Urban Highways Level of Service Improvement Based on Intelligent Ramp Metering

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Abstract. *Urban highways have undergone a transformation in the recent years due to increased traffic demand. Optimal usage of the existing road transport infrastructure has become a priority. To ensure efficient usage of the existing traffic system capacity, intelligence needs to be added to its control systems. Such control solutions are from the domain of intelligent transportation systems (ITS). Mostly used solutions are ramp metering and variable speed limit control (VSLC). This paper presents a new learning based cooperative ramp metering strategy in which several well-known ramp metering strategies (ALIENA, SWARM, HELPER) are used to create a learning set and then create an ANFIS based cooperative ramp metering controller. Proposed urban highway control approach is tested in simulations using an augmented version of the CTMSIM simulator, traffic data for a typical working day and city of Zagreb bypass as case study. Obtained results are compared to standard ramp metering approaches and VSLC using travel time, Delay, and maximum vehicle queue length as quality measures.*

Keywords. Ramp Metering, Speed Limit Control, ANFIS, Level of Service, ITS, Cooperative Control

1 Introduction

In the second half of the last century traffic slowdowns and congestions are the most prominent problems in urban road networks. Traffic congestion appears when too many vehicles attempt to use a common road infrastructure with limited capacity, [1]. Limited capacity of today's urban road networks is consequence of the inability to expand its capacity due to limited economic and physical resources. One among the last build-only solutions applied in order to mitigate congestions on urban road networks is the construction of urban highways. Urban highways are planned to provide a bypass to the urban road network by absorbing part of its traffic. Over the years urban highways were progressively integrated into the road network and urban environment. Nowadays urban highways have the same problem as the urban road network regarding limitation in capacity extension. Generally high Level of Service (LoS) projected for urban highways is significantly reduced due to negative differences between traffic supply and traffic demand.

LoS can be defined as a group of qualitative measures which characterize operational conditions within traffic flow and their perception by motorists and drivers, [2]. Mentioned group of qualitative measures are used to analyze highways by categorizing traffic flow and assigning quality levels of traffic based on performance measure like speed, density, etc. Six LoS are defined for each type of facility that has analysed procedure available. Letters designate each LoS level ranging from A to F, with LoS A representing the best and LoS F the worst operating conditions, [3]. LoS takes into account only mean density or/and speed of the mainstream so it is necessary to use several additional measures for highway service quality assessment especially when ramp metering is applied, [1]. Travel Time (TT) and Delay (D) are the two most used service quality measures. TT gives the information how much time one vehicle needs to travel through observed highway segment. It is measured in minutes. Delay is defined as the difference between the actual time spent by all vehicles on a congested highway and the time spent in case they have travelled at free flow speed. Delay also considers vehicles which are waiting in on-ramp queues or in mainstream queues caused by the bottlenecks. It is measured in vehicle-hours. In order to increase urban highway LoS, the imperative is to use optimal utilization of the available infrastructure via adequate application of a variety of traffic control measures, [1]. Nowadays most of the mentioned traffic control measures are known under domain of intelligent transportation systems (ITS).

Most prominent traffic problem on urban highways is known under the term downstream bottleneck which location can be seen in Fig. 1. Downstream bottleneck has impact on the area where on-ramp and mainstream flow are actually coming in interaction. Mentioned highway problem can be mitigated by use of a special ITS control measure which is known under the term - ramp metering. Ramp metering controls queues at on-ramps in order to maintain maximal capacity flow on a highway. This is achieved by restricting access of on-ramp traffic to mainstream traffic with special traffic lights and appropriate signalization, [4].

This paper describes and test a new learning based ramp metering strategy in which several ramp metering algorithms are used to create a learning dataset for ANFIS (Adaptive Neural Fuzzy Inference System) with emphasis of on-ramp queue length as continuation of the authors previous work. Another important control method is known under the term Variable Speed Limit Control (VSLC). Main purpose of VSLC as standalone application is to homogenize vehicle speeds and suppress shockwaves. This paper also describes cooperation between ramp metering and VSLC including analysis of their influence on on-ramp queue length. In order to enable and test mentioned type of cooperative control, macroscopic highway traffic simulator Cell Transmission Model SIMulator (CTMSIM) is adequately augmented, [8].

