New Concepts for Urban Highways Control

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1 ABSTRACT

In recent decades a significant increase in traffic demand has occurred. This trend is especially present in dense populated areas where daily traffic congestions during rush hours occur regularly. Congestions are significant in road traffic where they can simultaneously reduce public transportation level of service (LoS) also. As consequence, even more people are using their car additionally increasing the congestion problem. Classic solution for solving the road traffic congestion problem is infrastructure build up. Today's dense urban areas mostly do not allow this approach because of the lack of available building space. More advanced road traffic control solutions from the domain of intelligent transportation systems (ITS) are being more and more applied to optimally use the existing infrastructure (Papageorgiou et al., 2003.). Such solutions include coordination between several consecutive crossroads, dynamic traffic assignment, driver informing systems, etc. One of the ITS application areas is related to urban highways which present a class of highways used as a city bypass or are just passing a dense urban are. Their main characteristic is that they have a larger number of on- and off-ramps often placed at small distances. Due to the small distance, mutual on-ramp influence can occur enlarging the problems of daily congestions and associated decrease of highway LoS. In order to prevent the appearance of traffic standstill or to reduce its duration control approaches as ramp metering and variable speed limit control (VSLC) are being applied (Hegyi et al., 2010.). In recent years, new cooperative concepts between several on-ramps and VSLC are used as a combined urban highway control system (Ghods et al., 2007.). This paper presents a new learning based cooperative ramp metering strategy in which several well-known ramp metering strategies (ALIENA, SWARM, HERO) are used to create a learning set for an ANFIS (Gregurić et al., 2013.) based control structure. Optimal ramp metering values are obtained for a wide range of traffic demand on the urban highway and belonging on-ramps. Optimal ramp metering values for specific traffic demand characteristics obtained from most suitable ramp metering strategies are integrated into only one control strategy. Thus, the need of applying several ramp metering strategies and switching between them is avoided. Additionally, cooperation between VSLC and vehicle control by an on-board unit is described and a discussion about possible implementation is given. Proposed cooperative urban highway management approach is tested in simulations using the city of Zagreb bypass as case study. For simulation, the macroscopic highway traffic simulator CTMsim (Kurzhanskiy et al., 2008.) is used. Used CTMsim simulator augmented to enable simulation of VSLC and cooperative ramp metering approaches.

2 INTRODUCTION

Nowadays one of the most prominent problems of urban areas is traffic congestion. Traffic congestion can be defined as a condition on road networks that occurs as result of traffic demand increase and is characterized by lower speeds, longer trip times, and increased vehicular queuing. Most pronounced negative impact of traffic congestions are delays in goods delivery, public and personal transport, etc. Delays induced by traffic congestions cause waste of drivers and passengers time, and fuel. Fuel waste consequently produces increased air pollution and transport expenses. Furthermore, delays in public transport schedule and longer trip times cause general dissatisfaction for public transport use. As consequence even more people are using their personal vehicles additionally increasing the congestion problem. There are three main reasons for creation of congestion in urban areas: increased traffic demand in specific interval of a day (rush hours), large number of vehicles owned by residents and inability to expand urban traffic network capacity.

Urban highways are planned to provide bypass of the urban arterial roads by absorbing part of their traffic load. This solution has quickly shown as unsatisfactorily due to further increases in traffic demand and transit traffic, which also burdens urban highway capacity. Residents of urban areas regularly use urban highway to avoid congestion in urban traffic network during daily peak hours. Consequently, that behaviour

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combined with transit traffic at the mainstream commonly causes congestions at on-ramp areas. In other words generally high Level of Service (LoS) projected for urban highways is significantly reduced due to traffic overload. LoS is defined as group of qualitative measures that characterize operational conditions within traffic flow and their perception by drivers (Directive 2010/40/EU).

Nowadays traffic infrastructure cannot anymore track increase in traffic demand because of the lack of available building space. It is imperative to develop effective highway management control methods over the urban highway traffic flows in order to mitigate congestions and restore originally planned LoS. Such traffic management control methods are considered under intelligent transportation systems (ITS). ITS is functionally build as a superstructure of classic transportation system based on advanced optimization of transport processes with use of information-communication infrastructure and devices. This paper describes highway control strategies including ramp metering, prohibiting lane changes and variable speed limit control (VSLC). Additionally, paper proposes novel cooperative approach between them, along with automatic, and semi-automatic control over vehicles near urban highway on-ramps.

This paper is organized as follows. Second section briefly describes problems on urban highways regarding creation of congestions. Ramp metering control methods and its categorization is presented in the third section. Concept of learning based cooperative ramp metering is given in the fourth section. Fifth sections describes cooperation between highway management control methods. Simulation results of the comparative analysis of implemented ramp metering algorithms and VSLC is given in the sixth chapter. Paper ends with conclusion and future work description.

