HRVOJE PANDŽA, mag.ing.traff.
E-mail: pandzah@hotmail.com
Slavka Stolnika 19, Sesvete, HR-10360 Zagreb
MIROSLAV VUJIĆ, Ph.D.
E-mail: miroslav.vujic@fpz.hr
EDOUARD IVANJKO, Ph.D.
E-mail: edouard.ivanjko@fpz.hr
University of Zagreb
Faculty of Transport and Traffic Sciences
Vukelićeva 4, HR-10000 Zagreb, Republic of Croatia

A VISSIM BASED FRAMEWORK FOR SIMULATION OF COOPERATIVE RAMP METERING

ABSTRACT

Due to the increase of vehicle numbers in recent decades, there exists a significant problem of reoccurring road traffic congestion. Such congestions are a characteristic of densely populated urban areas. They occur daily during the morning and afternoon rush hours. The road traffic congestion problem can be solved by applying new traffic control approaches from the domain of intelligent transportation systems (ITS). One of the applied services from the domain of ITS related to road traffic management is known as ramp metering. It is used to increase the throughput of urban highways with many nearby on- and off-ramps. In order to obtain better control results, several nearby on-ramps are combined together into a cooperative control system. Prior to implementation, such cooperative traffic control systems have to be tested in simulations using appropriate traffic data. One of the simulator tools, which can be used for this task, is VISSIM. It enables a microscopic simulation of road traffic and the implementation of various approaches for traffic control. In this paper the VISSIM simulator is used to implement a framework for simulation of cooperative ramp metering between two nearby on-ramps. The implemented framework is tested using traffic demand values characteristic for rush hours.

KEY WORDS

Ramp metering; cooperative control; microscopic simulation; VISSIM; urban highways

1. INTRODUCTION

The increase of the number of vehicles in urban environments in the recent decades created significant problems with daily congestions in road traffic. Such congestions reoccur regularly in so called rush hour periods. There are usually two rush hour periods. The first one is in the morning when people travel to their working and education places and the second one is in the afternoon when people travel back to their homes. Classical solution to this problem is in expansion of the existing road infrastructure. But such an approach only attracts more vehicles increasing the problem. Today new traffic control approaches from the domain of intelligent transportation systems (ITS) are used in order to ensure the optimal usage of the existing infrastructure. One of the application areas are urban highways with many nearby on- and off-ramps. Problem is that in rush hours a bottleneck can occur in the area near an on-ramp. That can create a congestion shock-wave on the mainstream, which propagates upstream closing nearby upstream on- and off-ramps. Additionally, a queue on the on-ramp can occur that can overspill on the adjacent urban arterial roads. The described situation is presented in Fig. 1.

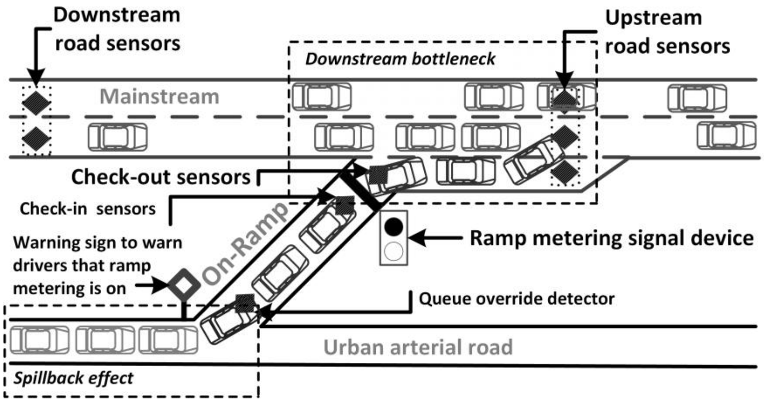

Figure 1 - Illustration of potential problems near an on-ramp [4]

To prevent the creation of or to reduce the congestion on the mainstream and the queue length on the on-ramp, the on-ramp can be equipped with a traffic light. This traffic light reduces the number of vehicles, which enter the mainstream, preventing so the congestion build-up. Such a control structure is called ramp metering (RM) and is usually implemented on urban highways with increased traffic demand. RM implementations are generally simulated by using various traffic simulation programs with the ability to simulate interaction of all existing traffic flows in a highway system. Traffic simulators can be divided into two major categories: macroscopic and microscopic [1]. Macroscopic simulators compute cumulative traffic flow parameters (e.g. speed, flow, and density) and their relationships to each other according to traffic flow equations. Individual vehicles are not considered. Most used macroscopic simulators are: CTMSIM, FREFLO, AUTOS, METANET and VISUM. Microscopic simulators continuously or discretely compute parameters (e.g. position, speed, maximum acceleration rate, etc.) of every individual vehicle during simulation. Most used microscopic simulators are: PARAMICS, MITSIM, CORSIM, VISSIM, AIMSUN and TRANSIM.

