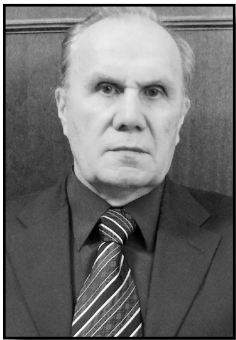
https://doi.org/10.30932/1992-3252-2019-17-4-22-35

Subsidiarity-Based Management and Control Systems for Railways


Boris A. LYOVIN **Victor Ya. TSVETKOV** **Yuriy V. DZYUBA**

Lyovin, Boris A., *Russian University of Transport, Moscow, Russia.*
Tsvetkov, Victor Ya., *Research and Design Institute for Information Technology, Signalling and Telecommunications on Railway Transport, Moscow, Russia.*
Dzyuba, Yuriy V., *Research and Design Institute for Information Technology, Signalling and Telecommunications on Railway Transport, Moscow, Russia.*

ABSTRACT

The increase in railway speeds and the transition to unmanned transport control result in the growth of the role of operational management technologies exempt from excessive control of corporate headquarters.

The objective of the work is to study the subsidiarity-based control as a new technology of controlling moving objects, and to identify borders of its efficiency.

A subsidiarity-based control's feature is that its efficiency may be revealed under certain conditions only and not always. Therefore, the application of subsidiarity-based control requires an analysis of operating conditions of vehicles. Subsidiarity-based control is an alternative to hierarchical control which is more efficient under simpler conditions.

The paper reveals the essence of subsidiarity in the social and engineering field, and results of the study on application and applicability of subsidiarity-based control for the railways, its core factors are analyzed. Comparison of signal block and subsidiarity-based control systems is made, followed by description of particularities of identification of the size of blocks within subsidiarity-based control system. Additional factors of subsidiarity-based control, comprising complementarity and astatism, are described. The relationship between subsidiarity-based management and control and implementation of digital railway concept is shown.

Keywords: *transport, management, railway, digital railway, subsidiarity, subsidiarity-based management, subsidiarity-based control, digital economy, block control.*

Information about the authors*:
Lyovin, Boris A. – D.Sc. (Eng), Professor, President of the Russian University of Transport, Moscow, Russia, tu@miit.ru.
Tsvetkov, Victor Ya. – D.SC. (Eng), Professor, Deputy Head of the Center for Strategic Analysis and Development of JSC Research and Design Institute for Information Technology, Signalling and Telecommunications on Railway Transport (NIIAS), Moscow, Russia, cvj2@mail.ru.
Dzyuba, Yury V. – Head of the Center for Strategic Analysis and Development of JSC Research and Design Institute for Information Technology, Signalling and Telecommunications on Railway Transport (NIIAS), Moscow, Russia, u.dzuba@vniias.ru.

Article received 23.04.2019, revised 30.07.2019, accepted 07.08.2019.

For the original Russian text of the article please see p. 22.

Introduction. The concept of subsidiarity

The ideas of subsidiarity were originally born in the social sphere, but now there is an opportunity for their implementation in the engineering sphere as well. The essence of the idea of subsidiarity in the management and engineering focuses on the transfer of decision making from the upper level to the operational level [1], particularly regarding subsidiary management [2; 3]. In the transportation field the increase in speed of railway rolling stock and the need to control the unmanned vehicles [4; 5] requires methods of operational control of moving objects, comprising subsidiarity-based control.