3 PROBLEMS OF URBAN HIGHWAYS

Despite the fact that urban highways are originally planned to provide high LoS, almost every day it is possible to observe traffic congestions or at least traffic slowdowns on them. In spatial and temporal aspects congestions are common in parts of the urban highway near on- and off-ramps during the early morning or late afternoon (Barcelo, 2010.). These types of congestion are known as peak hours. Daily migrations (to and from the place of employment, education, etc.) are the cause of peak hours congestions if they are intense and accurate enough. Periodic congestions such as peak hours are easy to predict and therefore easier to handle. On the other hand, various traffic accidents or events of great public interest (sport events, concerts, sell-outs in malls, etc.) are the sources of non-periodic congestions. Non-periodic congestions usually cause a sudden drop in the traffic throughput of a particular urban highway.

As mentioned earlier, problems with congestions on urban highways are most noticeable near on-ramps. Congestions at urban highways can have one or more following indicators: traffic demand in particular segments of highway exceeds capacity, increased number of accidents and incidents, queues on arterial roads that spill over into the highway or peaks in traffic demand resulting from platooned vehicle entry from on-ramps (Papageorgiou et al., 2003.). Area where on-ramp flow and mainstream are actually coming in interaction is known as downstream bottleneck. In Fig. 1 location of the downstream bottleneck close to the on-ramp and cooperative control infrastructure for ramp metering is given.

Even in case when mainstream is near maximum capacity, it can adopt one or two merging vehicle from on-ramp. However, in cases when platoons of vehicles attempt to do aggressive merging into the mainstream, this action usually leads to turbulences. These turbulences cause mainstream break down and consequently, congestion on highway (Treiber and Kesting, 2013.). Turbulences in the merging zones can also conduct various types of accidents during heavy traffic conditions.

4 RAMP METERING TRAFFIC CONTROL APPROACH

Uncontrolled platooned vehicle entry from on-ramps into mainstream can induce significant slowdowns in mainstream and queues at on-ramps. Highway management method, known as ramp metering, controls interactions between on-ramp and mainstream flow. Ramp metering uses special traffic signals at on-ramps to control the rate or size of vehicles platoons entering mainstream traffic according to the current traffic conditions (Papageorgiou and Kotsialos, 2002.). Awareness of current traffic conditions for particular highway segment (traffic flow, speed and occupancy levels, etc.) is achieved by analysing data collected in real time by road sensors (inductive loops, cameras, etc.). Sensors are usually placed on the on-ramps and on the main road as presented in Fig. 1. Control algorithm, which produces decisions about the amount of on-ramp vehicles that are allowed to merge with mainstream traffic flow, is the core part of ramp metering. It is possible to divide ramp metering algorithms in two major categories or strategies: local (or isolated) and coordinated.

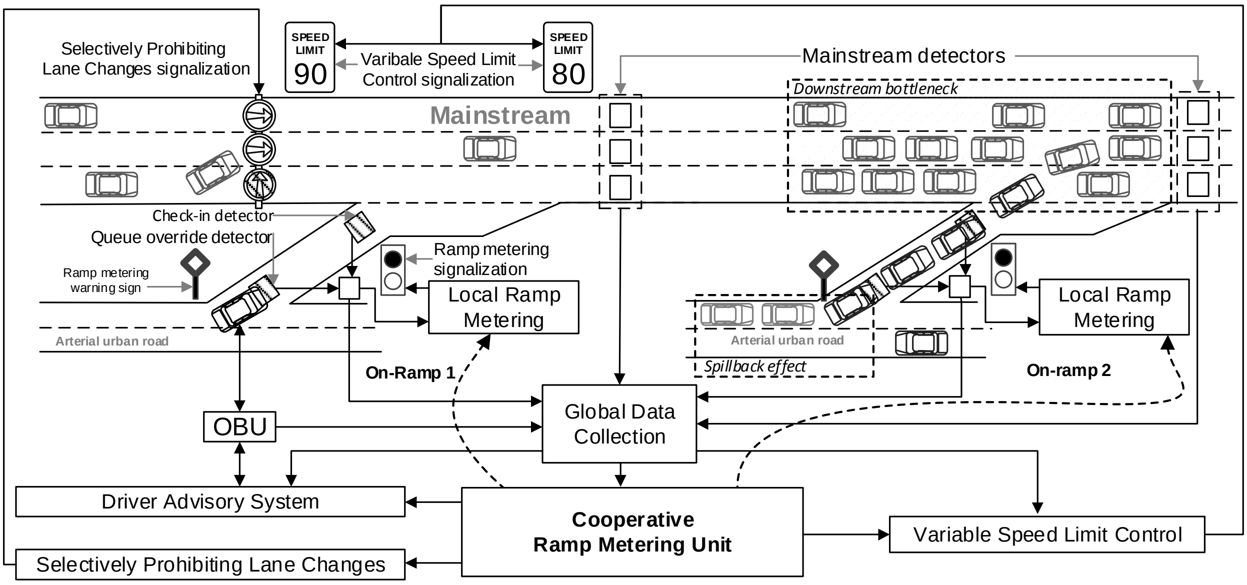

Fig. 1: Illustration of downstream bottleneck location with cooperative ramp metering architecture

