Archives of
Transport System
Telematics

Volume 12

Issue 3

September 2019

Telematics as a Method for Improvement the Transport Safety

A. LEWIŃSKI, T. PERZYŃSKI
UNIVERSITY OF TECHNOLOGY AND HUMANITIES IN RADOM, Malczewskiego 29, 26-600 Radom, Poland
EMAIL: a.lewinski@uthrad.pl

ABSTRACT
The transport systems are now equipped with more telematics devices for improvement the functionality and safety purposes. One of the methods of evaluating telematics systems is modeling. The paper presents the basic model of typical land transport means (vehicle with anti-collision system, railway system) related to standard reliability model including non-safety, critical state. This model based on Markov processes theory may be more detailed corresponding to "telematics" control state connected with system reaction for driving improper action or device failure and activation the emergency control procedure.

KEYWORDS: telematics systems, transport safety modelling, Markov processes

1. Introduction

Telematics, as a collection of solutions in the field of computer science, teleinformation, control and management systems, is one of the tools in the management of vehicle traffic. The term of telematics comes from the word *telematique*, which was first used by Simon Nora and Alain Minc, [14]. The main tasks of telematics are shown in Fig. 1.

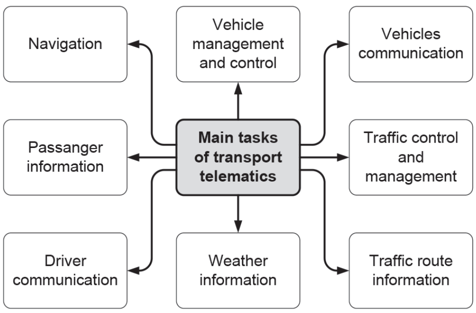

Fig. 1. Main tasks of transport telematics [own study]

Telematics allows the introduction of optimization in the management of transport and allows to increase the efficiency of the use of transport means. Telematics is also a tool for improving the safety of vehicle movements. Transport safety is one of the priorities of the Member States of the European Union. The activities of the European Commission are aimed to creating a uniform and common European transport area. The innovation strategy assumes the use of solutions based on new technologies, including the European Rail Traffic Management System (ERTMS) or intelligent transport systems (ITS) [4].

The paper presents the problem of transport safety in relation to telematics systems used in road and rail transport. As a tool for evaluating telematics systems, the authors used a mathematical apparatus in the form of Markov processes. Safety was defined as the probability of a dangerous, catastrophic state. Of course, the number of states controlled by the telematics system and the number of catastrophic states may be greater than one, and the models proposed in the paper may additionally take into account environmental conditions, health of the operator, road characteristics, etc. Two examples were analyzed in the paper, one with a car equipped with an anti-collision system (CA), the other with a train equipped with an automatic driving control system (ETCS). Both systems show how introduced telematics systems can reduce the likelihood of occurrence dangerous situations, accident. The conclusions suggest directions for the development of telematics systems towards autonomous vehicles.

2. New solutions in road and rail transport

One of the elements improving the process of managing transport means is the use of modern technologies. The development of teleinformatics systems has permitted creating solutions that allow for safer movement of vehicles. The information from sensors, cameras or other vehicles and its quick processing allow the use of telematics systems in systems responsible for safety movement of vehicles. Implementation of telematics solutions in vehicles, in many cases, may exemplify an autonomous safety system and a kind of redundant system for human errors. One of the solutions used to improve transport safety is the ERTMS / ETCS railway system or the anti-collision system dedicated to road transport.

2.1 Railway system ERTMS/ETCS

In order to unify the railway traffic control system in the European Union, a uniform ERTMS (*European Rail Traffic Management System*) rail traffic control system was developed already in the 1980s. The individual European Union member states have developed their own solutions regarding technical specifications for the management and control systems of railway traffic, which is a barrier for free movement of trains. There are currently around 30 different rail traffic management systems [11]. The main task of the ERTMS system is to unify mentioned different control systems. This task is accomplished by introducing technical tools, which allow interoperability. Interoperability allows for consistent functioning of different systems within the European community. With regard to safety, the ERTMS system can contribute to the elimination of events that may pose a threat to rail traffic, such as ignoring the "stop" signal and exceeding the speed limit on a given section of railway line. The solutions used in ERTMS allow for higher rolling stock speeds and higher throughput while maintaining a high level of safety. The ERTMS system consists of three main components [5, 12]:

- ETCS –*European Train Control System*,
- GSM-R –*Global System for Mobile Communication – Railway*,
- ETML –*European Traffic Management Layer*.

