# Comparison of Two Controllers for Variable Speed Limit Control

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***Abstract*—One of the traffic control methods from the domain of intelligent transport systems used to reduce congestions on urban motorways is variable speed limit control (VSLC). Main goal of VSLC is to reduce the traffic flow speed and to homogenize the traffic flow. Results are reduced density, increased safety, reduced vehicle emissions and improved throughput. To choose the best controller for VSLC prior testing in simulations is necessary. In this paper a simulation framework that enables testing and comparison of controllers for VSLC regarding traffic and environmental parameters is implemented. Using the implemented simulation framework two simple reactive controllers for VSLC are compared using a realistic urban motorway model.**

***Keywords*— Intelligent transport systems, Traffic control, Urban motorways, Variable speed limit, Vehicle emissions**

## I. Introduction

Urban areas are today prone to congestions that occur regularly in peak hours or irregularly as a consequence of incidents, big events, etc. They are most present in road traffic. Congestions occur when the traffic demand exceeds a critical value and the road network cannot cope with such an amount of vehicles. As a solution urban motorways were build to connect suburbs with the city center or to create a bypass around the city center. Since urban motorways cannot be expanded any more in most urban areas, different solutions have to be applied to cope with the increased traffic demand. One of them is the application of different services from the domain of intelligent transport systems (ITS) like various traffic control systems. Goal of these traffic control systems is to raise the level of service (LoS) of the urban motorway, increase traffic safety, reduce vehicle emissions, etc.

On urban motorways often variable speed limit control (VSLC) is applied and this control system will be in the focus of this paper. Goal of VSLC is to change the current speed limit according to the current traffic or weather situation by using variable message signs (VMS) to inform the drivers. Therefore, the speed limit value can be set appropriately to the current traffic conditions increasing traffic throughput and safety, and reducing travel time ($TT$) and vehicle emission. To implement such a VSLC system one has to create a closed control loop i.e. to measure current traffic parameters, apply a controller and present the new speed limit to the drivers. The controller is the central part and it contains a control law with appropriate settings on which the resulting LoS of the controlled urban motorway section depends.

In order to chose the most suitable control law and its settings such traffic control systems are simulated before implementation. For this an appropriate simulation framework and evaluation procedure has to be established. In this paper a simulation framework is implemented using the microscopic traffic simulator VISSIM [1], vehicle emission simulator EnViVer [2] and the platform Matlab [3] for implementation of the speed limit controller. The framework is used to compare the effects of two simple reactive speed limit controllers. Additionally, it enables the inclusion of environmental parameters into the evaluation procedure. Therefore, a better evaluation can be done in comparison when only traffic parameters are used for evaluation. This is especially important today since traffic control systems have to improve not only traffic parameters, but traffic safety and environmental parameters also.

This paper is organized as follows. In Section II the motivation and the concept of VSLC is defined. Section III explains the chosen reactive controllers for comparison. Following section IV describes the simulation environment. In section V simulation results are presented including a discussion about them. Paper ends with conclusion and a description of future work on this topic.

## II. Motivation and concept of VSLC

Urban motorways are designed to provide high LoS in aspect of fast and safe traffic flow. LoS is defined as a group of qualitative measures, which characterize operational conditions within the traffic flow and their perception by motorists and drivers [4]. Despite the road design for achieving high LoS, periodic congestions or traffic slowdowns are often happening throughout the day as a result of daily migrations. Such periodic congestions are easy to predict and are easier to handle, but they are not the only issue. Non-periodic congestions usually cause a sudden drop in the traffic throughput of a particular motorway and are hard to predict. The causes of the latter are various traffic accidents or events of great public interest. Such traffic situations are difficult to predict and so non-periodic congestions are harder to prevent [5]. As mentioned, one measure for urban motorway control applied to prevent congestions from the domain of ITS is VSLC. It consists of appropriate variable message signs (VMS) used for displaying variable speed limit (VSL) values in response to the prevailing traffic conditions. The VMS have to be mounted in

