ADVANCED APPLICATIONS FOR URBAN MOTORWAY TRAFFIC CONTROL

Martin Gregurić[1], Sadko Mandžuka[1], Krešimir Vidović[2]
[1](Faculty of Traffic and Transport Sciences, Vukelićeva 4, HR-10000 Zagreb, Croatia)
martin.greguric@fpz.hr, sadko.mandzuka@fpz.hr
[2](Ericsson Nikola Tesla, Krapinska 44, HR-10000 Zagreb, Croatia)
kresimir.vidovic@ericsson.com

ABSTRACT:
Nowadays urban motorways cannot fulfill their originally projected purpose as urban bypass due to congestions. Congestions are caused by recurrent traffic from the urban area, which tries to bypass controlled traffic intersection in the same urban area, and non-recurrent transit traffic. The problem cannot be solved by constructional build-up since they became surrounded by the urban and traffic infrastructure. This requires new approaches to make the traffic flows on them more efficient and safer. Modern information-communication technologies and advanced traffic control algorithms are introduced as an only valid approach for mentioned problems. This study proposes the latest approach of coordination between controlling on-ramp flows with ramp metering (RM) and Dynamic Route Guidance Information Systems (DRGIS), which reroute vehicles from congested parts of the motorway. In the next decades, road transport will undergo a deep transformation with the advent of autonomous vehicles, which are about to drastically change the way we commute. This paper also provides a quick overview of the Intelligent Speed Adaptation (ISA) implementation in the context of autonomous vehicles and connected driving.

Keywords: *Traffic Control, Ramp Metering, Route Guidance, Autonomous Vehicles*

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1. INTRODUCTION

Urban motorway can be considered as the former bypass of the larger urban area, which became heavily integrated with the traffic network of the urban area. Therefore, urban motorway has a direct connection with the arterial roads of urban traffic network through numerous and mutually close on- and off-ramps. Intense traffic demand generated at the urban motorway on-ramps can significantly reduce speed and increase the density of the mainstream flow near those on-ramps. That can lead to downstream congestions near overburdened on-ramps, what consequently induce queues on them. If those on-ramp queues are large enough, they can spill over into the urban traffic arterials ("spillback effect") and induce heavy congestions on urban traffic network. It is possible to conclude that on- and off-ramps are places where it is possible to make a significant impact on motorway mainstream traffic flow and at on-ramp queues [1], [2].

Ramp metering (RM) provides restriction for the vehicle which has the intention to access mainstream flow from on-ramp by using special traffic lights [2], [3]. A most important part of the RM system along with the detectors, appropriate traffic lights, and other signalization is the RM algorithm which determines the "access rate reduction" for the respective on-ramp flow [4]. The "access rate reduction" is computed according to the traffic parameters of the mainstream flow and number of vehicles which are queueing at the particular on-ramp. It is important to emphasise that RM provide control only over the vehicles which are already part of the queue at the particular on-ramp. In the case when the mainstream density near on-ramp is close to the maximal capacity of this section, there is no more space to adopt additional vehicles from a nearby on-ramp. In that case, on-ramp queue can grow proportional to the on-ramp traffic demand, what makes RM obsolete, and consequentially induce "spillback effect". It is possible to conclude that RM cannot provide control over the on-ramp traffic demand. In order to alleviate that problem, RM must be set in coordination with other motorway control methods such is variable speed limit control (VSLC) or route guidance system. VSLC in coordination with the RM can reduce motorway upstream mean speed if the congestion near particular on-ramp occurs. That type of coordination slows down incoming mainstream vehicles to the place of congestion and gives extra space to accommodate vehicle from congested on-ramps into the mainstream. It is possible to conclude that this coordination does not efficiently solve the problem if the traffic demand at congested on-ramp is too high. In that case, it is necessary to reroute vehicles which have the intention to use congested on-ramp. This can be done with the application of the Dynamic Route Guidance Information Systems (DRGIS). The problem of coordination of ramp metering and DRGIS is presented in section 2. In section 3. quick overview of the impact of autonomous vehicles on traffic control is given. Paper is concluded with the conclusion remarks in section 4.