In order to obtain simulation results, which correspond to the real world situation, an appropriate simulation framework has to be used. In this paper the microscopic simulator VISSIM is used, since it can simulate different behaviour of each individual driver of a road vehicle. Each vehicle is simulated as an individual entity and so more realistic simulation results can be obtained. This property makes VISSIM suitable for simulation of urban highways with RM on their on-ramps. To alleviate the creation of various simulation setups, a framework has been proposed in this paper. It consists of an urban highway model including traffic data and the control logic. With such a framework, each part can be changed separately and reused in other simulations. This is important when the control logic has to be adjusted to a particular highway segment. In this paper a cooperative control logic is implemented in the framework. It consists of two levels. A low level that contains a local RM algorithm (ALINEA in this paper) for each on-ramp in cooperation and a high level logic that enables cooperation between on-ramps.

This paper is organized as follows. Second Section describes the concept of RM and cooperative control in RM. The third Section presents the basic features of the VISSIM simulation environment used in this paper. Following fourth Section describes the proposed framework for simulation of cooperative RM. The fifth Section presents the simulation model and obtained results. Paper ends with a conclusion and future work description.

2. COOPERATIVE RAMP METERING

Main goal of RM is to reduce the impact of a downstream bottleneck on the mainstream highway traffic. In order to accomplish this, RM uses special traffic lights at on-ramps to control the rate or size of vehicles platoons entering mainstream traffic according to current traffic conditions [5]. While reducing the downstream bottleneck, RM may cause the traffic to spill over into feeder arterial roads as the on-ramp queue length increases. This situation occurs especially when the mainstream highway traffic flow is high [6]. Location of the downstream bottleneck close to the on-ramp and the spillback effect on the adjacent local urban road network is given in Fig. 1. Furthermore, Fig. 1 presents a general local RM system installation on an urban highway. Most important part of the RM system is the algorithm that determines the "access rate reduction" for the on-ramp flow [5].

Traffic light used on the on-ramp contains only the red and green light. So, only two phases exist in the signal plan. The duration of the green light phase is usually fixed so only one or two vehicles can leave the on-ramp. Usually 3 to 6 seconds are used. In order to determine the access rate, the duration of the red phase has to be obtained by the RM algorithm. RM is effective only when increased traffic demand is present. During night time and other very low traffic demand periods it is usually turned off. In such periods, the traffic light generates only an unnecessary delay when a vehicle wants to enter mainstream traffic.

Effectiveness of RM is measured by its influence on the level of service (LoS) of the controlled part of the urban highway. LoS is defined as a group of qualitative measures that characterize operational conditions within traffic flow and their perception by motorists and drivers [3]. Basic measure of service quality for RM is travel time (TT). TT is a simple measure that describes the time that one vehicle needs to travel through the observed highway part. The observed highway part is usually divided on several segments during the modeling process. TT is measured in minutes and computed using equation (1):

$$TT = T \sum_{i=1}^{N} 60 \frac{L_i}{v_i}, \tag{1}$$

where $v_i(k)$ denotes the traffic density on the highway segment *i*, L_i is the length of segment *i*, *N* is the total number of segments, and *T* is the simulation step in seconds. An unusual high value of TT is a clear sign for the LoS quality drop for the examined highway. Apart from TT, the average speed on the mainstream will be used in this paper as an additional LoS measure for the evaluation of the obtained simulation results.

2.1 The ALINEA algorithm

The ALINEA algorithm is a local strategy for RM [2]. Local strategies include RM algorithms that take into account only the traffic condition on a particular on-ramp and its nearby highway segment. The traffic condition on other nearby on-ramps is not taken into account so unwanted interaction between adjacent on-ramps can occur. ALINEA is the most often used standard local RM algorithm. This is because of the ALINEA's optimal ratio between simplicity and efficiency. Core concept is to keep the downstream occupancy of the on-ramp at a specified level by adjusting the metering rate (amount of vehicles allowed to enter mainstream). Specified level of downstream occupancy is called the occupancy set-point *O*. Its value is slightly lower or equal to the occupancy at the maximum downstream capacity [2]. The resulting metering rate can be obtained by the following equation:

$$r(k) = r(k-1) + K_R[O - O_{out}(k)], \quad (2)$$

where *r(k)* is the current metering rate, *r(k-1)* is the metering rate from the previous iteration, K_R is the regulating parameter, and O_{out}*(k-1)* is the measured downstream occupancy from the previous iteration. Recommended value for K_R is 70 [veh/h]. ALINEA has numerous enhanced versions and is used as part of many other local and coordinated RM approaches. Basic working principle of the ALINEA algorithm is shown in Fig. 2.