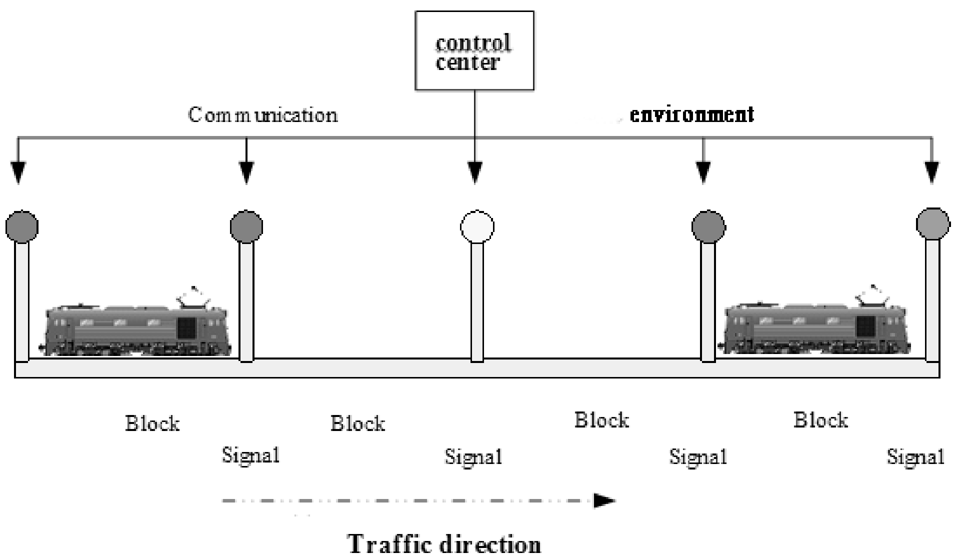
The efficiency of subsidiarity-based management is evident at the example of transport management in a megalopolis [6; 7]. It is practically impossible to draw up a detailed transportation timetable under the conditions of heavy traffic and numerous traffic jams. Therefore, the management of mass transit in a megalopolis is de facto a multi-purpose one [7; 8] and is carried out using the principle of subsidiarity.

Objective. The objective of the work is to study the technology of subsidiarity and to find the borders of the efficiency of its application in the transportation field.

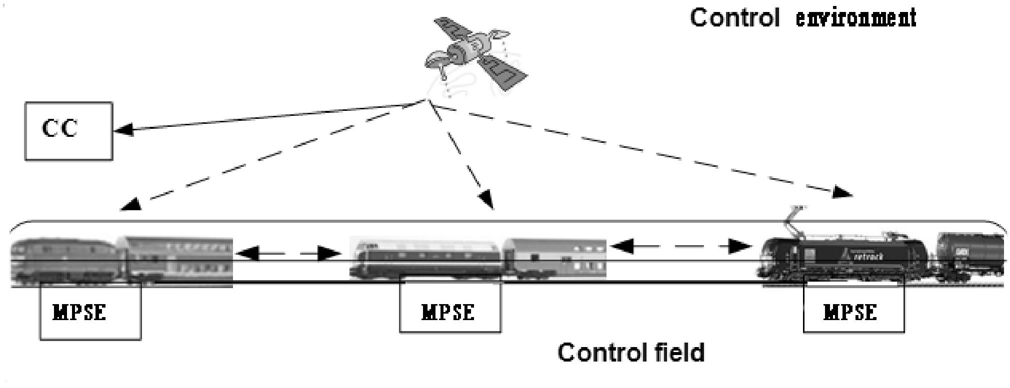
Methods. The research methods comprise system, comparative and management analysis.

The initial purpose of the idea of subsidiarity was to resolve the contradictions between an authoritarian personality and the society. The principle of subsidiarity in the social sphere dates back to the time of the Greek philosophers Plato and Aristotle. In the Catholic doctrine, the principle of subsidiarity was established by Pope Leo XIII (1891) [9] and became part of the official doctrine of the Catholic Church. From a political and civil points of view, the principle of subsidiarity is aimed at excluding authoritarian power and implies personal autonomy and self-esteem. All institutions of society, from the family to international bodies, should serve the person. Subsidiarity implies that the source of political power is the people, and so obliges the state and society to create conditions for the full development of the personality, including the provision of socio-economic human rights. So the subsidiarity can be considered a principle, as an attribute, and as a condition.

