Testing of Goods Controlling Device Based on Satellite Systems

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Abstract: *This article is devoted to reviewing the results of testing an electronic security seal. The electronic security seal is one of the main parts of Intelligent Transportation System Transit, intended to control the integrity and movement of cargo section of a carrier vehicle by means of the satellite navigation system, mobile cellular communication system and satellite communication system. The electronic security seal operates as remote, autonomous, outdoor used device, installed on the hinges of the cargo compartment doors. In this regard, the development of the electronic security seals is followed by tests to verify the desired characteristics and sustainability together with the resistance to external influences factors. Technical and operating characteristics of the electronic security seal were checked. Tests of the electronic security seal on resistance to such climatic factors as temperature and humidity were carried out. Tests of the electronic security seal on resistance to mechanical influences (vibration, mechanical shock) were performed.*

Key Words: *electronic security seal, transit corridors, testing, advanced management system, intelligent transportation system*

1. INTRODUCTION

According to experience of countries leading in intelligent transportation systems (ITS) development (USA, Japan, and Europe), the implementation of different types of ITS is an effective direction to improve the transport and logistics, economy and ecology (by contributing to the reduction of exhaust emissions into the atmosphere) by optimizing the traffic road [1]. In general, intelligent transportation systems can be classified into two groups [2], depending on their functions:

– advanced traveler information systems (ATIS);

– advanced management systems (AMS).

Advanced traveler information systems are designed to ensure the road convenience by providing people with a variety of route information, such as travel time and distance and traffic route [3]. Electronic payment systems, allowing fee payment without stopping the vehicle, are also related to ATIS [4].

Advanced management systems provide safety and efficiency of the transportation system by controlling each individual part of it, for example, different types of roads (e. g. highways, railways, and urban roads), vehicles (e. g. public vehicles, cargo transport and automobiles), services (e. g. transit service) and situations (e.g. emergency situations, road repairs and closures). This group includes traffic management systems, which are the most studied type of AMS ITS [5], corridors management systems, incident management systems and other [2].

Existing ITS solve a wide range of tasks, for example:

– management of traffic flows;

– video surveillance of traffic flow conditions;

– measurement of traffic flow characteristics in lanes (traffic intensity, average speed of traffic flows, highway occupancy, traffic flow composition by modes of transport);

– informing of road users about abnormal traffic conditions (accidents, congestion, road and harvesting operations, difficult weather conditions);

– parking management;

– photo-video recording of traffic violations;

– electronic collection of payments;

– control of vehicle weight, control and accounting of transported cargo, ensuring the safety of transported cargo.

Moreover, in the long term, automated with ITS transport infrastructure will act as the basis for the formation of traffic with driverless automobiles [6] and smart cities [2].

Of particular interest is the application of intelligent transport systems for monitoring the cargo transportation. The introduction of ITS into the sphere of cargo transportation is an effective way to increase the efficiency of transportation, which is especially important for the transportation of goods at international distances.

At present, the main information product actively used in the transport and logistics industry is logistics platforms. Logistics platforms are an element of transport infrastructure, within which centralized control of transportation is carried out [7]. The major logistics platforms are European Logistics Platform (ELP) [8] and LOGINK (China) [9]. At the same time, the use of logistics platforms does not provide traceability of the movement of goods and control of their safety, which is necessary for both customers and customs services in order to prevent illegal smuggling and tax evasion. An advanced management system named Transit intelligent transportation system can be used to address these challenges.

The Transit ITS is an automated system of monitoring of the movement of customs goods (cargos) across the territory of the Republic of Kazakhstan, determining the location of cargos, assessing the compliance with the actual and planned route of movement, monitoring the safety of goods and observing the regime of transportation of customs goods. Thus, the Transit ITS represents the hardware and software complex for controlling international transport transit corridors.