The ERTMS / ETCS system can be configured to work in one of the levels:

- Level 1 - solution based on the transmission of permits for driving with balis,
- Level 2 - GSM-R is used for transmitting driving licenses, in addition, the track is equipped with radio block centre,
- Level 3 – it is a development of the second level and allows driving according to the changable block distance. This level resigns from the axle counters and track circuits.

The ETCS system is a uniform ATC (*Automatic Train Control*) system for the European railways. The system calculates and controls the braking curves. Based on data such as train weight, braking force, calculates fixed or variable speed profiles, [5]. Elements of the ETCS system are shown in Fig. 2.

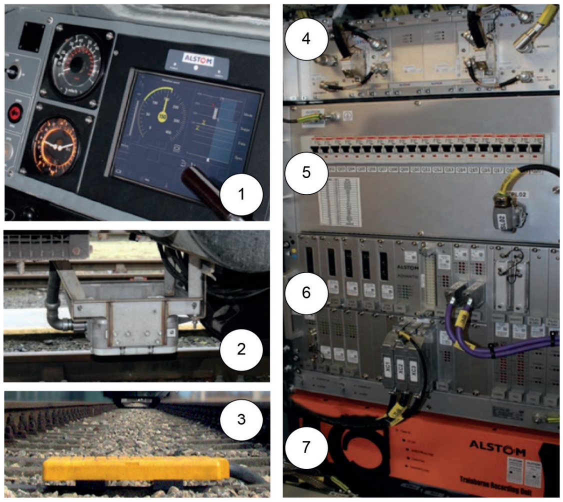

Fig. 2. Elements of the ETCS system [own study based on 6]

The individual marks in Fig. 2 show:

- 1 - driver's interface,
- 2 - antenna for track-vehicle transmission (mounted in the locomotive),
- 3 - eurobalise,
- 4 - GSM-R system,
- 5 - relay interface unit,
- 6 - on-board computer,
- 7 - data recording module.

In the ETCS system, data transmission uses digital transmission through eurobalises, euro loops, digital radio transmission and specialized transmission modules [10]. Selected technical data for eurobalises (Fig. 2, point 3) is shown in Table 1 [7].

Table 1. Eurobalise parameters [own study based on 7]

L.p.	Parameters	Values
1.	Speed range	0 do 500km/h
2.	Data transmission frequency	4,234 MHz
3.	Data transmission rate	565kbit/s
4.	Type of modulation	FSK
5.	Telegram length	341 do 1023 bits
6.	Usable data length	210 bits or 830 bits
7.	Ambient temperature	-40°C do +55°C
8.	Reliability (MTBF as per SN 29500)	S21 fixed-data balise > 800 years S21 transparent-data balise > 160 years

Eurobalise is a passive transponder. The telegrams transmitted by eurobalises contain information on speed limits and traffic conditions on the rail line. The train onboard subsystem, after receiving telegrams, analyzes the information and, if necessary, triggers automatic brakes in order to achieve the permitted speed on a given section of rail line. An important element of ETCS is also the adequate train equipment with ETCS devices (on-board devices - the Eurocab).

2.2 Car anti-collision system

One of the tools used to improve the safety of road transport is the use of telematics solutions. Implementation of new solutions in on-board systems of motor vehicles as well as in road infrastructure allows to limit the number of dangerous road accidents and theirs negative effects. As statistics show, the most common cause of road accidents is excessive speed, not adapted speed to the driving conditions prevailing on the road. It is worth mentioning that the only in 2017, 25300 people lost their lives on the roads of the European Union [8]. Delayed braking or insufficient braking force is often the cause of an accident. Introduced in serial production in 1978 by Bosch Company the ABS system certainly contributed to the improvement of safety. However, the development of the ABS system are solutions based on intelligent braking systems, an example of which is - Collision Avoidance (CA) system. Solutions of this type primarily use short and long range radar systems, lasers or cameras. The information obtained from the sensors together with data on the vehicle (including speed) allow early warning of the driver about the possibility of a dangerous situation. In the absence of a reaction from the driver, the system can ultimately automatically use the car brakes [9]. An example of the CA system algorithm is shown in Fig. 3.