4.1 Local Ramp Metering

Ramp metering algorithms categorized as local, take into account the traffic condition on particular on-ramp and nearby segment of urban highway where they are applied. Drawback of local ramp metering algorithms is unawareness of overall traffic situation on the controlled highway segment. One of the first ramp metering algorithms was Demand-Capacity algorithm. Mentioned algorithm uses the downstream occupancy measurement data. If downstream occupancy is above a specified critical occupancy, it is assumed that congestion exist and metering rate is set to the minimum value. Otherwise, metering rate is set according to difference between downstream capacity and the measured upstream traffic volume. Today, most often used local ramp metering is ALINEA. It has optimal ratio between simplicity and efficiency. Core concept of ALINEA is to keep the downstream occupancy of the on-ramp at a specified level by adjusting the metering rate (Papageorgiou et al., 1991.). Main disadvantages of ALINEA are its inability to resolve upstream congestions of the particular ramp and problems to locate optimal detector mounting zone. Modern approaches in local algorithm development include neural networks, which are using their learning capabilities to produce metering plans. Other modern approaches in local algorithm development are based on fuzzy logic and hybrid intelligent systems (Ghods et al., 2007.).

4.2 Coordinated Ramp Metering

Ramp metering algorithms are categorized as coordinated if they take into account the overall highway traffic situation (Hegyi et al., 2005.). According to overall highway traffic state, metering rate for every on-ramp is adjusted. It is possible to divided coordinated algorithms into: cooperative, competitive and integrated algorithms (Papageorgiou et al., 2003.). Usual procedure for cooperative algorithms is to detect bottleneck and enrol several upstream on-ramps to create virtual on-ramp queues. HELPER as the most prominent cooperative ramp metering algorithm is based on a hierarchical structure consisting of local ramp metering units and a cooperative unit. Cooperative unit uses data obtained from local ramp metering units to monitor the completely controlled highway section. If congestion or a long on-ramp queue is detected, it declares the belonging highway section with its on-ramp as master. Furthermore, several upstream on-ramps are declared as slave on-ramps. Slave on-ramps have the role to create virtual queues in order to reduce queue length on the congested on-ramp. Main idea is to exploit their queues capacity in order to mitigate downstream congestions at mainstream.

Competitive algorithms are based on two different control logics. Generally, there are locally and globally based control logics. During ramp metering algorithm execution, local and global control logics provide appropriate solution for current traffic situation. As final ramp metering value the more restrictive one is chosen. System-Wide Adaptive Ramp Metering (SWARM) is the most efficient algorithm in this group. SWARM contains two types of control algorithms: SWARM1 and SWARM2B. SWARM1 algorithm conducts global coordination by taking into account traffic state on each on-ramp. SWARM2B is a local algorithm and defines metering rate according to the difference between current and critical traffic density for a particular on-ramp. Metering rates obtained by local and global algorithm are compared and smaller value is selected.

Integrated algorithms are the most recent developed ramp metering algorithms and are still in experimental phase. Most important part of integrated algorithms is their control module. Control module logic is based on an optimization engine with defined boundaries and a goal that has to be achieved during control period. Typical representatives of these algorithms are METALINE, FHWA/BALL Space, DYNAMIC, and fuzzy logic based algorithms (Hegyi et al., 2005.). Most sophisticated algorithms in that group are algorithms based on fuzzy logic. Fuzzy logic based algorithm can be described as the one type of expert systems for ramp metering (Papamichail et. al., 2010.).

5 LEARNING BASED COOPERATIVE RAMP METERING

Adaptive neural-fuzzy inference system (ANFIS) algorithm is used in order to create a learning based cooperative ramp metering algorithm. ANFIS uses an artificial neural network (ANN) to modify parameters of a Takagi–Sugeno fuzzy inference system. ANN optimizes its interconnection structure trough learning methods and so provides optimization capabilities. Fuzzy inference system (FIS) contains a set of fuzzy IF–THEN rules that have learning capabilities to approximate nonlinear functions (Yu-Sheng et. al., 2010). Reasoning sub-mechanism provide inference procedure upon the fuzzy rules and given inputs to provide reasonable output.