The purpose of the creation of the Transit ITS is to provide the following:

– the ensuring effective regulation of foreign and mutual trade on the territory of the CIS member states;

– the reduction of time and cost of cargo delivery due to route optimization and control of compliance with traffic schedules;

– the traceability of cargo movement, operational monitoring and informing users about the location and safety of cargos;

– the control of movement of transit customs goods;

– identification of violations of the regime of transportation of customs goods;

– the suppression of transportation of smuggled goods (transparent market without contraband);

– the reduction of logistics costs due to processes automation;

– control over taxes and customs payment collection to the state budget;

– the rapid detection of the facts of opening or disengaging the cargo compartment, the reduction of the number of thefts and material damage from theft (electronic security control).

Relevance and efficiency of ITS transit implementation were confirmed by the simulation model of ITS Transit [10].

The Transit ITS consists of three subsystems:

– electronic security seal;

– data center, which is a subsystem for continuous and parallel in time receiving of data from electronic security seals on the state of objects of monitoring, archiving and processing of received data, removal of outdated data from the archive and output of data to the information portal;

– information portal, which is a subsystem of monitoring and displaying data and information to users.

Detailed information on the structure and functions of the Transit ITS subsystems is provided in paper [11].

2. ELECTRONIC SECURITY SEAL CHARACTERIZATION

The electronic security seal is an onboard navigation terminal with a mechanical locking device (standard one-time locking and sealing device with steal cable) and a reusable electronic unit with control sensors and navigation and communication modules. The electronic unit contains basic and peripheral hardware and software units with embedded software. The general structure of the electronic security seal is shown in figure 1. Detailed information on the technical means of the electronic security seal is provided in paper [12].

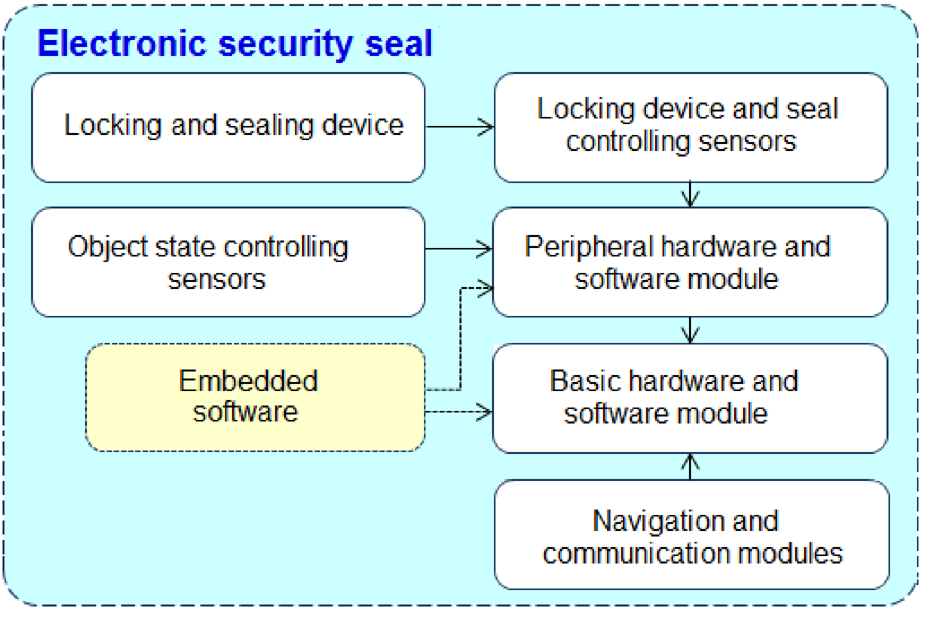

Fig. 1 – Electronic security seal structure

Installed on the hinges of the cargo compartment doors, the electronic security seal ensures locking and controlling the closed state of the doors during the traffic route. At the same time, it provides location coordinates measurement of the object using GNSS GLONASS/GPS signals, object parameters observation using sensors connected to the peripheral module, and data transmission to the data center via the channels of mobile cellular GSM and mobile satellite communications Iridium (in case of inaccessibility of cellular communication). In case of emergency (e.g., body or/and cable integrity disruption) the electronic security seal sends the alarm message to the data center, which in turn sends the alarm message to the information portal, where it is displayed. The working principle of the electronic custom seal is shown in figure 2.