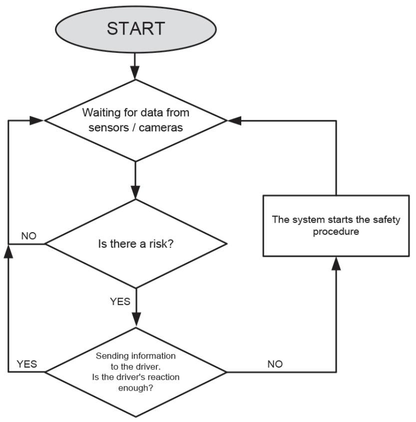

Fig. 3. A simplified algorithm for CA systems [own study]

3. Models of systems

In order to carry out the analysis, a stationary, ergodic and homogeneous character of Markov processes was assumed. Markov processes are a tool that allows modeling of transport processes and determination of characteristic safety-related indicators. Fig. 4 presents a general safety model that takes into account the equipment of the vehicle (railway vehicle, road vehicle) in a telematic system.

In the model from Fig. 4, we can distinguish:

- 0 - normal state, no dangerous situations,
- 1 - the state of danger. The vehicle is equipped with a system,
- 2 - the state of danger. The vehicle is not equipped with a system,
- *p* - the probability of equipping the vehicle with the system.

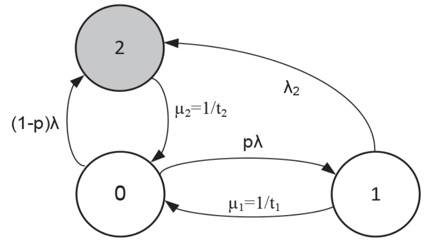

Fig. 4. Model with a telematics system in the vehicle [own study]

The model from Fig. 4 can be described by transitions matrix:

$$M=[p_{ik}]=\begin{bmatrix} p_{00} & p_{01} & p_{02} \\ p_{10} & p_{11} & p_{12} \\ p_{20} & p_{21} & p_{22} \end{bmatrix}=\begin{bmatrix} 0 & p\lambda_1 & (1-p)\lambda \\ \mu_1 & 0 & \lambda_2 \\ \mu_2 & 0 & 0 \end{bmatrix} \quad (1)$$

where $0 \le p_{jk} \le 1$, and $\sum_{k=1}^{j} p_{jk} = 1$ j,k = 1,2, …, n.

The most undesirable state in the model from Fig. 4 is the state 2. The limit probability of being in this state equal:

$$P_2(t)_{t\to\infty}=\frac{\lambda_1(\mu_1-p\mu_1+\lambda_2)}{p\mu_2\lambda_1)+\mu_1(\mu_3+\lambda_1-p\lambda_1)+(\mu_2+\lambda_1)\lambda_2} \quad (2)$$

To calculate the safety value defined as S = 1-$P_{dang.}$ authors assumed data as below:

- λ_1 – 12h^{-1},
- λ_2 – damage to the electronic module at the level 0.0001h^{-1} ,
- μ_1 – after 1s. returns to its normal state,
- μ_2 – after 2s. returns to its normal state,
- the probability value *p* of equipping the vehicle with a telematics system in the range from 0.5 to 0.9.

The results of calculations are presented in Table 2.

Table 2. Results of calculations [own study]

Probability p	0.5	0.6	0.7	0.8	0.9
Value $S(t)_{t\to\infty}$	0.53	0.61	0.68	0.74	0.79

The model proposed in Fig. 5 is a development of the model from Fig. 4 and is a model for the ERTMS / ETCS system. The entry point to the model are states 1 and 4. State 1 is responsible for the execution of commands in the ERTMS / ETCS system and state 4 is responsible for running the train according to the indications of the track-side signaling (without the full activity of the system devices).

In the model, we can distinguish:

- State 0 - normal operation.
- State 1 - state of receiving data. Execution of commands by the system.
- State 2 – state of controlled damage (eg damage to ERTMS / ETCS devices, no GSM-R transmission). Automatic train stop.

- State 3 – state of „isolation". Emergency displacement of the vehicle.
- State 4 – state „unfitted". Train running according to the track side signaling.
- State 5 – critical state, uncontrolled.