This paper is organized as follows. Second section briefly describes ramp metering in general. Description of cooperative control approaches on urban highways is presented in third section. Concept of learning based cooperative ramp metering is explained in the fourth section. Simulation results of the comparative analysis of implemented urban highway control approaches is given in the fifth chapter. Paper ends with conclusion and future work description.

2 Ramp Metering

Main goal of ramp metering is to reduce the impact of downstream bottleneck on the mainstream highway traffic, [7]. In order to accomplish that ramp metering uses special road signals at on-ramps to control the rate or size of vehicles platoons entering mainstream traffic according to current traffic conditions, [6]. While reducing the downstream bottleneck, ramp metering may cause the traffic to spill over into feeder arterial roads as the on-ramp queue length increases. Especially when highway traffic flow is high, [5]. 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 general local ramp metering system installation on a highway. Most important part of the ramp metering system is the algorithm which determines the "access rate reduction" for every on-ramp flow, [8]. Generally it is possible to divide ramp metering algorithms in two major categories: local (or isolated) and coordinated, [5].

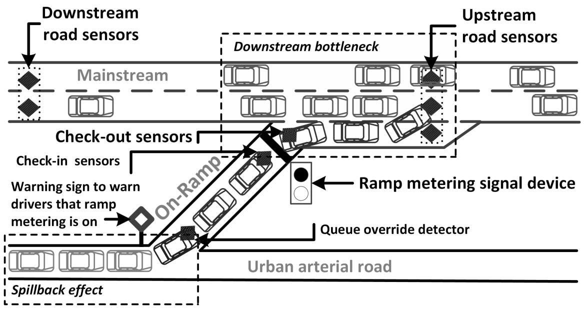

Figure 1: Local ramp metering installation with downstream bottleneck and spillback effect

2.1 Local ramp metering

Local ramp metering algorithms take into account only the traffic condition on particular on-ramp and nearby highway segment where they are applied. Main drawback of local ramp metering algorithms is unawareness of overall highway traffic situation.

The ALINEA algorithm is the most often used standard local ramp metering algorithm. Core concept of ALINEA is to keep the downstream occupancy of the on-ramp at a specified level by adjusting the metering rate, [1]. Specified level of downstream occupancy is usually called occupancy set-point. Value of occupancy set-point is slightly lower or equal to occupancy at maximum downstream capacity. Main disadvantages of ALINEA are its inability to resolve upstream congestions of the particular ramp and to locate optimal detector mounting zone.

2.2 Coordinated ramp metering

Coordinated algorithms are taking into account the traffic situation on the overall highway transportation system. In the literature these algorithms are further divided on: cooperative, competitive and integrated algorithms, [9].

Ramp metering algorithms based on cooperation work in two phases. In the first phase the metering rate for each on-ramp is computed by local ramp metering algorithms. Furthermore, in the second phase additional adjustment of each local on-ramp metering rate is done based on system-wide information about the traffic situation on the whole highway segment, [10]. HELPER algorithm is one among the first algorithms which have used mentioned cooperative ramp metering working principle. It includes several local traffic responsive metering algorithms which are communicating with a centralized operational unit with override possibility. HELPER algorithm creates virtual queues in upstream on-ramps to reduce queue length on the congested one, [6].

Competitive algorithms execute local and global control ramp metering logics, both of them compute appropriate solution for current traffic situation.

System-Wide Adaptive Ramp Metering (SWARM) is the most efficient algorithm in this group. SWARM contain 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, [7].

Integrated algorithms are based on optimization of a specific LoS value while considering constraints such as maximum allowable on-ramp queue, bottleneck capacity, etc. Most sophisticated algorithms in that group are algorithms based on fuzzy logic. Fuzzy logic based algorithm can be described as one type of expert systems applied for ramp metering, [8].

3 Cooperative control of urban highways

In general, a cooperative system can be defined as a system which involves multiple dynamic entities that share information or tasks in order to accomplish a common, though perhaps not singular objective, [11]. Main task of cooperative traffic control is to find the combination of control measures that results in the best traffic performance, [12]. At urban highways with dense traffic and complex interactions between traffic flows, cooperative control methods under the domain of the ITS are especially interesting. Cooperative highway control systems, according to results published in [8] and [12] are more effective in contrast to standalone control methods at highways.

