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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:

- it is necessary to minimize the energy consumption of the entire horizon. Since there is a relationship between the kinetic energy of the vehicle and its longitudinal traction/braking force, the objective is formed as a longitudinal force minimization criterion

$$|F_{long}| \rightarrow min! \tag{2}$$

- it is necessary to keep the traveling time as small as possible. It means that the speed of the vehicle on each section must be close to the speed limit, because the fastest possible traveling is related to the minimum traveling time

$$|v_i - v_{ref,i}| \rightarrow min! \tag{3}$$

The two performances are considered in the optimization through norm weights. R_1 represents the importance of the force minimization criterion, while R_2 is related to the time minimization. Moreover, the criterion $R_1+R_2=1$ is defined, which means that it is sufficient to use only one weight selected as R_1 in the further analysis. If R_1 has a high value then the speed of the autonomous vehicle varies depending on the forthcoming road slopes and speed limits. It results in energy-efficient cruising for the vehicle. If R_1 is reduced then the speed of the vehicle is close to the speed limit and the motion of the vehicle is smooth. Although it leads to a time-efficient cruising, the energy consumption of the vehicle increases. Therefore, the selection of R_1 has an important role in the cruising of the autonomous vehicle and its effect on the surrounding vehicles. In the following the aim of the paper is to analyze this impact.

3. Integration of the cruise control in the VISSIM simulation environment

In the paper the VISSIM microscopic traffic simulation software is used for analysis, in which the impact of autonomous vehicle cruising on the traffic flow is examined. Moreover, the computation of the optimal speed requires Matlab, which is connected to VISSIM. Through Matlab the parameters of the vehicle control can be selected. The interconnection between the softwares is guaranteed by the COM (Component Object Model) interface. Using COM interface the data transfer between VISSIM and Matlab during the simulations is performed. In the traffic simulation environments three kinds of network parameters exist, which must be handled in all scenarios:

- fix parameters,
- scenario dependent parameters and
- dynamic parameters.

The highway network is constructed directly in the VISSIM simulator, where the fix parameters of objects are set. These parameters cannot be overwritten during the analysis using Matlab. They are the length and the altitude of the road elements, which are gained from Google Earth. The scenario dependent network objects are different in every scenario and they are initialized after the network loads, such as traffic volume and the traffic compositions. The third group contains the dynamic parameters, for example the desired speed of the controlled vehicles. In this case the object-oriented programming feature provides identical numbers for each object, e.g. links, vehicle inputs, vehicles, etc. Since VISSIM places vehicles randomly in time and in place, they can be identified according to their ID in every simulation step.

The simulation is performed on a 20-km-long section of the Hungarian highway M1 between Budapest and Tatabánya, see Figure 1. The 20 km segment without ramps contains uphill and downhill sections, and it is modeled with three lanes, such as outer, middle and inner lanes. In the VISSIM simulation the highway is divided into 0.5 km long sections on the average. Moreover, the selected segment contains speed limits, i.e., the speed limitation is 130km/h on the entire highway, except a part of a 3-km-long section between 5 and 9 km points, where the speed limit is 90km/h. This highway is one of the busiest road in Hungary, because it connects the capital cities Budapest and Vienna. Moreover, in the Hungarian section the highway can be reached through 27. The selected section has high differences in the altitude values, which can have speed reducing effect. Furthermore, the traffic flow on the section often increases, which can lead to long queues and traffic congestion.

