IMPROVEMENT OF HIGHWAY LEVEL OF SERVICE USING RAMP METERING

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Abstract

Ramp metering is used to improve the Level of service of highways containing a higher number off on- and off-ramps with traffic load at peak hours. An overview of existing Ramp metering strategies, from early simple approaches to the recent more sophisticated control designs is given in this paper. A description of various case studies of implemented Ramp metering systems in EU is included in the overview. Most of implementation has been custom made to fulfil respective demands on reducing congestion, average travel time, and increasing traffic safety. Some EU research projects and initiatives with significant influence on the EU Ramp metering approach are described, also. An analysis of Ramp metering strategies on a section of the Zagreb bypass is given regarding implementation possibilities to improve its Level of Service and traffic safety.

Keywords

Ramp metering, Level of Service, Neural networks, Fuzzy logic

INTRODUCTION

Increased using of road vehicles in the last 30 years induced extremely high occupation of roads and especially urban highways. Such an amount of traffic is exceeding traffic capacities of urban highways and urban bypasses. There is no more space for constructional expansion of highways in most urban areas (build only approach) [1]. Both mentioned reasons make a contribution to the fact that most highways operate at or are approaching their capacity limit. In other words generally high Level of Service (LoS) projected for highways is significantly reduced due to traffic overload.

Highway entrance/exit ramps or on- and off-ramps are places where it is possible to make a significant influence on highway LoS using appropriate control strategies [2]. Such control of interactions between on-ramp and mainstream traffic flows is known as Ramp metering. Ramp metering uses road signals at on-ramps to control the rate or size of vehicle platoons entering mainstream traffic flow according to current traffic conditions. Whole system is based on traffic data collected in real time by road sensors (inductive loops, cameras, etc.) and controllable traffic lights. Sensors are usually placed on the ramps and on the main road. They measure and estimate the traffic flow, speed and occupancy levels.

Ramp metering generally has following main operative reasons for implementation:

- Congestion minimization and improved throughput of mainline traffic flows on the highway;
- Reduction of travel time on highways and increased reliability in the planning time required to travel across highways;
- Reducing traffic demand for highway usage in short journeys;
- Prevention of accidents and incidents on highway;
- Improving environmental protection as a result of reduced noise and rational fuel consumption.

Ramp metering is today more and more used in order to improve LoS of highways containing a higher number of traffic on- and off-ramps with periodically increased traffic load at peak hours [3].

An overview of existing Ramp metering strategies, from simple approaches to the recent more sophisticated control designs and strategies is given in this paper. Emphasis of the overview is on proactive and cooperative systems as they present current state of the art of Ramp metering. A description of various case studies of implemented Ramp metering systems in EU is included in the overview, also. Most of implementation has been custom made to fulfil respective demands on reducing congestion, average travel time, and increasing traffic safety. Some EU research projects and initiatives with significant influence on the EU Ramp metering approach are described, also. An analysis of Ramp metering strategies on a section of the Zagreb bypass is given regarding implementation possibilities to improve its LoS and traffic safety.

OVERVIEW OF MOSTLY USED RAMP METERING ALGORITHMS

Most important part of Ramp metering is the control algorithm which produces decisions about the amount of on-ramp vehicles that are allowed to merge with mainstream traffic flow. Generally it is possible to divide Ramp metering algorithms in two major categories or strategies: local (or isolated) and coordinated [4].

Local strategies

Local strategies include Ramp metering algorithms that take into account only the traffic condition on particular on-ramp and nearby segment of highway where they are applied. The ALINEA algorithm is the most often used standard local Ramp metering algorithm. Reason for this lays in the algorithms optimal ratio between simplicity and efficiency. The core concept of ALINEA is to keep the downstream occupancy of the on-ramp at a specified level by adjusting the metering rate. Main disadvantages of ALINEA are: inability to resolve upstream congestions of the particular ramp and to locate optimal detector mounting zone. It is also important to mention that ALINEA has numerous enhanced versions developed to include local and coordinated Ramp metering approaches properties. Most recent versions are: MALINEA, VC-ALINEA and X-ALINEA/Q. All these derived versions are less efficient than the original ALINEA algorithm, but are often used in cases when downstream highway occupancy measurement is not available or possible.

