AUTONOMOUS VEHICLES IN SUSTAINABLE CITIES: MORE QUESTIONS THAN ANSWERS

ANDRÁS SZELE[1] & LAJOS KISGYÖRGY[2]
[1]Institute for Transport Sciences Non-profit Ltd., Hungary
[2]Budapest University of Technology and Economics, Hungary

ABSTRACT

There are a lot of high expectations about the appearance and spread of autonomous vehicles. There are clear advantages, which can be almost assured: autonomous vehicles will be more comfortable, the number of road accidents will be decreased, more people will gain access to the passenger car's benefits, and unimaginable traffic and business services will be created. Just because of these benefits, it is worth investing considerable resources in the development of autonomous vehicles. There are other expected positive impacts, such as wide-range vehicle sharing and congestion alleviation. However, these latter impacts are not self-explanatory, and research should be taken to ensure that the widespread use of autonomous vehicles results more sustainable urban transport. In this paper, we analyse the impact of autonomous vehicles on congestion. Firstly, we introduce the traffic operation of the road network with recurrent congestion. Secondly, we show that shared use of vehicles reduces congestion only if the sharing of family-owned vehicles is dominant. Otherwise, the users are likely to be mainly former public transport users, cyclists, and pedestrians. Thirdly, we demonstrate that the widespread use of autonomous vehicles reduces congestion only when the new technology improves the capacity of the key cross-section of the network. The capacity of these key cross-sections can only be slightly improved without major construction work, so congestion can only be reduced if there are significantly less vehicles on the road network or the efficiency of traffic flow through autonomous vehicles increases. However, the latter, according to our calculation, is not so favourable to bring about a fundamental improvement in the traffic because of the expected increase in the motorization. Finally, we present some proposals that can contribute to the reduction of congestion on the urban road networks dominated by autonomous vehicles.

Keywords: autonomous vehicles, traffic design, network planning.

1 INTRODUCTION

Congestion is one of the most unpleasant phenomena in urban areas. The number, frequency, and extent of congestion are constantly increasing, as the number of cars growing in urban areas. Even in the developed countries, there is a fast increase in the number of cars and the traffic. The congestion charge is the best-known tool to solve the problem, but only in a very little application area. Using various toll systems could make a breakthrough, but their political support is low, the widespread is unlikely to be expected.

Today, the future of the transport is determined by the development of autonomous vehicles. There are numerous research and technological developments in this field. Developers of autonomous vehicles usually refer to three significant aspects that make these vehicles the future. The first is a drastic reduction in the number and severity of accidents. The second is the widespread use of shared vehicles, and the third is the alleviation of congestions. The last statement is usually not explained in detail if, however, it shows the possibility of avoiding special congestion situations and refers to declining traffic due to the use of shared vehicles.

Based on our research into the traffic operation of the road network with recurrent congestion, there is concluded that the expectations regarding the congestion reduction by autonomous vehicles are likely to be excessive. Autonomous vehicles will bring about changes that can be compared with the spread of mobile phones or the Internet. In this paper,

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we would like to draw attention to those factors relating to autonomous vehicles, which are more likely to propagate further congestion. This article is about autonomous passenger cars only; we do not deal with autonomous vehicles in the public transport and freight transport. We do not discuss the period of autonomous vehicles' coexistence with conventional vehicles, our focus is the completely autonomous period. The advantages and disadvantages of autonomous vehicles are examined only when they are relevant to the congestion.

2 HOW DOES RECURRENT CONGESTION HAPPEN?

Before discussing the relationship between autonomous vehicles and congestion, it is also worth speaking about the recurrent congestion. There are several types of congestion, but the greatest impact on our everyday life is done by recurrent congestion [1]. This kind of congestion is the most common, and the reason behind them is simply the gap between the capacity of the road network and the demand. In fact, we don't know too much about the traffic operation and dynamics of road networks with recurrent congestion. However, according to our research, there is much to be said. The most important point of such networks is the key cross-section. This is the cross-section, where the capacity is firstly exceeded. The key cross-section is not avoidable, so every single vehicle has to cross over. In every road network with recurrent congestion there is a key cross-section, causing congestion on the arterial roads (primary congestion). During the congestion, alternative routes are used intensively, which causes a significant (re-)joining demand in the vicinity of the key cross-section, often occurring congestion on the local roads (secondary congestion). As a result of this phenomenon, the queue of the primary congestion becomes slower due to the newer vehicles that join at the beginning of the queue [2]. Another important result is that the congested queue operates significantly differently than the non-congested queues: crossing the congested queue is much easier and joining such queue is simpler and faster than non-congested queue. These phenomena are influencing the priority conditions of the congested networks, and ultimately the total traffic control system as well [3]. The most commonly used tool to alleviate congestion is the capacity increase. The local results of this are unquestionable, but do not produce results at the network level. There are two reasons for this: firstly, latent traffic uploads the new capacities. Secondly, the capacity in the consecutive intersections of the network is usually quite similar, so with the extension of the capacity of the current key cross-section almost certainly will create another key cross-section in one of the adjacent intersections causing new congestion.

3 AUTONOMOUS VEHICLES AND CONGESTION

The literature outlines the expected impacts of autonomous vehicles on traffic operation [4]–[7], taking into account the benefits and disadvantages. The traffic operation-related impacts are:

- Driving is not linked to age, driving license or physical condition, so more people have access to the benefits of individual transport,
- The number of trips expected to increase significantly,
- A significant shift is expected in cities from traditional public transport to autonomous and shared vehicles,
- Improved route planning, smaller headways, vehicle to vehicle (V2V) communication, and communication between vehicles and infrastructure (V2I) reduce congestion and transportation costs,
- Improved utilization of travel time is likely to increase commuting distance,

- The use of autonomous vehicles is expected to reduce the proportion of walking and cycling,
- The proportion of empty runs of autonomous vehicles will be significant,
- Autonomous vehicles deliver their passengers exactly to their destination, thus avoiding the traffic searching parking place,
- Autonomous vehicles can bring the car back into fashion, so people may start using these vehicles again, which they have not done so far.

In this article, we focus on two of the above impacts: the effects of shared vehicles and the improving intersection efficiency due to the autonomous vehicles and V2I. Finally, we will show that autonomous vehicles can really help to avoid congestions only if serious vehicle size or traffic control changes will be made. For the latter, it is needed to learn the specific attributes of recurrent congestion.

4 THE IMPACTS OF SHARED VEHICLES ON CONGESTION

It is told that one of the biggest advantages of autonomous vehicles is the possibility of spreading the use of shared vehicles. At the same time, researchers in this field are agreed that shared autonomous vehicles will reduce car ownership but will increase traffic [7]. The value of the increase is estimated at between 3 and 11% [8], [9]. Another argument is against the congestion alleviation impact of shared vehicles that in rural and suburban areas are not expected to be as widespread as in urban areas because their use hardly benefits. It is an important argument that a large number of passengers using shared vehicles are likely to use these vehicles instead of public transport, cycling and walking. Finally, perhaps the most important argument is that the concept of the shared vehicle is very different from today's car-dependent lifestyle. Many people do not know, others do not want to live their life without their own car, and the car industry will certainly take the advantage of this demand.

To sum, it is unlikely that shared vehicles would bring a fundamental change to the entire transport system. However, their benefits are significant and their widespread use in urban, especially metropolitan environments is likely. The greatest success would be if the sharing of family cars would be on the agenda. This is a daring idea, such system could still work today, but it is not an available option.

5 THE IMPACT OF AUTONOMOUS VEHICLES ON THE CAPACITY OF SIGNALIZED INTERSECTIONS

The general argument to support autonomous vehicles is that the significantly smaller headway will entail a large increase in efficiency in the traffic flow. When vehicles are platooning just a meter apart, it's really different from today's traffic operation mode and its advantages are obvious, especially on motorways. At the same time, it is worth examining the expected situation in a signalized city intersection.

The traffic capacity of an intersection depends on many factors. It is a matter of traffic composition, speed, mode of regulation, green intervals, lane design, rate and volume of pedestrian and bicycle traffic, etc. It is expected that the traffic operation of intersections will not change dramatically in the near future, so the use of autonomous vehicles can only improve junction capacity only by improving the efficiency of the traffic flow. From this point of view the most important feature of the traffic flow is the headway, which describes the arrival of two consecutive vehicles. As a rule of thumb, in saturated flow, the headway of passenger cars is determined within 2 seconds regardless of the speed.

The dynamics of queue dissipation in the signalized intersections is important in the analysis of the expected operation of the traffic flow with autonomous vehicles. In the literature several studies can be found on headway, however, their findings are conflicting. Each of them confirms the start-up lost time at the first few vehicles, but after that the paths diverge. One group of the studies finds no change in headway values. HCM 2010 assumes a constant headway after the first few vehicles [10], which assumption is confirmed by some studies [11], [12]. However, other researchers reported compressing headway along the dissipating queue [13]–[19]. They account this phenomenon for the tailgating and hurrying drivers at the end of the queue. On the other hand, other studies found the headway would get longer after a certain point in time as the queue dissipating [20]–[23]. Rouhani analyzed the dissipation of queues in signalized intersections [24]. He concluded that the dynamics do not depend solely on location but on other factors such as green time and the ratio of heavy vehicles as well. There are other thorough and important studies about the headway and its relationship with the traffic congestions [25], [26]. The detailed findings of these papers confirm the statement of the state-of-the-art.

The impacts of headway on the traffic operation of autonomous vehicles were analysed [27], [28] with different conditions and for different scenarios. The outcomes are convincing, in the presented calculations, there is 25–40% capacity increase caused by smaller headways of the autonomous vehicles. Another important statement, that at the capacity limit even a minor increase in the capacity of the signalized intersection can lead to a dramatic improvement.

Let us assume that the conditions of urban traffic do not change basically with the spread of autonomous vehicles. In this case, the mode of operation of the intersections will not change, there will be pedestrians and cyclists at the intersections, and the characteristics of the operation of the signalized intersections, like clearance intervals, won't change. It is also likely that traffic of autonomous vehicles will drive at a speed of up to 50 km/h and because of the demand of travel comfort, the acceleration of these vehicles will be similar to today. In this case, the improvement of the capacity of the intersections can only be expected from the downward of headways. If we could reduce the headways from today's 1.7–2 seconds to 0.8 seconds, this would at least double the effectiveness of the key cross-sections, the most important capacity limiting points of the network. Unfortunately, there are other factors to be taken into consideration.

6 IMPACTS OF INCREASING MOTORISATION

It is also worth noting that by the time of the widespread of autonomous vehicles (~2040), it is assumed that traffic will increase significantly compared to today. Fig. 1 shows the growth of motorization in major regions of the world. The experience, that as long as the economy is prosperous and fuel prices are not extremely high, the number and use of passenger cars are constantly growing, sometimes being up to 4–5% per year. The increase in the number of vehicles obviously entails an increase in traffic, however, the relationship is probably not linear.

The impacts of this process are, however, very significant: if there is no change in the basic conditions, then the number of the passenger car may increase by 30–40% by 2040, which may occur a similar increase in traffic as well. In urban areas, the only reasons for no more increase in rush hour traffic today are the lack of parking places and congestion. There is significant latent rush-hour traffic demand in the urban areas, but it looks for new routes or different periods instead of the congested period. General experience, that drivers rarely

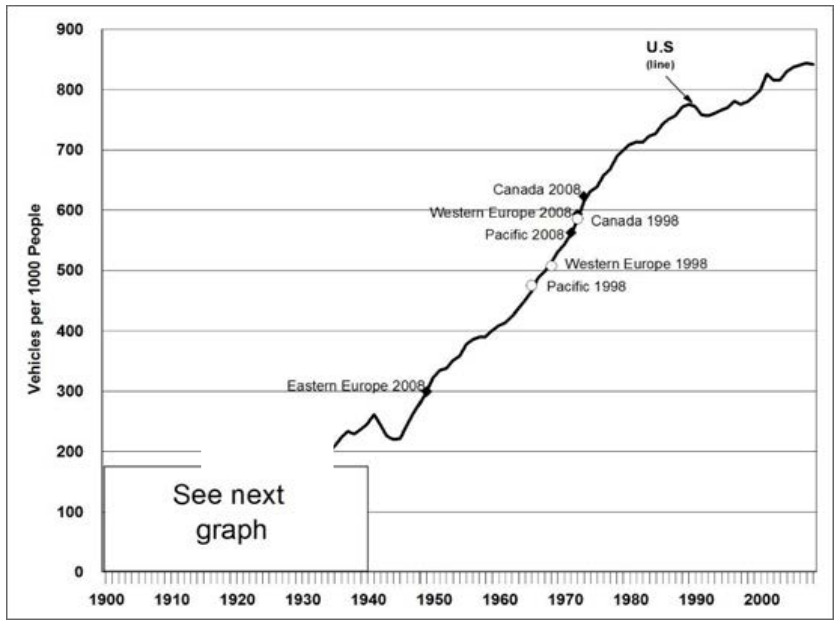

Figure 1: The increase of the motorization in the major regions of the world. *(Source: https://energy.gov/eere/vehicles/fact-617-april-5-2010-changes-vehicles-capita-around-world.)*

choose the public transport instead of the congested road network. As a result, traffic is spreading over time and space, so congestions are becoming more and more frequent.

As we can see, by the period of the proliferation of autonomous vehicles, significantly bigger traffic is expected than today. The significant intersection capacity increase can be compared to the predicted high degree of traffic growth. In this case, the more efficient nodal operation will serve much more traffic, which highlights the complexity of the relationship between autonomous vehicles and congestion.

7 OTHER POSSIBILITIES TO INCREASE THE CAPACITY OF THE SIGNALIZED INTERSECTION

Another supposition that the better routing and the better control of intersections caused by autonomous vehicles and V2I systems will result a smoother traffic flow. Without denying the importance of such developments, we want to draw attention to some limitations. The assumption behind this statement is, that in the intersections of the congested networks there is considerable available capacity, which could be used due to the better information flow. We represent a typical signalized key cross-section of a congested road network and its traffic volumes in the peak period (Fig. 2). The figure shows the 15-minute rush-hour traffic of the examined Egér Road (Budapest, Hungary) intersection.

The figure clearly shows that the traffic on the inbound arterial road is far the most significant. It is worth noting that almost all traffic direction is congested, except the “E”. However, it is also clear that small, sometimes very small traffic flows need green times. Most of the traffic directions in the node practically use all the available green time, except the non-congested outward direction.

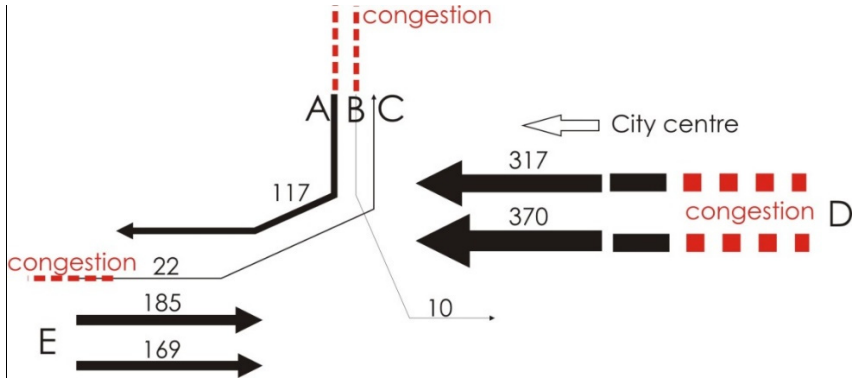

Figure 2: 15-minute traffic volume during the congestion on Egér Road (Budapest, Hungary) in the key cross-section. Nearly all traffic flows in the intersection are congested, the traffic designer has no good choices in the distribution of green times. To create a better traffic flow, large-scale capacity expansion or network design intervention is required.

What are the opportunities to gain extra green time for the congested arterial road?

- Rethinking the traffic flows in the intersection, for example, terminate direction B,
- Alternating lane use,
- Improve flow efficiency.

Firstly, it is recommended to rethink the traffic flows in the intersection, for example, to terminate the direction marked with "B". In this case, the designer should offer another possibility to this movement in another intersection, probably with similar difficulties. So the rethinking of the intersections is rarely an easy option in the congested networks.

Secondly, in the case studied, the traffic volume of the two outbound lanes is essentially equal to the traffic volume of one outbound lane, so it is possible to introduce the alternating lane use, gained extra capacity to the congested arterial direction. In this case, probably a new key cross-section and a new congestion would be created in the outbound direction. Such interventions must be examined individually in each case. In this case, the examined node may be suitable in the rush hours, but it should be examined the network impacts. Otherwise, in general, apart from the rush hour, the traffic difference between the directions is considerably lower than shown.

This also means that without substantial capacity expansion, probably only the smaller headways provided by the autonomous vehicles could help to increase the capacity of the signalized intersection on the congested networks because generally there is not enough free capacity or other possibilities to improve the operation of the signalized intersection and the road network. So the traditional solutions do not help, and it seems that autonomous vehicles do not a breakthrough as well. Therefore, it is worth focusing on other opportunities.

8 HOW COULD AUTONOMOUS VEHICLES HELP TO ALLEVIATE CONGESTION?

In the light of the mentioned statements, it may seem that the capacity increasing potential of autonomous vehicles is no more than that the increasing traffic can be served up to the today's

service level. Additionally, it is worth considering that the spread of autonomous vehicles, by many authors, will itself bring about a significant increase in traffic.

So how could autonomous vehicles help to reduce congestion? Firstly, the new technology brings with it the possibility of significant changes that are not closely related to the new technology. Such a possibility is to reduce the size of the vehicles. This is not a self-evident act, because the size of passenger cars is constantly growing. Reducing the size of vehicles would generally have a beneficial impact on the parking situation. A significant reduction in the width of the vehicles would provide an opportunity to make the existing roads and their lanes more efficiently, increase capacity, or provide space for non-motorized transport. Reducing the length of passenger cars would have a beneficial effect on headways and parking and could significantly improve the capacity of intersections. At the same time, the reduction in size requires a significant change in the car buyer's habits and the interests of the car industry. Most of the passenger cars have been bought for family purposes, but a two-seater small city car is not suitable for this. The modern lifestyle is determined by the family use of passenger cars, where the size is an essential component of usability. After all, it is not likely to be reduced the size of the cars, because of the resistance of the buyers and the car industry.

The speed and acceleration properties of autonomous vehicles could also help greatly to reduce congestion, but as we have already mentioned, these two aspects are unlikely to change significantly in urban environments due to the travel comfort and the unprotected road users in traffic. The reduction in headways is the only factor where significant improvement is expected, but its degree is still uncertain today.

Finally, autonomous and communicating vehicles and intersections provide a way to manage the entire congested road network. This is a great opportunity with huge challenges that can transform our lives. This system would allow for the simultaneous supervision and control of all vehicle trips from start to finish, align capacities and prevent congestion. However, it has a great price. The freedom of travel, like choosing the time of departure, arrival and routing would probably lose.

The real challenge in this system is the trip-determinate algorithm. Will the system able to operate with double so many vehicles than today? Will there be exceptions, and someone will access faster routes? Will there be periods when there is no permission required to start a trip? How will this system cooperate with parking fee, toll or congestion charges?

It is worth considering the experiences. Today, route planner navigation systems, like WAZE, are widely used. One of the main goals of the users is to avoid the congestions. However, their operation has raised many questions and problems. These problems have a significant impact on the above mentioned future control and operation system as well. One of the main issues with WAZE is that it drives significant traffic to the quiet residential streets. The control system can prevent this and keep traffic on the arterial roads, but in this case, traffic on the main network will increase, which will naturally lead to greater congestion. The main obstacle to the introduction of such a system is likely to be the widespread social, professional and political resistance. It is time to start thinking about the nature, limitations, advantages, and disadvantages of such a control system. This claim is supported by the OECD [1]: "The age of unmanaged access to highly-trafficked urban roads is coming to an end".

9 CONCLUSION

The impact of the emergence and spread of autonomous vehicles on congestion is at least controversial. In the literature, there is a general belief that these vehicles will increase traffic

while simultaneously improving the traffic flow in many ways. In this paper, we demonstrate some limits of congestion-related effects attributed to autonomous vehicles.