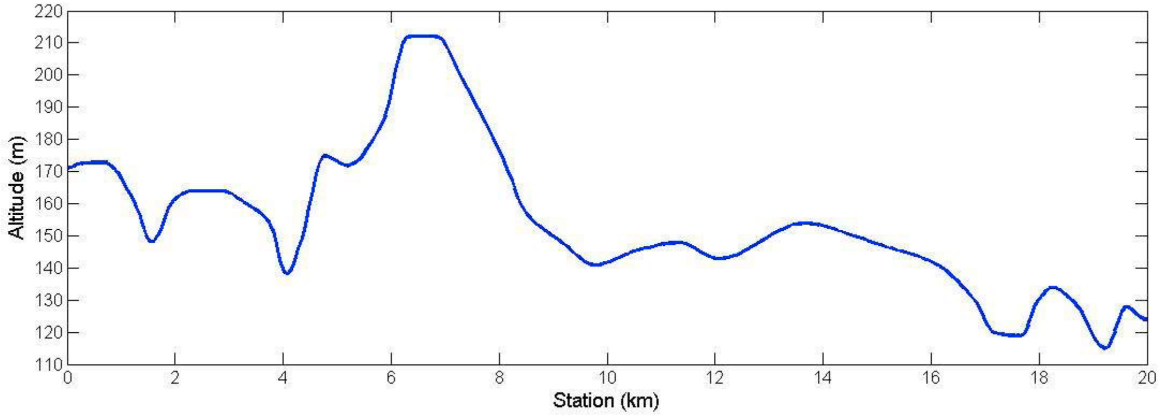

Fig. 1. Terrain characteristics of the Hungarian highway M1

4. Analysis on the traffic dynamics

In this section the analysis of the traffic flow with mixed autonomous and conventional human-driven vehicles is presented through simulation scenarios. The examination is based on the VISSIM and Matlab environments, which have been proposed in the previous section. During the simulations three parameters are varied

- the optimization parameter R_1,
- the rate of the autonomous vehicles in the entire traffic κ,
- the input flow of the highway q_{in}.

In the first simulation the rate of the controlled vehicles is 1%, which means that their impact on the traffic flow is negligible. The input volume is *3000 veh/h*, while the optimization parameter is selected as 0.7. The average speeds of the traffic in the different lanes are illustrated in Figure 2. This simulation is used as a comparison with the following scenarios, in which the rate of the controlled vehicles is increased. The conventional vehicles without the look-ahead control are considered to be human driven. In case of these vehicle the built-in driver model of VISSIM is used, see Wiedemann (1974).

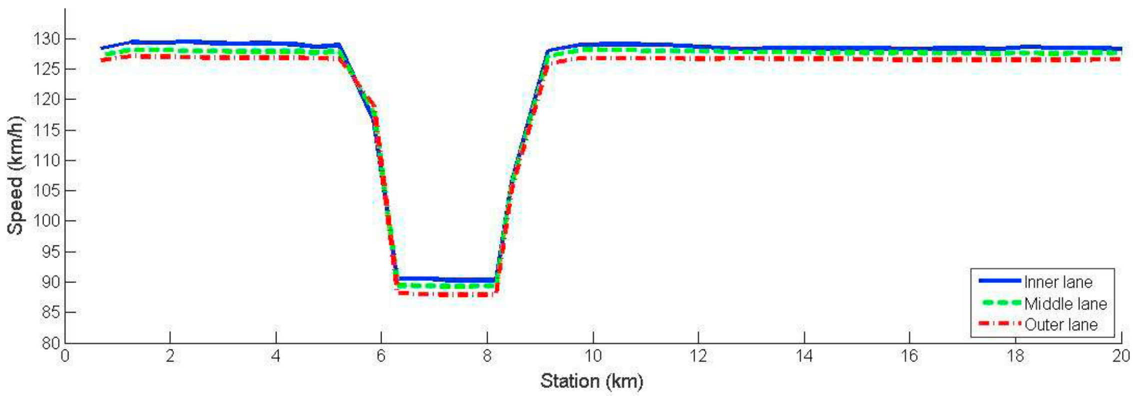

Fig. 2. Simulation scenario κ =1%, q_{in} =3000veh/h, R_1=0.7

The second simulation example illustrates the results, in which the rate of the controlled vehicles is 10%. It can be seen in Figure 3 that the speed of the traffic is varied slightly due to the increasing rate of controlled vehicles. In this case the conventional vehicles meet more often with controlled vehicles during their course. Furthermore the simulation presents the differences between the average speeds of the lanes. Since the energy-efficient controlled vehicles usually reduce their speeds depending on the forthcoming road slopes and speed limits, they are basically in the outer lane. Thus, the controlled vehicles have an increased impact on the traffic flow in the outer lanes.