2. COORDINATION OF RAMP METERING AND DRGIS

DRGIS is used to inform drivers about current or expected travel times and queue lengths so that they may reconsider their choice for a certain route [5]. Mentioned system transfer information about current/predicted travel times for critical parts of urban motorway system to the drivers by special DRGIS messaging signs, or it can be integrated as an advisory service within the existing GPS routing system. In Figure 1. it is possible to see a conceptual example of a system which enables coordination between DRGIS and RM.

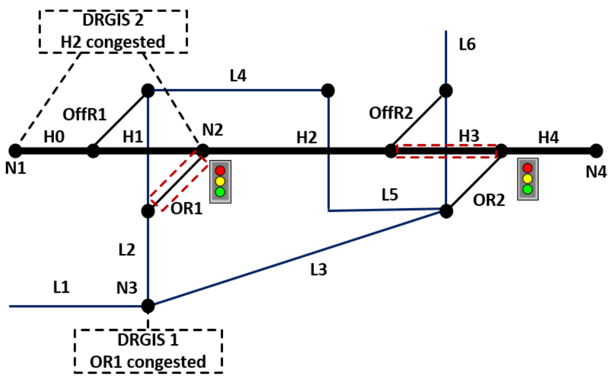

Fig. 1. A conceptual example of a system which enables coordination between DRGIS and RM

Special DRGIS messaging signs can be located near entry points to the on-ramps from the urban traffic network as it is the case in node N3 at Figure 1. At Figure 1. on-ramp OR1 is denoted as congested, DRGIS will advise drivers about long travel times at this on-ramp what will motivate drivers to use L3 link for accessing motorway by using on-ramp OR2 instead OR1. Furthermore, in Figure 1. nodes N1 and N2, are places where DRGIS signs are placed on the motorway itself so the drivers can obtain information about eventual downstream congestions, which in our case occurs at motorway section H3. DRGIS system will advise drivers to leave motorway by using one of the available downstream off-ramps if congestion in the H3 motorway section is strong enough. In the case presented in Figure 1. those alternative routes begin with the off-ramps OffR1 and OffR2. Drivers at motorway section H0 can choose the off-ramp OffR1, in order to avoid congestions at on-ramp OR1 and motorway section H3. In continuation of their new route drivers can access motorway through the uncongested on-ramp OR2 by using links L4 and L5. In the other hand drivers in motorway section H1, can choose a route to the off-ramp OffR2 and leave motorway in order to avoid congested motorway section H3.

It is possible to conclude that DRGIS can directly impact on traffic demand at the urban traffic system by informing the drivers about travel times on its crucial segments. Those information's will suggests drivers not to choose the route which contains segments of urban motorway with lower travel times or to avoid using congested on-ramps. Reduced traffic demand on congested urban motorway section or at congested on-ramp in coordination with the adequate ramp metering control strategies can prevent "spillback effect" and increase overall throughput of the urban motorways.

In [5] it is proposed that DRGIS in coordination with the RM compute optimized travel times (as a control signal) which are optimized in combination with and at the same time as the RM control signals. Model predictive control (MPC) is used as the optimization engine. This approach is proposed because instantaneous travel times are not reliable due to the stochastic traffic dynamics. In the other hand, predicted travel time, as another common output of DRGIS, is not suitable because resulting rerouting by the drivers may result in a traffic distribution that is not always optimal with respect to the total network performance [5]. In [6], a multi-class and multi-objective combined RM and routing control strategy is proposed, in order to reduce the total travel time and the total emissions in the motorway system in a balanced way. This study is based on the total travel time and total emissions prediction. Since this approach is based upon multi-class control strategy it is possible to specify different control policies for the different classes of vehicles, i.e. cars, trucks, and other types of vehicles that can be of interest for the considered application case [6]. This is especially important in the case when it is necessary to adequately reroute large platoons of trucks due to their negative impacts at on-ramp queues and their increased emissions while they are queuing.
Technically, for these purposes different technologies can be used for cooperative systems, such as for example public mobile networks and the like [7, 8]. In that sense, the application of the future 5G mobile network is of great importance. The source of information for these needs is for example the urban traffic management center, including traffic incident management center [9].

