Transportation Research Part C 52 (2015) 1–14

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Autonomous cars: The tension between occupant experience and intersection capacity

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A R T I C L E I N F O

Article history:
Received 14 August 2014
Received in revised form 4 January 2015
Accepted 5 January 2015
Available online 24 January 2015

Keywords:
Autonomous car
Occupant experience
Productive use of travel time
Road capacity

A B S T R A C T

Systems that enable high levels of vehicle-automation are now beginning to enter the commercial marketplace. Road vehicles capable of operating independently of real-time human control under an increasing set of circumstances will likely become more widely available in the near future. Such vehicles are expected to bring a variety of benefits. Two such anticipated advantages (relative to human-driver vehicle control) are said to be increased road network capacity and the freeing up of the driver-occupant's time to engage in their choice of leisurely or economically-productive (non-driving) tasks.

In this study we investigate the implications for intersection capacity and level-of-service of providing occupants of *automated* (without real-time human control), *autonomously-operating* (without vehicle-to-X communication) cars with ride quality that is equivalent (in terms of maximum rates of longitudinal and lateral acceleration) to two types of rail systems: [urban] light rail transit and [inter-urban] high-speed rail. The literature suggests that car passengers start experiencing discomfort at lower rates of acceleration than car drivers; it is therefore plausible that occupants of an autonomously-operating vehicle may wish to instruct their vehicle to maneuver in a way that provides them greater ride comfort than if the vehicle-control algorithm simply mimicked human-driving-operation.

On the basis of traffic microsimulation analysis, we found that restricting the dynamics of autonomous cars to the acceleration/deceleration characteristics of both rail systems leads to reductions in a signalized intersection's vehicle-processing capacity and increases in delay. The impacts were found to be larger when constraining the autonomous cars' dynamics to the more-restrictive acceleration/deceleration profile of high-speed rail. The scenarios we analyzed must be viewed as boundary conditions, because autonomous cars' dynamics were by definition never allowed to exceed the acceleration/deceleration constraints of the rail systems. Appropriate evidence regarding motorists' preferences does not exist at present; establishing these preferences is an important item for the future research agenda.

This paper concludes with a brief discussion of research needs to advance this line of inquiry.

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http://dx.doi.org/10.1016/j.trc.2015.01.002
0968-090X/

1. Introduction

Vehicle automation is rapidly rising up the agenda of the automotive sector; new cars increasingly contain systems that enable high levels of partial-automation (cf. US NHTSA (2013) for widely-recognized definitions of vehicle automation levels). There is also growing interest in the impacts on road network operations among transportation planners and road network managers.

Many observers speculate that two of the benefits of road vehicle automation will be (1) increased road network capacity (Li et al., 2013; Shladover, 2009; Ge and Orosz, 2014; Zohdy et al., 2014; Kesting et al., 2008; Fagnant and Kockelman, 2014), and (2) freeing up of the occupant's in-car time for a range of leisurely and economically-productive activities that are either not possible at all while one is driving, or are not as productive while driving because the driver must continuously devote a share of his/her cognitive resources to driving-related tasks (Smith, 2012; Speiser et al., 2014; Anderson et al., 2014; Preimus and Van Wee, 2013). Bhat and Howard (2014), for instance, ask: "*Will autonomous vehicles reduce roadway congestion and expand people's willingness to be in a car through reduced stress and ability to do other tasks, thereby increasing commute-sheds and lengthening trips?*" [underlining added].

Rail is widely described as being particularly well suited to leisurely or productive activities, as passengers are fully disengaged from vehicle operation (aside from the requirement for enough situational awareness that they exit the train at their desired station) (Halden, 2003; FIckling et al., 2009; Lyons and Urry, 2005; Lyons et al., 2007; Pawlak et al., 2012; Thalys, 2012). As is discussed in detail in Section 3, passengers on certain types of trains are also subject to smoother acceleration/deceleration profiles than car occupants. The smoother ride experienced by the passenger further enables leisurely or productive tasks. This is consistent with earlier work that suggests that car *passengers* (who can engage in leisurely or productive tasks that cannot be performed while driving) begin to experience discomfort at lower rates of acceleration than car *drivers* do (Tan, 2005; Fitzpatrick et al., 2007).

This paper investigates the impact on intersection capacity and level-of-service if autonomous cars are instructed by their occupants to travel subject to the maximum rates of longitudinal and lateral acceleration/deceleration experienced by rail passengers. The logic is that autonomous car occupants engaged in leisurely or productive activities are likely to be functionally more similar to 'car passengers' than 'car drivers'. We considered two quite distinct types of rail systems: [intra-urban] light rail transit (LRT) and [inter-urban] high-speed rail (HSR). HSR systems in many cases cater to business travelers, and provide passengers with a smoother ride quality than LRT systems do. We selected these two forms of rail travel in the interest of modeling diversity in ride quality.

The scenarios we analyzed must be viewed as boundary conditions, because autonomous cars' dynamics were by definition never allowed to exceed the acceleration/deceleration constraints of the rail systems. Appropriate evidence regarding motorists' relative preferences for ride quality, speed, and network capacity in the context of autonomous operation does not exist at present; establishing these preferences is an important item for the future research agenda.

The context of this analysis is the urban arterial street network, rather than freeway (uninterrupted-flow) conditions. Where it was necessary to draw on technical standards we did so from the state of California as described below; in California the majority (57%) of vehicle-miles of travel on public roads occur on the arterial (non-freeway) network (CalTrans, 2013). Using traffic microsimulation techniques, we evaluate a relatively near-term context characterized by:

- Mixed traffic streams (on a signalized urban arterial network) consisting of both human-driven cars and autonomously-operating cars which do not require continuous monitoring by the cars' occupant. Platooning does not take place; inter-vehicle headways between autonomous cars and the vehicles in front of them are equal to (or larger in certain scenarios, as described in Section 3) those of human-driven cars.
- No vehicle-to-X (vehicle-to-vehicle, vehicle-to-infrastructure, etc.) communications. Such communications capabilities enable cooperative behavior, but also introduce complexities (including novel types of liability in case of a mishap) and are therefore not in general present in the first generation of commercially-available driver-assist autonomous-operation systems (e.g. the systems available on the 2014 Mercedes S-Class, cf. Mercedes-Benz, 2014).

The findings of this analysis highlight the trade-offs between ride quality in autonomous cars and intersection capacity. Since it appears that car drivers and car passengers experience ride comfort differently (due to the driver being necessarily engaged in the driving task) (Tan, 2005; Fitzpatrick et al., 2007), it is plausible that autonomous car occupants wishing to engage in novel types of in-car leisurely or economically-productive tasks may wish to trade off between their ride comfort and travel time in different ways than car drivers do. The tension highlighted in this paper is a special case of the generic characteristic of congestible transportation networks that private costs/benefits and social costs/benefits are in general not perfectly aligned. The general notion that travelers seek comfort (which comprises multiple dimensions, including ride quality) in addition to seeking to minimize their travel time is uncontroversial (Jain and Lyons, 2008; Ortuzar and WIllumsen, 2011); if comfort were irrelevant to people's transport choices no person would walk anywhere: such trips would instead all be made at full sprinting pace.

These findings represent an important and timely contribution to the literature, as the tension analyzed here is not typically taken into account in planning for vehicle automation. For instance, Gucwa (2014) recently presented results of a first-of-its-kind activity-based analysis of the prospective impacts of road vehicle automation on travel patterns in the