Application of the principle of subsidiarity in the engineering and information fields allows to distinguish a special type of management and control, i.e. subsidiarity-based management and control. In modern society, twofold increase of the volume of data used in management occurring every 2 or 3 years [10], aggravates the weaknesses inherent in hierarchical systems, and requires the search for new approaches to



Pic. 1. Signal-block traffic.



Pic. 2. Subsidiarity-based railway control system.

the organization of management. The subsidiarity-based management is one of the required solutions, implementing the redistribution of powers and management functions between central and peripheral control bodies.

With the development of the information society, subsidiarity-based control systems began to be used in transportation («no traffic lights» traffic), in cybernetics (robotics), in the Internet of Things technology and in cyber-physical systems. At the same time, the application of subsidiary management is not always efficient, but only under certain conditions.

Results.

Core factors of subsidiarity-based control

Conventional traffic control is called signal-block control. It is implemented through signals that allow or prohibit movement (Pic. 1) [11].

Traffic control is carried out by the control center (CC) by organization of signals by means of communication environment. Communication environment (communications) performs the most important functions of supporting such control. Since there was no other control environment, the signal-block control was the main railway traffic control system.

The emergence of subsidiarity-based management was made possible by the advent of satellite and ground-based navigation systems. The emergence and use of on-board information and analytical devices built the second factor.

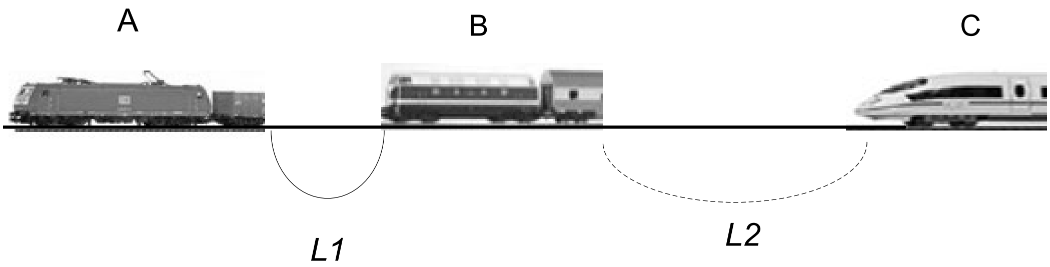
Subsidiarity-based management has its own specifics. This is defined by a set of principles [12] and factors of of subsidiarity-based management, the most important of which comprise «control environment», «control field», «situation to be managed», «management problem solution environment (MPSE)» (Pic. 2).

Under subsidiarity-based management, the control center remains, but it mainly performs monitoring functions and intervenes in emergency situations. The fundamental importance belongs to the emergence of a new means of communication between vehicles. This is either Global Navigation Satellite System (GNSS) or positional ground-based mobile communication systems. In both cases, in subsidiarity-based management, it becomes possible to independently position (coordinate) a vehicle with on-board devices (Pic. 2 can be compared to the Pic. 1).

Control environment is a physical and parametric spaces, which serve as a source of information about the situation, position and condition of the controlled object. The organization of the control environment is based on satellite and mobile positioning technologies.

Control field is a portion of a real information environment in which physical control of the object is possible.

Situation to be managed is a part of the control field and a parametric model of the information situation in which the controlled object is located.



Pic. 3. Moving block signaling technology.

The information situation characterizes the controlled object and all the important factors that affect its condition. Basically, subsidiarity-based management is situational (guided by situation) and refers to the school of «management under unforeseen circumstances» [13].

Management problem solution environment (MPSE) is a parametric information environment that contains expertise of previously made management decisions and serves as a resource for making decisions in various new situations. Its feature is that it is located within on-board devices of moving vehicles (Pic. 2). It is easy to see that Pic. 2 is a generalization of the digital railway scheme [14]. The objective of the MPSE of each on-board device is to quickly find a ready-made solution stereotype for the current situation, or to develop a new algorithm that can then be used as a cumulated expertise.

Other important factors of subsidiarity-based management, besides situational factor, are informativeness, complementarity, consistency, adaptivity, sustainability (stability).