Originally, cooperative control on urban highways implied only to exploitation of adjacent on-ramps queue, [8]. Nowadays, concept of cooperative control on highways is expanded to cooperation between ramp metering, VSLC, prohibiting lane changes system, various driver information systems and vehicle on-board-unit (OBU). Higher number of management strategies included into cooperation with ramp metering contributes to a more comprehensive control over highway section. Cooperative ramp metering architecture with all mentioned highway management strategies can be seen in Fig. 2.

3.1 Cooperation between on-ramps

Main problem with local or isolated ramp metering is a risk of fast upstream congestion propagation known as a "shock wave", [8]. Mainstream "shock wave" travels backward or upstream. Upstream on-ramps with local ramp metering applied cannot provide appropriate solution to stop the upcoming "shock wave" due unawareness of current traffic situation on the upstream on-ramps. In order to suppress such "shock waves" cooperation between on-ramps has to be applied, [9].

Cooperation between on-ramps demands that several local traffic responsive metering algorithms communicate with a centralized operational unit with override possibility. Cooperative algorithm in the centralized operational unit uses a control logic which exploits queue capacity of upstream on-ramps to reduce queue length on the congested one. In order to compute and adjust values of metering rates computed by local ramp metering algorithms, cooperative algorithm uses overall highway traffic information and mentioned control logic.

3.2 Cooperation between VSLC and ramp metering

Ramp metering is ineffective in two cases: (i) traffic demand is too low and (ii) traffic demand is extremely high, in which case traffic breakdown will happen anyway, [1]. The main goal of VSLC in cooperation with ramp metering is to prevent a traffic breakdown by limiting the inflow into the area where the traffic breakdown starts, [8]. Decreased mainstream speed induced by VSLC consequently increases the value of critical density in the highway segment where the traffic breakdown starts. Since the inflow is lower than the highway segment capacity where breakdown starts there will be some space left to accommodate the traffic from the on-ramp and traffic breakdown can be prevented, [12]. Due to higher value of critical density there is also possibility for ramp metering to increase metering rate in critical segment. This action consequently can have positive impact on overall highway throughput.

4 Learning based cooperative ramp metering

Extreme fluctuation in traffic demand is one of the most prominent traffic problems on urban highways. For example, at the peak hour traffic demand is extremely high, while at night traffic demand for highway transportation capacity is extremely low. It is possible to conclude that one ramp metering strategy cannot equally efficiently respond on every traffic situation on urban highway. This is the reason for development of a learning framework which will summarize knowledge from several different ramp metering strategies into one control structure.

Latest approaches in learning based cooperative ramp metering include use of hybrid intelligent systems such as fuzzy-neural control systems. They are used in order to perform adaptive mitigation of congestion which is varying in strength and in time. In [13] a conceptual design of the Fuzzy Neural Network Control Method for Ramp Metering is described. Mentioned design is used on a single on-ramp and on eight

