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Modeling and Simulation Based Analysis of Multi-Class Traffic with Look-Ahead Controlled Vehicles

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Abstract

In the paper the modeling and the analysis of the multi-class traffic flow focusing on the cruising of the look-ahead controlled vehicles are presented. The look-ahead controlled vehicles optimize their speed profile based on the energy consumption and traveling time minimization performances, considering the forthcoming terrain characteristics, speed limits and traffic environment. Therefore, the speed profile of the look-ahead controlled vehicles can significantly differ from the speed selection strategy of the conventional vehicles. The increasing number of cruise controlled vehicles can modify the dynamics of the traffic, the average speed and the critical density/speed parameters. Moreover, the cruising of the numerous look-ahead controlled vehicles can have an impact on the energy consumption of the vehicles in the entire traffic. The paper presents the modeling and analysis of the mixed-traffic based on various simulation scenarios. During the analysis VISSIM software is used, with which the effect of the look-ahead vehicles on the traffic is examined. The contribution of the paper can be used in the coordination of the look-ahead controlled vehicles and traffic control systems.

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Keywords: multi-class traffic; look-ahead control; modeling; VISSIM simulation

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1. Introduction and motivation

Increasing research activity on autonomous vehicles poses several questions on the future of traffic control systems. Since the motion profiles of autonomous vehicles are based on control rules, the deviance in their speed or acceleration is smaller. As a result numerous autonomous vehicles have an impact on the traffic dynamics, e.g. on the fundamental diagram, see Tettamanti et al. (2016). Moreover, the speed selection of the autonomous vehicles can influence the motion of the conventional vehicles with human drivers. If there are several controlled vehicles, which consider speed limits on a highway, they can prevent the human driver from exceeding the limitation. Thus, in the future research on the intelligent transportation systems the relation and interconnection between the autonomous vehicles, as microscopic elements, and traffic modeling, as a macroscopic view, have important roles.

In the topic of the analysis between the cruise controlled vehicles and the traffic modeling/control there are a number of existing results in the literature. In the paper by Li and Ioannou (2004) a traffic flow model which is able to consider the characteristics of the autonomous vehicles is presented. This flow of mixed traffic with controlled vehicles and human drivers is examined in Bose and Ioannou (1999). Recently, new results on the analysis of the relation in the traffic flow and the cooperative cruise control systems has been elaborated in van Arem et al. (2006). Further performances, such as optimality, energy consumption and emission are also examined, see e.g. Barth et al (2013) and Roncoli et al (2015). The relationship between the traffic flow and the eco-cruising controlled vehicles is presented in Németh and Gáspár (2017).

The goal of this paper is to analyze the impact of cruise controlled vehicles on the traffic flow, especially on the average speed of the traffic. In this paper the speed profiles of the controlled vehicles are computed through the energy-efficient look-ahead control technique, which is able to consider the terrain characteristics and speed limits of the forthcoming road sections on a finite horizon. In addition to the average traffic speed the energy consumptions of the vehicles are also examined. The contribution of the paper is a simulation-based analysis, which considers several parameters of the autonomous vehicle control systems and the traffic flow, such as the energy-efficient setting of the control, the ratio of the autonomous vehicles and the input volume.

In the paper the methodology of the eco-cruising control of the autonomous vehicles is presented briefly, see Section 2. After that the integration of the cruise control in the VISSIM simulation environment is demonstrated in Section 3. Section 4 proposes the simulation-based examinations with various vehicle control and traffic flow parameters. Finally, the results of the analyses are summarized in Section 5.

2. Methodology of eco-cruising with look-ahead control

The aim of the section is to present the cruise control of the autonomous vehicles to understand the characteristics of the speed profile. The following description provides only a brief overview of the control, the details and the mathematical background are found in Németh and Gáspár (2013).

Several eco-cruising control techniques have been developed in the past decades. One of the most promising is the look-ahead control, in which the information on the forthcoming road sections is considered through the generation of the speed profile, e.g. road slopes, speed limits or road infrastructure signals. In the topic of look-ahead control various approaches have been elaborated, considering passenger cars Saerens et al. (2013), buses Nouveliere et al. (2008) or trucks Hellström et al. (2009).

In the method the forthcoming road is divided into n number of sections. The section points are scaled with different weights, which represent the importance of the section's grade and speed limit in the computation of the actual reference speed. The first section point is represented by the weight Q, while the further n number sections have weight γ_i. The speed profile of the vehicle is formed as

$$v = f(Q, \gamma_i, v_{ref,i}, \alpha_i) \tag{1}$$

where $v_{ref,i}$ is the speed limit in section point i, while α_i is the grade of the road section. The function f represents an optimization, which incorporates two criteria: