Periodica Polytechnica
Transportation Engineering

44(4), pp. 244-250, 2016
DOI: 10.3311/PPtr.9464

RESEARCH ARTICLE

Impacts of Autonomous Cars from a Traffic Engineering Perspective

Tamás Tettamanti[1*], István Varga[1], Zsolt Szalay[1]

Received 11 May 2016; accepted 18 August 2016

Abstract
The era of autonomous vehicles infer new challenges in several fields. When autonomous vehicles take over the road in a large volume, consumer preferences around car-ownership will transform, traffic modeling and control will need correction, and moreover hackers will appear. These are just a few impacts which are expectable in the near future. Accordingly, the paper's aim is to enlighten trends and upcoming challenges of driverless vehicles and automated transportation system from a transportation engineering perspective.

Keywords
autonomous vehicles, self-driving cars, traffic models, vehicle design

[1] Department of Control for Transportation and Vehicle Systems, Faculty of Transportation Engineering and Vehicle Engineering, Budapest University of Technology and Economics, Stoczek J. u. 2., 1111 Budapest, Hungary

[*] Corresponding author, e-mail: tettamanti@mail.bme.hu

1 Introduction

In our days, transportation undergo substantial transformation resulting from the sweeping developments of computer science and infocommunication technology. The rapid changes strongly influence road transport vehicles and infrastructure, all travelers, and generally the society itself.

The paper intends to collect and enlighten the future challenges of autonomous vehicles and related infrastructure developments by focusing on the whole transportation system from the point of view of a transportation engineer. This is needed as the upcoming autonomous era represents a very special field raising interdisciplinary questions and problems, i.e. future transportation design has to take into consideration technical, economic, legal, and social aspects simultaneously.

The paper's outline is as follows. In Section 2, current development trends of transportation are summarized. The definition and the standardized levels of vehicle automation is proposed in Section 3. The main challenges in the field of autonomous car design are discussed by Section 4. Section 5 investigates the application potentials of self-driving vehicles. The effect of autonomous vehicles to classical traffic models are also introduced in Section 6. Finally, Section 7 enlightens a few social and economic benefits achievable trough autonomous transportation. The paper ends up with a short conclusion.

2 Development trends of road vehicles and transportation

The development of road vehicles has been accelerated in the last decades. One of the spectacular results of this process is the fast growing number of electronic control units (ECU) in vehicles. Nowadays, typical compact and mid-size cars contain about 50 pieces of ECUs. Beyond the basic functioning (such as engine control unit) these special elements also improve safety (e.g. Electronic Stability Program, ESP), assist the driver (e.g. Advanced Driver Assistance Systems, ADAS), as well as ameliorate passenger comfort. ECUs are also becoming increasingly intelligent devices, such that more and more functions are integrated inside them.

Moreover, communication systems are also appearing in modern vehicles, which are therefore capable to make contact with other cars or infrastructure. This is called V2V (Vehicle to Vehicle) or V2I (Vehicle to Infrastructure) communication. The development and standardization of V2V/V2I technologies are also ongoing processes of our days (Gáspár et al., 2014). Furthermore, a so called V2P communication technology is developing in the background where "P" means pedestrian (or other vulnerable road users like cyclists) and the idea is that the mobile phone of the pedestrians are capable of transmitting GPS based location and heading information via the built-in Wi-Fi network to the surrounding road vehicles thus providing automatic warning to prevent an accident.

Beyond the progressive technical solutions specific to vehicles and transport, recently the data generated by travelers has also been shown up as a new key factor. Namely, more and more information arise which are mostly used separately or not utilized at all at the present time. For the future, huge opportunities open up concerning transport management by exploiting transport related big data. As an illustrative example, one can mention data fusion methods which enable more reliable traffic modeling and forecasting by applying different "data crumbs" (Tettamanti et al., 2014).

The ongoing transport research generally focuses on the implementation of intelligent transport systems (ITS). In the ITS concept intelligent infrastructures must be also emphasized which build up a complex traffic network together with the partly or fully autonomous vehicles. Another relevant research direction is the calculability of everyday life and therefore that of transport needs. Barabási (2010) investigated the predictability of future human mobility based on the observation of cellular phone locomotion among others (Tettamanti and Varga, 2014). Esztergár and Rózsa (2015) elaborated a method for the organization of daily activity chains to decrease the travel time for travelers. These and similar researches contribute to a more extensive understanding and a better management of transportation processes. Furthermore, the development of autonomous vehicles will strongly modify the transport needs and traffic behavior parameters which will finally react to the newly emerged intelligent infrastructure.

3 Concept and levels of autonomous vehicles

First of all, the concept and definition of autonomous road vehicles must be introduced. This is needed in order to clarify the role of autonomous cars within the whole transport system.

As a basic definition one can say that road vehicles which are able for high-level sensing of the environment and controlled movements without a human driver can be called as autonomous vehicles. They are also designated as driverless, self-driving, or robotic cars. SAE (Society of Automotive Engineers) International determined the terminology and the taxonomy for autonomous vehicles in a standard (SAE International, 2014). Accordingly, levels of autonomy are tabulated into Table 1.

The last two columns of Table 1 represent the cross-compliance of SAE levels compared to the levels of the German Federal Highway Research Institute (BASt: Bundesanstalt für Straßenwesen) as well as that of the National Highway Traffic Safety Administration (NHTSA) of the USA.

As an interpretation to Table 1 SAE phrased the following: *"These levels are descriptive rather than normative and technical rather than legal. They imply no particular order of market introduction. Elements indicate minimum rather than maximum system capabilities for each level. A particular vehicle may have multiple driving automation features such that it could operate at different levels depending upon the feature(s) that are engaged."* (SAE International, 2014)

Basically, the defined levels indicate the balance of the dynamic driving tasks between human and machine from zero level (no automation) to fifth level (full automation). To achieve the full automation two evolution paths are possible: the concept of "something everywhere" or "everything somewhere" (International Transport Forum, 2015). The first variation means that automated driving systems appear gradually in the traditional vehicles according to the levels of Table 1, i.e. the drivers give more and more driving tasks to the automated systems. The second evolution concept assumes that the fully automated cars could be applied in driverless mode immediately together with traditional vehicles until a total market penetration is achieved.

Another interesting research has been published by the market research company IHS. The optimistic scenario shows that until 2025 the 20% of new cars sold will be partly or fully automated (see Fig. 1). On the other hand, even based on the less optimistic approach this selling rate will be 18% until 2030. This means that in about one or one and a half decade a significant number of cars will become automated which represents a quite short-term technological shift.

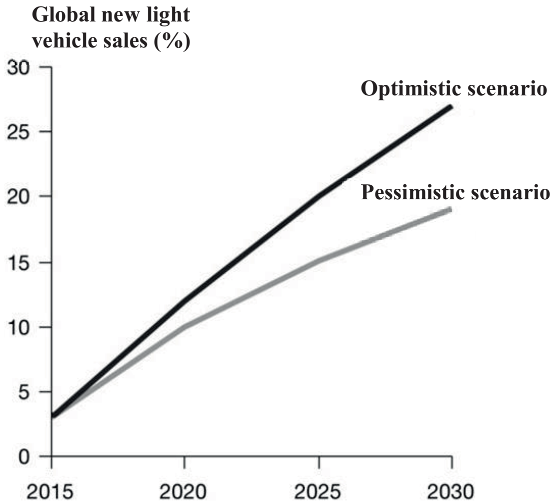

Fig. 1 Optimistic and pessimistic scenarios for the penetration of partly or fully autonomous vehicles (source: IHS, Viereckl et al., 2015)

Table 1 Levels of driving automation according to the SAE International (source: SAE International, 2014)

SAE level	Name and definition	Steering, acceleration, deceleration	Monitoring driving environment	Fallback performance of dynamic driving task	System capability (driving modes)	BASt level	NHTSA level
0	No Automation: the full-time performance by the human driver of all aspects of the dynamic driving tasks, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	-	Driver only	0
1	Driver Assistance: the driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2	Partial Automation: the driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task	**Human driver and system**	Human driver	Human driver	Some driving modes	Partially automated	2
3	Conditional Automation: the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene	System[1]	**System**	Human driver	Some driving modes	Highly auto-mated	3
4	High Automation: the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene	System	System	**System**	Some driving modes	Fully auto-mated	3/4
5	Full Automation: the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver	System	System	System	**All driving modes**	-	

[1] „System" refers to the driver assistance system, the combination of them, or the automated driver system.

4 Vehicle design challenges

4.1 Control structure of autonomous vehicles

Highly automated and autonomous control of a road vehicle requires a well-defined and separated structure of environment perception, potential trajectory analysis, decision making and decision execution. All these need to be happen real-time and in a fault-tolerant but at least fail-safe way. The technology related challenges are partially solved already today (e.g. series production of Adaptive Cruise Control or Lane Keeping Assistance functions), and although autonomous driving requires the next level in technology, the major challenges are not technology related. The question is how we can program responsibility into the ECUs.

Researchers and vehicle manufacturers may have different control structure implementations (see the HAVEit structure as an example in Fig. 2), but all of them have to ensure the following four layers for integrated vehicle control as a minimum:

1. The **driver interface layer** is not only responsible for interacting with the driver about the actual status of the autonomously running vehicle, but it also have to continuously evaluate the driver status and his/her capability to take over control in case a fallback performance is required.
2. The **environment perception layer** is responsible for providing comprehensive information about the traffic situation including the surrounding objects around the vehicle. There are different types of sensors installed all around the vehicle like sonars, radars, lidars, video cameras and laser scanners. They are combined with an e-Horizon based location data (GPS/Glonass/Beidou, etc.) and high definition mapping information. Since different sensors are working based on different phenomenon, the confidence level of the output data strongly depend on the environmental (e.g. weather) conditions they operate under. That is why sensor fusion algorithms have key importance in resulting reliable situation awareness and environmental information.
3. Depending on the automation level, the **trajectory planning layer** calculates possible vehicle trajectories with priorities ranks of performance and safety. It involves the calculation of longitudinal and lateral trajectory options, different route possibilities with respect to the surrounding environment, the ranking, prioritization of the different route options based on minimizing the risk of a collision, and ends up in the selection of the optimum trajectory.
4. The **trajectory execution layer** gets the selected trajectory as an input from the planning layer. Starting with the trajectory segmentation and the generation of the motion vector containing longitudinal and lateral control commands that will be carried out by the intelligent actuators of the execution layer. The execution of the motion vector is distributed among the intelligent actuators of the vehicle drivetrain.

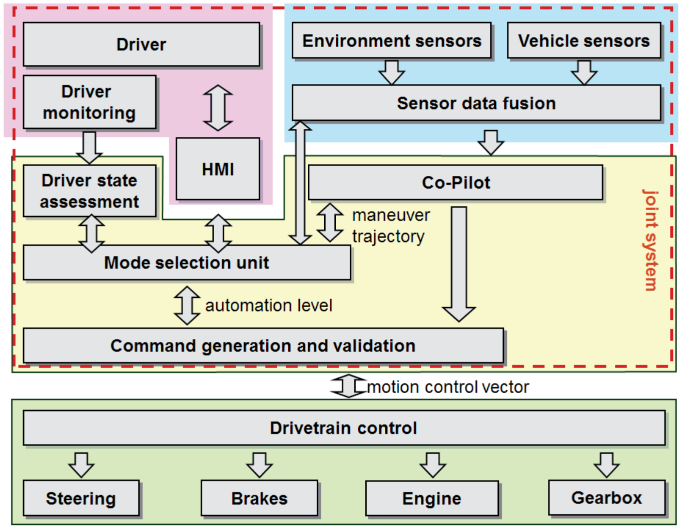

Fig. 2 Example of an integrated vehicle control structure (source: HAVEit, Hoeger et al., 2011)

4.2 How to program responsibility into vehicles?

Today's driver assistant systems are capable of performing tasks that were previously designed and tested by automotive engineers. These systems can handle certain scenarios (and only those scenarios) that were initially preprogrammed. In situations that the program is not prepared for, the vehicle control falls back to the driver. Today the human driver is responsible for every vehicle movement. When we step forward to autonomous driving we have to expect the unexpected, meaning that vehicles should be intelligent enough to make decisions instead of the driver in certain situations. The question is then: who will take the responsibility of those decisions? The human driver, the vehicle manufacturer or the system supplier? Good examples are the so called "death algorithms" that should make decisions in paradox unavoidable accident situations like going straight forward and hit the pedestrian crossing the road ahead, or a sudden steering to the opposite lane, save the pedestrian and frontally crash into the upcoming truck? What kind of program or programmer can make such decisions in advance taking the responsibility? On the other side how such functions can be approved? There are a lot of questions to be answered concerning the autonomous driving and not just from the technical side but also from the legal side.

4.3 Cyber vulnerability of autonomous vehicles

Valasek et al. (2014) showed that vehicles of our days are already target to hackers to demonstrate cyber security leaks in vehicle communication systems. Recent attacks showed taking over the control of the multimedia system of the car, unintentional reconfiguration of the airbag system and partial control of the vehicle dynamics (Szíjj et al., 2015; Greenberg, 2015). The risk is that conventional road vehicles do not have dedicated electronic interfaces for electronic vehicle control, but autonomous vehicles will definitely have. Highly automated and autonomous vehicles have dedicated control functions for longitudinal and lateral vehicle control (e.g. turn right or left, change lane, brake or accelerate). Comparing the hacking threat of externally changing the radio station or activating the windshield wiper to an intentionally wrong driven vehicle, there is a magnitude difference. The most threatening scenario is that if someone would like use the intelligent vehicle functions for malicious purposes, e.g. to make accident intentionally.

Beside vehicle cyber security, one should not forget that a connected car have access to other vehicles with relevant data (location, speed, etc.). Therefore, one has to make sure that sensitive data are used transparently and obey the requirements of privacy.

4.4 Smart infrastructure and autonomous cars

Beside the evolution of automated vehicles the infrastructure itself also undergoes a booming development continuously. This means that smart infrastructure is evolving based on the standardization of V2V/V2I communication platforms (Gáspár et al., 2014). Thus, intelligent cooperation among cars and infrastructure elements will be a part of everyday life in the future, e.g. a greater part of traditional traffic lights will certainly disappear over time giving way to virtual traffic lights applied inside cars. In fact, self-driving cars will also influence and change the infrastructure in which they are used.

5 Application potentials of autonomous vehicles and accompanying challenges

A typical vision for future in line with self-driving vehicles is the image of driverless personal cars circulating in public roads. It has to be emphasized that the application scope of autonomous technology is much wider than it appears at first sight. It might cover all fields of passenger and good transport. Innovations of personal car industry have been coming up with spectacular developments (e.g. by Apple, Audi, BMW, Ford, General Motors, Google, Honda, Mercedes, Nissan, Tesla, Toyota, and Volkswagen). Nevertheless, a more straightforward advent of driverless systems might be envisaged in public transportation sector for a very simple reason, i.e. public vehicles circulate on fixed routes (apart from rarely applied flexible transportation services). Note that automated subways have already been working since decades (the first automatic train operation started at Victoria line in London, 1967). Thus, it is clear that the first groups of automatized public transport means will consist of subways, trams, as well as BRT (Bus Rapid transit), and then public buses and trolleybuses might be developed to autonomous level.

Main advantages of public transport automation are briefly listed below:

- elimination of human drivers, therefore human errors in transport process;
- reduce of work organization problems caused by strict regulation for driving hours and rest periods;
- elimination of bus-bunching effect can be avoided, optimal headway control can be ensured;
- autonomous public vehicles will be able to cooperate, e.g. if more bus lines are on the same path they can communicate and choose optimal speed profile depending on the others, or in case of crossing of bus lines in a junction, the vehicles can make optimal choice for priority decision.

Another significant sector, where breakthrough development of autonomous technology is expected, is represented by taxi and any similar services in passenger transport. Conception of Telematics-based Shared Demand Responsive Transportation (TS-DRT) has been elaborated by Földes and Csiszár (2016). Several transportation modes are ’unified’ in this new mode. As an impressive example, one can observe Uber Technologies Inc. (with its own self-driving lab: www.uberatc.com) aiming to provide autonomous taxi cabs in the near future (indicated to be driverless by 2030). Similarly to taxi services, shared-ownership model of passenger transport will be also affected. For example, a self-driving personal car might circulate and earn money in a car-pooling system while the owner works in the office or sleep at home.

Beside the passenger transport, good transport vehicles are also developing (e.g. Volvo, Mercedes). Driverless camions and other vehicles in logistics (e.g. stacker truck or tow tractor) will strongly transform freight market. City logistic will also evolve with the help of autonomous technology.

It is also important to emphasize that though application potentials of autonomous vehicles seem to be very attractive, they also entail several economic, social and legal issues as well. The adequate solutions to the upcoming future challenges have to be sought and found by the corresponding disciplines.

6 Impact of autonomous vehicles to classical traffic models

Until now, we investigated the opportunities of driverless cars as well as the expectable effects to transportation in general. Nevertheless, the impact to classical traffic flow modeling is also important to examine as traffic analysis, planning, control, and generally transport management are strongly based on it. Simply saying, autonomous vehicles may mislead traditional modeling approaches. Currently, all static and dynamic control measures of road traffic are prepared to the traffic flow generated by human drivers solely. Traffic composition with driverless cars, however, determine much more complex requirements and control tasks to be satisfied. The main reason for this is that autonomous car dynamics might significantly differ from traditional human driven cars.

In the first period of the changes, presumably autonomous vehicles will drive in a more conservative way. This also means that thanks to their compliant behaviors during the period of heterogeneous traffic compositions (self-driving and human-driven cars together), headways will grow and average traveling speed will reduce. In the long term, however, the increase of automation (e.g. cooperative driving) will reverse this process. It is important that 100% penetration of fully automatized cars is not required for this turn. Partially automatized vehicles with V2V/V2I communication are also eligible to take part in an automatized traffic system.

All these changes mentioned above induce the rethink of current road traffic models. Traditional car-following (microscopic) models need a thorough investigation. This is important as the perceptibility and reaction time of self-driving vehicles go far beyond any human capability. Previously, car-following model were determined and tuned as psycho-physical parameters, see for example the model of Wiedemann (1974) which is the base of PTV Vissim traffic simulator. This also meant that these parameters were not exact, only statistically relevant. Automated cars, however, will have exact driving properties (expectedly as common basic standards later). Therefore, microscopic traffic models will be able to directly involve this knowledge. Simply, traffic dynamics will become totally predictable.

The macroscopic traffic modeling (both for freeway and urban network) has to be also investigated according to robocars. In case of macroscopic approach, the traditional vehicle-conservation law remains the same of course. However, the characteristic values of the macroscopic fundamental diagram (speed-flow-density relationship) and therefore the shape of that will significantly alter as well (Csikós et al., 2015). On the one hand, critical density (the maximum point of flow-density diagram where traffic system obtain the maximal throughput) and the whole polynomial curve will shift to right (see Fig. 3) due to the shortened headway of autonomous cars as they do not need the same following distances as human drivers. On the other hand, the dynamics within the right part of the diagrams (i.e. the instable regions, see Fig. 3) will also change as the instability here is typically induced by human driver's randomness.

In conclusion, the modeling of road traffic composed clearly by autonomous vehicles will represent a straightforward problem on condition that all vehicle parameters are available. However, the transitional period with heterogeneous traffic compositions (when self-driving and human-driven cars will exist together) will cause complex problems to traffic modeling as precise (from autonomous cars) and stochastic (from traditional cars) traffic behaviors will live side by side.

7 Social and economic benefits

In connection with the development aims of road transport systems the most important requirements to consider are as follows at all times:

- minimization of the number and severity of accidents,
- reduction in the environmental impacts,
- improvement of road traffic parameters, such as average travel time, traffic flow capacity, etc.