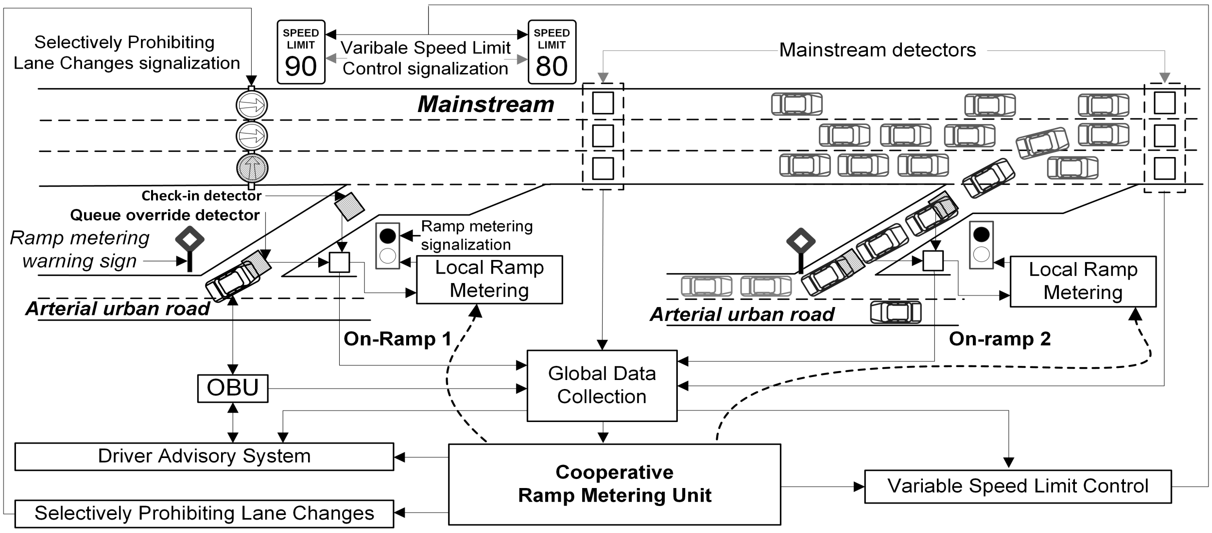

Figure 2: Cooperative ramp metering architecture

on-ramps which from two different directions converge at common mainstream. Between the eight on-ramps a coordinated control has been implemented, [13]. Recent work described in, [14] and [7] includes use of ANFIS algorithm. In [14] cooperative control between several on-ramps is achieved by the integration of several traffic inputs into all ramp controllers upstream of a bottleneck and a periodical update of the fuzzy control system every 25 minutes, by a hybrid learning procedure. To assess the impacts of the ANFIS cooperative ramp metering algorithm a section of 25 kilometers of the A9 highway was simulated with the FREQ model and compared with two other control scenarios (no control and linear programming control approach), [14]. In this paper ANFIS is trained by a hybrid learning algorithm, [13]. Proposed ANFIS based control architecture for cooperation between on-ramps is shown in Fig. 3. In order to acquire knowledge from different ramp metering algorithms it is necessary to define the ANFIS structure and select appropriate learning procedures. Firstly it is imperative to select teaching ramp metering algorithms with distinctively different control logic in order to cover wide range of traffic scenarios on particular urban highway, [7]. Following teaching ramp metering approaches have been chosen: ALINEA algorithm as local algorithm, HELPER as cooperative and SWARM as competitive ramp metering algorithm. ANFIS ramp metering learning scheme is shown in Fig. 4.

Next step is to create a learning dataset according to simulation results of all mentioned chosen teaching algorithms, [7]. It is imperative to select the best solutions provided by all the teaching ramp metering algorithms in a learning dataset for actual learning process. This is done according to the following criterion function:

$$f(r) = 0.5 \cdot TT + 0.5 \cdot D, \qquad (1)$$

where *f(r)* is metering rate function. 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 and appropriate fuzzification and defuzzification methods, [10].

Model used in this paper has 2 inputs variables and one output in form of ramp metering rate value. Fuzzification is achieved using Gaussian fuzzifiers. The middle of maximum method is used for defuzzification. Upon completion of the learning process, ANFIS output results 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 (RMSE), [14]. Learning dataset is created by the use of simulation results derived from Zagreb bypass (section between the nodes Jankomir and Lučko)as use case model. Traffic dataset of the use case model is reconstructed according to the traffic data of Ljubljana bypass.

During the learning process higher error values are reported due several reason. One of the reasons is lack of real use case traffic data so only a set of 24 hours traffic data is used. Another problem which cause higher error rate is sudden increase in traffic in-flow during afternoon peak hour. This scenario enables adequate test scenario for cooperative control strategies but requires sudden maximal increase in metering rates after the peak hour ends. This control behaviour is harder to learn. Potential solution which has to be tested in future work is in customization of the criteria function and fine tuning of ANFIS algorithm parameters. Graph of the relationship between learning/testing data and various combination of the two traffic inputs is shown in Fig. 5.

5 Simulation results

Urban highway section between the nodes Jankomir and Lučko on the Zagreb bypass is selected to be the simulation use case model. Traffic demand data for each on-ramp at the use case model is reconstructed by use of interpolated traffic data from Ljubljana bypass. Additionally, original CTMSIM environment is augmented in order to support simulation and verification of cooperative ramp metering algorithm HELPER and standalone VSLC, [8]. Furthermore, this section provide comparative analysis which involves following highway control strategies: commonly used ramp metering algorithms (ALINEA, SWARM, HELPER), standalone VSLC, cooperation between VSLC and HELPER, and proposed ANFIS based learning approach.

5.1 Simulator CTMSIM and its augmentations

CTMSIM is an interactive simulator based on macroscopic traffic models specifically designed for simulations of interactions between highway traffic flows, [15]. Macroscopic traffic model used by CTMSIM is based on the Asymmetric Cell Transmission Model (ACTM) [15]. ACTM model divides the highway model into I cells. CTMSIM simulation time is divided into K intervals with length Δt (equal to 5 minutes in this paper). The possibility of using various MATLAB toolboxes makes this simulator suitable for development of advanced ramp metering algorithms.