First, it is necessary to define the learning structure and select appropriate procedures for acquiring knowledge to teach the ramp metering algorithm. To cover wide range of traffic scenarios on a particular urban highway three algorithms are chosen in this paper as teaching ramp metering. ALINEA algorithm is chosen as local algorithm, HELPER as cooperative and SWARM as competitive ramp metering algorithm. Proposed ANFIS based ramp metering algorithm learning scheme is shown in Fig. 2.

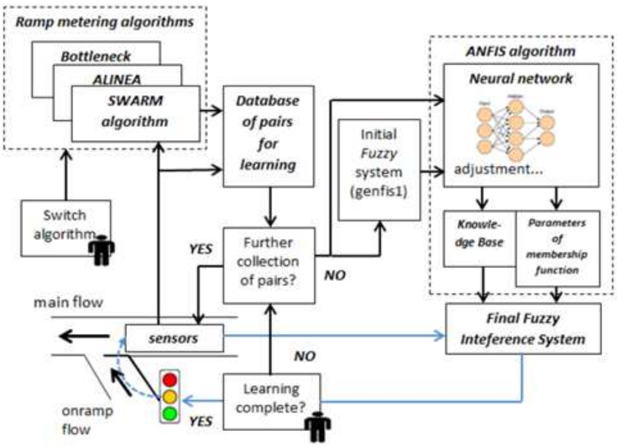

Figure. 2: Scheme of ANFIS algorithm for ramp metering control.

Next step is to create a learning dataset, which contains different types of traffic parameters according to the simulation results of all mentioned teaching algorithms. After creation of a learning dataset, best solution between all solutions provided by all the simulated ramp metering algorithms has to be selected. This is done by using the following function:

$$f(r)=0.5\ \text{traveltime}+0.5\ \text{delay}. \qquad (1)$$

According to the adjusted learning data set it is necessary to select suitable inputs and outputs among traffic variables relevant for ramp metering. This procedure is achieved by brute force optimization (Gregurić et al., 2013.), appropriate fuzzification, and defuzzification methods. Presented model has two input variables and each input variable has five membership functions and one output in form of ramp metering rate value. For fuzzification combination of Gaussian and triangular fuzzifiers is used. The middle of maximum method is used for defuzzification. ANFIS is commonly trained by a hybrid learning algorithm (Feng et al., 2011.).

Combination of feedback error propagation and least squares is used as ANN learning method. During the learning process, every element of the training data set (only inputs) is presented to the ANN in order to calibrate parameters of fuzzy interference system (Gregurić et al., 2013.). ANFIS returns an output in form of metering rate prediction. Output predictions are compared with output training data. Based on the difference between these two values, degree of matching is derived in form of Root Mean Square Error.

6 COOPERATION BETWEEN RAMP METERING, VSLC AND VEHICLES

Cooperative ramp metering implies cooperation between adjacent on-ramps in order to perform effective mitigation of congestion related to a particular highway area. At urban highways with dense traffic, mentioned control strategy is not efficient enough to resolve congestions. To increase efficiency of original cooperative ramp metering several other highway management strategies are considered to be added into the cooperative framwork. Generally, cooperative systems can be defined to be a set of control entities that share information and/or tasks to accomplish a common, though perhaps not singular, objective. According to this definition, other highway management strategies are entities, which communicate with original ramp metering algorithm entity in order to effective mitigate congestion. Effective mitigation of congestions is the goal of every highway management strategy regardless if its implemented separately or as part of a cooperative traffic control system.

Latest work in cooperative ramp metering includes cooperation between classic cooperative ramp metering framework and other highway management services, driver information systems and vehicles itself (Gregurić et al., 2013.). Proposed cooperative ramp metering architecture with all mentioned highway management strategies can be seen in Fig. 1.

6.1 Ramp Metering and VSLC

VSLC is in most cases used as standalone traffic management system at urban highways. It uses Variable-Message Signs (VMS) to inform drivers. Main purpose of VSLC as standalone application is to homogenize vehicle speeds. Induced reduction of speed differences among vehicles and mean speed differences between lanes by VSLC provide suppression of the congestion shockwaves (Hegyi et al., 2010.). Simultaneously traffic safety is increased. Possibility of cooperation between VSLC and ramp metering with benefits of such cooperation is described in (Hegyi et al., 2005.).

VSLC in cooperation with cooperative ramp metering algorithm such as HELPER has the main function to decrease speed of the incoming vehicles to the area between last slave on-ramp and congested highway segment. Virtual queues provided by HELPER and speed reduction in area between last slave on-ramp and congested highway segment induced by VSLC significantly reduce traffic density upstream of the congested on-ramp. Lower upstream density of the congested on-ramp leaves additional mainstream capacity to accept vehicles, which have origin from congestion back-propagation.