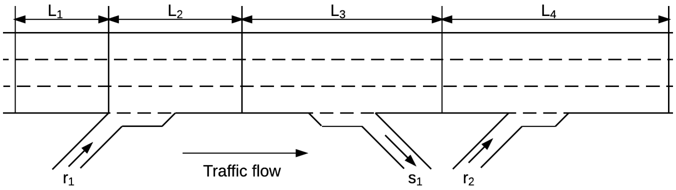


Figure 1. Uni-directional motorway stretch divided into $N$ sections

a motorway section preceding the section where congestion occurs (Fig. 1). In most cases, VSL values are mandatory, that is, legally equivalent to fixed speed limits. They may even be enforced to increase driver compliance and hence the impact of VSLC also. The main impact of VSLC on the traffic flow can be according to [6], [7] expressed as:

- Reduction of the mean speed at under-critical densities;
- Homogenization of speeds (reduction of speed differences among vehicles and of mean speed differences among lanes).

Using VSLC, mean speed of vehicles is reduced under the values that can cause occurrence of critical traffic density and consequently traffic congestion [6], [8]. Result is that the congestion pre-phase can be prolonged and the congestion phase avoided or shortened. Homogenization of vehicle speeds reduces the speed difference between vehicles and consequently induces a much more stable and safer traffic flow. Main motivation to use VSLC is enhanced traffic safety, and the selection of motorway sections for installation of VSLC in several countries is guided by the frequency of registered accidents. The positive impact of VSLC on traffic safety is due to speed reduction and speed homogenization, which are correlated with a reduction in accident probability [6].

Even though motorways are designed to serve higher traffic load in some cases they can be overloaded. Such situation is known under the term congestion. It is characterized by low speed and high traffic density what consequently reduces the motorway LoS. Congestions on motorways are most common on motorways with a larger number of adjacent on- and off-ramps. If those ramps are connected with a nearby dense urban area, they can be generators of high traffic demand for the motorway mainline capacity. Traffic demand originating from the urban area combined with transit traffic, which is also commonly served by urban motorways or bypasses, can create good predispositions for congestion build up. If the spatial and temporal synchronisation between different types of traffic demands on motorways occurs, and if they are all intense enough, congestion will appear.

Place on motorway where congestion starts is usually known under the term bottleneck. In traffic shockwave theory that describes moving congestions, this place is called head of the shockwave. Static congestions are usually present near on-ramps or near places of traffic incidents. VSLC can be applied also as one of the control strategies to mitigate such congestions. Speed limit values can be set according to the

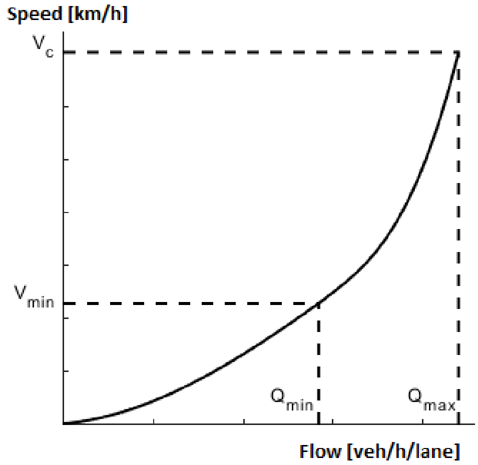


Figure 2. Strictly increasing function $f(Q)$ from $[Q_{min}, Q_{max}]$ to $[V_{min}, V_c]$ used to obtain the VSL value [9]

current traffic using an appropriate controller unlike fixed speed limit values.

## III. Chosen reactive controllers for comparison

VSLC is a system that was first introduced in Germany more than three decades ago. In literature two main approaches can be found for VSLC aiming at traffic flow improvement. The first emphasizes the homogenization effect while the second approach is focused on preventing traffic breakdown or resolving existing jams by reducing the flow by means of speed limits [8]. In this paper two reactive controllers for VSLC are chosen for a comparative analysis regarding their impact on traffic throughput. Both controllers are from the second group and based on the fundamental flow-density relationship mapped to the speed values given in Fig. 2 [9]. The controllers are explained into more details in continuation.

### A. Mainline virtual metering

The mainline virtual metering (MVM) control approach is designed based on the concept of ramp metering. Generally, ramp metering reduces congestion on the motorway by limiting the on-ramp inflow. One of the most used local ramp metering algorithms is ALINEA [10]. It has an optimal ratio between simplicity and efficiency. ALINEA uses a pure integral control action represented as [10]:

$$R(kT_1) = R((k-1)T_1) + K_r[O_d - O(kT_1)], \qquad (1)$$

where $k$ is the time step, $T_1$ is the discretization time, $R((k-1)T_1)$ is the ramp metering command from the previous time step, $K_r$ is a control parameter, $O(kT_1)$ the measured downstream occupancy in the current time step, and $O_d$ the desired value for the downstream occupancy that is typically chosen close to the critical occupancy $O_c$.