To enable simulation of cooperative ramp metering approaches two modifications have been made to CTMSIM, [8]. First modification involves implementation of VSLC for every cell in the simulation model. Original equation for mean speed in *i*-th cell is changed into eq. 2 in order to implement VSLC into CTMSIM environment:

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

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 represents on-ramp flow blending coefficient, both from interval [0, 1]. Free flow speed value is denoted by v_i^{ff} for cell *i*, and $L_{i[k]}$ represents length of cell *i*. Mainstream flow during interval k in cell i is represented by $f_{i[k]}$. Speed limit value for *i*-th cell is represented by v_i^{SLC} must be lower than free flow speed value of the current cell.

5.2 Zagreb bypass and traffic flow data

Physical use case model of Zagreb bypass between nodes Lučko and Jankomir is designed according to its real constructional parameters. ACTM model of section between nodes Lučko and Jankomir is shown in Fig. 6. This section has an expressed traffic load at peak hours at nodes Lučko and Jankomir. Additionally, this section contains 70 % of traffic generated by the nearby town Zagreb, [16]. On-ramps traffic demand characteristics and in-flow of the Zagreb bypass simulation model are reconstructed according to interpolated Ljubljana bypass traffic data. Traffic behaviour patterns of Ljubljana bypass are similar to Zagreb's since city of Ljubljana has also a bypass and in the summer season many tourists are using its bypass when travelling to the Croatian seaside. This action is taken due unavailability of accurate hourly traffic flow data for the Zagreb bypass.

Created use case model combines constructional parameters of Zagreb bypass and traffic dataset from Ljubljana bypass characterized by increased traffic load during the peak hours. Additionally, created model contains many close on- and off-ramps making

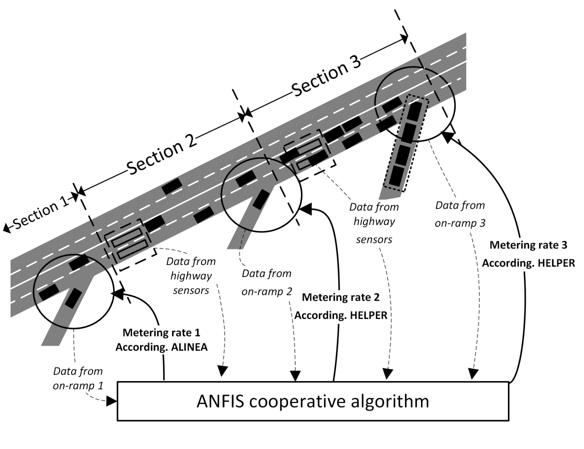

Figure 3: ANFIS based control architecture for cooperation between on-ramps

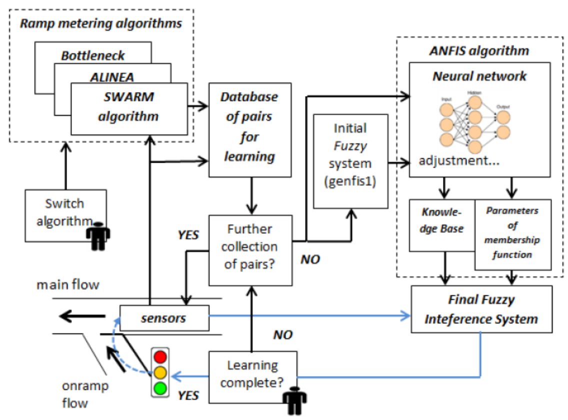

Figure 4: ANFIS algorithm scheme for ramp metering learning, [10]

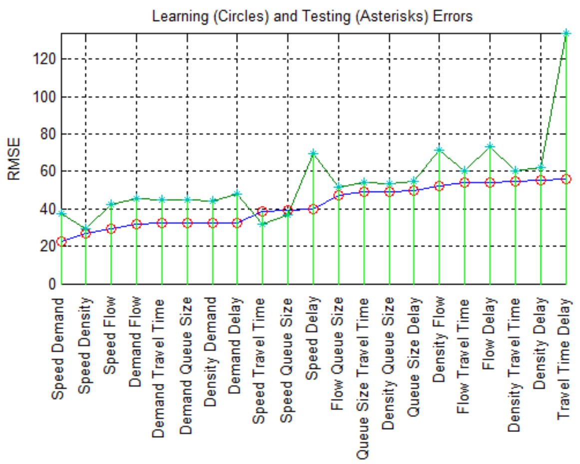

Figure 5: Relationship between learning/testing data and various combination of the two traffic inputs