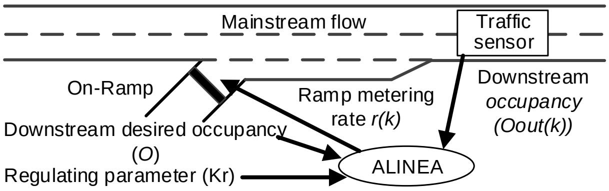

Figure 2 - Scheme of the basic working principle of ALINEA

2.2 Cooperation between on-ramps

A cooperative control system is defined as a set of control entities that share information and/or tasks to accomplish a common, though perhaps not singular, objective. Cooperation in RM is achieved by exploiting adjacent on-ramp's queueing capacities in order to perform effective mitigation of congestion related to a particular area with several close on-ramps. As mentioned, in such a highway network configuration there exists the risk that mainstream congestion originating from an on-ramp can cause severe congestion that includes one or more upstream on-ramps. Such upstream congestion propagation closes also the access of mainstream vehicles to upstream off-ramps enlarging the congestion problem.

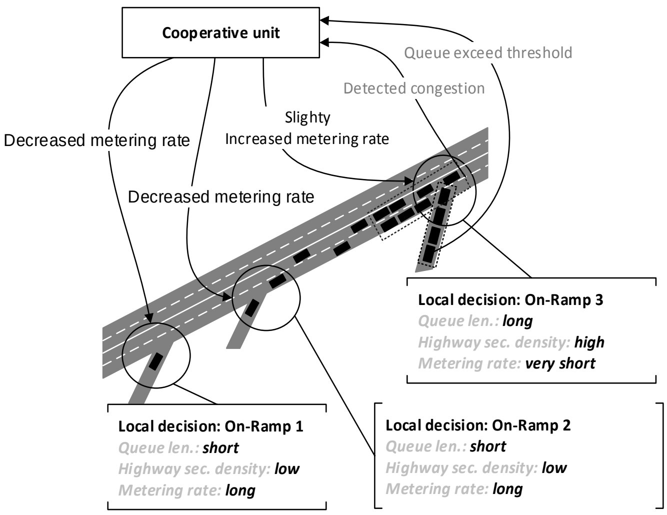

Figure 3 - Basic functionality of cooperative RM algorithms

Cooperation between on-ramps demands that several local traffic responsive metering algorithms communicate with a central cooperative unit. The central unit has an override possibility, i.e. it can alter the local metering rate for each on-ramp. Cooperative algorithm in the centralized operational unit uses a control logic, which exploits the queuing capacity of upstream on-ramps, to reduce the queue length on the congested one. In order to compute and adjust the values of metering rates computed by local RM algorithms, the cooperative algorithm uses the overall highway traffic information and mentioned control logic. Basic working principle of cooperation between several on-ramps can be seen in Fig. 3 that presents a part of a highway with three on-ramps. In the area near the third on-ramp congestion started to build-up. The high level cooperative unit obtains this information and changes the RM rate of the upstream on-ramps to decrease the number of vehicles entering the mainstream. In such a way a time period of decreased traffic demand can be created enabling the congestion to resolve or to prevent further congestion build-up.

3. CHARACTERISTICS OF THE VISSIM SIMULATOR

In order to test traffic control algorithms accurately, an appropriate simulation model of the corresponding transport network has to be used. To build a model for the simulation of a road transport network, one has to gather data about the roads (number of lanes, road segment lengths, crossroad configuration, etc.) and vehicles travelling through the road network (origin-destination matrices, percentage of cars and trucks, characteristics of driver behavior, etc.). The accuracy and validity of a simulation model mostly depends on the quality of gathered traffic data and behavior of vehicles in the simulated traffic network. In this paper, the VISSIM simulation tool was used. It is a simulation tool for modeling of urban traffic networks on a microscopic level. Unlike other simulation tools, which use a constant vehicle speed and deterministic logic of pursuing, VISSIM uses a psychophysical model of driver behavior developed by Rainer Wiedemann in 1974 [7]. The basic concept of this model is that the driver of a faster moving vehicle starts to decelerate as he reaches his individual perception threshold to a slower moving vehicle. Since he cannot exactly determine the speed of that vehicle, his speed will fall below that vehicle's speed until he starts to slightly accelerate again after reaching another perception threshold.

VISSIM simulates the traffic flow by moving driver-vehicle units through a road network. The units depend on corresponding vehicle and driver characteristics. Every specific vehicle has a driver assigned with his own specific behavior. So, to each driver-vehicle unit the following attributes are assigned: (i) technical specifications of the vehicle (vehicle length, maximum speed, accelerating power, actual speed and acceleration/deceleration); (ii) behavior of the driver-vehicle unit (psychophysical perception thresholds of the driver, driver's memory, acceleration based on current speed and driver's desired speed); and (iii) interdependence of driver-vehicle units (reference to vehicles in front and trailing vehicles on own and adjacent lanes, reference to next traffic signal).