The ALINEA integral control strategy can be generalized in order to regulate the metered flow rate $Q_i$ from motorway section $i-1$ to section $i$. Mentioned generalization process produces a speed limit control algorithm based on the fundamental flow-density relationship. The desired flow rate $Q_i$ can be obtained using the following inequalities:

$$Q_i(kT_1) = \begin{cases} Q_{max}, & if\ \overline{Q}_i(kT_1) \geq Q_{max} \\ Q_{min}, & if\ \overline{Q}_i(kT_1) \leq Q_{min} \\ \overline{Q}_i, & otherwise \end{cases}. \tag{2}$$

Equation (3) provides the regulation of the flow at a particular section of the motorway, where $K_v$ is the controller parameter, $\rho_i$ is the traffic density on the particular motorway section and $\rho_d$ is the desired density.

$$\begin{aligned} \overline{Q}_i(kT_1) = Q_i((k-1)T_1) + \\ K_v \sum_{m=1}^{N_C} [\rho_d - \rho_{i+1}((k-1)N_C T_0 + mT_0)] \end{aligned} \tag{3}$$

The flow command has to be mapped into a speed limit command using the flow-speed relationship shown in Fig. 2. Speed of the traffic flow in each section *i* has to be bounded between the maximum speed limit ($V_{max}$) allowed and the lowest speed limit ($V_{min}$) we want to apply. Each of these speed values has a corresponding flow value ($Q_{max}$ and $Q_{min}$) as presented in Fig. 2. The mapping $f(Q)$ is based on the estimated flow-density relationship that is assumed to be:

$$q = \rho V_f\ exp\ \left[ -\frac{1}{\alpha} \left( \frac{\rho}{\rho_c} \right)^{\alpha} \right], \tag{4}$$

where $V_f$ is the free flow speed, $\rho_c$ is the critical density, and $\alpha$ is estimated online or offline using real traffic data. In case when control variable of each controlled motorway section $C_i$ is inactive, the desired speed limit change its default speed limit. Furthermore, if $C_i$ is active, section *i* requires calculation of a new speed limit. The new value of desired speed limit can be determined by the function:

$$\overline{V}_i(kT_i) = f(Q_i(kT_i). \tag{5}$$

However, $\overline{V}_i$ generated by (5) may lead to unsafe changes of speed limits. Therefore, the following speed limit $V_i$ is used:

$$V_i(kT_1) = \begin{cases} V_i((k-1)T_1) - C_v, \\ \quad if\ \overline{V}_i(kT_1) \leq V_i((k-1)T_1) - C_v \\ V_{i+1}(kT_1) + C_v, \\ \quad if\ \overline{V}_i(kT_1) \geq V_{i+1}(kT_1) + C_v \\ \overline{V}_i(kT_1), \quad otherwise \end{cases}, \tag{6}$$

where $C_v$ is a positive constant that represent the maximal allowed change of the speed limit (usually 10 $km/h$) [9].

### B. Simple proportional speed controller

The MVM controller is usually active when the mainline traffic volume is high. Moreover, the dynamic variable speed limit is only necessary when a disturbance happens [9]. Because of this reason it is possible to create a simple proportional speed limit controller (SPSC) that responses to changes in downstream density instead of a fixed desired density. In order to conduct this control approach the MVM controller can be further simplified into the SPSC.

SPSC controller generates command signals every $T_1$ seconds ($T_1 = N_c T_0$). Here $T_0$ denotes discretization time and $N_c$ is a positive design integer. The controller generates the desired speed limit $\overline{V_i}$ for section $i$ as presented in Fig. 1. To determine when $C_i$ is active or not, density in the following section $\rho_{i+1}$ for the moment $nT_1$ has to be measured [11]. The following decisions observe three cases:

- S1. If $\rho_{i+1}(kT_1) \geq (1+\delta_+)\rho_c$, where $\delta_+$ is a positive design parameter, then $C_i$ is active;
- S2. If $\rho_{i+1}(nk) \leq (1+\delta_-)\rho_c$, where $\delta_-$ is a negative design parameter, then $C_i$ is inactive;
- S3. If neither of the two inequalities are not satisfied, $C_i$ maintains its status as in the previous control cycle.