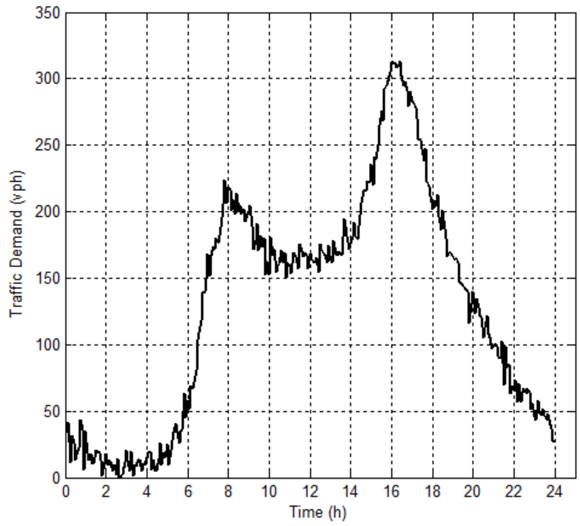

Figure 7: Highway mainstream traffic in-flow characteristic

it suitable for analysis of cooperative ramp metering algorithms such as HELPER.

In Fig. 7 it is possible to see characteristics of use case model traffic in-flow curve which is reconstructed and interpolated according to the city of Ljubljana traffic data. Main feature of the in-flow curve is expressed traffic load in the afternoon peak hour. Average LoS of all cells in described use case model (section between Lučko and Jankomir) is E according to [3] and [16].

5.3 Cooperation between on-ramps

In this section HELPER algorithm is considered under the domain of cooperative ramp metering algorithms. HELPER ramp metering algorithm is developed using the mentioned CTMSIM augmentation for cooperative ramp metering. HELPER is compared with local (ALINEA), competitive (SWARM) and learning based (ANFIS) ramp metering algorithms in order to verify its operational work. All mentioned ramp metering algorithms are simulated under the same simulation model using settings for a typical working day (24 hours).

Results of comparative analysis are shown in Table 1. According to Table 1, among the standalone ramp metering algorithms cooperative algorithm HELPER has achieved second best TT value due to its restrictive nature. HELPER restrictive nature is a result of the decreased metering rates on several upstream on-ramps regarding the congested on-ramp. Mentioned upstream so-called "slave" on-ramps are affected by creation of virtual queues. This behaviour causes longer queues at "slave" on-ramps increasing the average Delay, respectively. Such control logic reduces impact of congestion back-propagation on the mainstream throughput which consequently decreases TT. HELPER algorithm has achieved LoS categorization C.

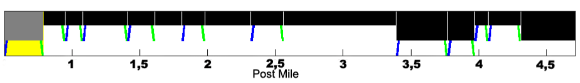

Figure 6: ACTM model of section between nodes Lučko and Jankomir

SWARM algorithm has achieved best TT, because SWARM control logic completely stops traffic flow at the on-ramps affected by congestion. Consequence of mentioned behaviour is highest value of average Delay achieved by SWARM ramp metering algorithm. Best A categorization of LoS is achieved by the SWARM algorithm what is expected since this algorithm has lowest TT value.

As a conclusion, HELPER algorithm achieves slightly higher values of TT compared to the SWARM algorithm, but significantly smaller average Delay values compared to the same algorithm. Smallest Delay was achieved in the simulation scenario without ramp metering. This result can be explained by used simulation settings enabling immediately merging of on-ramp flows with mainstream under the condition that in a current cell maximal mainstream capacity is not exceeded. Such behaviour induces absence of on-ramps queues but significantly increases traffic density of mainstream which increases average TT also. These specific behaviours can be seen in Figs. 8 and 9.