Situational factor

Situational factor means controlling with due regard to the current traffic situation. Subsidiarity-based control admits a possibility of appearance of unforeseen obstacles. Therefore, once there is a general action plan and a main objective, the current goal is determined by the situation, involving, e.g., obstacles on the track, braking of a train in front, etc.

Situational factor leads to the need to solve auxiliary problems in order to achieve the main goal. Each auxiliary problem has its own purpose, so subsidiarity-based management is situation-oriented and multi-purpose.

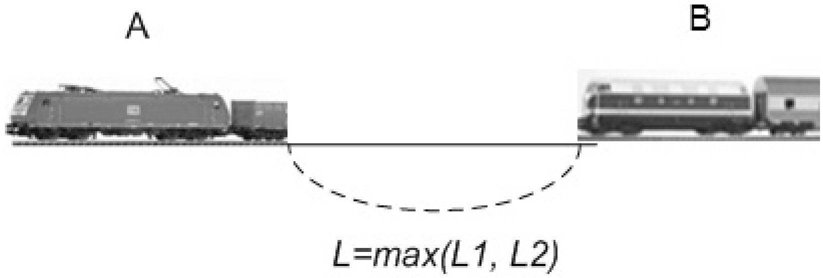
At present, subsidiarity-based management is implemented in «no traffic lights» traffic and is being developed for the digital railway. In practices, the technology of Moving block signaling is used [11]. As a matter of fact, these blocks determine the situational factor, as it is explained in Pic. 3. The situational factor is that the distance between trains is calculated based on situational traffic factors and affects the movement features of the next train.

Pic. 3 shows three sequentially running trains A, B, C and the intervals L_1, L_2 between them, which define the moving blocks. In the Moving block signaling technology (Pic. 3) each mobile object (e.g., B) has an on-board information computation system [8] and performs information interaction with other objects (for instance, with the object A in front and the next object C).

Depending on the speed and mass of the train, the distances between trains are calculated, which are called «block length» (L_1, L_2). Block dimension L is not fixed but is calculated using components l_1, l_2, l_3, l_4:

$$L = l_1 + l_2 + l_3 + l_4.$$

Parameter l_1, (inertial or physical) is the primary parameter. It is calculated on the basis of safe stopping distance and adjusted according to speed, load, traffic and other conditions. Parameter l_2, (time parameter) is determined by the total time of delay of decision making. The higher the system performance and the faster the calculation algorithm are, the less is the impact of this parameter. Parameter l_3 (navigation) is determined by the actual location error based on the Global navigation satellite system (GNSS) technology used and



Pic. 4. Calculation of safety block for subsidiary-based organization of railway traffic.

the mode used. Besides, when using a mobile location, it is determined by the accuracy of this technology. Parameter l_4 (a control parameter) is determined by delay of control signal from the moment of receiving information on object status [1].

The linear size of the block varies in real time depending on the situation. Obviously, the length of the block varies considerably from vehicle to vehicle. The higher the speed and the larger the mass of the train are, the larger should be the block. Pic. 3 conditionally shows that a block is less than the other: $L_1 < L_2$.

The utmost limit of the moving block (Pic. 3) for object (B) is determined either by the rear end of the preceding train (A) or by other obstacles which are independent of communication with the onboard sensors. There can be objects on the track, captured using video, infrared images, acoustic signals, data from radio relay stations.

In general, it is said to be a long-range view or a «blind» view. «Blind» view means viewing of tracks not visible from the driver's cabin in the absence of optical visibility but recorded using technical means. Long-range digital monitoring warns of unforeseen obstacles on the track and is all-weather.

The subsidiarity-based organization of railway traffic with no traffic lights has a feature non-existing within regular signal-based traffic (Pic. 1). A driver must monitor not only the position of vehicles in front, but also a vehicle behind to avoid rear-end collision. It is expressed through the fact that the length of the safety block calculated by the onboard computer must take into account the trains going both in front and behind. This is shown in Pic. 4.