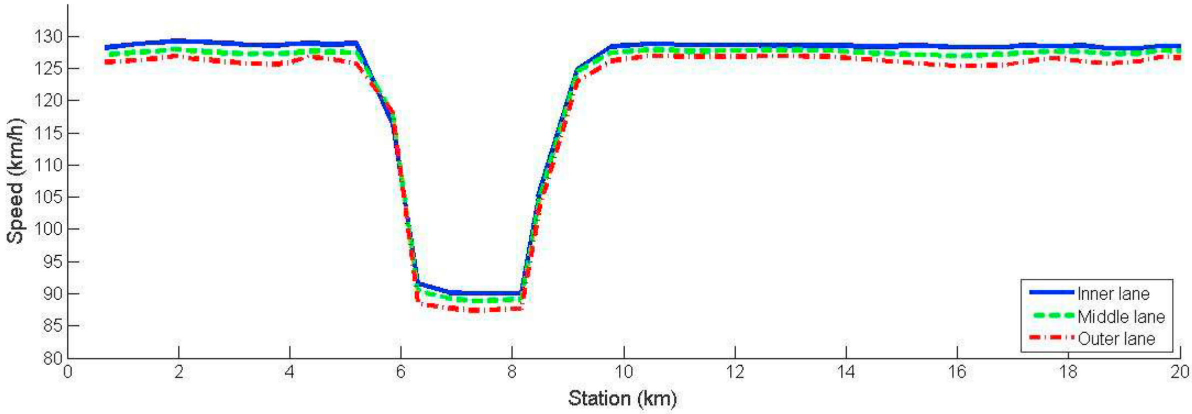

Fig. 3. Simulation scenario κ =10%, q_{in} =3000veh/h, R_1=0.7

In the third simulation example the optimization parameter is selected to R_1,=0.9. The controlled vehicles are focused on the minimization of the energy consumption, which results in the increased variation of the traveling speed. It has a significant effect on average speed in the outer lane, see Figure 4. Moreover, the prioritization on the first optimization criteria leads to the increase of the traveling time. Thus, it is necessary to find a balance between the energy consumption and the traveling time, because high R_1 can also have disadvantageous impacts on the entire traffic flow.

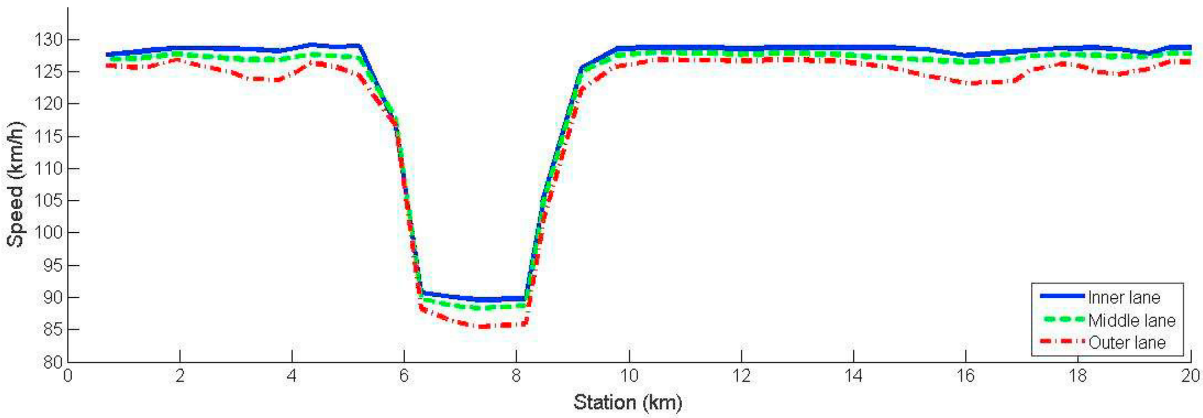

Fig. 4. Simulation scenario κ =10%, q_{in} =3000veh/h, R_1=0.9

The fourth scenario is a simulation with increased traffic inflow, such as q_{in}=5000veh/h, see Figure 5. The results show that the effect of the controlled vehicles slightly depends on the traffic volume. Moreover, the impact of the volume increase is smaller than the impact of R_1 increase.

