Interdisciplinary Description of Complex Systems 16(1), 176-185, 2018

ON THE DEVELOPMENT OF INTELLIGENT RAILWAY INFORMATION AND SAFETY SYSTEMS: AN OVERVIEW OF CURRENT RESEARCH

Dániel Tokody[1,]*, Mária Tor[2], Endre Szűcs[1], Francesco Flammini[3] and Laszlo Barna Iantovics[4]

[1]Óbuda University, Doctoral School of Safety and Security Sciences
Budapest, Hungary

[2]Óbuda University, IIVR Project Office
Budapest, Hungary

[3]Linnaeus University
Växjö, Sweden

[4]Petru Maior University
Tirgu Mures, Romania

DOI: 10.7906/indecs.16.1.14
Regular article

Received: 31 December 2017.
Accepted: 17 March 2018.

ABSTRACT

The present article focuses on the research and development planning for innovative railway systems. Within such a general framework, the specific objectives of the research have been defined within the framework of a large Intelligent Railway System project in Hungary. Our theoretical research work at the university is combined with practical experience gained at the Hungarian State Railways. In the course of this research work, the development of an intelligent railway system has been investigated by leveraging on the fruitful cooperation between academic and industrial partners, in order to promote the application and integration possibilities of the development results, as well as the introduction of innovative components in the railway system. In such a context, this article discusses the research plan, preliminary and long-term expected results, sharing objectives and experiences with the aim of providing novel views in an extremely current and challenging field of research.

KEYWORDS

railways, R&D, intelligent systems, critical infrastructures, safety and security

CLASSIFICATION

APA: 4090, 4100, 4120, 4140

JEL: L92, R41, O18

PACS: 89.40.Bb, 89.40.-a

*Corresponding author, η: tokody.daniel@mav.hu; –;
Doctoral School of Safety and Security Sciences of Obuda University,
H – 1428 Budapest, Pf.:31, Hungary

INTRODUCTION

The age of the elements of the Hungarian railway system automation can be compared to that of a middle-aged human. This fact has great importance when considering the operation of the system and the scheduling of its necessary reconstruction. Such reconstruction work must be scheduled by railway professionals many years in advance, on the basis of the data collected manually and of their professional experience, taking into account the economic circumstances and the limited human resources available. The railway sector faces multiple challenges at a European level, too. Participants of the railway sector are now developing a more service-centred attitude by focusing on passenger demands, while also making changes in operation by using the latest results of continuous technological advancements. The European Committee aims to make railway transport the backbone of European transportation. In order to take this leading role, however, it is necessary to increase the competitiveness of the railway with regard to other alternatives. In case of long-distance journeys, these alternatives are the low-cost flights and international bus services in Europe. Meanwhile, some other players have appeared recently in the field of mobility further expanding the range of travel options. Public transportation must compete with new service providers using unconventional business models, such as various car-sharing companies [1].

Further objectives include increasing the safety of railway transport, ensuring high-speed transportation, developing transport management at a European level and achieving sustainability in transportation. In the long term, the railway system providing energy-efficient and reliable services can make part of a sustainable way of travelling which integrates various means of transport all over Europe [2-5].

Changing passenger demands generated by the transformation of the society – following the new trends in everyday life – call for the development of the railway industry and services, too.