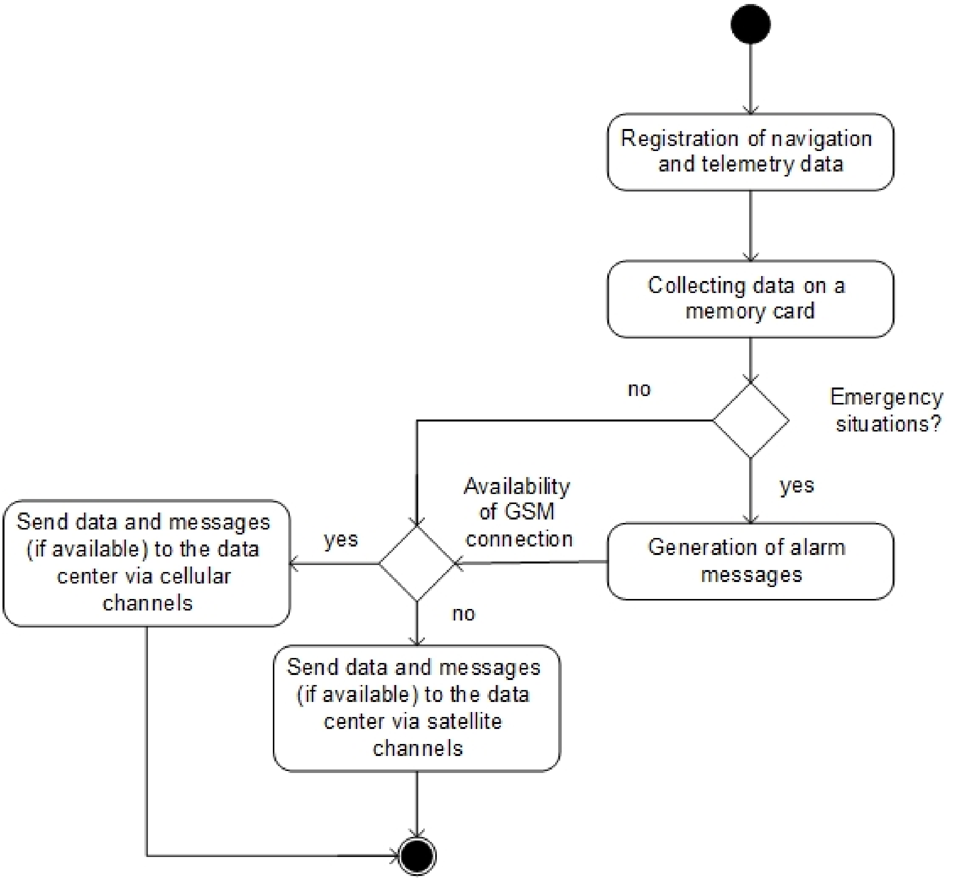

Fig. 2 – Electronic security seal working algorithm

The electronic security seal is designed for outdoor use, in the conditions of moving vehicles and cargo. In this regard it should provide resistance to climatic factors of the external environment, in particular, changes in ambient temperature over a wide range (form minus 40°C to plus 60°C), heating from solar radiation, precipitation in the form of rain, snow and hail, splashes and jets of water, icing, high humidity, frost and dew, atmospheric pressure change. In addition, the electronic security seal should be resistant to external mechanical influences: vibration and shocks, sand jets and dust clouds.

Thus, electronic security seal should provide the following characteristics:

– battery lifetime of the electronic security seal from the built-in rechargeable battery without recharging at least 45 days with data transmission of period 1 every 30 minutes;

– degree of protection against solid particles and liquid ingress by body of IP67;
– resistance to mechanical impacts during transportation;
– minimum ambient operating temperature of minus 40°C;
– maximum ambient operating temperature of plus 60°C;
– automatic notification in the data center regarding any changes in the object state (such as cable breaking and seal integrity disorder);
– satellite navigation using GLONASS/GPS signals with a standard deviation of 7.5 m;
– data transmission to the data center via GSM cellular communication channels;
– data transmission to the data center via Iridium satellite communication channels;
– data storage in the built-in memory of the electronic security seal (in case of the absence of communication with the data center).