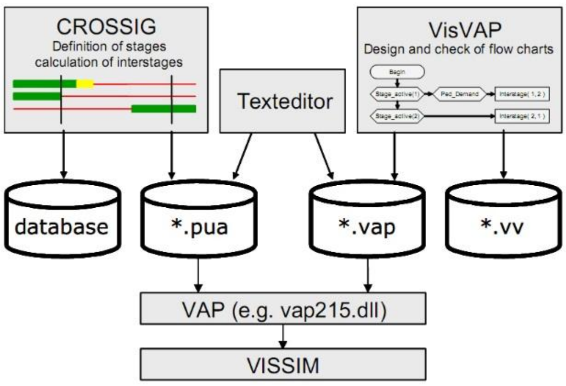

Figure 4 – Components of the VisVAP module [8]

For the development and simulation testing of traffic control algorithms, the add-on module for the VISSIM simulation tool VisVAP (Vehicle Actuated Programming) was used. VisVAP enables the use of object-oriented programming. The logic of the traffic control algorithm is implemented using flowcharts. The layout of the flowcharts and its components is given in Fig. 4. According to Fig. 4, it is evident that it is necessary to create an ASCII database with the extension "pua" that contains information on the number of signal groups, intergreen matrices, definition of signal plans, etc. The next step is the creation of an algorithm in the VisVAP module and after that an ASCII file with the extension "vap" is generated. This file is then loaded into the VISSIM simulation tool. The connection between the "vap" program control and VISSIM are detectors and traffic lights placed in the simulated road network. Using measurements from detectors, the signal plans for traffic lights on a specific crossroad or an on-ramp can be managed in a closed control loop.

4. SIMULATION FRAMEWORK

To create a simulation framework, two main components have to be implemented. First component is a model of the road transport network including corresponding detectors, traffic lights and traffic data. In this paper, an urban highway model has been implemented. The second component is the control logic, which is in this paper an algorithm for RM, with cooperative properties. In continuation this two components are described with more details.

4. 1 Urban highway model

The implemented urban highway model consists of a mainstream part and two on-ramps that feed the mainstream flow as shown in Fig. 5. Mainstream includes a fast and a slow lane, both 5067 m long. On-ramps have only one lane, the first is 710 m and second 713 m long. For simulation purposes, both mainstream lanes have differently defined vehicle speeds and driver characteristics. The fast lane is mostly occupied with cars and faster drivers, and the slow lane with more heavy vehicles and slower drivers. With differently defined vehicle speed and driver behavior, it was possible to make the simulation as realistic as possible. Mainstream is separated in three segments to enable a detailed simulation results analysis. Figure 5 also shows the detector locations that are used for collecting traffic data. Every detector is placed on an optimal position where it can gather relevant traffic data. Traffic volume used in this simulation consists of 98% personal vehicles. Other 2% are heavy vehicles (trucks, busses), which have a lower defined vehicle speed to match the real world situation. Simulation results showed that heavy vehicles had no significant effects.

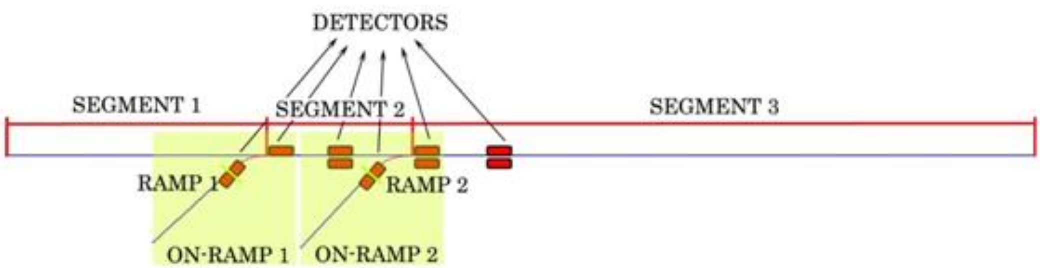

Figure 5 – Simulated road network

4. 2 Control logic for cooperative ramp metering

Used VISVAP module has a specific work logic. Every iteration of the simulation executes the control logic presented with the flowchart in Fig. 6 [9].