Zone algorithm is based on metering zones which can contain one or more metered and unmetered on- and off-ramps. Zones have one upstream boundary which denotes free-flow area and one downstream boundary. Downstream boundary usually denotes the place where bottlenecks occur. Zone algorithm frequently adjusts metering rate to maintain a constant traffic density within a particular zone. Decision about the metering rate value is based on entering and exiting traffic volumes from mainstream traffic flow. Modern approaches in local Ramp metering algorithm development also include neural networks which are using learning capabilities to produce metering plans. Other modern approaches in local Ramp metering algorithm development are based on fuzzy logic and hybrid intelligent systems [5].

Coordinated algorithms

Coordinated algorithms are taking into account the traffic situation on the longer part of the highway (highway segment) or highway network as a whole. In the literature these algorithms are divided on: cooperative, competitive and integrated algorithms [6]. Ramp metering algorithms based on cooperation are working in two phases. In the first phase the metering rate for each on-ramp is computed by local Ramp metering algorithms. In the second phase further adjustment of each local on-ramp metering rate is done based on system-wide information about the traffic situation on the whole highway segment. Basic functionality of cooperative Ramp metering algorithms can be seen in Fig. 1.

HELPER algorithm is one among the first algorithms which have used mentioned cooperative Ramp metering working principle. It includes several local traffic responsive Ramp metering algorithms which are communicating with a centralized operational unit equipped with local metering rate override possibility. HELPER algorithm creates virtual queues in upstream on-ramps to reduce queue length on the congested one.

HEuristic Ramp metering coOrdination (HERO) is primary developed to establish cooperation between usually independent Ramp metering algorithms such as the ALINEA algorithm. HERO algorithm primary assigns to every local on-ramp control algorithm certain relative queue threshold and waits until one of the on-ramp queues exceeds its threshold. In a case when for the first time an on-ramp queue threshold is exceeded this on-ramp becomes the so-called “master”. Second step is to enlarge the exploitable storage space available on the “master” ramp, by gradually recruiting upstream on-ramps as “slaves” [7].

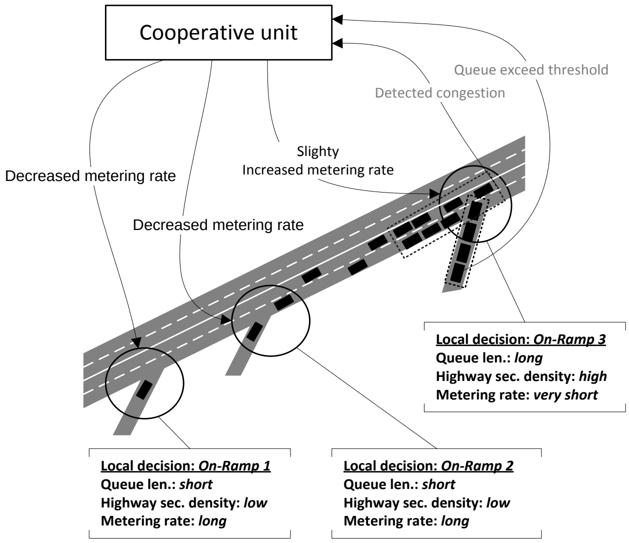

Figure 1: Basic functionality of cooperative Ramp metering algorithms

ACCEZZ algorithm is a coordinated Ramp metering algorithm based on Fuzzy logic control and genetic algorithm optimization. Generally genetic algorithm achieves global optimum of all metered on-ramps metering rates produced by local Fuzzy logic algorithms and thereby better coordination between them is established [7].

Table 1: Comparison of Ramp metering algorithms

	Algorithm features					
Ramp metering algorithms	**Algorithm category***	**Complexity level****	**Proactive**	**Used in EU**	**Ability to resolve: Upstream Congestion**	**Ability to resolve: Downstream Congestion**
ALINEA	L	L		x		x
ZONE	L	M			x	x
HELPER	C	M			x	
HERO	C	H		x	x	
ACCEZZ	C	H		x	x	x
SWARM	C	H	x		x	x
(*)L – Local, C – Coordinated (**) L-Low, M-medium, H-High						

System-Wide Adaptive Ramp metering (SWARM) uses two different types of control algorithms: SWARM1 and SWARM2B. SWARM1 algorithm works on a global coordination level by taking into account traffic state on each on-ramp. For final Ramp metering rate value computation SWARM1 algorithm uses also predictions of highway traffic bottlenecks based on historical traffic parameters data. SWARM2B is a local Ramp metering algorithm and defines metering rate according to 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. In Tab. 1. it is possible to see comparison of mentioned Ramp metering algorithms using basic Ramp metering algorithm features.