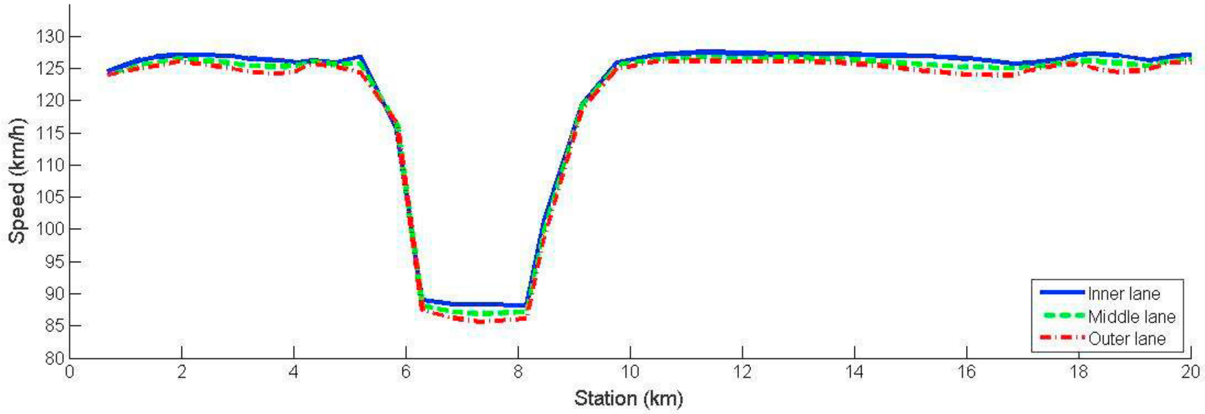

Fig. 5. Simulation scenario κ =10%, q_{in} =5000veh/h, R_1=0.7

Finally, in the fifth simulation the ratio of the autonomous vehicles is increased to 30%. Figure 6 shows that it leads to significant variations of the speeds in each lanes. If the rate of the controlled vehicles increases, their motion influence the speed of the human-driven vehicles significantly.

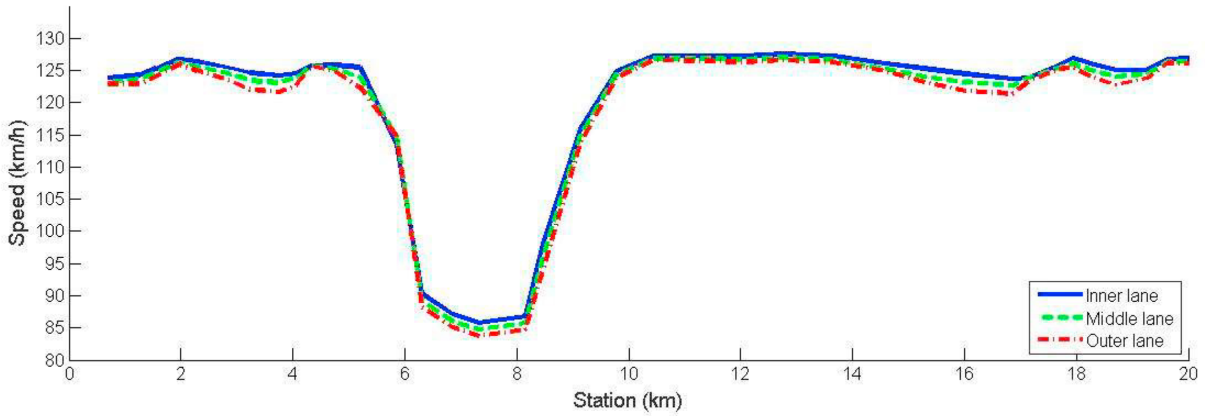

Fig. 6. Simulation scenario κ =30%, q_{in} =5000veh/h, R_1=0.7

The average values of the actuated longitudinal forces on the autonomous and the human-driven vehicles are presented in Table 1. It can be seen that the three parameters have impact not only on the average traffic speed, but also on the longitudinal force of the vehicles. For example, the ratio of the controlled vehicles influences the force of the conventional vehicles, at κ =1% its value is 679.4N, while at κ =10% it is reduced to 673.1%. Moreover, the optimization parameter R_1 has a huge impact on the longitudinal forces: it is able to generate 2% force consumption for the entire traffic, see the scenarios κ =10%, q_{in} =3000veh/h, R_1=0.7 and κ =10%, q_{in} =3000veh/h, R_1=0.9.