According to our results, autonomous vehicles will not be able to break through in alleviating congestion. The main reason for this is the constant increase in traffic. The positive effects of autonomous vehicles and the communicating intersections will not be enough to compete with the increasing traffic. Although it is expected up to 40% intersection capacity improvement, there will certainly be a key cross-section at the network level, where the capacity is first exhausted and where the first queues will be created. The level of network congestion is determined by the outflow capacity of the key cross-section and is formulated by the recurrent congestion phenomena described. The management of these requires the rethinking of the current traffic management philosophy and its extension to the network level. Autonomous vehicles will create a more efficient traffic flow but cannot solve the problem of recurrent congestion as they have no effect on the most important factors such as the adverse effects of alternative road use or the vitality of joining traffic flows, and even, for routing, without further regulatory steps adverse effects are also likely to increase. Autonomous vehicles do not change the fact that road traffic near the capacity is unstable and prone to be congested. Options that can be a solution, like reducing vehicle size or create a general traffic control system are risky and may cause problems.

REFERENCES

[1] Managing Urban Traffic Congestion, European Conference of Ministers of Transport, OECD. www.itf-oecd.org/sites/default/files/docs/07congestion.pdf. Accessed on: 4 Jun. 2018.

[2] Szele, A. & Kisgyörgy, L., The vitality of traffic directions on road network with recurrent congestion and its effect on road traffic design. *Proceedings of the International Conference on Traffic and Transport Engineering*, pp. 1012–10158, 2016.

[3] Szele, A. & Kisgyörgy, L., A torlódó sorok speciális tulajdonságai és ezek szerepe a forgalmi tervezésben (Special properties of congested queues and their role in traffic planning). *Proceedings of the Conference on Transport Sciences*, pp. 33, 2018.

[4] Thomopoulos, N. & Givoni, M., The autonomous car – a blessing or a curse for the future of low carbon mobility? An exploration of likely vs. desirable outcomes. https://doi.org/10.1007/s40309-015-0071-z. Accessed on: 4 Jun. 2018.

[5] Bahamonde-Birke, F.J. et al., A systemic view on autonomous vehicles: Policy aspects for a sustainable transportation planning. http://elib.dlr.de/108647/1/Paper_TR-A.pdf. Accessed on: 4 Jun. 2018.

[6] Litman, T.A., Autonomous Vehicle Implementation Predictions – Implications for Transport Planning, Victoria Transport Policy Institute. https://www.vtpi.org/avip.pdf. Accessed on: 4 Jun. 2018.

[7] Fagnant, D.J. & Kockelman, K., Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. *Transportation Research Part A: Policy and Practice,* **77**, pp. 167–181, 2015.

[8] Schoettle, B. & Sivak, M., Potential impact of self-driving vehicles on household vehicle demand and usage, The University of Michigan Transportation Research Institute. www.driverlesstransportation.com/wp-content/uploads/2015/02/UMTRI-2015-3.pdf. Accessed on: 4 Jun. 2018

[9] Trommer, S. et al., Autonomous driving – the impact of vehicle automatisation on mobility behaviour, Institute for Mobility Research. www.researchgate.net/

publication/312374304_Autonomous_Driving_-_The_Impact_of_Vehicle_Automation_on_Mobility_Behaviour. Accessed on: 4 Jun. 2018.

[10] Transportation Research Board, *HCM 2010 Highway Capacity Manual*, Transportation Research Board, Washington, DC, 2010.

[11] Cohen, S.L., Application of car-following systems to queue discharge problem at signalized intersections. *Transportation Research Record: Journal of the Transportation Research Board*, (1802), Transportation Research Board of the National Academies, Washington, DC, 2002. DOI: 10.3141/1802-23.

[12] Khosla, K. & Williams, J.C., Saturation flow at signalized intersections during longer green time. *Transportation Research Record: Journal of the Transportation Research Board,* (1978), Transportation Research Board of the National Academies, Washington, DC, pp. 61–67, 2006. DOI: 10.3141/1978-10.

[13] Bonneson, J.A., Modeling queued driver behavior at signalized junctions. in transportation research record, (1365), TRB, National Research Council, Washington, DC, pp. 99–107, 1992.