Equation (6) is used when computation of a new speed limit is required. If $C_i$ was inactive at time $(k-1)T_1$ and becomes active at time $T_1$ the speed limit is given as:

$$V_i(kT_1) = \begin{cases} V_{i+1}((k-1)T_1) + C_v, \\ \quad if\ \overline{V}_i(kT_1) \geq V_{i+1}(kT_1) + C_v \\ \overline{V}_i(kT_1) = f(\rho_{i+1}(kT_1)v_{i+1}(knT_1)), \\ \quad otherwise \end{cases}. \tag{7}$$

By using the fundamental equation of traffic flow $Q = \rho v$, the function $f(\rho_{i+1}(kT_1)v_{i+1}(knT_1))$ in (7) can be expressed as a function of $f(Q)$. Then $\overline{V}_i(kT_1)$ can be determined with the mapping $V = f(Q)$ as shown in Fig. 2 [12].

## IV. Simulation environment

Urban motorway, which consists of three main lanes, two on- and one off-ramp is used as a model for simulation. Block scheme of the implemented simulation framework consisting of above mentioned software packages is given in Fig. 3.

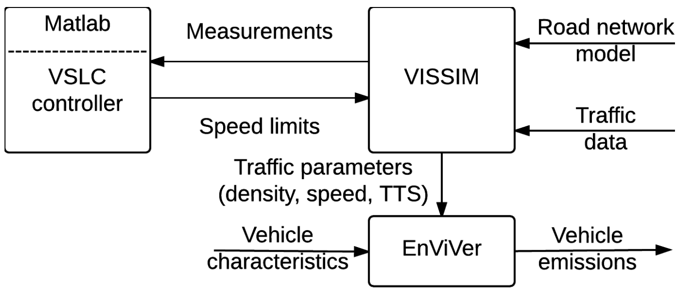


Figure 3. Block scheme of the simulation framework

### A. Microscopic simulator VISSIM

VISSIM is a simulation tool that is based on a microscopic simulation environment [1]. In microscopic simulations each entity (car, truck, train, pedestrian, etc.) is simulated on an individual level. It means that each of the entities in simulation is represented with a separate entity with all of its associated attributes. The latter describes the behaviour characteristics of a single vehicle pair in traffic flow, with assumption that such behaviour can be applied to every other pair of vehicles. For this reason vehicle parameters that describe motion of each vehicle type are used (e.g. speed, headways and distances).

### B. Emissions simulator EnViVer

EnViVer is a software based on the VERSIT+ exhaust gas emissions model [2]. It enables researchers to study the exhaust emissions of traffic simulations results obtained in the simulator VISSIM. For this VISSIM simulation results (speeds, accelerations, number of vehicles, vehicle types and traffic flow data) are forwarded into EnViVer and then EnViVer calculates the exhaust emissions of the simulated traffic flows. EnViVer can calculate the emission rates of several different exhaust gasses ($CO_2$ and $NO_X$) and particle matter.

## V. Simulation results

In this section the chosen VSLC controllers will be evaluated in comparison with the case of no VSLC regarding their impact on the traffic flow and the environment. To measure the LoS appropriate measures of effectiveness (MoE) have to be chosen. In this paper $TT$ and total time spend ($TTS$) are used for traffic related LoS. $TT$ is a simple measure that can answer the question of how much time one vehicle needs to travel through an observed highway stretch. This measure is related to mainstream traffic only. $TTS$ represents the amount of time spent by all of the vehicles on the motorway. For the environmental part vehicle emission regarding carbon dioxide ($CO_2$), nitrogen oxides ($NO_X$) and particulate matter with a mean diameter of 10 $\mu m$ ($PM10$) are used.