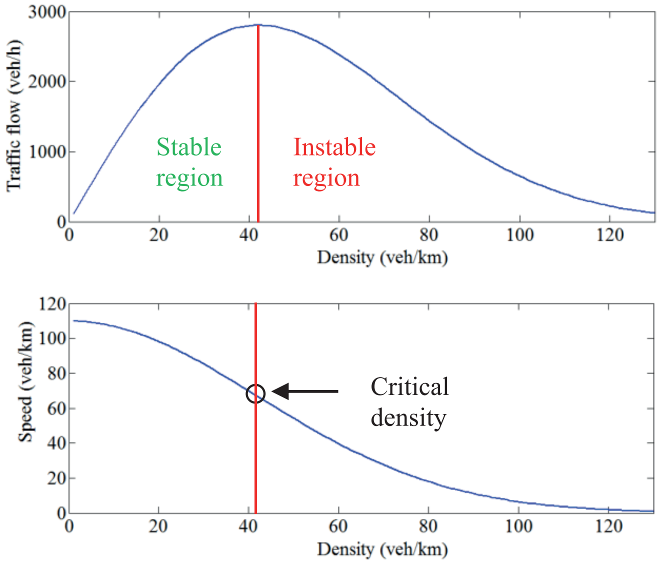

Fig. 3 An example for the fundamental diagrams based on the macroscopic speed relationship $V(\rho) = v_{free}$, where ρ is the density and v_{free} is the free flow speed, and is a calibration parameter

The objectives listed above are closely inter-linked and are essential elements. Moreover, a common aspect of them is represented by the cost-efficiency. It is obvious that all of these factors can be significantly improved by applying adequate management and control of autonomous vehicles and intelligent infrastructures creating new ways for intelligent transport systems and smart cities. Accordingly, the advent of autonomous technologies also entails social and economic aspects.

It is estimated that self-driving technology can save 30,000 lives per year in the USA only and of course huge property damage (Greenblatt, 2016). Schoettle and Sivak (2015) published an interesting analysis report of real-world crashes involving robotic cars. They found that self-driving cars were not faulty in any crashes they involved in. Furthermore, the overall severity of crash-related injuries has been lower for autonomous vehicles than for conventional cars.

It is highly predictable that driverless vehicles will totally change the traditional car-ownership model. Note that cars are not moving in most of their life cycles. Greenblatt (2016) says private cars are parked typically 95% of the time. If a cost-efficient shared-ownership (Csonka and Csiszár, 2016) or taxi model could be built up for autonomous vehicles, people will easily refuse to buy and maintain private cars. This phenomenon will also influence city parking and land use. Autonomous vehicles do not have to park in the vicinity of the traveler necessarily. Indeed, they can park themselves anywhere.

Beyond the economic benefits, social gains will be also expectedly attained as all sectors of society will have the opportunity for mobility. People without driving license might "drive" a car, e.g. elderly and disabled persons or even children. Furthermore, as self-driving are able to circulate without human, they can be sent anywhere to pick up the passenger.

These changes will significantly rewrite the current transport models which are based on traditional economic and demographic parameters and do not consider the free mobility of autonomous vehicles at all.

Finally, an important point has to be also concerned. Namely, laws and regulations are important and critical aspects in the course of the autonomous technology evolution. Some opinions argue that legal questions are too complex and therefore will hinder driverless vehicles spread. Although the skeptical voices, it is important to opinionate that legal issues must be handled not as obstacles but as problems to solve as soon as possible. This is especially important as the legal system of our days only try to follow the development process of autonomous technology instead of supporting it and keeping pace with it.

8 Conclusions

In this article, our intention was to position autonomous driving in a wider sense and examine the phenomenon from different aspects.

We investigated the trends and new challenges caused by fast developing road transport automation. Partly or fully autonomous vehicles already have a strong impact on the automotive industry and the whole transportation systems of our days. Moreover, in near future self-driving cars will fundamentally reformulate road transportation inducing technological and socio-economic developments and requiring adaptation of the applicable law and social acceptance as well.

Acknowledgement

Supported through the new National Excellence Program of the Ministry of Human Capacities.