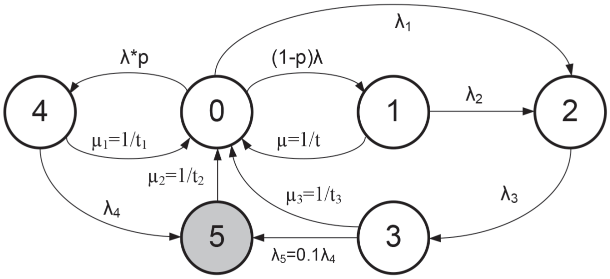

Fig. 5. A model that takes into account the ERTMS / ECTS system [own study]

For the model from Fig. 5, we can write state equations:

$$\begin{cases} \frac{dP_0(t)}{dt} = -[(1-p)\lambda + \lambda_1 + \lambda p]P_0(t) + \mu P_1(t) + \mu_1 P_4(t) + \mu_3 P_3(t) + \mu_2 P_5(t) \\ \frac{dP_1(t)}{dt} = (1-p)\lambda P_0(t) - \mu P_1(t) - \lambda_2 P_1(t) \\ \frac{dP_2(t)}{dt} = \lambda_2 P_1(t) + \lambda_1 P_0(t) - \lambda_3 P_2(t) \\ \frac{dP_3(t)}{dt} = \lambda_3 P_2(t) - \mu_3 P_3(t) - \lambda_5 P_3(t) \\ \frac{dP_4(t)}{dt} = \lambda P_0(t) - \mu_1 P_4(t) - \lambda_4 P_4(t) \\ \frac{dP_5(t)}{dt} = \lambda_4 P_4(t) + \lambda_5 P_3(t) - \mu_2 P_5(t) \end{cases} \tag{3}$$

In the model from Fig. 5, it was assumed that state 5 is the most undesirable. Using the Mathematica software, the limit probability of being in a state 5 was calculated:

$$P_5(t)_{t\to\infty}=[(\mu\lambda_1 + (\lambda + \lambda_1)\lambda_2)\lambda_3(\mu_1 + \lambda_4)\lambda_5 + p\lambda\lambda_3(\mu\lambda_4(\mu_3 + \lambda_5) + (\mu_3\lambda_4\mu_1\lambda_5))] / [p\mu_2\mu_3\lambda\lambda_2\lambda_3 + \mu_2\mu_3\lambda\lambda_2\lambda_4 - p\mu_2\mu_3\lambda\lambda_2\mu_2\mu_3\lambda_1\lambda_2\lambda_4 + \mu_2\mu_3\lambda_3\lambda_4 p\mu_2\mu_3\lambda\lambda_3\lambda_4 + \mu_2\mu_3\lambda_2\lambda_3\lambda_4\lambda\lambda_2\lambda_3\lambda_4 - p\mu_2\lambda\lambda_2\lambda_3\lambda_4 + p\mu_3\lambda\lambda_2\lambda_3\lambda_4 + \mu_2\lambda_1\lambda_2\lambda_3\lambda_4 + ((\mu_2(\lambda + \lambda_1)\lambda_2 + (\lambda + \lambda_1)\lambda_3 + \mu_2(\lambda + \lambda_2)\lambda_3)\lambda_4 + p\mu_2\lambda (\lambda_2\lambda_3 - (\lambda_2 + \lambda_3)\lambda_4)) \lambda_5 + \mu(p\lambda\lambda_3(\mu_2 + \lambda_4)(\mu_3 + \lambda_5) + \mu_1(\lambda_1\lambda_3\lambda_5 + \mu_2(\lambda_1\lambda_3 + \mu_3 (\lambda_1 + \lambda_3) + (\lambda_1 + \lambda_3)\lambda_5)) + \lambda_4 (\lambda_1\lambda_3\lambda_5 + \mu_2(\lambda_1\lambda_3 + \mu_3(\lambda_1 + \lambda_3) + (\lambda_1 + \lambda_3)\lambda_5))) + \mu_1((\lambda - p\lambda + \lambda_1)\lambda_2\lambda_3\lambda_5 + \mu_2(\lambda_1\lambda_2 \lambda_3 + \mu_3(\lambda_2(\lambda_1 + \lambda_3) - (-1 + p) \lambda(\lambda_2 + \lambda_3)) + \lambda_2(\lambda_1 + \lambda_3)\lambda_5 - (-1 + p)\lambda(\lambda_2\lambda_3 + (\lambda_2 + \lambda_3) \lambda_5)))] \tag{4}$$

Assuming parameters as in Table 3:

Table 3. Assumptions for the model from Fig. 5 [own study]

Parameter	λ	λ_1, λ_2	λ_3	λ_4	λ_5	μ	μ_1	μ_2	μ_3
Value [h^{-1}]	6	0.00001	1	0.001	10% λ_4	30	2μ	0.083	1

the limit of safety value was calculated depending on the probability p of using the ERTMS / ETCS system by the vehicle:

- for $p = 0.9 \to S(t)_{t\to\infty} = 0.999898$,
- for $p = 0.7 \to S(t)_{t\to\infty} = 0.999691$,
- for $p = 0.5 \to S(t)_{t\to\infty} = 0.999476$,
- for $p = 0.3 \to S(t)_{t\to\infty} = 0.999254$,
- for $p = 0.1 \to S(t)_{t\to\infty} = 0.999024$.