5.4 Variable speed limit control

It is possible to notice that standalone VSLC only effects TT, since it is applied to mainstream flow. VSLC produces vehicle platoons which are traveling at lower speeds in comparison to the free flow speed. This impacts the process of mainstream congestion back-propagation. In Table 1, it is possible to observe

Table 1: Results of cooperative analysis between different ramp metering algorithms

	No Control	ALINEA	SWARM	HELPER	VSLC	HELPER + VSLC	ANFIS
LoS (HCM2010)	E	D	A	C	E	C	B
Average TT [min]	14,32	5,61	3,99	4,41	11,01	4,63	6,42
Average Delay [vh]	5,42	20,53	24,18	10,94	4,51	7,62	6,75
Maximum queue [veh]	0	79	89	58	13	57	38

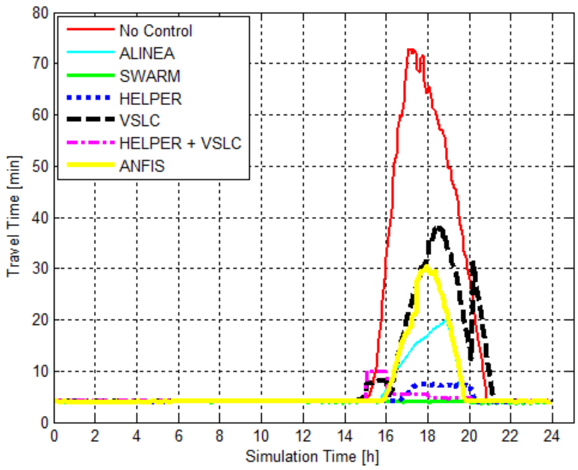

Figure 8: Comparative analysis according to TT

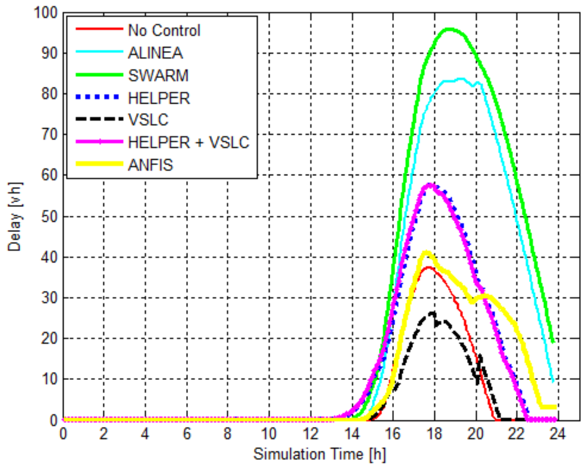

Figure 9: Comparative analysis according to Delay

that application of standalone VSLC produces smaller value of TT compared to the situation without any traffic control. Additionally, application of standalone VSLC has achieved best average Delay regarding all other traffic control methods. Lowest value of Delay is consequence of vehicle platoons which are traveling with lower speeds. Mentioned scenario enables more space at mainstream traffic lines due to slower arrival of vehicle platoons to the congested area. VSLC standalone application has achieved same LoS as the situation without any control what is expected since the both case have highest TT value.

5.5 ANFIS ramp metering approach

Proposed ANFIS based approach has produced highest average TT values compared to the other ramp metering algorithms involved into analysis except for VSLC. In the other hand, ANFIS has produced lowest Delay values compared to the other ramp metering algorithms except VSLC what is consequence of the generally higher TT values. According to eq. 1, it is possible to conclude that ANFIS learning process of finding the best combination of inputs and outputs within the learning dataset which will achieve results with desired ratio between TT and Delay can be tuned.

Furthermore, according to Table 1, it is possible to conclude that ANFIS average TT value is similar to the value of HELPER teaching ramp metering algorithm. ANFIS TT characteristic (Fig. 8) has higher values compared to the other teaching ramp metering algorithms. This fact enables ANFIS algorithm to provide lowest Delay values in contrast to the other teaching ramp metering algorithms what can be seen in Fig. 9. It is possible to assume that ANFIS algorithm has learned that increasing the value of TT simultaneously lowers the value of Delay. At this point it is possible to conclude that ANFIS based ramp metering algorithm has achieved balance between TT and Delay values due to similar average values of TT and Delay. It is important to notice that ANFIS algorithm has achieved LoS categorization B which is the second best LoS result.

6 Conclusion and future work

In this paper an intelligent ramp metering algorithm realized through an ANFIS structure is described and analysed by means of LoS, TT, Delay and queue length. It presents a foundation of a learning based framework in which several standard ramp metering strategies (local ALINEA, competitive SWARM and cooperative HELPER) are used as a learning dataset to create a cooperative ramp metering strategy.