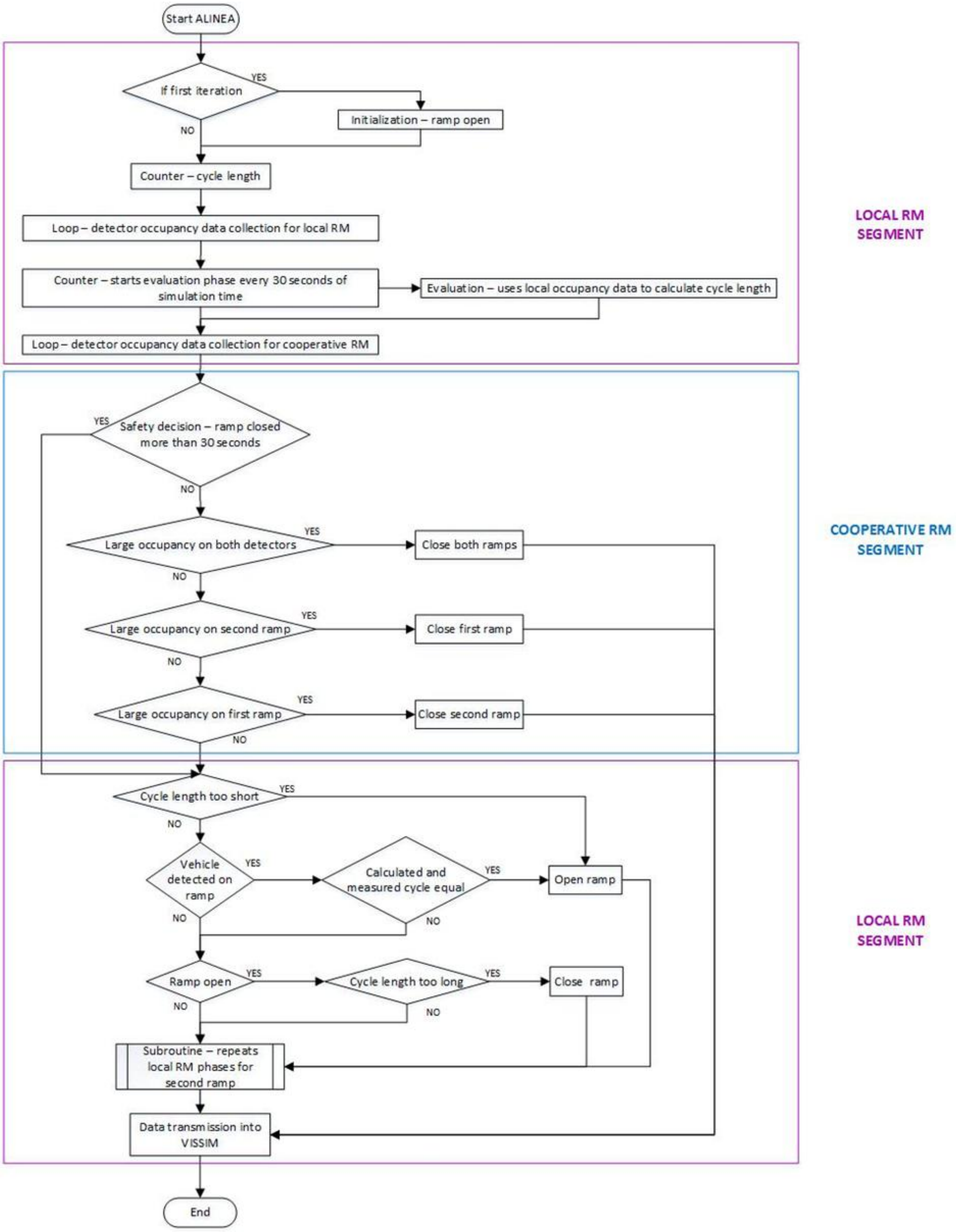

Figure 6 – Control logic framework for the ALINEA based cooperative RM

Only the first iteration uses the initialization phase to set all on-ramps to open. Initialization phase is used to prevent unnecessary waiting on ramps. First counter measures the traffic light cycle length while on-ramps are opened or closed. Every iteration increases this counter by 1. Second counter is used for the traffic light cycle evaluation phase that starts every 30 seconds. This process of evaluation uses local RM data only. First loop collects information about detector occupancy for both lanes. Data collection is carried out in every iteration and collected data are used for local RM. These data are used to obtain the cycle length according to equation 2. The algorithm compares both, calculated and measured cycle length to open or close the on-ramps depending on their mutual ratio.

As the next flowchart segment comes the second loop that collects detector occupancy data for cooperative RM. Cooperative RM has priority over local RM and therefore the algorithm can skip the local RM segment when the cooperative segment is active. This is also the beginning of the cooperative algorithm part. First there is a safety decision that prevents that the on-ramp is closed for too long. Main goal is not to exceed the maximum wait time calculated for real-time traffic flow. Right after the safety decision, the algorithm starts to check conditions regarding the occupancy of both detectors on the mainstream. If both mainstream detectors are largely occupied, the algorithm closes both on-ramps. If only the first detector is largely occupied, the algorithm closes the second on-ramp to prevent the creation of a bottleneck on the mainstream. The same logic is used when only the second detector detects large occupancy. Only this time the algorithm closes the first on-ramp. The cooperative RM segment of the flowchart ends with this condition.