6.2 Ramp Metering and Vehicles

Additional cooperation between vehicle On-Board-Unit (OBU) and on-ramp control computer (RMS-r2v) in order to provide semi-automatic support can be established. Support is oriented to the inexperienced drivers, which are waiting in on-ramp queue and intend to perform merging with mainstream flow. Inexperienced driver in on-ramp queue end usually turn the engine off to safe fuel or hesitate to perform merging with mainstream if the driver is first in the queue. Hesitation in merging and failing in turning on the engine can cause situations in which an inexperienced driver does not perform merging with mainstream traffic during the green light phase. Several consecutive failed merging (on-ramp green light) phases can lead to increased number of vehicles in on-ramp queue.

To avoid that problem cooperation between vehicle and ramp metering should be established when the vehicle is stopped at the on-ramp queue and is waiting for green light. The on-ramp control unit keeps the vehicle engine in running state if vehicle is the first in on-ramp queue. When the green light is turned on, on-ramp control unit obtains throttle control over the first vehicle in queue. Engines of other vehicles in queue are also turned on if they are not currently running. The on-ramp control unit will forward all necessary merging manoeuvre data to the vehicle OBU. Types of mainstream merging manoeuvres depend on the subsystem, which is in cooperation with the ramp metering control system. Diagram of basic RMS-r2v activities can be seen in Fig. 3.

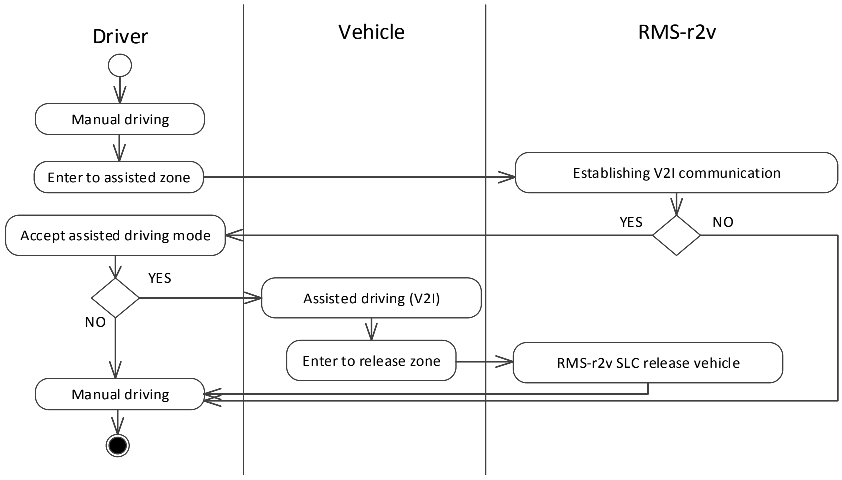

Fig. 3: Basic activity diagram of on-Ramp Metering System based on ramp metering-to-vehicle communication.

7 SIMULATOR CTMSIM AUGMENTATION

Working principle of cooperative ramp metering algorithms can be very complex and sensitive considering fluctuations in traffic parameters. Because of the mentioned reasons, it is imperative to conduct simulations in order to analysis impact of cooperative ramp metering on the traffic flows. In this paper, CTMSIM is selected as an appropriate simulator for such systems. It is an open-source interactive simulator based on macroscopic traffic models specifically designed for highway traffic flows and respective control systems simulations. It is developed and run under MATLAB program package and allows implementation and development of user-pluggable on-ramp flow and queue controllers (Kurzhanskiy and Varaiya, 2008.). Highway model is based on the Asymmetric Cell Transmission Model (ACTM).

CTMSIM does not support direct cooperative ramp metering features so it was necessary to develop adequate simulation framework augmentation. Firstly, framework for the cooperation between on-ramps is developed. This framework was used to implement HELPER cooperative ramp metering. Additionally, this framework is then augmented in order to support cooperation between HELPER and VSLC.

7.1 Augmentation for cooperative ramp metering

In order to simulate cooperative highway control systems first step in CTMSIM augmentation was to design a cooperative ramp metering module. Main task of this module is to provide support for cooperation between on-ramps. As it can be seen in the bottom part of Fig. 4 the original CTMSIM simulation sequence goes only through defined highway cells in a particular time step. An additional simulation step related to the cooperative ramp metering module is added to enable simulation of cooperative control systems as it can be seen in the top part in Fig. 4. Cooperative module has access to data from all cells. This feature enables computation of optimal local ramp metering rates and VSLC values used in the next simulation time interval.