Simulation results obtained by proposed ANFIS algorithm are compared with results obtained by its teaching ramp metering algorithms. Additionally, ANFIS algorithm is compared with approaches based on cooperation between VSLC and HELPER, and standalone VSLC. The Zagreb bypass between nodes Lučko and Jankomir is used as highway simulation model for evaluation of implemented ramp metering algorithms. According to the simulation results it is possible to conclude that ANFIS algorithms has achieved smallest Delay values compared to the other ramp metering algorithms. Overall smallest average Delay value is achieved by VSLC standalone application. Smallest TT values are achieved by SWARM, and cooperation between HELPER and VSLC but with longer queue lengths.

Proposed ANFIS algorithm shows promising results in achieving an effective balance between values of TT and Delay. Its LoS categorization value is B with small on-ramp queue lengths. These results are promising for future development of this algorithm. Relevance of this research is also in the fact that the proposed ANFIS learning framework can be used for learning ramp metering algorithms with various criteria functions. So a learning platform for other cooperative highway control strategies is established. Future work will include augmentation of ANFIS learning framework to enable cooperation between ramp metering and VSLC.

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References

[1] Papageorgiou, M; Diakaki, C; Dinopoulou, V; Kotsialos A; Wang, Y. *Review of road traffic control strategies*, Proceedings of the IEEE, 91(12):2043-2067, 2003.

[2] Treiber, M; Kesting, A. *Traffic flow dynamics - Data, Models and Simulations*, Springer-Verlag, Berlin, Heidelberg, 2013.

[3] Ryus, P. *Highway Capacity Manual 2010.*, Transportation Research Board. Retrieved 15, January, 2012.

[4] Lee, C; Hellinga, B; Ozbayc, K. *Quantifying effects of ramp metering on freeway safety*, Proceedings of 38^{th} Conference on Accident Analysis and Prevention, Ontario, pp. 279-288, 2006.

[5] 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.

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

[7] Gregurić, M; Ivanjko, E; Mandžuka, S. *New concepts for urban highways control*, REAL CORP 2014. - Clever plans for smart cities, pp. 423-432, Vienna, Austria, 2014.

[8] Gregurić, M; Ivanjko, E; Mandžuka, S. *Cooperative ramp metering simulation*, International convention on Information and Communication Technology, Electronics and Microelectronics - MIPRO 2014., pp. 1204-1209, Opatija, Croatia, 2014.

[9] Papamichail, I; Kotsialos, A; Margonis, I; Papageorgiou, M. *Coordinated ramp metering for freeway networks - A model - predictive hierarchical control approach*, Transportation Research Part C, 18(3):311-331, 2010.

[10] Gregurić, M; Buntić, M; Ivanjko, E; Mandžuka, S. *Improvement of highway level of service using ramp metering*, Proceedings of the 21^{th} International symposium on electronics in transport - ISEP 2013, Ljubljana, Slovenia, 2013.

[11] Murphey, R; Pardalos, P. *Cooperative Control and Optimization, Series: Applied Optimization*, Springer, 2002.

[12] Hegyi, A; De Schutter, B; Hellendoorn, H. *Model predictive control for optimal coordination of ramp metering and variable speed limits*, Transportation Research Part C, 13(3):185-209, 2005.

[13] Feng, C; Yuanhua, J; Jian, L; Huixin, Y; Zhonghai, N. *Design of Fuzzy Neural Network Control Method for Ramp Metering*, Proceedings of Third International Conference on Measuring Technology and Mechatronics Automation 2011, Vol. 1., pp. 966-969, 2011.

[14] Bogenberger, K; Keller, M; Vukanovic, S. *A Neuro-Fuzzy Algorithm for Coordinated Traffic Responsive Ramp Metering*, 2001 IEEE Intelligent Transportation Systems Conference Proceedings,Oakland (CA), USA - August 25-29, pp. 94-99, 2001

[15] Kurzhanskiy, A; Varaiya, P. *CTMSIM Traffic Macro - Simulator for MATLAB*, User Guide, TOPL Group, UC Berkeley, 2008.

[16] Štefančić, G; Marijan, D; Kljajić, S. *Capacity and Level of Service on the Zagreb Bypass*, Promet - Traffic and Transportation, Zagreb, Croatia, 24(3):261-267, 2012.