Last segment starts with the cycle length decision. If the cycle length is too short, the on-ramp is opened and the algorithm starts the subroutine phase. However, if the cycle length is not too short the algorithm checks for vehicle presence on the on-ramp. If there is a vehicle detected, and the calculated and measured cycle are equal, the algorithm opens the on-ramp and immediately starts the subroutine phase. Otherwise, the algorithm starts the third decision branch where the on-ramp closes if it is currently open and the cycle length is too long. After that the subroutine phase is invoked. Mentioned subroutine phase repeats the whole local RM segment for the second on-ramp. Last step of the algorithm sends values of every variable into the VISSIM simulation module so it can compute the next iteration of the simulation.

5. SIMULATION RESULTS

The proposed framework was tested using the above described simulation model and control logic. Three different scenario with the same traffic demand data were used to evaluate the influence of local and cooperative RM. Obtained results where compared according to average speed and travel time on the mainstream. Used traffic data and results are described with more details in continuation.

5. 1 Traffic data and simulation scenarios

To obtain realistic simulation results of the implemented local and cooperative RM algorithm, the simulation model used traffic flow characteristics, which contain low and high traffic demand, as presented in Fig. 7. Traffic flow on the mainstream is changing like in real world situations while traffic volume for both on-ramps was set to constant values to simulate a rush hour situation. During rush hours there is a common situation that the on-ramps have long queues of vehicles giving constant inflow to the mainstream. Simulation time was set to 1 hour and mainstream traffic flow changed every 5 minutes. Mainstream flow starts with a value of 2000 veh/h, after 30 minutes it reaches its peak of 7000 veh/h and starts to decrease. Traffic flow for the first on-ramp was set to 1500 veh/h and for the second to 1100 veh/h.

To test the implemented framework, simulations of the same urban highway model where conducted using three different scenarios. First scenario represents a traffic situation without RM applied. In this scenario, vehicles from the on-ramps have to merge with the mainstream without any help from a traffic control system. The second scenario uses local RM to alleviate the congestion on the highway by limiting vehicle inflow from the on-ramps. In the third scenario, communication between the two on-ramps was enabled to test the cooperative part of the implemented RM algorithm.

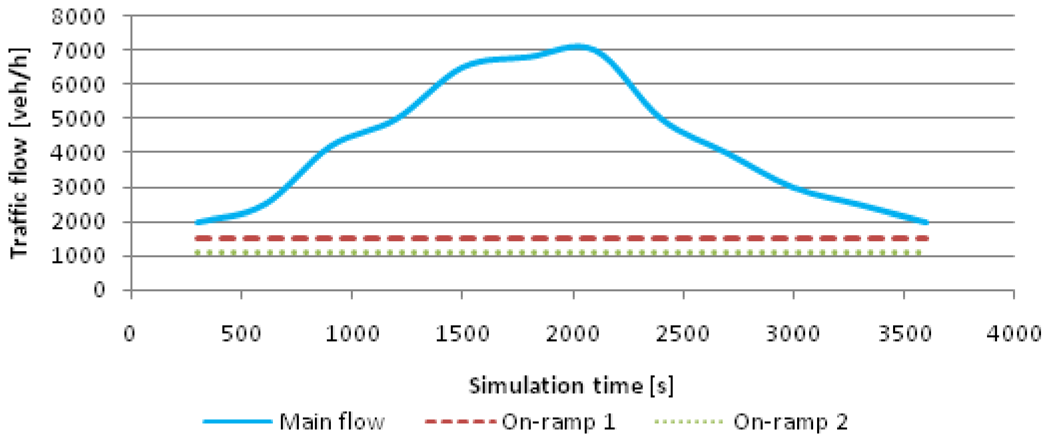

Figure 7 – Traffic flow characteristics for the mainstream and on-ramps

5.2 Obtained results and discussion

As denoted in Fig. 5 the modeled highway section is divided into segments. This enables better evaluation of simulation results using measurement data from the detectors in the simulation model and other data gathered by VISSIM. For example, average traffic flow speed can be gathered and analyzed for every lane separately. In Figs. 8 to 10 the average speed on the corresponding segments of the highway is given for the slow (right) lane. Same characteristics can be obtained for the fast (left) lane [9] but are not presented here due to page limitation. From these figures it can be noticed that application of RM increases the average speed on the first two segments. Thereby, cooperative RM shows a significant larger speed increase and a shorter duration of the congestion on the highway. Congestion starts later and resolves faster on the first two segments. This property can be detected by observing the moment when the speed begins to decrease significantly and the moment when the speed begins to return to its starting value. The third segment is located after the area where congestion happens so RM does not affect the average speed on this segment significantly. In this segment vehicles accelerate after they have left the congestion area and this behavior is the same for all scenarios.