### A. Traffic model and traffic flows

As mentioned, the motorway simulation model contains three main lanes and is divided into four cells (Fig. 1). VSLC is applied within cells: $L_1$ (1 $km$), $L_2$ (0.7 $km$), and

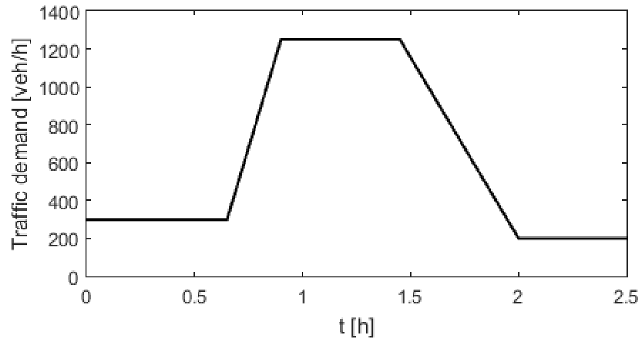


Figure 5. Traffic demand on ramp $r_2$

$L_3$ (0.8 $km$), while the last cell $L_4$ (2 $km$) is without VSLC. The main traffic flow is defined by a constant traffic demand of 4200 $[veh/h]$ during whole simulation. One on-ramp $r_1$ with constant traffic demand of 1250 $[veh/h]$ is located in cell $L_2$. Cell $L_3$ has an off-ramp $s_1$ that outputs 5 % of traffic flow on that section of the motorway (main traffic flow and the inflow from the first on-ramp). A second on-ramp $r_2$ is in the section $L_4$ whose traffic demand changes as shown in Fig. 5.

### B. Obtained traffic parameters

Impact of VSLC on the traffic parameters of the main flow is shown in Fig. 9. The cell $L_1$ is not shown due to negligible changes in traffic flow by applying VSLC and without it. The most significant changes and impact of VSLC can be seen in cells $L_3$ and $L_4$. On the density graph for cell $L_3$ the effect of VSLC is evident with actions that actively keep the density of traffic flow within acceptable values (in our case the critical density is 30 $[veh/km/lane]$). This is specially the case for the MVM controller. By maintaining the density of traffic flow within the acceptable value a higher average traffic flow speed is achieved. VSLC based on MVM has led to a considerable increase in the speed of traffic flow in the cell $L_4$ also. In evaluation of travel time, results were obtained for $TT$ in $[s]$ and for $TTS$ in $[veh{\cdot}h]$. Obtained results are shown in Table I.

In Figs. 4 and 6 the output value of the speed limit controllers sent on VMS throughout the simulation is shown. Both speed limit controllers induce lower speeds of the mainstream flow in time of higher on-ramp demand, what consequentially

