Transportation Research Part C 52 (2015) 173–186

Contents lists available at ScienceDirect

Transportation Research Part C

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

Analysis of a cooperative variable speed limit system using microscopic traffic simulation

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ARTICLE INFO

Article history:
Received 1 November 2013
Received in revised form 12 November 2014
Accepted 17 November 2014
Available online 19 December 2014

Keywords:
Cooperative systems
Intelligent transport systems
Infrastructure to vehicle communication
Variable speed limit
Microscopic traffic simulation
Emission model

ABSTRACT

Variable speed limit systems where variable message signs are used to show speed limits adjusted to the prevailing road or traffic conditions are installed on motorways in many countries. The objectives of variable speed limit system installations are often to decrease the number of accidents and to increase traffic efficiency. Currently, there is an interest in exploring the potential of cooperative intelligent transport systems including communication between vehicles and/or vehicles and the infrastructure. In this paper, we study the potential benefits of introducing infrastructure to vehicle communication, autonomous vehicle control and individualized speed limits in variable speed limit systems. We do this by proposing a cooperative variable speed limit system as an extension of an existing variable speed limit system. In the proposed system, communication between the infrastructure and the vehicles is used to transmit variable speed limits to upstream vehicles before the variable message signs become visible to the drivers. The system is evaluated by the means of microscopic traffic simulation. Traffic efficiency and environmental effects are considered in the analysis. The results of the study show benefits of the infrastructure to vehicle communication, autonomous vehicle control and individualized speed limits for variable speed limit systems in the form of lower acceleration rates and thereby harmonized traffic flow and reduced exhaust emissions.

1. Introduction

Traffic congestion on motorways is a common problem in many countries around the world. The increasing traffic flows result in various problems related to safety as well as system efficiency. Another problem that is receiving more and more attention is the energy and environmental impacts of road traffic congestion, including excess fuel consumption and pollutant and greenhouse gas exhaust emissions.

Today, extensive efforts are focused upon solving problems related to congestion on motorways by applying a wide range of Intelligent Transport System (ITS) technologies to manage and control traffic flows. One commonly used motorway control strategy is a variable speed limit system (VSLS) where variable speed limit signs are linked together via a decision algorithm often based on local speed or flow. VSLSs are often, together with functions such as lane closure and queue warning, included in motorway control systems (MCSs). The purpose of a VSLS is to make drivers aware of current conditions, leading

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http://dx.doi.org/10.1016/j.trc.2014.11.004

to a decrease in accidents and an increase in traffic efficiency. Evaluations of already implemented VSLS in the UK (Highway Agency, 2007) and the Netherlands (van den Hoogen and Smulders, 1994) indicate benefits in terms of safety, system efficiency and reduced exhaust emissions.

Recent advances in communication technology have opened up new perspectives for the development of ITS that utilize vehicle to vehicle (V2V), vehicle to infrastructure (V2I) and infrastructure to vehicle (I2V) communication, so called cooperative systems. The general expectation is that cooperative systems will improve safety and efficiency and reduce the environmental impacts of road traffic in an even more efficient manner than the existing ITS.

The aim of this paper is to study the potential benefits of infrastructure to vehicle communication, autonomous vehicle control and individualized speed limits for variable speed limit systems. We do this by proposing such a cooperative VSLS (C-VSLS) as an extension to an existing VSLS. The proposed C-VSLS builds upon the ideas introduced by Grumert et al. (2013) and Grumert and Tapani (2012, 2013). By I2V communication the variable speed limits are communicated to the vehicles before the variable message signs become visible to the drivers. The C-VSLS is designed as an autonomous speed control system that controls the speed of individual vehicles based on the variable speed limit, the speed of the vehicle and the distance to the variable speed limit sign in front of the vehicle. Controlling the speed of individual vehicles at an earlier stage leads to the hypothesis that the C-VSLS will result in flow harmonization and thereby a reduction in environmental impacts compared to the standard VSLS. To test this hypothesis, a study combining microscopic traffic simulation and an exhaust emission model has been conducted. The contribution of the paper is an estimation of the size of potential benefits, in terms of traffic performance and exhaust emissions, of extending existing motorway VSLSs with I2V communication, autonomous vehicle control and individualized speed limits. The sensitivity of the performance of the C-VSLS to different system settings and traffic penetration rates is considered. The effect of the individualized speed limits of the C-VSLS, and the sensitivity of the effects of the VSLS with respect to different assumptions regarding drivers' ability to read the speed limit signs in front of the vehicles, have been evaluated.

The remainder of the paper is organized as follows. In the Section 2, reviews are presented of existing studies of VSLS and of exhaust emission models. In Section 3, we introduce the C-VSLS and describe the speed control algorithm of the system. The method of the simulation study to evaluate the proposed C-VSLS is presented in Section 4, including the utilized microscopic simulation tool and the emission model adopted. Computational results comparing the C-VSLS to the original standard VSLS are presented in Section 5. Finally, conclusions from the study and directions for further research are discussed in Section 6.

2. Literature review

Evaluations of already implemented VSLS have been performed as field-tests and by the use of traffic simulation. Using traffic simulation, studies prior to implementation can be made of new control algorithms, as well as other improvements of existing systems. Section 2.1 presents some of the published field-tests and simulation based evaluations of VSLSs. The choice of exhaust emission model is of importance in studies of ITS such as the C-VSLS. It is necessary that the emission model used is able to reflect the effects of the traffic and system dynamics on the resulting emissions. A short review of existing exhaust emission models is presented in Section 2.2.

2.1. Variable speed limit systems (VSLSs)

VSLSs have already been implemented in many countries with various functionalities depending on the purpose of the system, the location, etc. Examples of implemented VSLSs include the before mentioned systems in the UK (Highway Agency, 2007) and the Netherlands (van den Hoogen and Smulders, 1994). Studies of these systems indicate benefits in terms of road safety and traffic efficiency, with harmonized traffic flows, more homogenous headways and decreased variance in speed. Concerning the environmental impacts, the system implemented on the M25 in the UK has resulted in reductions of exhaust emissions by 2–8%, depending on type of emission (Highway Agency, 2007). In addition, a state-of-the-art study on systems implemented in Germany, the Netherlands and the UK shows results for Germany and the Netherlands that are in line with the findings in the UK, with harmonized flows as the most highlighted benefit (Smulders and Helleman, 1998). No significant improvements could be concluded on congestion, throughput and capacity in this study. Both advisory and compulsory variable speed limits can be used in a VSLS. A study on the Swedish VSLS indicates however that the effects, when using only advisory speed limits, are very limited (Nissan and Koutsopoulos, 2011).

Besides field tests, one direct way to study VSLS is by the use of traffic simulation. Traffic simulation may lead to a less costly evaluation of existing systems, but more importantly, it will be possible to evaluate systems that are not yet implemented. Numerous studies have been conducted on variable speed limits and VSLS using traffic simulation, resulting in good indications on the general system performance. Whereas most of the simulation studies have been focusing on safety, see e.g. Abdel-Aty et al. (2006), Allaby et al. (2007), Lee et al. (2006), Hellinga and Mandelzys (2011) and Piao and McDonald (2008) and efficiency, see e.g. Papageorgiou et al. (2008) and Torday et al. (2011), few simulation-based evaluations of VSLS that consider environmental impacts have been found in the literature. One exception is the evaluation of impacts of VSLS on air pollution presented by Torday et al. (2011). Most of the studies presented above are based on microscopic traffic simulation, with one exception, Papageorgiou et al. (2008), where macroscopic traffic simulation was used.