Pic. 4 shows that the length of the block between trains is selected as the largest of the two blocks: L_1, L_2 (Pic. 3).

Use of subsidiarity-based control increases efficiency and traffic capacity excluding additional work on installation of tags and signaling devices. Such traffic model is implemented at Moscow Central Circle Line. Using of moving blocks increases the traffic efficiency and provides opportunity to use integral traffic control [15]. Integral control is carried out with account of the time interval between the trains running in the same direction and not of a fixed distance between them. Thus, in case of a higher speed, a larger distance between trains is maintained and it can be decreased in the case of lower speed.

Other factors of subsidiarity-based control

Adaptivity. Adaptivity of subsidiarity-based management and control responses to the need to change traffic conditions in accordance with the current situation and a flexible traffic schedule. It is determined by the need for structural adjustment of the traffic chart and the local control goal. Structural adjustment of the management information model is facilitated by the presence of elementary components from which the control model can be formed or rebuilt. In information management, such components are information units [16], which are also analogous to elements of a complex system. Information units are the basis of any information structure including a transport management model. The adaptive model includes virtual block management and allows the use of systems with a variable structure. The variable structure requires an elementary basis from which the structure is created, which comprises the mentioned information units. Adaptivity demands inclusion of a certain mechanism into the subsidiary management which ensures adaptation to changing conditions and situations.

Informativeness. Informativeness is associated with the digital economy and as a matter of fact, is a form of its implementation. Searching for «problem environment» and «solution environment» involves acquisition and processing of information. The information subsidiarity-based management uses information models and information technologies to analyze and manage traffic. It is necessary to differentiate information management and information control [17]. Information control finds its roots in technical control. Management is more related to organization management. Subsidiarity-based control is a technical (engineering) one and is linked to information control. Informativeness is related to the use of on-board computing devices and certain resources for storing information data on different situations.

Complementarity. In the presence of complex traffic control models or a considerable amount of controlled objects, contradictions and so called parasitic cycles may occur during the implementation of management decisions. Management is effective only when contradictions in the management model are minimized. This is possible if management technologies are complementary [18]. Hence, an important factor in subsidiary management is ensuring complementarity for technological and information management tools. Complementarity is a new factor that appears with subsidiarity-based traffic control, and hence requires additional (complementary) analysis to ensure coherence.

Consistency. Subsidiarity-based management uses expertise-based methods in combination with situational methods. Management is easier to implement and analyze when it is an integrated system. This leads to the need to apply a system approach [19, 20] for the organization of subsidiarity-based management. A system approach involves the use of elements as components of a system, which are information units.

Stability (sustainability). Subsidiarity-based management must be sustainable in the presence of traffic interference. This involves the concept of astatic control, which is based on maintaining traffic parameters face to interference caused by external environment. It is vividly demonstrated regarding maritime navigation ships [21–23], and on the contrary is not used in the railway traffic based on signal-blocks. It is slightly manifested in the «no traffic lights» road traffic, that is, within subsidiarity-based control system. This theory can be transferred to the field of subsidiarity-based railway management. It includes the development of algorithmic support based on the application of optimization methods of control theory and the ideology of computer-aided design. In contrast to the known methods of synthesis of control laws that improve separate dynamic features, the multi-purpose approach supports the state of the controlled object in the most comprehensive way. It is particularly important that the controlled object has the property of astatism regarding controllable key parameter, that is the ability to reduce the error of traffic parameters to zero in the presence of external influence.Modeling of such systems is a non-trivial problem, as its formulation and solution with the use of modern mathematical and computer methods substantially depends on the type of object, its parameters and purpose.