Another model proposed for analysis is a model a vehicle equipped with an anti-collision system (CA).

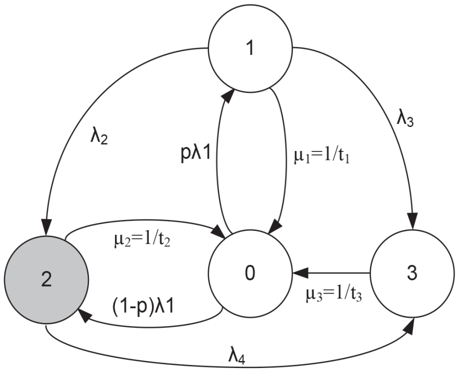

Fig. 6. Model with a CA system [own study]

For the model from Fig. 6 we can write the equations of state:

$$\begin{cases} \frac{dP_0(t)}{dt} = -p\lambda_1 P_0(t) + \mu_1 P_1(t) + \mu_3 P_3(t) + \mu_2 P_2(t) - (1-p)\lambda_1 P_0(t) \\ \frac{dP_1(t)}{dt} = -(\lambda_2 + \lambda_3)P_1(t) - \mu_1 P_1(t) + p\lambda_1 P_0(t) \\ \frac{dP_2(t)}{dt} = \lambda_2 P_1(t) - \mu_2 P_2(t) + (1-p)\lambda_1 P_0(t) - \lambda_4 P_2(t) \\ \frac{dP_3(t)}{dt} = \lambda_4 P_2(t) - \mu_3 P_3(t) + \lambda_3 P_1(t) \end{cases} \tag{5}$$

In the model, we can distinguish:

- 0 – normal state, no dangerous situations,
- 1 – state of danger. The vehicle is equipped with a system,
- 2 – state of danger. The vehicle is not equipped with a system,
- 3 – dangerous state, collision condition,
- p - the probability of equipping the vehicle with the system.

In the model from Fig. 6, the most dangerous state is state 3. The limit probability of being in state 3 is:

$$P_2(t)_{t\to\infty} = [\lambda_1((\mu_1 + \lambda_2 + \lambda_3)\lambda_4 + p(\mu_1 \lambda_3 - \mu_1\lambda_4)] / [(\lambda_2+\lambda_3)(\mu_2\mu_3 + \lambda_1\lambda_4 + \mu_3 (\lambda_1+\lambda_4)) + \mu_1(\mu_2\mu_3 -(-1 + p)\lambda_1\lambda_4 + \mu_3(\lambda_1 - p\lambda_1 + \lambda_4)) + p\lambda_1(\mu_2(\mu_3 + \lambda_3) + \mu_3(-\lambda_3 + \lambda_4))] \tag{6}$$

Assuming parameters as for the model from Fig. 4 and:

- λ_3 – one situation per 1000 leads to a dangerous situation ($0.001h^{-1}$),
- λ_4 – 10% of dangerous situation, $\lambda_4=0.1\lambda_3$,
- μ_3 – back to the normal state after 2h,

calculation results, depending on the percentage of vehicle equipment in the CA system, are shown in Table 4.

Table 4. Results of calculations [own study]

Probability p	0.5	0.6	0.7	0.8	0.9
Value $S(t)_{t\to\infty}$	0.982	0.986	0.989	0.991	0.993

4. Conclusion

Efficient and safety transport is an indispensable condition for the development of the economy. These assumptions can be achieved through the use of transport telematics systems. Telematics systems have become a tool for controlling and managing vehicle traffic, taking into account the principles of safety movement. However, the implementation of transport telematics systems requires modernization of vehicles and infrastructure. In many cases, the effects of investments will be felt for many years. An example is the ERTMS / ETCS system. As estimated by the European Court of Auditors, the cost of equipping the European rail network (TEN-T) with the ERTMS system can amount to 188 billion euros [11]. However, this does not change the fact that a uniform rail transport management system for the European area is indispensable for the creation of a common and uniform transport area. Transport safety is one of the most important socio-economic problems. The activities of the European Union are also focused on improving safety in road transport, where the priority is to reduce the number of road fatalities to almost zero by 2050 [4, 13].