[14] Al-Ghamdi, A.S., Entering headway for through movements at urban signalized intersections. *Transportation Research Record: Journal of the Transportation Research Board,* (1678), Transportation Research Board of the National Academies, Washington, D.C., pp. 42–47, 1999. DOI: 10.3141/1678-06.

[15] Lin, F.B., Tseng, P.Y. & Su, C.W., Variations in queue discharge patterns and their implications in analysis of signalized intersections. *Transportation Research Record: Journal of the Transportation Research Board*, (1883), Transportation Research Board of the National Academies, Washington, DC, pp. 192–197, 2004. DOI: 10.3141/1883-22.

[16] Chaudhry, M.S. & Ranjitkar, P., Capacity and signal timing analysis of signalized intersection with increasing saturation flow rate. *Proceedings of 92nd Annual Meeting of Transportation Research Board*, Washington, DC, January 13–17, 2013.

[17] Dey, P.P., Nandal, P. & Kalyan, R., Queue discharge characteristics at signalized intersections under mixed traffic conditions. *European Transport\Trasporti Europei*, **55**(8). ISSN 1825-3997.

[18] Lee, J. & Chen, R.L., Entering headway at signalized intersections in a small metropolitan area. *Transportation Research Record 1091*, B, National Research Council, Washington, DC, pp. 117–126, 1986.

[19] Akcelik, R. & Besley, M., Queue discharge flow and speed models for signalized intersections. *Proceedings of the 15th International Symposium on Transportation and Traffic Theory*, University of South Australia, Adelaide, Australia, 2002.

[20] Teply, S., Saturation flow at signalized intersection through magnifying glass. *Proceedings of Eighth International Symposium on Transportation and Traffic Flow Theory*, Toronto University Press, 1983.

[21] Li, H. & Prevedourous, P.D., Detailed observations of saturation headways and start-up lost times. *Transportation Research Record No. 1802*, pp. 44–53, 2002. DOI: 10.3141/1802-06.

[22] Day, C.M. et al., Revisiting the cycle length-lost time question with critical lane analysis. *Transportation Research Record: Journal of the Transportation Research Board*, (2355), Transportation Research Board of the National Academies, Washington, DC, 2013. DOI: 10.3141/2355-01.

[23] Gao, L. & Alam, B., Optimal discharge speed and queue discharge headway at signalized intersections. *Transportation Research Board 94th Annual Meeting*, 2015.

[24] Rouhani, O.M., Queue dissipation shockwave speed for signalized intersections. *MPRA*, (53161), 2013. https://mpra.ub.uni-muenchen.de/53161/.
[25] Nagel K., Wagner P. & Woesler R., *Still Flowing: Approaches to Traffic Flow and Traffic Jam Modeling*, Institute for Operations Research and the Management Sciences. https://pubsonline.informs.org/doi/pdf/10.1287/opre.51.5.681.16755. Accessed on: 25 Jun. 2018.
[26] Qu, Z. et al., The Departure Characteristic of Traffic Flow at the Signalized Intersection. *Mathematical Problems in Engineering*, 2013. http://dx.doi.org/10.1155/2013/671428. Accessed on: 3 July 2018.
[27] Maurer, M., Gerdes, J.C., Lenz, B. & Winner, H., Autonomous Driving – Technical, legal and social aspects. https://link.springer.com/content/pdf/10.1007%2F978-3-662-48847-8.pdf. Accessed on: 4 Jul. 2018.
[28] Le Vine, S., Liu, X., Zheng, F., Polak, J., Juster, R. & Young, S., Queue discharge characteristics of automated vehicles at signalized intersections with defensive driving strategies, Power Point presentation, Imperial College London, SUNY New Paltz, Southwest Jiaotong University, University of Maryland Center for Advanced Transportation Technology, National Renewable Energy Laboratory. http://higherlogicdownload.s3.amazonaws.com/AUVSI/c2a3ac12-b178-4f9c-a654-78576a33e081/UploadedImages/Proceedings/Posters/Research%20Sessions/Queue%20Discharge%20Characteristics%20of%20Automated%20Vehicles%20at%20Signalized%20Intersections%20with%20Defensive%20Driving%20Strategies.pdf. Accessed on: 25 Jun. 2018.