Conclusion

The use of subsidiarity-based management for railway transportation makes it possible to organize a flexible and denser train schedule. Subsidiarity-based management includes multi-purpose control of a series of objects, uses a common mechanism and rules, making it possible to implement such traffic organization model for intelligent transportation and cyber-physical systems. Subsidiarity-based control system is an alternative to hierarchical control [24] with a rigid timetable. It allows flexible planning to achieve a strategic goal. The analysis of subsidiarity-based management contextually reveals two important factors: a model of information situation and a model of information units. The entire subsidiarity-based management and control model is based on the creation and use of a model of the information situation. Information units serve as the basis for control adaptability, consistency and sustainability. Subsidiarity-based control is especially efficient for situational control [25, 26] under the conditions of dynamically changing traffic conditions, influence of external factors and high traffic intensity. These are just the traffic conditions of the megalopolis. However, the application of this approach for railway transport requires special mathematical methods for analyzing traffic conditions that are not used in conventional transportation management and control. The essence of subsidiarity-based and astatic management is to minimize human involvement in management. The effect of subsidiarity-based management is to increase the speed of decision-making. It is possible to consider subsidiarity-based management and control systems as reactive ones, that is quickly responding to changing traffic situation. The advantage of such systems is that they can be used within automated and intelligent traffic control system. This enables accumulation of experience of automated control for further transferring it to intelligent transportation and transport cyber-physical systems [27].

REFERENCES

1. Tsvetkov, V. Ya. Application of the principle of subsidiarity in the information economy [*Primenenie printsipa subsidiarnosti v informatsionnoj ekonomike*]. *Finansovij biznes*, 2012, Iss. 6, pp. 40–43.

2. Manolopoulos, D. The concept of Autonomy in the Subsidiary Management Research: A Conceptual Investigation. *Journal of Transnational Management*, 2006, Vol. 11, Iss. 4, pp. 45–62. DOI: 10.1300/J482v11n04_04.

3. Paterson, S. L., Brock, D. M. The development of subsidiary-management research: review and theoretical analysis. *International Business Review*, 2002, Vol. 11, Iss. 2, pp. 139–163. – DOI: 10.1016/S0969-5931(01)00053-1.

4. Murthy, S. N. [*et al*]. Methodology for implementation of unmanned vehicle control on FPGA using system generator. 7th International Caribbean Conference on Devices, Circuits and Systems, IEEE, 2008, pp. 1–6. DOI: 10.1109/iccdcs.2008.4542645.

5. Cummings, M. L. [*et al*]. The impact of human–automation collaboration in decentralized multiple unmanned vehicle control. *Proceedings of the IEEE*, 2011, Vol. 100, Iss. 3, pp. 660–671. DOI: 10.1109/jproc.2011.2174104.

6. Liu Y. [*et al*]. Metropolis parking problems and management planning solutions for traffic operation effectiveness. *Mathematical Problems in Engineering*, Vol. 2012, Article ID678952, 6 p. [Electronic resource]: http://dx.doi.org/10.1155/2012/678952. Last accessed 07.08.2019.

7. Fadare, S. O., Ayantoyinbo, B. B. A study of the effects of road traffic congestion on freight movement in Lagos metropolis. *European Journal of Social Sciences*, 2010, Vol. 16, Iss. 3, pp. 429–437. [Electronic resource]: https://www.researchgate.net/ publication/287900193_A_study_of_the_effects_of_ road_traffic_congestion_on_freight_movement_in_lagos_metropolis. Last accessed 07.08.2019.

8. Tsvetkov, V. Ya. Multipurpose Management. *European Journal of Economic Studies*, 2012, Iss. 2, pp. 140–143.

9. Leo X. Rerum Novarum. 1891. Catholic Social Thought: The Documentary Heritage, 1931. [Electronic resource]: http://w2.vatican.va/content/leoxiii/en/encyclicals/documents/hf_l-xiii_enc_15051891_rerum-novarum.html. Last accessed 07.08.2019.

10. Ozherelieva, T. A. Zipf's law in information field [*Zakov Tsipfa v informatsionnom pole*]. *Slavianskij Forum*, 2017, Iss. 2, pp. 62–67.