EUROPEAN FRAMEWORK FOR RAMP METERING IMPLEMENTATION

Most significant EU project in domain of Ramp metering is EURAMP. Capital deliverable of this project is described in [7] and can be understood as a framework for future implementation of Ramp metering on European highways. General conclusion is that LoS on all tested sites is improved after Ramp metering implementation. Published EURAMP documentation does not strictly prescribe which algorithm must be used for a particular traffic scenario. It provides instructions for user campaigns that should inform drivers about their required behaviour on metered on-ramps. Deliverables of EURAMP also propose metering policies, ramp layouts and rules, and mainstream traffic condition.

Most important initiative in increasing LoS on European roads with harmonized intelligent transportation systems (ITS) based solutions related to Ramp metering is EasyWay. Its vision of the Ramp metering service is focused on end-user aspects (drivers and operators), ensuring that drivers across Europe encounter similar conditions (including “look and feel”) when driving in ramp metered areas. In another words, this initiative studies technical-legal aspects of Ramp metering [8]. The presentation given in Fig. 4. provides a graphical illustration of the service added value of EasyWay which are: safety, efficiency and environment.

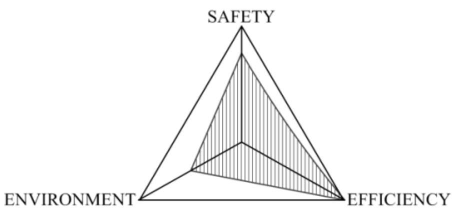

Figure 2: Ramp metering & EasyWay common objectives

Regarding the European framework for Ramp metering implementation, it is important to also mention an undergoing project: Intelligent Cooperative Sensing for Improved traffic Efficiency (ICSI) funded under Seventh Framework Programme (FP7). ICSI will propose a new architecture for road LoS improvement based on advanced cooperative sensing and traffic management strategies including Ramp metering [9].

MEASURES FOR HIGHWAY LoS ASSASSMENT

Generally there are three basic measures for highway LoS assessment on which Ramp metering can have influence: Travel Time (TT), Travel Delay (TD) and Productivity Loss (PL), [10]. Travel time is a simple measure which informs how much time one vehicle needs to travel through observed highway segment. Intuitively TT must be on the most possible minimal value to provide higher LoS. Numerous measures improvements to aid in the evaluation of travel time reliability were recently developed in USA. One of them is travel time index (TTI) which is a comparison between travel conditions in the peak-period to free-flow conditions.

Additional two important performance measures are Vehicle Hours Travelled (VHT) and Vehicle Kilometres Travelled (VKT). VHT is defined for a given unit of time and a given section of the evaluated highway and indicates the amount of time spent by all of the vehicles on the highway. Performance measure VKT is also defined for a given unit of time and a given section of the highway, but indicates the sum of travel distance driven by each vehicle on a highway. According to previous definitions TD can be calculated as the difference between the actual VHT and the respective VKT value vehicle would travel at free flow speed [sec/veh]. Similar as for TT, TD must be equal to most possible minimal value. If the TD value has increased for a highway section, it is likely that this highway section is experiencing some sort of congestion. Such a situation directly leads to poor LoS regarding this highway section.

Another cost criterion is the total time spent (TTS) by all vehicles in the traffic network. TTS value includes the total waiting time (TWT) at an on-ramp and total travel time (TTT) spent in the mainstream traffic (TTS = TTT + TWT). The minimization of the TTS criterion includes also minimization of the on-ramp waiting time which is a natural optimization objective for the traffic control system considered in this paper.