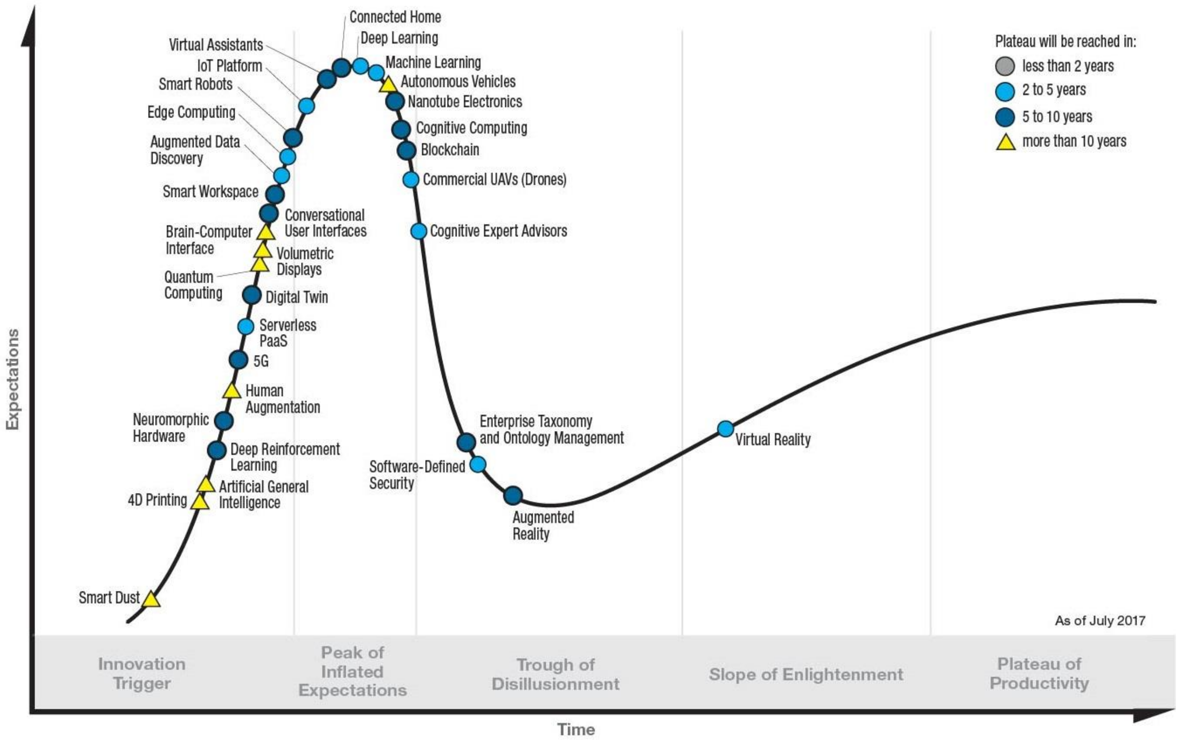

Figure 1. Gartner Hype Cycle for Emerging Technologies 2017, © Gartner [6].

Digitalisation has a significant role in this process, more specifically in the digital transformation of various transportation methods. Global technological concepts of digitalisation, such as Internet of things (IoT), Big Data, Machine-to-Machine (M2M) communication, autonomous vehicles, robots and other emerging technologies are also gaining importance in the field of transportation (Fig. 1) [7-12].

For passengers, this means the provision of real-time travel information, a uniform ticketing system and increased automation in transportation [13].

RESEARCH OBJECTIVES

The main topic of the research on intelligent railway information and safety systems can be made more specific by setting concrete objectives. Based on these objectives, the main lines of the research can also be defined. At the same time, the timeliness and significance of the topic of the research have also been pointed out [14, 15].

The fundamental research objective is to generalise, complete and expand the knowledge related to Intelligent Transport Systems (ITS), its various aspects and components that can be relevant from the viewpoint of railway systems (RITS – railway intelligent transportation systems [15]). The dominance of ITS in road transport can be disproved by modifying the common road-transport specific correlations [16-19].

In the course of the research, the following objectives have been set.

Research objective 1: Specifying and summarising the timely definition of railway automation through international research, supplemented by the definition of the intelligent railway system [20, 21].

Research objectives 2: Defining the concept of machine intelligence through research, and analysing its application possibilities in transportation, and more precisely, in the railway system [22-24].

Research objective 3: Finding and specifying the necessary recommendations, methods and procedures to define machine intelligence in the railway system [22-25].

Research objective 4: Analysing and defining the requirements of developing an intelligent railway system [22].

Research objective 5: Discovering and examining the possible methods of developing an intelligent railway system [22].

Research objective 6: Enhancing the protection of critical railway infrastructure by finding new methods and procedures. Examining the effects of new intelligent system elements through their applicability [22, 26, 27].

