19th EURO Working Group on Transportation Meeting, EWGT2016, 5-7 September 2016, Istanbul, Turkey

Look-ahead speed planning for heavy-duty vehicle platoons using traffic information

Ingrid Johansson [a,*], Junchen Jin [a], Xiaoliang Ma [a], Henrik Pettersson [b]

a System Simulation & Control, Department of Transport Science, Teknikringen 10, SE-100 44 Stockholm, Sweden
b Scania CV AB, 151 87 Södertälje, Sweden

Abstract

Freight transport is a fast increasing transportation mode due to the economic growth in the world. Heavy-duty vehicles (HDV) have considerably greater fuel consumption, thus making them a suitable target when new policies in road transport emphasize increased energy efficiency and mitigated emission impacts. Intelligent transportation systems, based on emerging V2X communication technology, open new possibilities for developing fuel-efficient driving support functions considering real traffic information. This indicates a large potential of fuel saving and emission reduction for freight transport. This paper studies a dynamic programming-based optimal speed planning considering a maximum acceleration model for HDVs. The optimal speed control is applied for the deceleration case of HDV platoons due to received information on traffic speed reduction ahead. The control can optimize fuel consumption as well as travel time, and theoretical results for the two cases are presented. For maximal fuel saving, a microscopic traffic simulation study is performed for single HDVs and HDV platoons running in real traffic conditions. The results show a decrease in fuel consumption of more than 80% compared to simulations without applying optimal control, while the fuel consumption of other vehicles in the simulation is not significantly affected.

Keywords: Intelligent transportation systems; Heavy-duty vehicle platooning; Microscopic traffic simulation; Fuel economy; Eco driving; Optimal control; Infrastructure-to-vehicle communication.

1. Introduction

The demand for freight transport is continuing to grow, while at the same time fuel consumption and emissions need to decrease in order to counteract climate change and reduce the environmental impact. One way to tackle this challenge is to make use of emerging intelligent transportation systems (ITS) such as infrastructure-to-vehicle (I2V), vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication. V2V communication can be used to

---

* Corresponding author. Tel.: +46-8-790-84-99 ; fax: +46-8-790-84-61.
  E-mail address: ingrid.johansson@abe.kth.se

manage heavy-duty vehicle (HDV) platoons on highways. HDV platooning means to group HDVs together with small inter-vehicle distances in order to reduce air-drag resistance and, thereby, reduce the fuel consumption, stated e.g. by Turri (2015).

How to manage cruising HDV platoons is currently a hot research topic. However, highway traffic also suffers from occasional congestions where the speed is lowered, thus forcing the platoons to decelerate from their preferred cruising speed. Assuming an I2V communication system on highways, information about the traffic state ahead can be disseminated, as shown by Grumert et al. (2015). In that way, HDV platoons can be informed that in a given distance the speed has to be decelerated to a given value. Additionally, it is well-known that the driving style has a significant influence on the energy efficiency for HDVs. Studies on optimal speed control with an objective of minimizing fuel consumption have been proposed since the 1980s, e.g. by Hooker et al. (1983). It is still a hot research topic due to the development of in-vehicle systems as well as ITS techniques. However, there is still a lack of studies on the effects on the other vehicles when HDVs or HDV platoons apply the optimal speed control strategies. This study applies an optimal control to decide the optimal deceleration trajectory with respect to fuel consumption as well as travel time. The effects are compared to the case with no applied optimal speed control and the effect on other vehicles is studied.

Traffic simulation is a widely applied tool for evaluation purposes in traffic management and operation practice. Among different classes of traffic simulation models, microscopic simulation models describe the traffic system at the vehicle level capable of modeling vehicle-vehicle and vehicle-road interactions within a traffic stream. Therefore, microscopic traffic simulation is an appropriate evaluation tool for research topics on V2V and V2I applications.

The remainder of the paper is structured as follows. Section 2 introduces the HDV models, optimal speed control strategies and HDV platoon modelling as well as the simulation framework applied for evaluation. Section 3 presents the simulation-based case study and discusses the results in the aspects of both HDVs and passenger cars. Section 4 closes the paper with conclusions and suggestions for future work.

2. Methodology

2.1. Maximum acceleration for an HDV

The acceleration capacity for an HDV is limited by its maximum acceleration and maximum deceleration. This study uses a constant value for the maximum deceleration, while the maximum acceleration is heavily dependent on the speed. Therefore, we model it by basic physical properties of HDVs.

Let M_i denote HDV mass, $m_{e,i}$ engine inertial mass, $m_{w,i}$ wheel inertial mass and $a_i(t)$ the acceleration for HDV i, where t denotes time. The forces acting on HDV i are the tractive force $F_{t,i}(t)$ produced by the engine, the braking force $F_{b,i}(t)$, the aerodynamic force function $F_{a,i}(t)$ depending on the HDV speed $v_i(t)$ and relative distance $d_i(t)$, the rolling resistance force $F_{r,i}(t)$ and finally the gravitational force $F_{g,i}(t)$. Newton's second law for HDV i is then

$$(M_i + m_{e,i} + m_{w,i})a_i(t) = F_{t,i}(t) - F_{b,i}(t) - F_{a,i}(t) - F_{r,i}(t) - F_{g,i}(t). \tag{1}$$

The air drag force, adapted from Alam (2014), is modelled by

$$F_{a,i}(t) = \frac{1}{2}\rho_a C_a A_i(1 - \psi(d_i(t)))v_i^2(t) \tag{2}$$

with

$$d_i(t) = \begin{cases} s_i(t) & \text{if } i > 0 \\ s_1(t) & \text{if } i = 0, \end{cases} \tag{3}$$

where ρ_a is air density and C_a denotes the air drag coefficient. Furthermore, A_i is the HDV frontal area, $v_i(t)$ is HDV speed and $\psi(d_i(t))$ is the air-drag reduction rate with respect to the relative distance $d_i(t)$, all for HDV i. Relative distance here means the inter-vehicle distance $s_i(t)$ in front of HDV i, except for the platoon leader, where it means the distance $s_1(t)$ to the HDV behind it. Some function values used for $\psi(d_i(t))$ were obtained from Hucho and Sovran (1993) with the missing values estimated by linear interpolation. The respective models of maximum tractive force, rolling resistance force and gravitational force used in this study are referred to Rakha et al. (2001), with

$$F_{t,i}^{max}(t) = \min(\eta_i \frac{P_i}{v_i(t)}, M_{t,i}g\mu_i), \tag{4}$$