Productivity Loss (PL) is basically a facility throughput measure. It is defined as the number of lane-kilometres-hours on the highway lost due to reduced traffic flow, while operating under traffic congestion instead of free-flow conditions. Except with the productivity loss, facility throughput can be measured also with: throughput of vehicle or person volumes, facility speeds, volume to capacity (V/C) ratio, or queuing measures (length and frequency). It is possible to expand mentioned technical measures with additional supporting measures such as the mobility measure which uses a metric of aggregative total person-hours of travel (PHT) or spot measurements of speed. Traffic safety can be measured through obtained crash-records kept by one or more emergency respond agencies or the respective department of transportation. Final data often include number of crashes classified by severity or crash type (injury type, fatal injuries, property damage, etc.). Additional standard and novel measures for LoS evaluation can be found in [4, 7].

CASE STUDIES OF RAMP METERING SYSTEMS

The most extensive case studies in domain of Ramp metering approaches in EU are done in scope of the already mentioned EURAMP project. Four case studies done in this project are: Paris (A6) in France, Utrecht (A2) in Nederland, Munich (A94) in Germany, and Tel Aviv (Ayalon) in Israel. As mentioned, general conclusion of this project is that LoS in all case studies improved after Ramp metering implementation. After obtained results comparison it can be concluded that HERO algorithm gives best results for large-scale field implementations of coordinated Ramp metering strategies. Second best algorithm regarding coordinated Ramp metering approaches is ACCEZZ. If the merge area of a particular on-ramp is also actual place where the traffic bottleneck occurs then the EURAMP project recommends implementation of local Ramp metering algorithms like ALINEA or one of its modifications.

Another simulation based case study is Amsterdam (A10) in Nederland [11]. Authors used the METANET simulator to compare no control state with local ALINEA and HERO Ramp metering algorithm. Uncoordinated ALINEA based local control is quite successful in reducing the TTS and reducing traffic congestion up to a certain degree without an on-ramp queue limit. Coordinated algorithm HERO gives better results reducing TTS up to 47.8 [%] with queue limit of 200 vehicle. In Tab. 2. it is possible to see comparison of mentioned Ramp metering case studies. All values given in Tab. 2. are computed with respect to the no control state prior Ramp metering implementation.

Table 2: Comparison of existing Ramp metering case studies

Case study sites	**Ramp Metering algorithms**	**Simulations (S) or real-world (RW) implementation**	**Measure for LoS assessment**	**Improvements after Ramp metering implementation [%]**
Paris (A6)	VC-ALINEA	RW	TT	13
	HERO			17
Utrecht	1 or 2 car per green	RW	TT	5
Munich (A94)	ALINEA	RW	TT	7
	ACCESZZ			9
Tel Aviv (Ayalon)	ALINEA	RW	TT	6.7
Amsterdam (A10)	ALINEA	S	TTS	45
	HERO			47.8

INCREASING LOS ON ZAGREB BYPASS BY RAMP METERING IMPLEMENTATION

When Ramp metering implementation or test sites are being considered, appropriate traffic network configuration and traffic problems have to exist. Otherwise new Ramp metering traffic control strategy will not make an improvement. Traffic network around Croatian capital city, the Zagreb bypass can be proposed as new highway test corridor for Ramp metering implementation.

Geographical and constructional definition of Zagreb bypass

Zagreb is both, origin and destination of many travels routes that take place over six (A1, A2, A3, A4, A6 and the future A11) motorway routes. Common for all mentioned travel routes is that they all finish or start on the lateral south road – the existing Zagreb bypass, the place where European corridors X, Xa and Vb intersect. It serves traffic coming from adjacent highways heading to Ljubljana, Slovenia, Budapest Hungary, and highways to the south and eastern regions of Croatia. Section between nodes Jankomir, Lučko and the Lučko tollbooth plaza have already become part of urban road network on which about 70 [%] of traffic is generated by the nearby town urban traffic. Distance between centre of Zagreb and closest node is ~5.96 [km]. In 2009 the Average Annual Daily Traffic based on traffic count data at Zagreb bypass was recorded to be 54,542 [veh/day] [12].

For Ramp metering it is important that Zagreb bypass has an expressed traffic load at peak hours. So this is an ideal site for evaluation of coordinated Ramp metering algorithms. Zagreb bypass is also a highway with low dependency level between (average distance between nodes ~5.36 [km]) nodes and on-ramps what is not good for coordinated Ramp metering algorithms except for peak hour situations. Zagreb bypass with marked nodes can be seen in Fig. 3.