Railway automation refers to the widespread use of infocommunication systems, the integration of system elements into networks and the generation of a growing amount of data on the network level. In the increasingly complex railway system, human problem-solving processes are being transferred to computers in order to improve efficiency in operation.

The timeliness of the research can be illustrated by the ongoing developments, among which the example of the Mobility 4.0 initiative of the German railway must be specially mentioned. As a result of widespread digitalisation, German railway professionals managed to connect 200 trains into a uniform network. This will be further expanded in the future. Another result of this modernisation is that nearly 2 000 different parts can now be produced by 3D printing. According to plans, by the end of 2018, this new technology will be used to produce 15 000 different parts to ensure railway operation. The Deutsche Bahn group has 150 ongoing projects which involve the digitalisation of transportation [28, 29].

RESEARCH METHODS

At the initial phase of the research, the general research methods have been employed. The method of comparison has been used to analyse the existing railway automation systems and to compare the concepts and practical examples presented in our earlier studies. Further methods used in this phase include the methods of reviewing the literature and providing definitions.

At the next phase, a number of experiments are conducted in the research field based on the use of empirical methods, with a view to the non-disjoint competence fields of the topic. These experiments allow the verification of the observed facts.

Finally, at the analysis of railway systems, the theoretical (primary) – logical (secondary) research methods are used. The conclusions of the hypothesis are made by synthesising the inductions drawn from the experience of individual cases and the deductions based on generalisations, by exploring the analogues between railway and other transport system applications (e.g. ITS) and by applying the scientific method of generalisation.

The research is aimed at finding answers to the following research questions (RQ) in accordance with the objectives defined previously.

RQ 1: What is the relationship between automation, digitalisation and the development of intelligent systems?

RQ 2: What does machine intelligence (MIQ) mean and can it be measured and defined with regards to railway automation systems?

RQ 3: Is there any relevance of the application of intelligent systems in the railway?

The main hypothesis of the research states that it is possible to develop a technical system within the railway system to ensure high-level automation and to achieve the goals of increased railway safety, high-speed transportation and the support, management and sustainability of transportation on a European level. This system must also make part of the European cooperative Intelligent Transport Systems.

OVERVIEW OF PRELIMINARY RESULTS

This section provides a short summary of project plan and results of the preliminary study.

The answer to the first RQ: Intelligent systems are highly automated systems. The progress of digitalisation can be simply illustrated by such global phenomena as the M2M or IoT. As a result of these global technological changes, automated systems will be able to offer extended functionality and a higher level of automation; as a result, the autonomy of those systems can also be increased [22].

The answer to the second RQ: The intelligence of machine systems can be fundamentally measured, as it has been described by numerous international studies. The above-mentioned autonomy is only one of the indicators that are able to characterise intelligent machine systems. In the current research, further indicators (e.g. Self-Organizing, adaptation, observability, etc.) have been defined that can be used to describe the intelligence of railway automation systems [30].

The answer to the third RQ: As an example, the EN50128 standard for railway applications mentions AI (Artificial Intelligence) Fault Correction in the first place among applicable solutions. Since the issuance of the standard in 2011, research on machine intelligence has provided further results. We believe those results will have even greater significance in the implementation of intelligent railway systems in the future. It is enough to mention, for example, the application of an expert system that is able to provide prediction analysis of the throughput capacity of railway infrastructure in real-time [31].

The preliminary study that has been performed can be divided into two parts: theoretical (primary) research and logical (secondary) research.

The elements of the theoretical (primary) research included a systematic review of the literature, standards, EU Regulations, Directives and other acts, Technical Specifications for Interoperability, resulting in fact and relationship findings as well as knowledge improvements.

The elements of the logical (secondary) research included surveys with the participation of various players of the international railway industry (Operators, Infrastructure managers, Manufacturers, System integrators), resulting in speculative thoughts and railway-specific knowledge improvements.

The results, conclusions and statements are here provided by synthesising the results of the primary and secondary research by sub-topics (e.g.: railway automation, ITS, creating new definitions, implementing the methods of using machine intelligence in railway systems, defining the Hungarian Digital Railway Strategy, etc.).