Table 1. Numerical results of the simulations

Scenario	$\|F_{long}\|$ conventional vehicles	$\|F_{long}\|$ autonomous vehicles	Travelling time
κ =1%, q_{in} =3000veh/h, R_l=0.7	679.4N	631N	608.3s
κ =10%, q_{in} =3000veh/h, R_l=0.7	673.1N	628.8N	611.8s
κ =10%, q_{in} =3000veh/h, R_l=0.9	662.7N	614.6N	619.7s
κ =10%, q_{in} =5000veh/h, R_l=0.7	670.8N	624.8N	614.5s
κ =30%, q_{in} =5000veh/h, R_l=0.7	670.4N	624.1N	618.3s

5. Conclusions

The analysis has proposed that autonomous vehicles can have significant impact on the traffic flow, including the average speed. Furthermore, the results have shown that the controlled vehicles influence the energy consumption of the vehicles, including the human-driven vehicles. The relationships between the ratio, the optimization parameter of the autonomous vehicles and the traffic speed have been examined based on the VISSIM macroscopic traffic simulator. The results of the paper can be used in the speed profile optimization of the vehicle cruise control systems. Through this way the energy-efficiency of the vehicles can be improved without disadvantageous effects on the traffic flow.

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References

Barth, M., Boriboonsomsin, K., Wu, G., (2013) The potential role of vehicle automation in reducing traffic-related energy and emissions, In 2013 International Conference on Connected Vehicles and Expo (ICCVE),, pp. 604–605.

Bose, A., Ioannou, P., (1999) Analysis of traffic flow with mixed manual and semi-automated vehicles,” California PATH Research Report

Hellström, E., Ivarsson, M., Aslund, J., Nielsen. L., (2009) Look-ahead control for heavy trucks to minimize trip time and fuel consumption. Control Engineering Practice 17, pp. 245–254.

Li, K., Ioannou, P., (2004) Modeling of traffic flow of automated vehicles, IEEE Transactions On Intelligent Transportation Systems, vol. 5, no. 2, pp. 99–113.

Németh, B., Gáspár, P., (2013) Design of vehicle cruise control using road inclinations. International Journal of Vehicle Autonomous Systems, Vol. 11., No 4., pp. 313-333.

Németh B., Gáspár P. (2017) The Relationship Between the Traffic Flow and the Look- ahead Cruise Control. IEEE Transactions on Intelligent Transportation Systems.

Nouveliere, L., Braci, M., Menhour, L. and Luu, H.T. (2008) Fuel consumption optimization for a city bus, UKACC Control Conference, Manchester, UK, pp.1–6.

Roncoli, C., Papageorgiou, M., Papamichail, I., (2015) Traffic flow optimisation in presence of vehicle automation and communication systems - Part II: Optimal control for multi-lane motorways, Transportation Research Part C, vol. 57, pp. 260–275.

Saerens, B., Rakha, H.A., Diehl, M., Van den Bulck. E., (2013) A methodology for assessing eco-cruise control for passenger vehicles. Transportation Research Part D 19, pp. 20–27.

Tettamanti T., Varga I., Szalay Zs.,, (2016) Impacts of Autonomous Cars from a Traffic Engineering Perspective. Periodica Polytechnica Transp. Eng., (44)4, pp. 244-250.

van Arem, B., van Driel, C. J. G., Visser, R., (2006) The impact of cooperative adaptive cruise control on traffic-flow characteristics, IEEE Transactions On Intelligent Transportation Systems, vol. 7, no. 4, pp. 429–436.

Wiedemann, R. (1974) Simulation des Strassenverkehrsflusses. Schriftenreihe des Instituts für Verkehrswesen der Universität Karlsruhe, vol 8, Karlsruhe, Germany.