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A conceptualization of vehicle platoons and platoon operations ☆

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ABSTRACT

Vehicle platooning, a coordinated movement strategy, has been proposed to address a range of current transport challenges such as traffic congestion, road safety, energy consumption and pollution. But in order to form platoons in an ad-hoc manner the vehicles have to 'speak the same language', which is in current practice limited to vehicles of particular manufacturers. There is no standard language yet. Also in research, while the current literature focuses on platoon control strategies, intra-platoon communication, or platooning impacts on traffic, the conceptualization of platooning objects and their operations remained unattended. This paper aims to fill this fundamental gap by developing a formal model of platooning concepts. The paper proposes an ontological model of platooning objects and properties and abstract basic building blocks of platoon operations that can then be aggregated to complex platooning behavior. The presented ontological model provides the logical reasoning to support vital decision-making during platoon lifecycles. The ontological model is implemented and demonstrated.

1. Introduction

With global urbanization, a continuous growth of travel demand is observed all over the world (Bayliss, 2008), both for people and freight. It results in more motor vehicles on the road, and vehicles traveling for longer distances. Global motor-vehicle sales have grown by nearly 3% a year for the past two decades (Gao et al., 2014). The impact on traffic is raising congestion, accidents, and air pollution (Deng, 2016). For example, as reported by the European Environment Agency (EU Commission, 2009), in 2006 transport accounted for 23.8% of total GHG emissions and 27.9% of total CO_2 emissions in EU-27. In order to reduce the carbon footprint and traffic congestion, and to enhance road safety, the concept of vehicle platooning has been proposed (Deng, 2016). Vehicle platooning refers to close and coordinated following mechanisms of vehicles without any mechanical linkage while maintaining a safe distance. Platooning has been primarily targeted for freight transportation of heavy duty vehicles (Nowakowski et al., 2015; Alam et al., 2010; Tsugawa et al., 2011), and planned to be extended further for public transportation.[1] Looking at the social, financial and ecological benefits, it is obvious that vehicle platooning will play a significant role in Intelligent Transportation Systems (ITS) in the near future.

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[1] Autonomous Coordinated Control of Public Transport Platoons, http://www.robotics.unsw.edu.au/r5/Autonomous-Coordinated-Control-of-Public-Transport-Platoons, accessed June, 2016.

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The concept of platooning has emerged since the 1970s and became popular in more recent ITS literature. This literature mainly focuses on platoon control strategies (Gehring and Fritz, 1997; Ploeg et al., 2014; Swaroop and Hedrick, 1999), on vehicle-to-vehicle communication within platoons (Bergenhem et al., 2012a; Fernandes and Nunes, 2010), and on the impact of platooning on fuel efficiency or traffic throughput (Alam et al., 2010; Deng, 2016). Correspondingly, different research projects, namely *PATH* (Nowakowski et al., 2015), *iQFleet* (Alam et al., 2010), *KONVOI*,[2] *CHAUFFEUR*,[3] *Energy ITS* (Tsugawa et al., 2011), *SARTRE*[4] and *COMPANION*[5] are investigating different platooning aspects, such as dynamic coordination, control strategies, human-machine interaction, realization and demonstration of platooning.

The literature had to address platooning objects and some platoon operations, but did so mostly in the context of control, communication or simulation. Thus, a gap is observed toward an agreed formalization of the platooning objects, the platoon properties, and the platoon operations. Only with an agreed formalization platoons of vehicles of various manufacturers can coordinate and deal with complex traffic scenarios. Throughout a platoon lifecycle, starting from platoon creation up to the platoon disintegration, the coordination requires from each platoon member to apply certain behavior in order to synchronize with other group members as well as to cope with the general traffic around. Each platoon maneuver needs to be executed in an a priori agreed manner, and yet depends on the individual platoon members' status and properties. Therefore, this paper sets out to identify and analyze a set of platoon operations, platoon properties and individual member properties, and the dependency of platoon operations based on predefined platoon rules. The objective of this work is to describe formally platooning objects, platoon properties and basic blocks of platoon operations in order to contribute an agreed understanding at a conceptual level.

Thus, the research challenges addressed are:

1. *Formalization of a platooning objects* – A formal approach to distinguish a platoon from other forms of coordinated autonomous driving behavior, such as car following (Brackstone and McDonald, 1999; Newell, 2002).
2. *Defining platoon properties* – Platoon properties are need to be classified in two different levels. The lower level defines properties of individual members whereas the higher level defines properties of a platoon as a whole. A platoon leader's decisions and the corresponding platoon operations depend on both higher and lower level property values. Since this research focuses on the operation, not the control mechanisms of platoons, only operation related properties are specified. Platoon control related properties are out of the scope of this paper.
3. *Identification and abstraction of platoon operations* – The basic blocks of platoon operations need to be identified that a platoon can handle any complex traffic behavior. In general, the identification of basic operational blocks can be done by analyzing different traffic scenarios that a platoon can experience, the interaction of platoon with the rest of the traffic, and the issues the other traffic can face caused by a platoon. While abstracting the platoon operations, the validation of rules, the information updating, and the information synchronization need to be taken care of. This research aims to identify and abstract the basic operation blocks which can define all other complex platoon behaviors referred in the literature. The complex platoon behaviors can be treated as derived operations or higher level operations. Point to note, this research avoids the communication level or control level detailing such as specification of communication protocol or acceleration-deceleration which can be implementation specific. Planning and optimization of the platoon operations are beyond the scope of this paper.

Addressing these challenges, the key contributions of this work are:

1. the conceptualization of platooning objects and platoon properties;
2. the identification and abstraction of platoon operations; and
3. a demonstration how objects, properties, and operations interact to enable any complex behavior.

The paper starts with the review of existing literature on the general concept of vehicle platooning, presented in Section 2. Section 3 introduces the formal representation of platooning objects and platoon operations, and Section 4 demonstrates the flow of a more complex operation in a given scenario. In order to demonstrate the completeness of the specifications, Section 5 maps these objects and operations to the platooning concepts mentioned in the literature. Section 6 concludes the paper.

2. Background

The term *platoon* originally appeared in the defense domain and was defined as a subdivision of a company of soldiers, usually forming a tactical unit that is commanded by a subaltern or lieutenant and divided into three sections.[6] In the transportation domain, platooning is used for similar semantical interpretation. Vehicle platooning refers to a closely following

[2] KONVOI, http://www.ika.rwth-aachen.de/en/research/projects/driver-assistance-vehicle-guidance/1636-konvoi.html, accessed February 2016.
[3] The Chauffeur II Project, http://www.itsforum.gr.jp/Public/E4Meetings/P01/fremont5_2_2.pdf, accessed March 2016.
[4] The SARTRE Project, http://www.sartre-project.eu/en/faq/how_it_works/Sidor/default.aspx, accessed February 2016.
[5] Companion, http://www.companion-project.eu, accessed January 2016.
[6] Oxford Dictionary, http://www.oxforddictionaries.com/definition/english/platoon, accessed June 2016.