According to their areas of application, the results of the research can be divided into two main categories. Results can be relevant both in academic/theoretical and in industrial/practical fields. The two-phase (preliminary) research provides the basis for the research, development and innovation projects currently underway at the university. Therefore, the results of our research will be directly used in the development project ("The Development of Integrated Intelligent Railway Information and Safety System") lasting until 31/10/2020.

Academic/theoretical results: It can be expected that the work of the research, development and innovation team (approximately 80 people) at the university will bring long-term results in the research of the designated topic, in the field of disciplinary research, extending curriculum and applied research. In order to start the project, it is necessary to conduct preliminary studies, which provide bases for the research work at the university. The results described in the present article can be considered as the results of the preliminary study, as they can help to conduct the original research to gain new knowledge. The R&D (Research and Development) project of the university is directed toward a specific practical objective and will have final results that can be applied in the railway system.

Through the project organisation, a research and development team has been created which is able to deliver a project whose ambition is to be competitive at international levels. Until now, it has not been common to build a project organisation of this size around a single topic. Consequently, one of the significant results of our research in the academic world is that it has allowed the creation of this research infrastructure by specifying appropriate development plans and procedures. This means that, through the study of the appropriate system of rules, we have created the environment for a high-quality and highly-dependable (e.g.: SIL 4) development work. Our preliminary research has provided the bases for the start of more specific research projects, the circumstances of which had not been ensured at the university before. Our research, therefore, can be regarded as a kind of combination among meta-research, feasibility study and multi-year plan from the viewpoint of academic research.

Besides the main research and development staff, BSc, MSc and PhD students are also involved in the university project, working in 17 workgroups and 21 work packages. These students are expected to write various scientific studies and publications in this field, and the project offers topics for theses and dissertations, too.

Industrial results include a pilot project, product and technology development and at least one patent application.

The impact of our preliminary study can be of direct use for the industrial partners of the project (consortium members), as by the end of the experimental development based on this preliminary study, a marketable product will be created (i.e. project results feature a very high Technology Readiness Level). The expected product will go through a conformity assessment carried out by a notified body, and it must be tested in a pilot project and approved by at least one national authority.

The knowledge synthesised from the results of the preliminary studies, the original research and the practical experience will allow industrial partners to create new products, new devices, new systems and to introduce and develop new services, which, in the long term, will have an effect on multiple players of the railway industry e.g. Operators, Infrastructure managers, Manufacturers, System integrators, etc. The Integrated Intelligent Railway Information and Safety System and its various elements (e.g.: control device, HMI, etc.) can be considered as an example of such a new product. Furthermore, the protection of innovations and intellectual contents must be also ensured within the framework of this project.

SUMMARY OF THE RESEARCH PLAN

The present research work provided the basis for a number of theses considering the development of interoperable railway system energy (ENE) and control-command and signalling system (CCS). These theses are discussed in view of the objectives and previously defined research questions.

Thesis 1: Automation and digitalisation determine the characteristics and implementation of intelligent systems [5, 15, 22, 30, 32].

Thesis 2: The intelligence of machine systems can be defined by using Smartness Indicators [5, 13, 14, 33].

Thesis 3: Intelligent systems have an important role in ensuring sustainability and the well-being of humans [5, 34].

Thesis 4: By increasing the adaptability of critical railway infrastructure, its vulnerability can be reduced [5, 16, 33].

Thesis 5: Adaptability can be achieved through the application of intelligent system elements [5, 33].

Thesis 6: In a complex, multi-level system, both distributed and centralised intelligence can be used [5].

Thesis 7: The criticality of system elements can be defined. The integration of the subsystems with the same level of criticality can ensure the flexibility of the system [5].

Thesis 8: Intelligence, as an element of the railway infrastructure, can be measured and planned [5, 13, 14, 16].

APPLICATION AND DIRECTIONS FOR FUTURE RESEARCH

The current and expected research results of this project can be generalized to several fields of technical sciences, more specifically in military technical sciences, as well as in experimental development for military and defence purposes, as well as in various technological and technical innovations. Those research results can be used in particular in protecting critical infrastructures, and applying advanced processes and devices in the field of safety technology, technical safety and industrial automation, as well as in other related scientific and engineering field, whether railway-specific or not. Results include the development of new procedures, methods and technologies for railway automation, providing new procedures for:

- planning the implementation of the Intelligent Railway System
- elaborating a new general model of such system,
- describing and explaining the operation of intelligent elements in the railway system
- creating a new framework to measure the intelligence of the railway system [35, 36].