References

Barabási, A.-L. (2010) *Bursts: The Hidden Pattern Behind Everything We Do*. Plume

Csikós, A., Tettamanti, T., Varga, I. (2015) Nonlinear gating control for urban road traffic network using the network fundamental diagram. *Journal of Advanced Transportation*. 49(5), pp. 597-615. DOI: 10.1002/atr.1291

Csonka B., Csiszár Cs. (2016) Service Quality Analysis and Assessment Method for European Carsharing Systems. *Periodica Polytechnica Transportation Engineering*. 44(2), pp. 80-88. DOI: 10.3311/PPtr.8559

Esztergár-Kiss, D., Rózsa, Z. (2015) Simulation results for a daily activity chain optimization method, MT-ITS 2015. In: 4th International Conference on Models and Technologies for Intelligent Transportation Systems, Budapest, Hungary, June 03-05, 2015, pp. 259-264. DOI: 10.1109/MTITS.2015.7223265

Földes D., Csiszár, Cs. (2016) Conception of Future Integrated Smart Mobility. In: Smart Cities Symposium, Prague, Czech Republic, May 26-27, 2016. (accepted)

Gáspár, P., Szalay, Zs., Aradi, Sz. (2014) *Highly Automated Vehicle Systems*. BME MOGI, 2014. URL: http://www.mogi.bme.hu/TAMOP/jarmurendszerek_iranyitasa_angol/index.html

Szíjj, A., Buttyán, L., Szalay, Zs. (2015) Hacking cars in the style of Stuxnet, Hacktivity, Budapest. URL: https://hacktivity.com/en/archives/hacktivity-20151/

Greenberg, A. (2015) Hackers Remotely Kill a Jeep on the Highway—With Me in It. WIRED, URL: https://www.wired.com/2015/07/hackers-remotely-kill-jeep-highway/

Greenblatt, N. A. (2016) Self-driving cars and the law. *IEEE Spectrum*. 53(2), pp. 46-51. 2016. DOI: 10.1109/MSPEC.2016.7419800

Hoeger, R., Zeng, Z., Hoess, A. (2011) HAVEit- The future of driving, Final Report, Continental Automotive GmbH and partners, URL: http://haveit-eu.org/LH2Uploads/ItemsContent/24/HAVEit_212154_D61.1_Final_Report_Published.pdf

International Transport Forum (2015) Automated and Autonomous Driving, Regulation under uncertainty, Corporate Partnership Board Report, OECD, URL: www.internationaltransportforum.org

SAE International (2014) Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems, SAE standard, nr. J3016__201401, 2014-01-16, URL: http://standards.sae.org/j3016_201401

Schoettle, B., Sivak, M. (2015) A Preliminary Analysis of Real-World Crashes Involving Self-Driving Vehicles, University of Michigan, Transportation Research Institute, Report No. UMTRI-2015-34, URL: http://www.umich.edu/~umtriswt/PDF/UMTRI-2015-34_Abstract_English.pdf

Tettamanti, T., Horváth, M. T.,Varga, I. (2014) Road traffic measurement and related data fusion methodology for traffic estimation. *Transport and Telecommunication*. 15(4), pp. 269-279. DOI: 10.2478/ttj-2014-0023

Tettamanti, T., Varga, I. (2014) Mobile Phone Location Area Based Traffic Flow Estimation in Urban Road Traffic. Columbia International Publishing Advances in Civil and Environmental Engineering. 1(1), pp. 1-15. URL: http://paper.uscip.us/aceeg/ACEEG.2014.1001.pdf

Valasek, C., Miller, C. (2014) Adventures in Automotive Networks and Control Units Technical White Paper, IOActive. URL: http://www.ioactive.com/pdfs/IOActive_Adventures_in_Automotive_Networks_and_Control_Units.pdf

Viereckl, R., Ahlemann, D., Koster, A., Jursch, A. (2015) Connected Car Study 2015: Racing ahead with autonomous cars and digital innovation. URL: http://www.strategyand.pwc.com/reports/connected-car-2015-study

Wiedemann, R. (1974) Simulation des Straßenverkehrsflusses, Schriftenreihe des Instituts für Verkehrswesen der Universität Karlsruhe, Heft 8