtually linked trucks that drive closely behind one another using automated driving technology. Benefits of truck platooning include cost savings, reduced emissions, and more efficient use of road capacity. To fully reap these benefits in the initial phases of technology deployment, careful planning of platoons based on trucks' itineraries and time schedules is required. This paper provides a framework to classify various new transportation planning problems that arise in truck platooning, surveys relevant operations research models for these problems in the literature and identifies directions for future research.

1. Introduction

Novel semi-automated driving technologies, collectively referred to as Cooperative Adaptive Cruise Control (CACC), enable trucks to drive very close together as a platoon. Trucks in a platoon are virtually linked and communicate with each other through wireless communication technology. The leading truck is manually driven at the first position of the platoon and automatically followed by one or more following trucks. This means that the following trucks automatically brake, steer and (de)accelerate based on the actions of the leading truck.

Truck platooning has been the subject of heightened interest recently because of the different benefits it provides, both for individual truck operators and society. Driving close together reduces fuel consumption as it improves the aerodynamics of all trucks in the platoon (Patten et al., 2012; Zabat et al., 1995). Test track experiments suggest savings of up to six percent for the leading truck and ten percent for the following trucks (Alam et al., 2015; Lammert et al., 2014).

While less fuel consumption leads to costs savings for the truck operators, it also reduces emissions (Scora and Barth, 2006). This is relevant as heavy-duty road transport is responsible for a large part of all traffic emissions (European Commission, 2016). Furthermore, platooning can enhance traffic safety by providing significantly lower reaction times and less room for human error within the platoon, which can reduce the number of rear-end collisions. Also, trucks in a platoon take up less road space than when driving separately, which may reduce traffic congestion (Schladover et al., 2015; Van Arem et al., 2006) and therefore, increases traffic throughput (Lioris et al., 2017).

Automated driving has been successfully deployed in closed environments in various logistics and freight transportation settings such as port terminals (Kim and Bae, 2004) and warehouses and factories (Azadeh et al., 2017; Roodbergen and Vis, 2009). Truck platooning can be considered as a first step towards automated freight transportation in an open and

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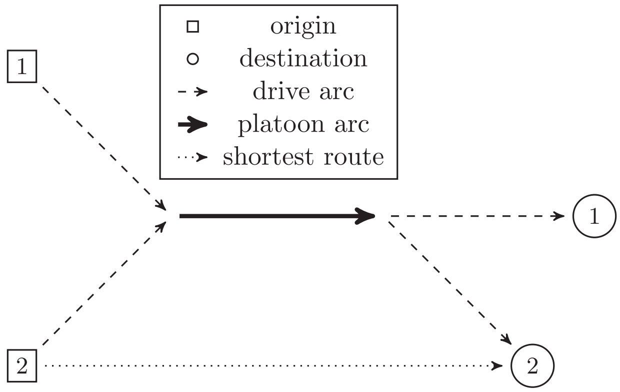

Fig. 1. A two-truck platoon.

uncontrolled environment. Given the development of automated driving technology, we expect that the following trucks in a platoon would not require drivers in the future (Kilcarr, 2016).

All major truck manufacturers have developed technologies that allow platooning, and several field tests are planned or are currently taking place in Europe (Eckhardt et al., 2016), the U.S. (Peloton Technology, 2016), Singapore (Ministry of Transport - Singapore, 2017), Japan (Tsugawa, 2014) and Australia (UNSW Engineering, 2016). The first road-legal trucks equipped with platooning technology are expected soon.

When a sufficient number of vehicles are capable of platooning, it is likely that platoons can be spontaneously formed without planning in advance. However, in the initial stages, when the deployment of platooning technology is not widespread or on routes with little freight traffic, careful centralized planning is required to create platoons (Janssen et al., 2015). A so-called platooning service provider (Roland Berger, 2016; Janssen et al., 2015) could bring together trucks from different fleets in a platoon. Platoons can be scheduled in advance or planned in real-time during execution.

To establish a platoon, the departure times, travel speeds and the routes of the trucks in the platoon must be synchronized. A truck may, for instance, adjust its route and possibly even make a small detour to join a platoon. Fig. 1 depicts an example of a platoon between two trucks in which one of the trucks makes a detour to form the platoon.

Complex planning problems may arise in creating platoons, especially when considering detours. To fully reap the benefits of truck platooning, now and in the future, sophisticated decision support models and tools are required. Such models are not only useful to support platooning operations but can also help quantify the potential benefits of different types of platooning. While there has been much attention for the technological issues (see Maiti et al., 2017 and Bergenhem et al., 2012 for an overview of recent projects), safe manoeuvring of platoons (see Kavathekar and Chen, 2011 for an overview), human factors (for example, Heikoop et al., 2017; Hjamdähl et al., 2017; Yamabe et al., 2012; Larburu et al., 2010), we are not aware of a paper that systematically reviews the challenges of platooning from a planning and transportation optimization perspective.

This paper aims to fill the above mentioned gap by classifying the different planning problems that arise in truck platooning, reviewing the emerging literature related to this planning, and identifying directions for future research. More specifically, the goal of this paper is fourfold: (1) provide a systematic overview of different forms of platooning; (2) identify and define relevant planning problems to support the different forms of platooning; (3) provide an overview of relevant operations research models and approaches for these problems in the literature and; (4) identify gaps and areas for future research.

This paper focuses on truck platooning but similar issues may arise in the planning of platoons of regular cars and other vehicles not only on the road but also on water (see Lauf, 2017; TU Delft 3mE, 2017) and in air (see Chen et al., 2015; Richert and Cortés, 2012).

The paper is structured as follows. Section 2 explains the main characteristics of platooning planning. In Section 3, we compare platooning with other collaborative transport systems such as ride-sharing and freight consolidation. Section 4 describes different platoon settings and related static planning problems from the literature. Section 5 discusses planning problems that arise when technology and legislation allow platoons with (partially) driverless trucks. Section 6 discusses the planning of platoons in real-time. Section 7 looks at vehicle routing with platooning. The effects of platooning on network design are discussed in Section 8. Finally, Section 9 identifies some future research opportunities and concludes the paper.

2. Characteristics of truck platoon planning

This section discusses several important characteristics of platoon planning. First, we discuss the planning process and the planning dynamics. Then, we present possible planning objectives and constraints. We conclude this section with a discussion on the issues related to dividing the benefits of platooning among the different participants.