In general, the relevance of scientific results in the field of technical sciences can be determined by their roles in the industrial development. The above research results have not yet been put into everyday practice in the main railway environment. However, considering the current social changes in Europe and in the world, it is clear that further research work needs to be done in the field of transportation.

In recognition of the stated issues, the research performed at Óbuda University for several years has effectively supported the conceptualisation and planning phase of the railway system consisting of intelligent elements, namely IntelliSys-R (Intelligent System for Railway [22]).

CONCLUSIONS

There is a growing demand for implementing various railway developments [37] on the bases of the latest scientific results. Intelligent transport systems will have to provide a holistic solution for all transportation means. The infrastructure of transportation (including its vehicles) can be considered critical from the point of social well-being; therefore its protection is of primary importance. Machine intelligence and smart systems are transforming our societies, and intelligent machines must also be used in the railway system, in view of the exponentially growing complexity of such infrastructural networks. Networking and communication-based operation will also have an increasingly important role in railway systems. A large amount of data [38] generated by the network-based operation will be automatically transformed into information allowing the basic forms of automatic operation in the railway system. In conclusion, the use of machine intelligence will lead to increased efficiency, sustainability and safety in transportation in the future.

ACKNOWLEDGEMENT

The research on which the publication is based has been carried out within the framework of the project entitled "The Development of Integrated Intelligent Railway Information and Safety System" (Economic development and innovation Operational Program (GINOP), application number: GINOP-2.2.1-15-2017-00098).

REFERENCES

[1] Holicza, P. and Tokody, D.: *Field of Challenges: A Critical Analysis of the Hungarian SME Sector within the European Economy*.
Hadmernok **9**(3), 110-120, 2016,

[2] Kiss Leizer, G.K. and Tokody, D.: *Radiofrequency Identification by using Drones in Railway Accidents and Disaster Situations*.
Interdisciplinary Description of Complex Systems **15**(2), 114-132, 2017,
http://dx.doi.org/10.7906/indecs.15.2.1,

[3] Tokody, D.; Maros, D.; Schuster, G. and Tiszavölgyi, Z.: *Communication-based Intelligent Railway – Implementation of GSM-R System in Hungary*.
14th International Symposium on Applied Machine Intelligence and Informatics, January 21-23, 2016. Herlany, pp.99-104, 2016,

[4] Tokody, D.; Schuster, G. and Holicza, P.: *Development of the Infocommunication System for the Intelligent Rail Transport System of Dangerous Goods in Hungary*.
International Conference on Applied Internet and Information Technologies. Jun 03-04, 2016. Bitola, pp.321-332, 2016,

[5] Tokody, D. and Flammini, F., *Smart Systems for the Protection of Individuals*. Key Engineering Materials **755**, 190-197, 2017, http://dx.doi.org/10.4028/www.scientific.net/KEM.755.190,

[6] Panetta, K.: *Top Trends in the Gartner Hype Cycle for Emerging Technologies*. http://www.gartner.com/smarterwithgartner/top-trends-in-the-gartner-hype-cycle-for-emerging-technologies-2017, accessed 15th August 2017,

[7] Kovács, T.; Nyikes, Z. and Tokody, D.: *Komplex monitoring-rendszer használata vasúti felépítmény vizsgálatában az Ipar 4.0-hoz*. Műszaki tudományos közlemények 6., November 26, 2016. Kolozsvár, pp.151-162, 2017,

[8] Mester, G.; Plet, S.; Pajor, G. and Jeges, Z.: *Flexible planetary gear drives in robotics.* Proceedings of the 1992 International Conference on Industrial Electronics, Control, Instrumentation and Automation. San Diego, pp.646-649, 1992, http://dx.doi.org/10.1109/IECON.1992.254556,