Figure 3: Zagreb bypass with marked nodes

According to the calculation method suggested in Highway Capacity Manual average LoS mark for all Zagreb bypass nodes is B [12]. This mark leads to conclusion that Zagreb bypass has generally speaking relatively low traffic load which can be effect of greater distance from the city centre. Higher traffic load on Zagreb bypass is common during summer tourist season what is especially noticeable in form of long waiting queues at Lučko tollbooth plaza.

Zagreb bypass simulation

To simulate traffic flows at Zagreb bypass CTMSIM simulator has been used. CTMSIM is an interactive simulator based on macroscopic traffic models developed and run under the MATLAB program package. It is based on the Asymmetric Cell Transmission Model (ACTM) and allows user-pluggable ramp flow and ramp queue controllers. It is assumed that data which contain On-Ramp demand are based on the overall traffic state on Zagreb bypass and small distance of a particular node with Zagreb centre. In Fig. 3. it is possible to see the model of Zagreb bypass created using ACTM methodology. Every segment of highway is presented by a cell which can contain on-ramps (blue lines) or/and off-ramps (green lines). Zagreb bypass is totally presented by 30 cells.

Figure 3: ACTM model of Zagreb bypass

Proposed ANFIS Ramp metering algorithm

An Adaptive Neural-Fuzzy inference system (ANFIS) algorithm using artificial Neural network (ANN) to modify parameters of Takagi–Sugeno fuzzy inference system is proposed for Ramp metering control of the Zagreb bypass. ANFIS inference system contains a set of Fuzzy logic IF–THEN rules that have learning capabilities to approximate nonlinear functions [13]. First phase in development of proposed ANFIS algorithm includes structure definition and selecting appropriate procedures for teaching Ramp metering algorithms. To cover wide range of traffic scenarios on Zagreb bypass two Ramp metering algorithms are chosen as teaching algorithms for the proposed ANFIS based algorithms. First of them is a local (ALINEA) and the second one is a coordinated (SWARM) algorithm.

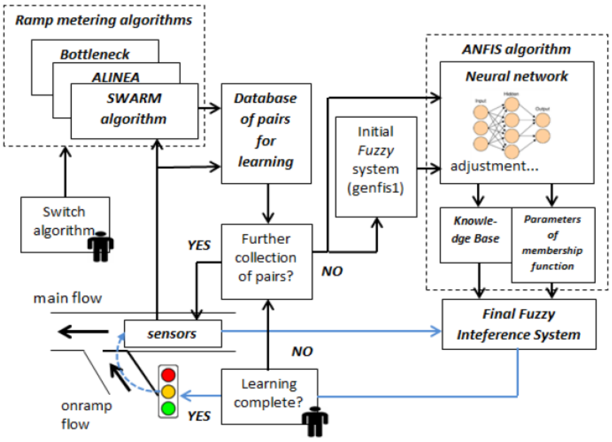

Figure 4: Functionality scheme of proposed ANFIS algorithm for Ramp metering [5]

Using the CTMSIM simulator a learning database of different traffic parameters was generated. Exhaustive search was used to select appropriate parameters which would be used in the input/output teaching set of the ANFIS algorithm [5]. Functionality scheme of the proposed ANFIS based Ramp metering algorithm can be seen in Fig. 4.

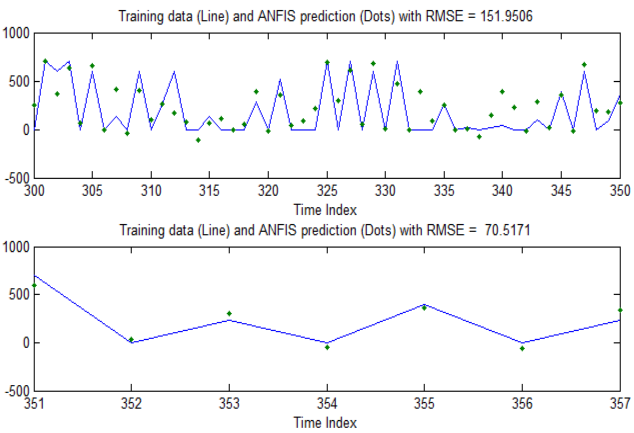

Figure 5: Graphs of the relationship between learning / testing and ANFIS prediction

ANN training is accomplished by combination of learning using feedback error propagation and least squares. Every element of the training data set (only inputs) is presented to ANN and based on current state of inference system ANFIS returned an output in form of metering rate prediction. Output predictions are compared with output training data and based on the difference between these two values, degree of matching is derived in form of Root Mean Square Error as it can be seen in Fig. 5. Higher error values during ANN training are achieved due to lack of real Zagreb bypass traffic data so only a relative small training set is used.

