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How to assess the benefits of connected vehicles? A simulation framework for the design of cooperative traffic management strategies

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A B S T R A C T

Advances in Information and Communication Technologies (ICT) allow the transportation community to foresee dramatic improvements for the incoming years in terms of a more efficient, environmental friendly and safe traffic management. In that context, new ITS paradigms like Cooperative Systems (C-ITS) enable an efficient traffic state estimation and traffic control. C-ITS refers to three levels of cooperation between vehicles and infrastructure: (i) equipped vehicles with Advanced Driver Assistance Systems (ADAS) adjusting their motion to surrounding traffic conditions; (ii) information exchange with the infrastructure; (iii) vehicle-to-vehicle communication. Therefore, C-ITS makes it possible to go a step further in providing real time information and tailored control strategies to specific drivers. As a response to an expected increasing penetration rate of these systems, traffic managers and researchers have to come up with new methodologies that override the classic methods of traffic modeling and control. In this paper, we discuss some potentialities of C-ITS for traffic management with the methodological issues following the expansion of such systems. Cooperative traffic models are introduced into an open-source traffic simulator. The resulting simulation framework is robust and able to assess potential benefits of cooperative traffic control strategies in different traffic configurations.

1. Introduction

1.1. Context

Cooperative Intelligent Transport Systems (C-ITS), a.k.a. connected vehicles, are new technologies that allow vehicles to communicate with other vehicles and with the infrastructure. The vehicle is equipped with bidirectional communication and sensors that enable to both capture and report on vehicles' surrounding traffic conditions and environment. More specifically, they refer to vehicle integrated systems that aim to provide the driver with a more comfortable and safer driving task. Vehicles are becoming more and more autonomous due to recent development of embedded technologies and Advanced

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Driver Assistance Systems (ADAS). Automated technology includes lane departure warning systems, emergency braking and adaptive cruise control (see Lu et al., 2005, for a non-exhaustive review). In addition to autonomous technologies like ADAS, vehicles and infrastructure can be equipped with wireless communication devices. The recent developments of dedicated communication channels (e.g. Dedicated Short Range Communication-DSRC, WIFI, WIMAX) increase the possibilities and amount of information potentially exchanged. Within these technologies, On-Board Units (OBU), Road Side Units (RSU), in-vehicle (ADAS) and on-road sensors (loop detectors, cameras) would play their key role (Communication Consortium, 2008). The extensive use of the umbrella term "cooperative systems" in traffic-related research paper and projects is debatable as connected vehicles will obviously not cooperate with each other in the first deployment phases. Considering the advent of connected but not automated vehicles, cooperation can be seen as a combination of a high level of coordination and decentralization. The connected vehicle must be autonomous enough to ensure a self-decision process.

Such a communication framework looks very suitable for a decentralized approach, where vehicles are acting as mobile agents supplied by real time personalized and tailored recommendations, but also to a more centralized approach through the use of Road Side Units.

As new data sources as well as mobile sensors, connected vehicles revolutionize traffic management. Within connected vehicles environment, a twofold vision of vehicle is widely accepted:

1. as a probe delivering Connected Vehicle Data with extended capabilities;
2. as an actuator for traffic control.

Within the former, the vehicle will deliver rich and valuable information. Current probe data generated by vehicles deliver their current position, motion, and time stamp. Connected vehicles will enrich vehicle data with additional attributes such as headway, traction information, brake status, hard braking, activation of emergency lights, anti-lock brake status, air bag deployment status, windshield wiper status, etc. In addition, high resolution data such as vehicle trajectories may be provided. Probe data may be transmitted at various frequencies using a range of wireless communication technologies, including DSRC (Dedicated Short Range Communication), cellular, Wi-Fi, WiMAX, etc. In Dinh et al. (2014), we have proposed a queue-end detection algorithm on freeways, which is based only on the use of connected vehicle data. The results underline the capability of a simple algorithm to detect the end of a moving queue, *i.e.* a critical zone in terms of traffic safety, even with a low penetration rate (15% of traffic). With respect to the second vision, the connected vehicle can be seen as an actuator for traffic control. Based on the information received in real time from all vehicles through Vehicle to Infrastructure communication (V2I), the Traffic Management Centre may send to the vehicle tailored and location-based recommandation or guidance through Infrastructure to Vehicle (I2V) communication. C-ITS enables the drivers more decisions, based on information from other vehicles and from the infrastructure. Different levels of interaction established by cooperative systems can potentially lead to changes in users behavior and ultimately to a Cooperative Traffic Management (CTM). However, the future deployment of these cooperative systems raises many issues and challenges in terms of modeling, network management and control which should be anticipated. Indeed, during the deployment phase of C-ITS, a situation of mixed traffic with connected and non-connected vehicles will perpetuate. Important developments are then necessary in order to achieve a Cooperative Traffic Management. In this respect, the European Network of Excellence NEARCTIS, led by our group, has contributed by identifying research gaps and elaborating an integrated research agenda and roadmap (Consortium, 2012). Unfortunatley, so far a comprehensive field data on connected vehicles is still limited and simulation studies are then crucial for understanding and modeling how to anticipate driver behaviour and the impacts on network flow dynamics, and how to use this information and multisource data to improve traffic control, which is a prerequisite for a better achievement of a Cooperative Traffic Management.

1.2. Contributions and organization of the paper

The objectives of this paper are to come up with new contributions anticipating and supporting deployment programs of connected vehicles. As an additional contribution to an extensive research in the past two years (Jin and Orosz, 2014; HomChaudhuri et al., 2016; Ploeg et al., 2015; Osman and Ishak, 2015; Ngoduy and Wilson, 2014), the main point of our paper is the integration of our previous research efforts (Monteil et al., 2013, 2014; Sau et al., 2014) into a robust decision support tool for cooperative traffic simulation. The paper summarizes the following research efforts:

- The integration of multi-agent cooperative traffic modeling into the MovSim Traffic simulator.
- The coupling of different dynamics (physical, informational) to account for sensors reliability issues.
- Simulation results about the impact of cooperative traffic on traffic flow homogenization and the effects of sensors failure.
- The design of RSU-based control strategies with on- and off- ramp scenarios.

The paper is organized as follows. Section 2 defines more precisely the concept of cooperative vehicle used in this paper and presents the multi-agent model (adapted from Monteil et al., 2013). In Section 3, the implementation of the model into MovSim is detailed. In Section 4, simulation results are presented and then discussed in the final section.