[9] Mester G., Pletl S., Pajor G. and Rudas I.: *Adaptive Control of Robot Manipulators with Fuzzy Supervisor Using Genetic Algorithms*. In: Kaynak, O., ed.: Proceedings of International Conference on Recent Advances in Mechatronics. Istanbul, pp.661-666, 1995,

[10] Laghari, S. and Niazi, M.A.: *Modeling the Internet of Things, Self-Organizing and Other Complex Adaptive Communication Networks: A Cognitive Agent-Based Computing Approach*. PLoS One **11**(1), 2016, http://dx.doi.org/10.1371/journal.pone.0146760,

[11] Rodić, A.; Mester, G. and Stojković I.: *Qualitative Evaluation of Flight Controller Performances for Autonomous Quadrotors*. In: Pap, E., ed.: *Intelligent Systems: Models and Applications*. TIEI 3. Springer Verlag, Berlin & Heidelberg, pp.115-134, 2013, http://dx.doi.org/10.1007/978-3-642-33959-2_7,

[12] Nyikes, Z. and Rajnai, Z.: *The Big Data and the relationship of the Hungarian National Digital Infrastructure*. Applied Internet and Information Technologies, September 17-19, 2015. pp.7-12, 2015,

[13] Tokodi, D.; Schuster, G. and Papp, J.: *The challenges of the intelligent railway network implementation*. 3rd International Conference and Workshop Mechatronics in Practice and Education, May 14-16, 2015. Subotica, pp.179-185, 2015,

[14] Tokody, D.; Schuster, G. and Papp, J.: *Study of how to implement an intelligent railway system in Hungary*. Proceedings of the 13th IEEE International Symposium on Intelligent Systems and Informatics. Subotica, pp.199-204, 2015, http://dx.doi.org/10.1109/SISY.2015.7325379,

[15] Ning, B.; Tang, T.; Gao, Z.; Yan, F. and Zeng, D.: *Intelligent railway systems in China*. IEEE Intelligent Systems **21**(5), 80-82, 2006, http://dx.doi.org/10.1109/MIS.2006.99,

[16] Tokody, D. and Shuster, G.: *I^2 - Intelligent Infrastructure*. 5th International Scientific Videoconference of Scientists and PhD. students or candidates, November 18, 2015. Bratislava, pp.121-128, 2015,

[17] Tokody, D.; Mezei, I.J. and Schuster, G.: A*n overview of autonomous intelligent vehicle systems*. In: Jármai, K. and Bolló, B., eds.:*Vehicle and Automotive Engineering*. Lecture Notes in Mechanical Engineering. Springer, Cham, pp.287-307, 2017, http://dx.doi.org/10.1007/978-3-319-51189-4_27,

[18] Schuster, G.; Tokody, D. and Mezei, I.J.: *Software Reliability of Complex Systems Focus for Intelligent Vehicles*. In: Jármai, K. and Bolló, B., eds.:*Vehicle and Automotive Engineering*. Lecture Notes in Mechanical Engineering. Springer, Cham, pp.309-321, 2017, http://dx.doi.org/10.1007/978-3-319-51189-4_28,