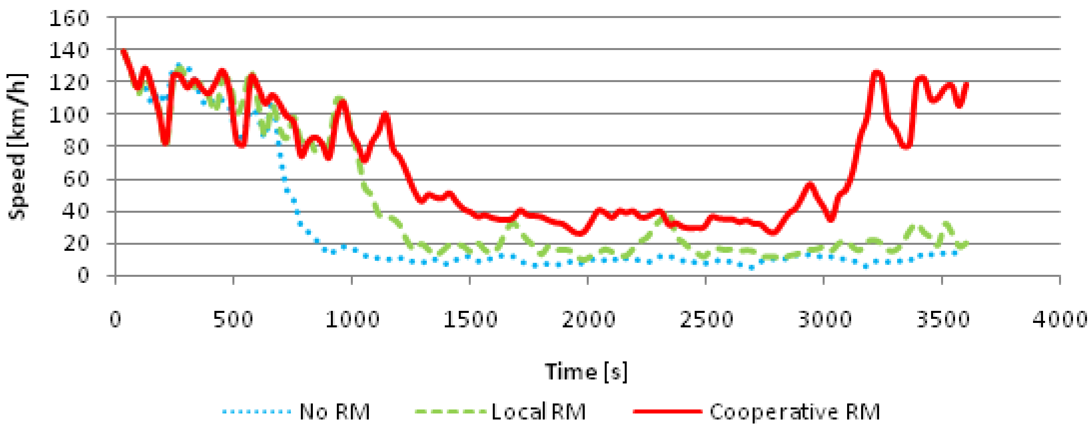

Figure 8 – Slow lane speed for the first segment

In Table 1 the average vehicle speed values are given for both lanes. It can be denoted that congestion significantly reduces the average speed on booth lanes. The speed drop is more profound on the slow lane that accepts the vehicles from the on-ramps. According to the results given in Table 1, one can conclude that RM can increase the average speed on the mainstream. This effect is even more pronounced in the case of cooperative RM. Similar result can be observed in Table 2 where average travel times for the mainstream for all three scenarios are given. The effect of smaller speed decrease and shorter congestion duration also significantly reduces travel time when cooperative RM is applied.