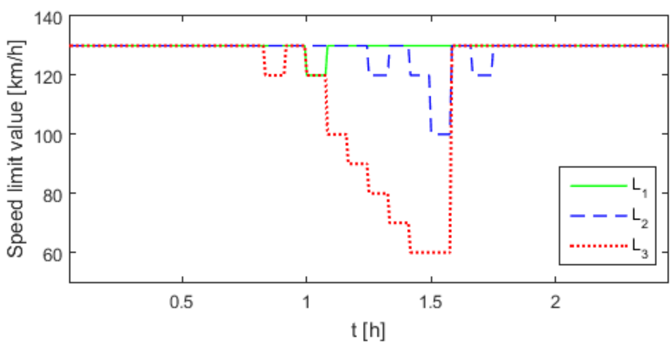


Figure 4. Activation intervals of MVM

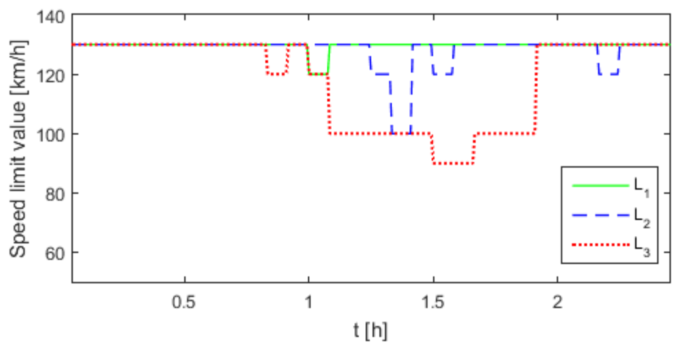


Figure 6. Activation intervals of SPSC

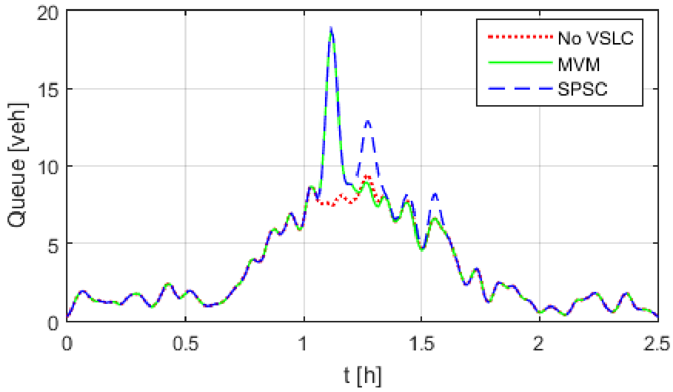


Figure 7. Queue at on-ramp $r_2$

TABLE I
OBTAINED TRAFFIC MOE

| | No VSLC | MVM | SPSC |
|---|---|---|---|
| Maximal $TT$ $[s]$ | 228 | 205 | 216 |
| Average $TT$ $[s]$ | 160 | 151 | 156 |
| $TTS$ $[veh \cdot h]$ | 716 | 675 | 701 |

produced longer on-ramp queues. This effect for the on-ramp $r_2$ can be seen in Fig. 7 and presents a drawback of VSLC. But overall LoS measured with $TTS$ improves with VSLC applied as given in Table I.

### C. Vehicle emissions

As mentioned, exhaust gases that where measured are $CO_2$ and $NO_X$, and harmful particles that where measured are $PM10$. To analyze the obtained results, a comparison of obtained results with and without the use of VSLC has been made as shown in Table II. It can be noticed that application of VSLC reduces vehicle emissions. In Fig. 8 it is possible to observe the spatial distribution of $PM10$ exhaust emissions on the observed motorway stretch. Exhaust emissions for other examined gases are equivalent so there are not shown here. It is possible to conclude that higher values of exhaust $PM10$ emissions are most noticeable on motorway parts after the on-ramps. These motorway parts are known under the term downstream bottlenecks and they are characterized by lower speeds due to interactions of on-ramp and mainstream flow followed by higher speeds due to vehicle accelerations after successful merging of the main and on-ramp flow.

### D. Discussion about simulation results

Work principle of both VSLC controllers is essentially based on the timely detection of congestion in traffic flow and taking a preventive action by changing the speed limit. All with the aim to keep the traffic parameters within acceptable values. Applying VSLC, density of traffic flow in the cell $L_3$ during peak load across the on-ramp was maintained within acceptable limits. In the case without VSLC, density in the cell $L_3$ significantly exceeds the value $\rho_c$. By reducing such significant changes of traffic flow density, formation of major congestions is prevented. This avoids sudden deceleration and acceleration of vehicles, resulting in reduced fuel consumption and lower exhaust emissions. The MVM controller shows better results regarding vehicle emission reduction of 3 % and 1.3 % compared to the case without VSLC. Improvement has been achieve in $TT$ also where the application of the MVM VSLC achieved shorter travel time with the value of 151 $[s]$, which represents an improvement of 6 %. Regarding $TTS$, an improvement of around 6 % with the amount of 675 $[veh \cdot h]$ has been achieved in the case of the MVM controller. The SPSC also improves $TT$, $TTS$ and vehicle emissions. But in somewhat lower values then the MVM controller.

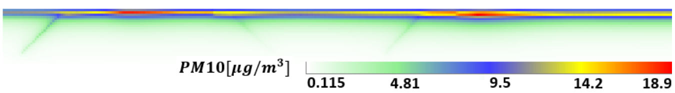


Figure 8. Spatial distribution of $PM10$ exhaust emissions on the observed motorway stretch

## VI. CONCLUSION AND FUTURE WORK

Despite that motorways are build for higher LoS, traffic congestion can occur (specially on urban motorways) and consequently reduce the LoS on a particular stretch of the motorway. Higher LoS can be achieved by affecting the observed motorway section fundamental diagram. One of the used control approaches for affecting the mentioned fundamental diagram is VSLC. By reducing the mean speed on the motorway mainstream lanes, VSLC enables speed homogenization and consequently reduces traffic congestions and air pollution, and induces a smaller possibility of traffic accidents.