3. TEST PROGRAM AND METHODOLOGY

On the basis of required technical and operational characteristics and sustainability and resistance to external climatic and mechanical impacts we decided to carry out the following tests:
– functions tests;
– mechanical tests;
– climatic tests.

Verification of electronic security seal functions

Checking the battery lifetime of the electronic security seal for at least 45 days with the data transmission period of 30 minutes is performed in “accelerated” mode under normal climatic conditions with the data transmission period of 3 minutes, while the duration of the battery lifetime check is reduced to 4.5 days (108 hours). By the beginning of the test, the electronic security seal battery should be fully charged. The electronic security seal is activated through the information portal interface, in the operator’s working window. The test is completed and the electronic security seal is switched off after reaching 4.5 days (108 hours) of operation. By the time of switching off, the electronic security seal should be operational and transmit data to the data center. The value of the battery charge level is checked according to the electronic security seal data in the information portal interface. The test on the seal integrity is carried out with an active electronic security seal by intentional opening (integrity violation) of the body. Then the body integrity is restored and the electronic security seal is restarted. Five cycles of opening /restoring the body and restarting the electronic security seal are performed. The test result is considered successful if an alarm message is recorded in the information portal at each seal opening. The test on the cable integrity is carried out with an active electronic security seal by deliberate breaking (cutting) the cable. Then the locking and sealing device (of single use) is changed and the electronic security seal is restarted. Five cycles of breaking the cable, replacing the locking and sealing device and restarting the electronic security seal are consistently performed. The test result is considered successful if an alarm message is recorded in the information portal at each break of the cable. Testing the function of satellite navigation is performed by visual observation of a series (sequence) of points (coordinate marks) of the electronic security seal location on the screen of the operator’s workstation, against the background of an electronic map of the area, when moving the electronic security seal in any way. The measurement of the accuracy of satellite navigation is conducted by placing the electronic security seal at a point with known “true” (measured by a high-precision instrument) coordinates. The seal is kept at a given point motionless for 5 hours. With the data transmission period of 3 minutes, the electronic security seal will transmit to the data center 100 measured coordinates of one "true" point of the terrain. Then a visual assessment is performed on the operator's screen by counting the number of points inside a circle with a diameter of 15 meters and centered at the "true" coordinates. At least 68% of the total number of measured points should be placed inside this circle. In case of cohesion of points on the map, one should calculate the number of points outside the circle; their number should be less than 32% of the total number of measured points.

Checking the function of transmitting data from the electronic security seal to the data center via cellular and satellite communication channels and channel switching and verification of build-in memory are performed according to the following scheme (see figure 3). When cellular communication channel is available, data are transmitted in standard mode: data packets are transmitted one by one at regular interval from the electronic security seal to the data center, via GSM communication channel (▲). After receiving several packets of data by GSM/ GPRS, the cellular module is turned off manually, and the satellite communication channel is automatically turned on. After receiving several data packets by Iridium SBD (■), the satellite module is turned off manually. Without any available communication channels, the electronic security seal saves data in build-in memory (○), and after turning on both cellular and satellite communication modules all stored data packets are transmitted via GSM channel (▲*). After that, the standard data transmission mode resumes (▲).

Fig. 3 – Communication channels and build-in memory testing scheme

Checking electronic security seal sustainability and resistance to external influences

In order to simulate the mechanical impacts during exploitation of electronic security seal sinusoidal vibration and mechanical shock tests are carried out. Climatic conditions are reproduced as influence of low and high temperature and humidity at high temperature. The experimental equipment used in tests for mechanical and climatic factors simulation and factors characteristics and values are shown in table 1.