The solutions presented in the article and the analysis carried out are an inseparable element of actions related to transport safety. ERTMS/ETCS for rail transport and the collision avoidance system for road transport are examples of telematics systems that can contribute to vehicle traffic safety but also bring social benefits.

The mathematical apparatus used in the form of Markov processes allowed for analysis of the proposed models. Presented in the paper universal model of safety with the telematics system (Fig. 4) has been developed towards model for rail transport (Fig. 5) and road transport (Fig. 6). The obtained calculations indicate that along with the increase of telematics devices installed for a given group of vehicles, this has an impact on improving the safety indicators.

Both solutions presented in the paper support driving of vehicles and in dangerous situations help to reduce the impact of the human factor on the possibility of a dangerous event. The proposed models may also include other factors affecting safety, including mentioned human factor. The value of this factor for rail transport was estimated in paper [3]. Limitation the impact of human factor on the control process is particularly important in the case of autonomous vehicles, where the human role in this process is limited to a minimum. Therefore, the development of this type of vehicle depends on development of telematics systems [15].

Bibliography

[1] CARNEVALI L., et al.: Non-Markovian Performability Evaluation of ERTMS/ETCS Level 3. In: Beltrán M., Knottenbelt W., Bradley J. (eds) Computer Performance Engineering. EPEW 2015. Lecture Notes in Computer Science, vol 9272. Springer, Cham, 2015

[2] PERZYŃSKI T.: Selected telematic systems in safety and management in land and inland transport. Publishing House Kazimierz Pulaski University of Technology and Humanities in Radom. Monographs Series, No. 201. (in Polish), Radom 2016

[3] QIU S., et al.: Modeling of ERTMS Level 2 as an SoS and Evaluation of its Dependability Parameters Using Statecharts. IEEE Systems Journal. 8. 10.1109/JSYST.2013.2297751. 2014

[4] European Commission: White Paper on Transport. Roadmap to a single European transport area — Towards a competitive and resource-efficient transport system. Luxembourg: Publications Office of the European Union, 2011

[5] BIAŁOŃ A., GRADOWSKI P., TORUŃ A.: Nowoczesne systemy zarządzania ruchem kolejowym (ERTMS). Problemy Kolejnictwa – Zeszyt 148, 2009

[6] UNIFE – The European Rail Industry „International freight corridors equipped with ERTMS". ERTMS Factscheet, no. 15, 2014

[7] SIEMENS: Trangular Eurobalise S21 and S22 for track – to – train Communications. Siemens AG, 2014

[8] Report of European Commission: Road Safety in the European Union – Trends, statistics and main challenges. April 2018. Luxembourg: Publications Office of the European Union, 2018

[9] https://www.euroncap.com/en/vehicle-safety/the-rewards-explained/autonomous-emergency-braking/ [date of access: 06.01.2019]

[10] CHRZAN M., PIROSZ P.: Determinants of the introduction of the railway radio communication system based on standard GSM-R in Poland. Logistyka, Nr 6, pp. 2676-2685, 2014

[11] European Court of Auditors. Special report no 13/2017: A single European rail traffic management system: will the political choice ever become reality? Luxembourg, 2017

[12] MŁYŃCZAK J., TORUŃ A., BESTER L.: European Rail Traffic Management System (ERTMS). In: Sładkowski A., Pamuła W. (eds) Intelligent Transportation Systems – Problems and Perspectives. Studies in Systems, Decision and Control, vol 32. Springer, Cham, 2016

[13] PERZYŃSKI T., LEWIŃSKI A.: The Influence of New Telematics Solutions on the Improvement the Driving Safety in Road Transport, in Mikulski J. (ed) Management Perspective for Transport Telematics, Springer Verlag, Berlin Heidelberg, CCIS 897, 2018

[14] https://www.ladocumentationfrancaise.fr/var/storage/rapports-publics/154000252.pdf [date of access: 13.01.2019]

[15] ANDERSON J.M., et al.: Oluwatola, Autonomous Vehicle Technology: A Guide for Policymakers, Santa Monica, Calif.: RAND Corporation, RR-443-2-RC, 2016. As of January 14, 2019: https://www.rand.org/pubs/research_reports/RR443-2.html [date of access: 13.01.2019]