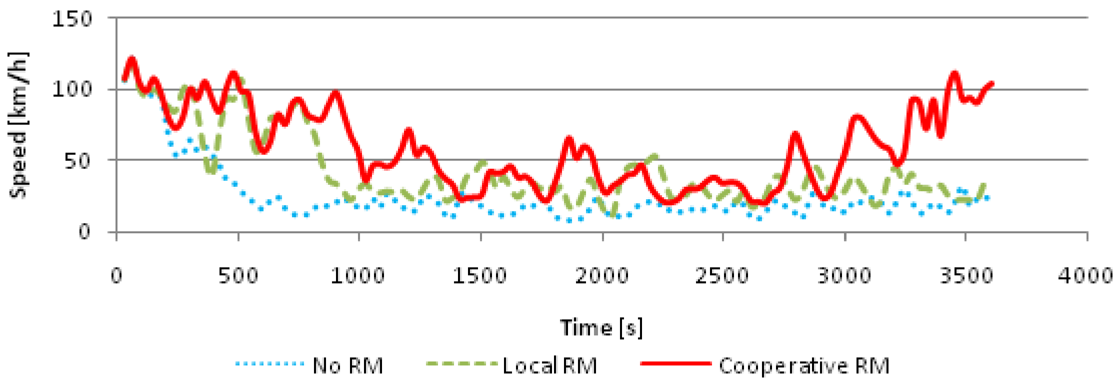

Figure 9 – Slow lane speed for the second segment

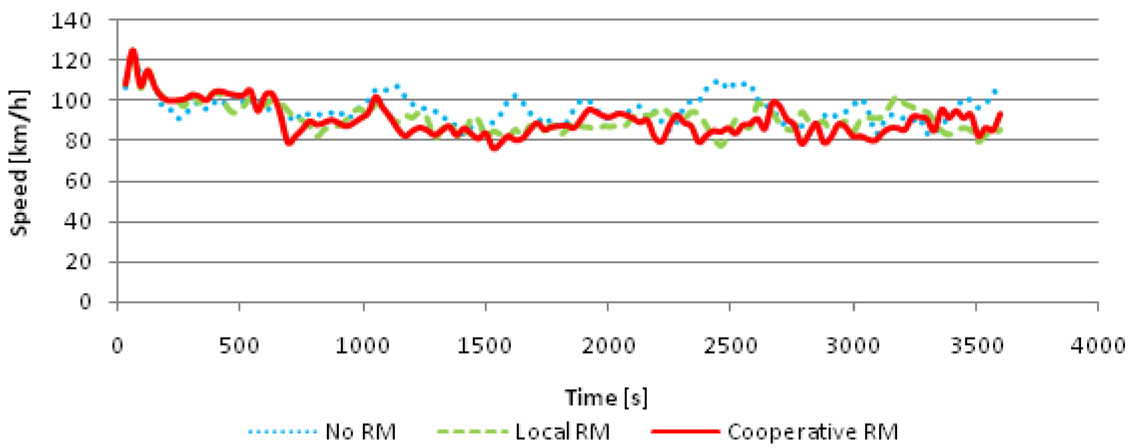

Figure 10 – Slow lane speed for the third segment

Table 1 - Average vehicle speed on the slow lane in km/h

Scenario	**Segment 1**		**Segment 2**		**Segment 3**	
	Slow lane	Fast lane	Slow lane	Fast lane	Slow lane	Fast lane
No RM	30.32	42.66	25.06	40.86	96.42	98.82
Local RM	44.00	53.74	43.66	53.45	91.24	93.46
Cooperative RM	69.11	72.54	59.44	67.01	90.26	92.14

Table 2. Average travel time on the highway

Scenario	**Main flow**
No RM	436.35 s
Local RM	380.86 s
Cooperative RM	263.59 s

6. CONCLUSION

In this paper a framework for simulation of cooperative RM for the microscopic simulator VISSIM is proposed and implemented. The framework consist of a road network model with corresponding detectors and traffic lights, traffic data for simulation and a control logic implemented in the VisVAP module. By adapting the traffic light signal plan and using only two phases (red and green) the simulation of RM is enabled. To test the framework a simulation model of an urban highway with two on-ramps has been created. Three simulation scenarios were defined and obtained results were compared according to average speed and travel time. Obtained results verify that the proposed framework can simulate RM systems and enable a deeper analysis of the implemented traffic control system prior its application on a real world system.

Future work on this topic will include augmentation of the framework with a module that enables implementation of advanced traffic control algorithms in the programming language C#. Additionally, variable speed limit control will be added into cooperation with the RM control system.

Acknowledgment

The research reported in this paper is partially funded by the FP7 - Collaborative Project: Intelligent Cooperative Sensing for Improved traffic efficiency - ICSI (FP7-317671), the University of Zagreb Faculty of transport and traffic sciences, and by the EU COST action TU1102 Towards autonomic road transport support systems.

REFERENCES

[1] Gregurić, M., Ivanjko, E., Mandžuka, S.: *Cooperative ramp metering simulation*, 37th International convention on Information and Communication Technology, Electronics and Microelectronics - MIPRO 2014, 26.–30. May, 2014.

[2] Papageorgiou, M., Hadj-Salem, H., Blosseville, J. M.: *ALINEA: a Local Feedback Control Law for Onramp Metering.* Transportation Research Record, 1320, pp. 58-64, 1991.

[3] Treiber, M., Kesting, A.: *Traffic flow dynamics*, Springer-Verlag, Berlin Heidelberg, 2013.

[4] Gregurić, M., Ivanjko, E., Galić, I., Mandžuka, S., Gold, H.: *Urban Highways Level of Service Improvement Based on Intelligent Ramp Metering*, Proceedings of 25th

International Central European Conference on Information and Intelligent Systems, CECIIS2014, Varaždin, Croatia, 17.–19. September, pp. 296-303, 2014.

[5] Papageorgiou, M., Kotsialos, A.: *Freeway ramp metering: An overview*, Proceedings of IEEE 5th Intelligent Transportation Systems Conference, pp. 271-281, Oakland, California, USA, 2002.

[6] Esposito, M. C., Polak, J. W., Krishnan, R., Pleydell, M.: *A Global Comparison of Ramp-Metering Algorithms Optimizing Traffic Distribution on Motorways and Arterials*, Road Transport Information and Control Conference and the ITS United Kingdom Members' Conference – RITC 2010, pp. 1-6, London, UK, 2010.

[7] Higgs, B., Abbas, M., Medina, A.: *Analysis of the Wiedemann Car Following Model over Different Speeds using Naturalistic Data*, 3rd International Conference on Road Safety and Simulation, Indianapolis, Indiana, USA, 2011.

[8] PTV – Planung Transport Verkehr AG: *VISVAP User Manual*, 2005.

[9] Pandža, H.: *Cooperative ramp metering of Zagreb bypass*, Diploma thesis, Faculty of transport and traffic sciences, University of Zagreb, 2014.