Table 1 – Characteristics and values of mechanical and climatic factors

№	Impact factor	Factor characteristic	Factor value
1	Sinusoidal vibration	frequency sweep, Hz	from 10 to 100
		acceleration amplitude, m/s^2 (g)	39.2 (4)
		duration of impact, min. (X, Y, Z)	90 (30+30+30)
2	Mechanical shock	peak impact acceleration, m/s^2 (g)	250 (25)
		duration of impact, ms	6
		number of impacts (axes X, Y, Z)	4000+4000+4000
3	Low temperature	working temperature, °C	minus 40
		temperature limit, °C	minus 55
		soaking time, hours	2
4	High temperature	working temperature, °C	60
		temperature limit, °C	65
		soaking time, hours	2
5	Elevated temperature humidity	relative humidity, %	93
		temperature, °C	40
		duration of impact, hours	144

The tests for mechanical and climatic impacts are performed with activated electronic security seal to control its operability and data in the information portal during the whole test. Sinusoidal vibration test is produced by fixing the electronic security seal on the vibration stand table alternatively along the three X, Y, Z axes and subjecting it to three frequency sweep cycles from 10 to 100 Hz at the acceleration amplitude of 39.2 m/s^2 (4 g) for 30 minutes in the direction of each axis.

The mechanical shock test is conducted by fixing the electronic security seal on the shock stand table alternatively along the three X, Y, Z axes and subjecting it to 4000 mechanical shocks along each axis, characterized by the peak impact acceleration of 250 m/s^2 (25 g), impact duration of 6 ms.

To carry out climatic tests, the electronic security seal should be placed into chambers, where communication signals are disabled. In this case, the electronic security seal saves data in build-in memory and transmits them to the data center after being removed from the camera and restoring GSM/Iridium communication channels.

The climatic test begin with the low temperature test, which is carried out to check the electronic security seal for resistance to extreme low temperature of minus 55°C (i.e. during transportation) and to the effects of low working temperature of minus 40°C (i.e. during operation) according to the scheme given below in figure 4, a.

The high temperature test is carried out to check the electronic security seal for resistance to the effects of a high working temperature of plus 60°C (i.e. during operation) and for resistance to the effects of the extreme high temperature of plus 65°C (i.e. during transportation) according to the scheme given below in figure 4, b.

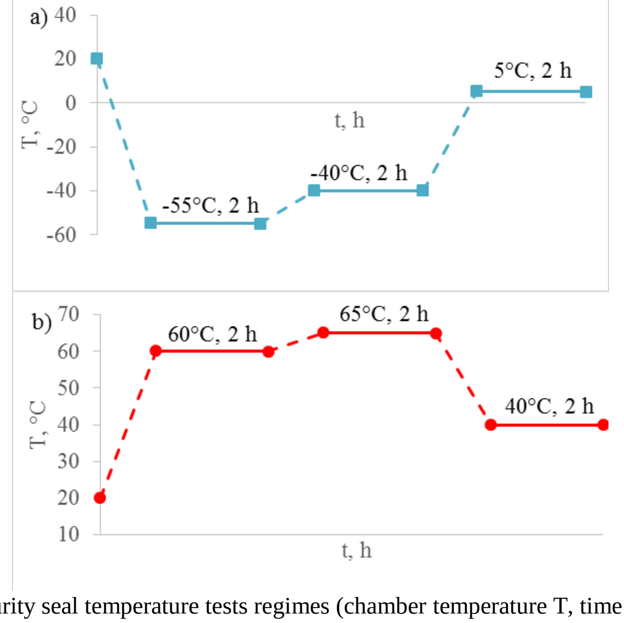

Fig. 4 – Electronic security seal temperature tests regimes (chamber temperature T, time t): a –cold temperature test, b – high temperature test (dash line is for heating and cooling process, solid line is for residence)

The elevated temperature humidity test is conducted by placing the electronic security seal into the moisture chamber, where the temperature is set at 40°C; after 2 hours the relative humidity of the chamber is increased to 93% and the countdown begins. The impact duration is 144 hours.

At the end of the test, normal climatic conditions values are set in the chamber, and the electronic security seal is kept for 2 hours; after that the chamber is disabled.

4. RESULTS AND DISCUSSIONS

An experimental sample of electronic security seal shown in figure 5 was assembled for the tests. The electronic unit and the device for locking and sealing of experimental sample fully correspond to those of utility model. However, at the stage of testing electronic security seal body was made of polymethylmethacrylate, whereas the utility model body is expected to be made of plastics. This decision allows performing a full functional test of electronic security seal and checking the resistance of electronic unit to external influences described in the previous section.