3. IMPACT OF AUTONOMOUS VEHICLES ON TRAFFIC CONTROL

Penetration of upcoming autonomous vehicle on the urban traffic network will have a huge impact on the traffic flows and control over them, and it will happen gradually. This is the reason why is very important to estimate the impact of autonomous vehicles on the one of the most basic traffic parameter such is traffic speed on urban motorway [10], [11]. Nowadays, speed on urban motorways is controlled by VSLC. Those VSLC applications are oriented on the infrastructural traffic signs for posting appropriate speed limits such as Variable Message Signs (VMS). Speed limits are computed in response to the prevailing traffic conditions which is measured by the static traffic detectors. It is possible to conclude that the effectiveness of VSLC is related to the driver compliance rate to the posted speed limit value on VMS. It [12] it is shown that the VSLC system becomes inefficient if drivers do not adjust the speed of the vehicle according to the posted speed limit value. Those problems can be efficiently alleviated by higher penetration rate of the autonomous vehicle.

An autonomous vehicle with their numerous sensors and connectivity possibilities with other vehicles and infrastructure can be considered as moving traffic sensors (FCD – Floating Car Data). Data from those vehicles can be used to produce a more comprehensive and accurate picture of the traffic flows based on which, it will be possible to compute desired speed profiles for much smaller time frames compared to the current VSLC. Furthermore, it is possible to use autonomous vehicles as the one form of the information routers which will pass information about current speed profiles to the vehicles which are too far from the broadcasting range of the roadside unit. All mentioned technical advantages of autonomous vehicles are used for the implementation of the Intelligent Speed Adaptation (ISA). An autonomous vehicle with ISA will automatically reduce its current speed or just inform the driver about necessary action according to the acquired speed limit from ISA roadside unit. Even with a smaller penetration rate of autonomous vehicles with ISA, speed homogenization effect of classic VSLC that enable reductions of fluctuations in traffic parameters, i.e. speed differences of vehicles between lanes and within the same lane, can be improved [13]. The architecture block scheme of a system that presents communication between autonomous vehicles and traffic management system of ISA is presented in Figure 2.

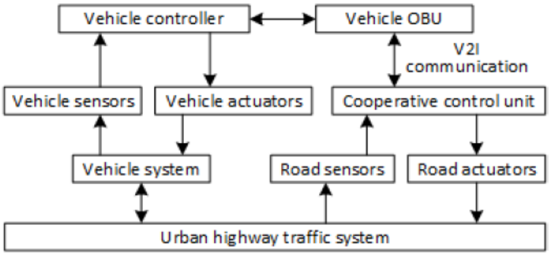

Fig. 2. Block scheme of an architecture for communication between a vehicle and the traffic control system of ISA [7]

4. CONCLUSION

Nowadays, urban motorways cannot fulfill their originally projected Level of Service (LoS) due to congestions caused by local urban and transit traffic. Urban motorways are fully integrated with the urban infrastructure and urban traffic network so there is no more space for constructional expansion of existing motorway capacities. The only solution for dissolving congestions is the application of advanced traffic control strategies and information systems for urban mobility. Latest approaches propose coordination between traffic control system such as RM and traffic information system such as a route guidance system. On the other hand, ISA can provide a feasible solution for the problem of a higher percentage of vehicles that do not comply with the posted speed limit in the upcoming era of autonomous vehicles. Abilities of ISA regarding the more accurate computing of the speed profiles for each vehicle based on the more comprehensive traffic picture of overall motorway can be extended, if it is placed in cooperative environment with the motorway infrastructure.

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CORRESPONDANCE:

Martin Gregurić, Ph.D.T.E.
University of Zagreb
Faculty of Transport and Traffic Sciences
Vukelićeva 4,
10000 Zagreb, Croatia
martin.greguric@fpz.hr

Sadko Mandžuka, Ph.D.E.E.
University of Zagreb
Faculty of Transport and Traffic Sciences
Vukelićeva 4,
10000 Zagreb, Croatia
sadko.mandzuka@fpz.hr

Krešimir Vidović, Ph.D.T.E.
Ericsson Nikola Tesla
Krapinska 44,
10000 Zagreb, Croatia
kresimir.vidovic@ericsson.com