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On Microscopic Modelling of Adaptive Cruise Control Systems

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Abstract

The Adaptive Cruise Control (ACC) system, is one of the emerging vehicle technologies that has already been deployed in the market. Although it was designed mainly to enhance driver comfort and passengers' safety, it also affects the dynamics of traffic flow. For this reason, a strong research interest in the field of modelling and simulation of ACC-equipped vehicles has been increasingly observed in the last years. In this work, previous modelling efforts reported in the literature are reviewed, and some critical aspects to be considered when designing or simulating such systems are discussed. Moreover, the integration of ACC-equipped vehicle simulation in the commercial traffic simulator Aimsun is described; this is subsequently used to run simulations for different penetration rates of ACC-equipped vehicles, different desired time-gap settings and different networks, to assess their impact on traffic flow characteristics.

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1. Introduction

As we are advancing in the 21st century, new vehicle technologies arise, some of which affect not only safety and comfort of the passengers, but also traffic efficiency. The last decade has been a very productive one, since a continuing interdisciplinary effort has been made by the automobile industry and various governmental and research institutions around the world to plan, develop, and start deploying a variety of Vehicle Automation and Communication Systems (VACS) (Kesting et al., 2007; Shladover, 2012; Suzuki, 2003). Although vehicle intelligence is increasing, one must not assume that traffic efficiency will automatically increase too; therefore modelling and simulation of such automation systems is needed, inter alia, for the systematic design and testing of

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future traffic control strategies. The first system that will potentially change significantly the dynamics of traffic flow is the adaptive cruise control (ACC) system (Kesting et al., 2007). Various automotive companies have already introduced such systems, while several research teams have been working on their conceptual and numerical modeling (Darbha and Rajagopal, 1999; Rajamani et al., 2005; VanderWerf et al., 2001; Wang et al., 2013). Regarding their microscopic modelling, issues to be considered are the control law of the ACC system, the number and meaning of its parameters, the impact of the response time and its string stability properties. Additional aspects, which are, however, outside the scope of this paper, could be safety implications, legal issues and technical restrictions, such as performance of ACC sensors in turning maneuvers, braking, hills, weather conditions etc. (Gurulingesh, 2004).

The first objective of this work is to summarize the available information in the existing literature for modelling and simulating of ACC-equipped vehicles. The second objective is to describe the development and evaluation of such a system, within the framework of one of the commercial microscopic traffic flow simulators. Aimsun, developed by Traffic Simulation Systems (TSS), was chosen for this work.

The review of available ACC systems and their simulation addresses the related control objectives, spacing selection policy, control laws and constraints. The different types of headway policy are examined, namely constant space-headway, constant time-headway, and variable time-headway. Moreover, the various control laws, proposed for controlling the longitudinal movement of ACC-vehicles, are briefly discussed, in order to conclude on the trends in the field.

Regarding the microscopic simulation framework used in this work, a short description of Aimsun is included, along with the corresponding API and MicroSDK tools. The details of the simulated networks and the respective car following models as well as the values of the parameters used for the conducted microscopic simulations are also described.

Finally, simulation results for two different cases are presented, to examine a) the impact of ACC on capacity for different penetration rates and different time-gap settings for an open-stretch road, and b) the effect of ACC on preventing the formation of stop-and-go waves in a ring-road. For the simulation of manually driven vehicles, two different models were applied, Gipps and IDM, the second one implemented using the MicroSDK platform of Aimsun.

2. Available models for ACC-equipped vehicles

2.1 Control approach and objectives

Regarding the control structure, a two-level (higher/ lower) approach is a common choice (Liang and Peng, 1999; Zhou and Peng, 2005). The higher level deals with calculating the necessary or desired acceleration, depending on the vehicle's distance (range) to the leading vehicle and the difference in the corresponding velocities (range rate). The lower level deals with "transforming" the acceleration, computed at the higher level, into throttle or braking commands (Fig. 1). The control objectives should be the following (Shladover et al., 2012):

- To travel with the maximum speed set by the driver in cases where there are no leading vehicles in the range covered by the sensors, or leading vehicles exist within that range but their velocities are higher than the maximum speed set by the user. This is also referred as *speed control mode* (Shladover et al., 2012).
- To maintain vehicle speed equal to the speed of the leading vehicle at a specified distance, when the leading vehicle is in range and its speed is lower than the maximum speed set by the driver. This is also referred to as *gap control mode* (Shladover et al., 2012).
- The transitions between the two aforementioned objectives should be as smooth as possible, in order not to cause discomfort to the passengers, e.g. due to abrupt accelerations or decelerations. Clearly, during lane-changing or cut-in maneuvers, a sudden change to the distance from the leading vehicle may occur, which may cause strong reactions from the system.

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