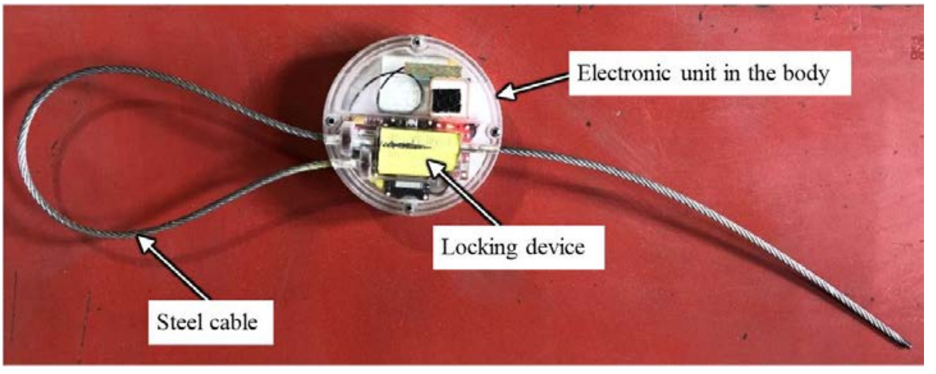

Fig. 5 – Electronic security seal test sample

The electronic security seal battery lifetime checking for 4.5 days with data transmission period of 3 minutes showed that the fully charged battery has been discharged up to 15%. On that end, the battery lifetime with data transmission period of 30 minutes is expected to be 45 days at least under normal climatic conditions. The seal and cable integrity tests were successful: as a result of all cables cuttings and seal openings, alarm messages were received in the information portal. The testing result of the electronic security seal navigation function is shown in figure 6. Providing the car with an electronic security seal made it possible to reliably determine its position.

Fig. 6 – Result of dynamic recording of positioning of the car using electronic security seal (white markers relate to navigation data registered and transmitted by the electronic security seal within 1 hour)

The navigation tests showed that the electronic security seal provides the object navigation with a standard deviation of 7.5 m. In figure 7, the result of static recording of positioning accuracy is shown: 73 % of dots lie within a circle of 15 meters in diameter and centered at the "true" coordinates.

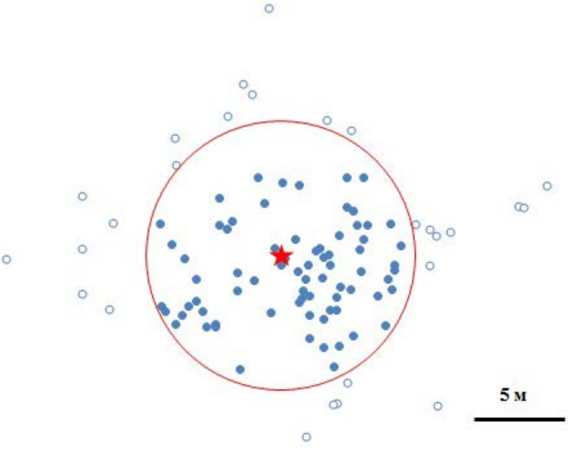

Fig. 7 – Result of static recording of position of the electronic security seal within 5 hours ("true point" is marked as star)

The test of the function of data transmission from the electronic security seal to the data center via cellular and satellite communication channels and channel switching and verification of build-in memory passed successfully. The electronic security seal enables data transmission via cellular and satellite channels without any failures. If there is no communication, the electronic security seal saves all data to the build-in memory and transmits them when the communication appears.

The conducted mechanical and climatic tests showed that electronic components of electronic unit of electronic security seal provide reliable operation in conditions close to the real ones. During mechanical tests, electronic security seal continuously transmitted data packets to the data center and information was displayed in information portal, despite the fact that the body began to collapse during mechanical shock testing.

During climatic tests, the electronic security seal saved data from locking device and seal controlling sensors in build-in memory and at the end of the tests all archived data were displayed in information portal.