SIMULATION RESULTS

In Fig. 6. a 3D diagram presenting relation among VHT, simulation runtime and distance in highway model is given. It can be noticed that VHT rapidly increases its value in areas after nodes with high traffic demand. This behaviour can be explained with sudden increase in density immediately after node what is side-effect of merging process. Close to the following node, the value of VHT decreases because of low density regarding increased headways between vehicles. Main goal of the applied control algorithm is to reduce bottlenecks near nods.

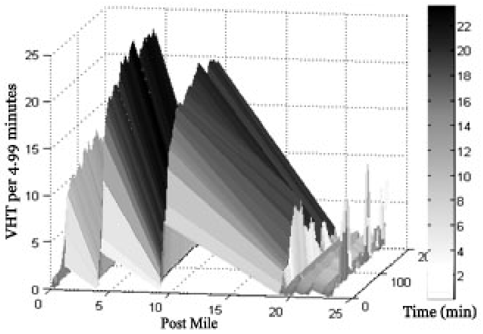

Figure 6: 3D diagram of relation among VHT, simulation runtime and distance in highway model

For selection of an optimal Ramp metering algorithm implementation ANFIS, ALINEA and SWARM algorithms are compared using the productivity loss measure. Results of comparison are presented in Fig. 7.

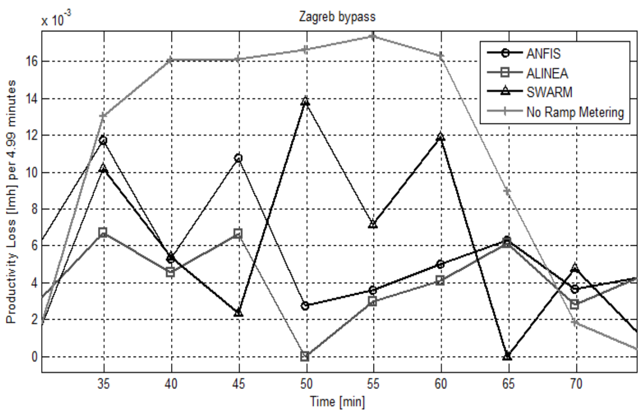

Figure 7: Comparison of productivity loss for evaluated Ramp metering algorithms

Productivity loss is used for LoS assessment due its ability to present direct influence of on-ramp traffic flows at mainstream. ALINEA algorithm achieves highest road lane usability due to generally reduced metering rates in opposition of other algorithms. Also it can be concluded that neural network was successful in training the ANFIS algorithm in basic principles of Ramp metering by means of combined coordinated and local Ramp metering algorithm properties usage for learning. It can be also seen that ANFIS was not successful to achieve better result than ALINEA. Main reasons for that is lack of larger data set of real traffic parameters data and adopted higher values of metering rates due to SWARM predictive nature influence.

CONCLUSIONS

Ramp metering presents an effective traffic control method to increase LoS on highways with a significant number of on- and off-ramps. Places where these ramps interconnect the highway and adjacent urban traffic network are also places with a higher probability of traffic congestion occurrence. Using controlled entrance of vehicles into the highway network and on-ramps as temporally storage of vehicles traffic congestion probability in both, highway and adjacent urban traffic network can be reduced or even completely removed. Optimal LoS for the whole highway section is achieved without significant difference of Ramp metering rates and waiting times between on-ramps belonging to the controlled highway section.

Furthermore, first simulation results on Zagreb bypass are promising and suggest possible LoS improvement by Ramp metering implementation. Proposed ANFIS algorithm shows promising results in increasing LoS of the Zagreb bypass. Achieved performance is similar to the ALINEA algorithm. In future work proposed ANFIS algorithm will be trained with a larger data set and developed in direction of proactive cooperative strategies.

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BIOGRAPHIE

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