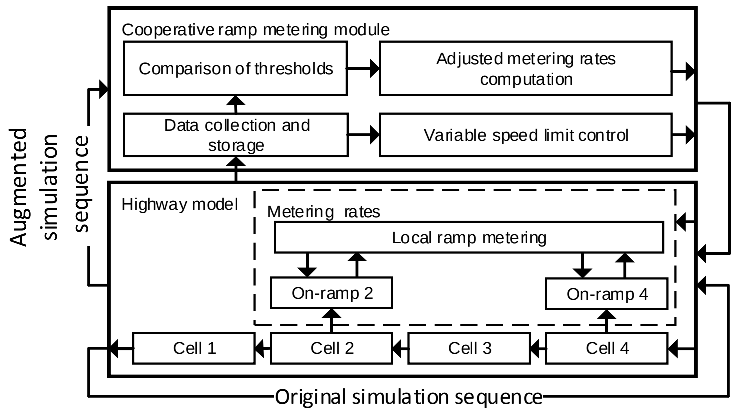

Fig. 4: Augmented CTMSIM simulation structure.

With use of mentioned cooperative module, the HELPER algorithm was implemented. Cooperative ramp metering module now monitors traffic conditions at every on-ramp during simulation. If critical density is exceeded in a current simulation time step, central monitor module marks this cell's on-ramp as the master on-ramp. HELPER algorithm uses information about master on-ramps locations obtained by cooperative module to decrease metering rate for 10 % of current traffic demand. Three upstream cells with on-ramps regarding the master on-ramp location are declared as slave on-ramps. Metering rate at the slave on-ramps are decreased for 40 % of current traffic demand what creates virtual queues on them.

Additionally, cooperative module has one more important task. During every simulation interval, HELPER firstly computes metering rates for every on-ramp according to the local algorithm. If master on-ramp is detected, cooperative module computes new metering rates for master on-ramp and three upstream on-ramps. Metering rates computed by local algorithm are overridden with these new values. Override possibility is added to the cooperative ramp metering module if existence of a master on-ramp is detected.

7.2 Augmentation for VLSC

CTMSIM was upgraded with possibility to perform simulation of VSLC system. Original CTMSIM traffic fundamental diagram GUI is modified to support adding the default speed limit value for every cell in the model. This is implemented through modification of the cell mean speed equation described in (Kurzhanskiy and Varaiya, 2008.) into:

$$v_i^c = \min\left(v_i^{SLC},\ \frac{f_{i[k]}/(1-\beta_{i[k]})}{n_{i[k]}+\gamma r_{i[k]}}\left(\frac{L_i}{\Delta t}\right), v_i^{ff}\right), \qquad (2)$$

where parameter $r_{i[k]}$ denotes number of vehicle entering cell *i*, from its associated on-ramp at time step *k*, while $\beta_{i[k]}$ denotes split ratio for off-ramp flow. Parameter γ denotes on-ramp flow blending coefficient, both from interval [0, 1]. Free flow speed value is denoted by v_i^{ff} for cell *i*, and L_i denotes length of cell *i*, v_i^{SLC} denotes the current SLC value for *i*-th cell. Mainstream flow during interval *k* in cell *i* is denoted by $f_{i[k]}$. Simulation time is divided into *K* intervals with length Δt where $n_{i[k]}$ denotes number of vehicles (or mainstream density) in cell *i* at time step *k*. Default VSLC value must be lower than free flow speed value of the current cell. Modification to the fundamental diagram GUI to include the VSLC option is presented in Fig. 5. VSLC enables changes in speed limit values during simulation.

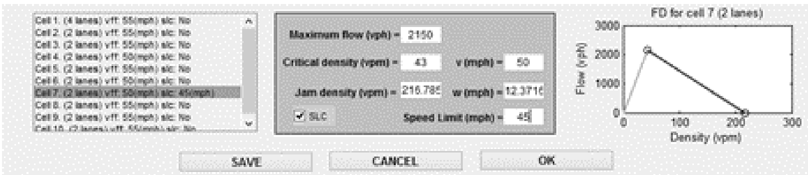

Fig. 5: Fundamental diagram GUI agumentation for definition of the SLC.

8 SIMULATION RESULTS

This section firstly presents results from comparative analysis between commonly used ramp metering algorithms and proposed ANFIS based learning based approach. The simulation of the cooperation between vehicles and ramp metering is beyond the scope of this paper. Urban highway section between the nodes Jankomir and Lučko on the Zagreb bypass is selected as the simulation use case model. Additionally, this section includes comparative analysis between cooperation of VSLC with the HELPER ramp metering algorithm, representatives of different ramp metering algorithm types and VSLC as a standalone application. Analysis is conducted using the following ramp metering algorithms: ALINEA (local), SWARM (competitive) and HELPER (cooperative).