[19] Tokody, D. and Schuster, G.: *Driving Forces Behind Smart City Implementations – The Next Smart Revolution*.
International Journal of Emerging Research and Solutions in ICT **1**(2), 1-16, 2016,
http://dx.doi.org/10.20544/ERSICT.02.16.P01,
[20] Niazi, M.A. and Hussain, A.: *Complex Adaptive Systems*.
In: Cognitive Agent-based Computing-I. SpringerBriefs in Cognitive Computation. Vol 1. Springer, Dordrecht, pp.21-32, 2013,
http://dx.doi.org/10.1007/978-94-007-3852-2_3,
[21] Gershenson, C. and Niazi, M.A.: *Multidisciplinary applications of complex networks modeling, simulation, visualization, and analysis*.
Complex Adaptive Systems Modeling **1**(1), 17, 2013,
http://dx.doi.org/10.1186/2194-3206-1-17,
[22] Tokody, D. and Flammini, F.: *The intelligent railway system theory*.
International Transportation **69**(1), 38-40, 2017,
[23] Iantovics, L.B. and Georgieva, V.: *Detecting Outlier Intelligence in the behavior of intelligent coalitions of agents*.
Proceedings of the IEEE Congress on Evolutionary Computation (CEC). San Sebastian, pp.241-248, 2017,
http://dx.doi.org/10.1109/CEC.2017.7969319,
[24] Iantovics, L.B. and Enăchescu, C.: I*ntelligent Complex Evolutionary Agent-Based Systems*.
AIP Conference Proceedings, November 5-7, 2008. Târgu Mureș, pp.116-124, 2009,
[25] Iantovics, L.B.; Emmert-Streib, F. and Arik, S.: *MetrIntMeas a Novel Metric for Measuring the Intelligence of a Swarm of Cooperating Agents*.
Cognitive Systems Research **45**, 17-29, 2017,
http://dx.doi.org/10.1016/j.cogsys.2017.04.006,
[26] Flammini, F.; Gaglione, A.; Mazzocca, N.; Moscato, V. and Pragliola, C.: *Wireless Sensor Data Fusion for Critical Infrastructure Security*.
Proceedings of the International Workshop on Computational Intelligence in Security for Information Systems CISIS'08. Berlin, pp.92-99, 2009,
http://dx.doi.org/10.1007/978-3-540-88181-0_12,
[27] Niazi, M. and Hussain, A.: *Agent-based computing from multi-agent systems to agen-based models: a visual survey*.
Scientometrics **89**(2), 479-499, 2011,
http://dx.doi.org/10.1007/s11192-011-0468-9,
[28] Brickwede, S.: *3d printing @ Deutsche Bahn: fast. in time. reliable.*
http://www.railforum.nl/wp-content/uploads/2017/03/170626_Presentation_Railway-Forum-Eindhoven_public.pdf, accessed 19th December 2017,
[29] *Deutsche Bahn AG: Digitalisation sets the pace.*
http://www.deutschebahn.com/en/group/im_blickpunkt/11887110/digitalisierung_en.html, accessed 19th December 2017,
[30] Bien, Z.; Bang, W.-C.; Kim, D.-Y. and Han, J.-S.: *Machine intelligence quotient: its measurements and applications*.
Fuzzy Sets and Systems **127**(1), 3-16, 2002,
http://dx.doi.org/10.1016/S0165-0114(01)00149-X,
[31] CENELEC: *"EN 50128 - Railway applications. Communication, signalling and processing systems. Software for railway control and protection systems."* 2011.
[32] Tokody, D. and Mezei, I.J.: *Creating smart, sustainable and safe cities*.
Proceedings of the 13th IEEE International Symposium on Intelligent Systems and Informatics. Subotica, pp.000141-000146, 2017,
http://dx.doi.org/10.1109/SISY.2017.8080541,
[33] Tokody, D.; Schuster, G. and Papp, J.: *Smart City, Smart Infrastructure, Smart Railway*.
International Conference on Applied Internet and Information Technologies , October 23, 2015. Zrenjanin, pp.231-258, 2015,

[34] Tokody, D.; Mezei, I.J. and Schuster G., *Autonóm intelligens járművek helyzete Európában*. Köztes Európa Társadalomtudományi Folyóirat A VIKEK Közleményei **1-2**(19-20), 199-206, 2017,
[35] Transport Research and Innovation Portal (TRIP): *Research for a smart and competitive railway system*.
[36] International Union of Railways: *A global vision for railway developement*. International Union of Railways Communication Department, Paris, 2015, https://uic.org/IMG/pdf/global_vision_for_railway_development.pdf,
[37] Smith, R.A.: *Railway Technology – The Last 50 Years and Future Prospects*. Japan Railway and Transport Review **27**, 16-24, 2001,
[38] Nyikes, Z. and Rajnai, Z.: *Big data, as part of the critical infrastructure*. Proceedings of the 13th IEEE International Symposium on Intelligent Systems and Informatics. Subotica, pp.217-222, 2015,
http://dx.doi.org/10.1109/SISY.2015.7325383.