Navigation data were not recorded due to the unavailability of the signal into chambers. At the same time, after each climatic test, the electronic security seal stayed functional, registered and transmitted data collected from controlling sensors to the data center. It should be noted, that cold temperature test leads to an increase in the discharge rate of the battery, which must be taken into account during operation.

5. CONCLUSIONS

In accordance with the results of functional tests, the electronic security seal provides for an autonomous operation up to 45 days and ensures reliable functioning:

– the electronic security seal provides control of the locking and sealing device body and cable;
– navigation data are recorded with an acceptable error;
– data transmission via GSM and Iridium is uninterrupted;

– the function of switching between the data transmission channels depending on the conditions of their availability works well (the GSM cellular communication channel is duplicated by a satellite communication channel);

– all registered data are recorded on a memory card.

The climatic and mechanical tests provide the verification of the electronic unit resistance to external influences. The electronic security seal is operable in a wide range of ambient temperatures ranging from minus 40 to plus 60°C and high humidity, as well as if there are mechanical effects (vibrations, shocks) that are typical of objects mounted on ground wheeled vehicles.

Thus, the developed electronic security seal has technical capabilities to implement the continuous remote control over the transport movement and safety regime of transit goods during the cargo traffic route.

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REFERENCES

[1] F. Jimenez, *Chapter 1 – Introduction*, in F. Jimenez (Ed) *Intelligent Vehicles: Enabling Technologies and Future Developments*, pp. 1–20, Butterworth–Heinemann, 2018.

[2] A. Sumalee and H. W. Ho, Smarter and more connected: Future intelligent transportation system, *IATSS Research*, vol. **42**, no. 2, pp. 67–71, 2018.

[3] O. Kem, F. Balbo and A. Zimmermann, Traveler-Oriented Advanced Traveler Information System based on Dynamic Discovery of Resources: Potentials and Challenges, *Transportation Research Procedia*, vol. **22**, pp. 635–644, 2017.

[4] M. Barth, Environmentally beneficial Intelligent Transportation Systems, *IFAC Proceedings Volumes*, vol. **42**, no. 5, pp. 342–345, 2009.

[5] Y. Fan, A. J. Khattak and E. Shay, Intelligent Transportation Systems: What Do Publications and Patents Tell Us?, *Journal of Intelligent Transportation Systems*, vol. **11**, no. 2, pp. 91–103, 2007.

[6] A. Elentably and S. Alharbi, The role of vehicle autonomous to activating driverless indoor transport systems, *International Journal of Research in Technology and Management*, vol. **5**, no. 4, pp. 17–23, 2019.

[7] O. N. Dunayev and T. V. Kulakova, Trans-logistic platform: development of logistical information platforms, *Transport of the Russian Federation. A magazine of science, economy and practice,* vol. **62**, no. 1, pp 36–39, 2016.

[8] * * * European Logistics Platform, Our Mission, Available at www.european-logistics-platform.eu.

[9] X. Li, S. Lee, B. Liu and L. Wang, *Contemporary Logistics in China: Interconnective Channels and Collaborative Sharing*, Springer, Singapore, 2019.

[10] D. Akhmedov, D. Yeryomin, D. Zhaxygulova and S. Trepashko, Simulation model of transport traceability system for transit customs goods within the EEU, *Transport and Telecommunication Journal*, vol. **20**, no. 2, pp. 133–141, 2019.

[11] D. Sh. Akhmedov, D. I. Yeryomin, D. G. Zhaxygulova and S. Trepashko, Architecture of transport traceability system of goods in the Republic of Kazakhstan, *Herald of the Kazakh-British Technical University*, vol. **16**, no. 3, pp. 335–342, 2019.

[12] D. Sh. Akhmedov, D. I. Yeryomin, D. G. Zhaxygulova, R. A. Kaliyeva and I. N. Afanasyev, Goods controlling and data collecting and transmitting electronic customs seal of the transit intelligent transportation system, *T-Comm: Telecommunication and transport*, vol. **13**, no. 9, pp. 59–63, 2019.