8.1 Simulation setup

Zagreb bypass can be categorized as urban bypass highway with prominent seasonal overloads and therefor it is selected for use case scenario. To simplify the simulation model, section between the nodes Jankomir and Lučko of the Zagreb bypass is isolated. Physical simulation model of the Zagreb bypass is designed according to its real constructional parameters. In 2009 the Average Annual Daily Traffic (AADT) based on traffic count data at Zagreb bypass was recorded of 54,542 [veh/h] (Štefančić et. all., 2012.). The Zagreb bypass with marked on-ramp nodes can be seen in Fig. 6.

Fig. 6: Zagreb bypass with marked nodes.

Section between nodes Jankomir and Lučko, and the Lučko interchange have already become part of the Zagreb urban road network on which about 70% of traffic is generated by the nearby town Zagreb (Štefančić et. all., 2012.). This section is interesting as use case model also due to the combination of increased traffic load during whole day and prominent effect of daily migrations. On-ramps traffic demand characteristics of the Zagreb bypass simulation model are reconstructed according to Ljubljana bypass traffic data.

8.2 Cooperative Ramp Metering

This paper considers two cooperative ramp metering algorithms. First of them is HELPER which is implemented using proposed CTMSIM augmentation for cooperative ramp metering. Second cooperative algorithm is based on proposed learned ANFIS algorithm. Both cooperative ramp metering algorithms will be compared with local (ALINEA) and competitive (SWARM) ramp metering algorithms. All mentioned ramp metering algorithms are simulated under the same simulation model for the sake of comparison. For implemented ramp metering algorithms comparison LoS measures travel time (TT) and delay are used. TT gives information how much time one vehicle needs to travel through observed highway segment. This measure observe throughput of mainstream in the same time ignoring queues at on-ramps and it is measured in minutes. Difference between the actual time spend by all vehicles on a congested highway and the time spend in case they have travelled at free flow speed is defined as delay. Unlike TT delay considers also vehicles are waiting in on-ramp queues or at mainstream queues caused by the bottlenecks. Delay is measured in vehicle-hours. Results of comparative analysis can be seen in Tab. 1.

Traffic control algorithm	TT (min)	Delay (vehicle-hour)
None	7.06	15.87
ALINEA	3.90	36.88
SWARM	3.71	41.49
HELPER	3.40	22.63
VSLC	5.59	12.24
HELPER + VSLC	3.30	21.50
ANFIS	4.10	19.75

Table 1: Results of cooperative analysis between different traffic control algorithms.

According to the results given in Tab. 1 it is possible to conclude that cooperation between HELPER ramp metering algorithm and VSLC provides best value of TT. Among the stand-alone ramp metering algorithms, cooperative algorithm HELPER has achieved best TT due its restrictive nature. ANFIS has achieved higher TT value compared to the ALINEA and SWARM ramp metering algorithms but TT value achieved by ANFIS algorithm is a much lower compared to the situation without ramp metering and standalone VSLC. It can be concluded that ANFIS algorithm has learned necessary ramp metering control knowledge based on higher values of metering rates.

In simulation scenario without ramp metering, on-ramp vehicles are immediately merged with mainstream vehicles. Process is conducted only under the condition that in a current cell maximal mainstream capacity is not exceeded. This is reason why scenario without ramp metering provides best values of delay. HELPER induces in both cases, standalone and in cooperation with VSLC longer queues at particular slave on-ramps increasing the delay, respectively. ANFIS achieved best average delay value among compared ramp metering algorithms and its value is similar to the HELPER algorithm delay value. Such result was expected due to the higher value of TT. Additionally, this result confirms that ANFIS has partly adopted HELPER on-ramp virtual queue control strategy during the learning process.

8.3 Cooperation between Ramp Metering and VSLC

This section provides simulation results analysis between cooperative ramp metering algorithms and cooperation between HELPER and VSLC. Into analysis results with standalone VSLC application and previously analysed ramp metering algorithms are also included. VSLC as the standalone application and in cooperation with HELPER is applied in the cells 2, 5 and 6. In both cases, the primarily role of VSLC is to gradually decrease speed of the upstream flow before congestion starts. VSLC firstly reduce speed of vehicles in mainstream at segment before congested zone and in segments near the place where congestion starts to form. This action enables higher speeds in upstream cells compared to the congested cell during the congestion period. Figure 7 presents results of comparative analysis regarding TT (left part in Fig. 7) and delay (right part in Fig. 7).