In this paper a comparison of two controllers for VSLC is given. Simple reactive speed limit controllers MVM and SPSC are compared in a scenario with and without VSLC. Comparative analysis is conducted on a motorway stretch that contains two on-ramps and one off-ramp. Results show that both VSLC controllers increase the LoS regarding traffic and environmental parameters compared to the situation with no VSLC applied. Increased LoS consequentially reduces exhaust emissions on the overall observed motorway stretch. The MVM controller produces better results regarding LoS and exhaust emissions compared to the SPSC controller. These results are directly confirming that VSLC can alleviate traffic congestion. Of course, under the assumption that vehicles comply to the imposed speed limit.

Future work on this topic will include an extension of the simulation framework that will enable simulation of different compliance rates of drivers to the imposed speed limit. Additionally, more complex control laws based on optimal control and machine learning will be developed with emphasis on a criteria function containing traffic safety parameters also.

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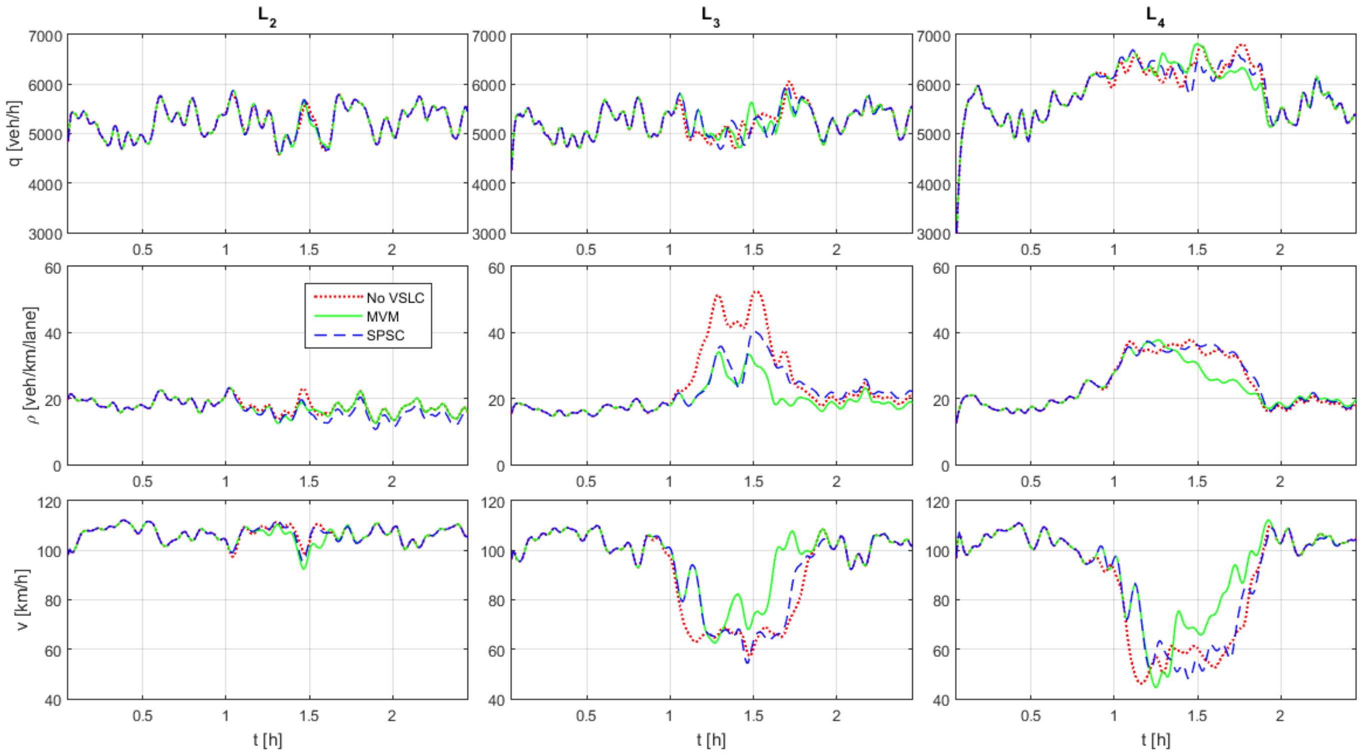


Figure 9. Obtained flow, density and average speed in sections $L_2$, $L_3$ and $L_4$