11. Shchennikov, A. N. Using virtual blocks in transport management [*Primenenie virtual'nykh blokov v upravlenii transportom*]. *Nauka i tekhnologii zheleznykh dorog*, 2019, Iss. 1, pp. 17–26.

12. Kozlov, A. V. Principles of subsidiarity [*Printsipy subsidiarnosti*]. *Slavianskij Forum*, 2018, Iss. 2. pp. 28–35.

13. Tsvetkov, V. Ya. Development of management technologies [*Rasvitie tekhnologij upravlenija*]. *Gosudarstvennij sovetnik*, 2015, Iss. 4, pp. 5–10.

14. Lyovin, B. A., Tsvetkov, V. Ya. Digital railway: Principles and technologies [*Tsifrovaja zheleznaja doroga: printsipy i tekhnologii*]. *World of Transport and Transportation*, 2018, Iss. 3, pp. 50–61.

15. Tsvetkov, V. Ya. Integrated control of high-speed line [*Integralnoje upravlenie vysokoskortostnoj magistralju*]. *World of Transport and Transportation*, 2013, Iss. 5, pp. 6–9.

16. Romanov, I. A. The use of information units in management [*Primenenije informatsionnykh edinits v upravlenii*]. *Perspectives of science and education*, 2014, Iss. 3, pp. 20–25.

17. Zamyshlyaev, A. M. Information management in the transport sector [*Informatsionnoe uravlenie v transportnoi sfere*]. *Nauka i tekhnologii zheleznykh dorog*, 2017, Iss. 4 (4), pp. 11–24.

18. Shchennikov, A. N. Logical complementarity in information processing [*Komplementarnost pri obrabotke informatsii*]. *ITSEM: Information technologies in science, education and management*, 2019, Iss. 1, pp. 24–30.

19. Kudj, S. A. Systematic approach [*Sistemnij podhod*]. *Slavianskij Forum*, 2014, Iss. 1, pp. 252–257.

20. Kozlov, A. V. System analysis of subsidiary systems [*Sistemnij analiz subsidiarnykh system*]. *Slavianskij Forum*, 2019, Iss. 1, pp. 116–122.

21. Veremey, E. I., Korchanov, V. M., Korovkin, M. V., Pogozhev, S. V. Computer simulation of ship navigation control systems [*Kompjuternoe modelirovanie system upravlenija dvizheniem morskikh podvizhnykh objektov*]. St. Petersburg, SPBU, 2002, 370 p.

22. Lukomskij, Yu. A., Korchanov, V. M. Marine moving objects navigation control [*Upravlenie morskimi podvizhnymi objektami*]. St. Petersburg, Elmor, 1996, 320 p.

23. Sotnikova, M. V. Multipurpose laws of digital control of moving objects [*Mnogotselevye zakony tsyfrovogo upravlenija podvizhnymi objektami*]. *Doctoral Thesis in Physical and mathematical Sciences*, St. Petersburg, SPBU, 2007, 371 p.

24. Ugolnitsky, G. A. Hierarchical management of sustainable development [*Ierarhicheskoje upravlenie ustojchevym razvitiem*]. Moscow, Fizmatlit, 2010, 336 p.

25. Dyshlenko, S. G. Situational analysis in the transport network [*Situatsionnij analis v transportnoj setji*]. *Nauka i tehnologii zheleznykh dorog*, 2018, Iss. 1, pp. 26–33.

26. Kovalenkov N. I. Situational management in the field of railway transport [*Situatsionnoe upravlenie v sfere zheleznodorozhnogo transporta*]. *Gosudarstvennyj sovetnik*, 2015, Iss. 2, pp. 42–46.

27. Lyovin, B. A., Tsvetkov, V. Ya. Cybernetics and Physical Systems for Transport Management [*Kiberfizitcheskije sistemy v upravlenii transportom*]. *World of Transport and Transportation*, 2018, Iss. 2, pp. 138–145.