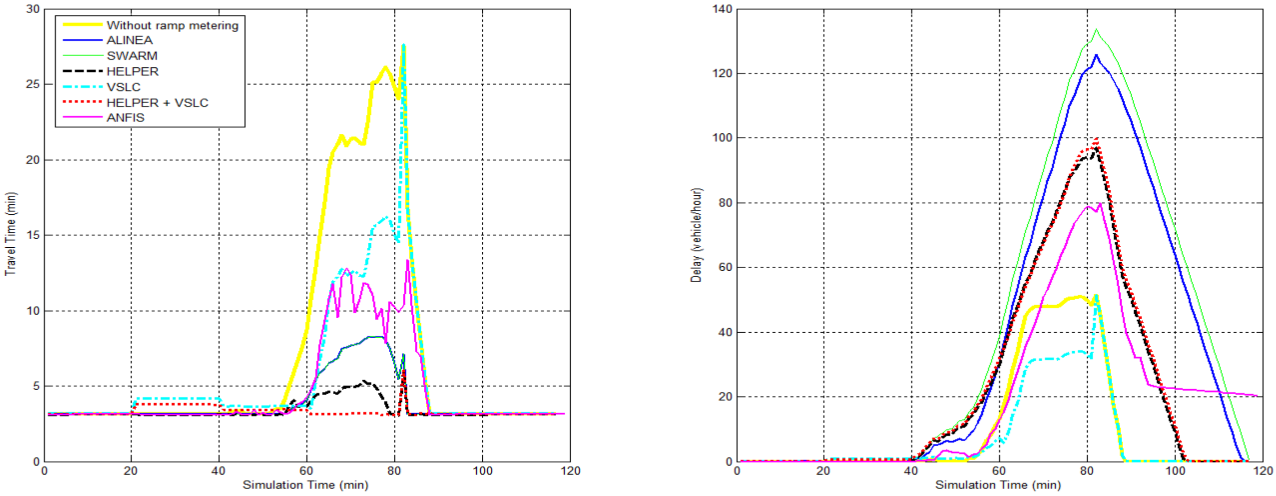

Fig. 7: Results of comparative analysis according to TT and delay.

According to Fig. 7 it is possible to conclude that cooperation between HELPER ramp metering algorithm and VSLC produces smallest TT. Zone between congested and last slave on-ramp is affected by decreased speed induced by VSLC what consequently decrease values of density in that zone. Virtual queues provided by HELPER ramp metering algorithm, which cooperates with VSLC, additionally reduce traffic density upstream of the congested on-ramp. Lower upstream density of the congested on-ramp leaves additional mainstream capacity to accept vehicles, which originating from congestion back-propagation.

Similar values of delay are produced by standalone HELPER and in case of cooperation between HELPER and VSLC. In both cases reduction of metering rates on the slave on-ramps by HELPER ramp metering algorithm is present, which is the main reason for similar results regarding delay. Reduced metering rates create queues at on-ramp, which increases values of delay. It can be concluded that VSLC has lower influence on delay if the mainstream density is decreased by HELPER exploitation of on-ramp queues. Standalone VSLC produces better delay results because of higher value of mainstream density. Other ramp metering algorithms produce higher values of delay due to higher number of vehicles in the congested on-ramp queue. ANFIS has produced values of TT higher than other ramp metering algorithms. Its TT curve shows similarities with the behaviour of other ramp metering algorithms TT curves. This feature verifies ANFIS learning capabilities, which can be additionally tuned in future development. ANFIS delay values are lower than other ramp metering algorithms what is consequence of generally higher TT values. Furthermore, from the similarity of the ANFIS TT curve during the most of the simulation to the HELPER delay curve can be concluded that ANFIS algorithm has partialy learned HELPER strategy of creating virtual queues.

9 CONCLUSION AND FUTURE WORK

In this paper a new approach to urban highway management control based on cooperation is proposed. Cooperative control concepts are introduced between ramp metering, prohibiting lane changes, VSLC and the vehicle itself. In order to ensure a suitable simulation platform the CTMSIM simulator is augmented to enable development and implementation of cooperative ramp metering approaches. With use of mentioned CTMsim augmentation, cooperative ramp metering algorithm HELPER is implemented to verify proposed simulator augmentation. Higher level of highway traffic control systems cooperation is achieved by adding

VSLC into cooperation with HELPER. Additionally, a learning framework based on ANFIS is designed to provide platform for cooperation between different ramp metering algorithms. The Zagreb bypass between nodes Lučko and Jankomir is used as test case for situational evaluation of proposed ANFIS based ramp metering algorithm learning framework.

According to the simulation results cooperation between VSLC and cooperative ramp metering provides best ratio between TT and delay values compared with other ramp metering algorithms. Overall results archived by ANFIS based approach indicate its potential to learn control strategies of several different ramp metering algorithms. Proposed achieved best delay, while TT value is still larger compared to other standalone ramp metering algorithms. Future work will include an optimization algorithm for better cooperation between ramp metering and VSLC. Additionally, possible adjustments of learning criterion function for ANFIS based approach will be examined in order to achieve better results.

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