TABLE II
OBTAINED VEHICLE EMISSIONS

| **Emission type** | **No VSLC** | **MVM** | | **SPSC** | |
|---|---|---|---|---|---|
| | | **Obtained** | **Reduction**[%] | **Obtained** | **Reduction** [%] |
| $CO_2$ | $15.42 \cdot 10^6\ g$ | $14.98 \cdot 10^6\ g$ | 2.85 | $15.21 \cdot 10^6\ g$ | 1.36 |
| | $6.167 \cdot 10^6\ g/h$ | $5.994 \cdot 10^6\ g/h$ | 2.81 | $6.084 \cdot 10^6\ g/h$ | 1.35 |
| | $223.5\ g/km$ | $217.2\ g/km$ | 2.82 | $220.5\ g/km$ | 1.34 |
| $NO_X$ | $42.53 \cdot 10^3\ g$ | $41.16 \cdot 10^3\ g$ | 3.22 | $41.78 \cdot 10^3\ g$ | 1.76 |
| | $17.01 \cdot 10^3\ g/h$ | $16.46 \cdot 10^3\ g/h$ | 3.23 | $16.71 \cdot 10^3\ g/h$ | 1.76 |
| | $0.6164\ g/km$ | $0.5966\ g/km$ | 3.21 | $0.6056\ g/km$ | 1.75 |
| $PM10$ | $3080\ g$ | $3040\ g$ | 1.30 | $3068\ g$ | 0.39 |
| | $1232\ g/h$ | $1216\ g/h$ | 1.30 | $1227\ g/h$ | 0.41 |
| | $0.04465\ g/km$ | $0.04407\ g/km$ | 1.30 | $0.04447\ g/km$ | 0.40 |

## REFERENCES


[1] PTV Group, "PTV Vissim simulation software." http://vision-traffic.ptvgroup.com. [accessed 05 December 2015.].

[2] TNO, "EnViVer simulation software." http://www.tno.nl/. [accessed 11 January 2016.].

[3] Mathworks, "MATLAB/SIMULINK computing platform." http://www.mathworks.com. [accessed 20 Novmeber 2015.].

[4] J. Barcelo, ed., *Fundamentals of Traffic Simulations*. Springer Science Business Media, LCC., 2010.

[5] M. Gregurić, M. Buntić, E. Ivanjko, and S. Mandžuka, "Improvement of highway level of service using ramp metering," in *Proceedings of ISEP2013*, (Ljubljana, Slovenia), pp. R14–pages 6, 2013.

[6] M. Papageorgiou, E. Kosmatopoulos, and I. Papamichail, "Effects of variable speed limits on motorway traffic flow," *Transportation Research Record*, vol. 2047, pp. 37–48, 2008.

[7] P. Rama and A. Schirokoff, "Effects of weather-controlled variable speed limits on injury accidents," in *18th International Cooperation on Theories and Concepts in Traffic Safety*, (Helsinki, Finland), 2005.

[8] A. Hegyi, S. P. Hoogendoorn, M. Schreuder, H. Stoelhorst, and F. Viti, "Specialist: A dynamic speed limit control algorithm based on shock wave theory," in *11th International IEEE Conference on Intelligent Transportation Systems*, pp. 827–832, Oct 2008.

[9] M. Hadjipollas, M. Lestas, O. Ioannou, G. Hadjipollas, and A. Pitsillides, "Evaluation of new ramp metering and variable speed limit algorithms on the Cyprus Highway Network," *International Trade and Freight Transportation Conference (ITFTC2008)*, pp. 171–177, 2008.

[10] M. Papageorgiou, H. Hadj-Salem, and J.-M. Blosseville, "ALINEA: A local feedback control law for on-ramp metering," *Transportation Research Record*, no. 1320, 1991.

[11] M. Gregurić, E. Ivanjko, N. Korent, and K. Kušić, "Short review of approaches for variable speed limit control," in *International Scientific Conference Perspectives on Croatian 3pl Industry in Acquiring International Cargo Flows ZIRP2016*, (Zagreb, Croatia), pp. 41–52, 2016.

[12] I. Grabec, "Forecasting of traffic jams at disturbed sections of highways," *Journal of Applied and Computational Mathematics*, vol. 3, no. 168, 2014.