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Social and economic prerequisites and trends in the development of transport innovations*

Dmitry A. Macheret[1,2]✉, Anastasia V. Kudryavtseva[1,2]
[1] Scientific Research Institute of Railway Transport (VNIIZHT); Moscow, Russian Federation;
[2] Russian University of Transport (RUT (MIIT)); Moscow, Russian Federation
[1] macheretda@rambler.ru✉
[2] anastasiya.izmaykova@mail.ru

ABSTRACT In the context of innovative development of modern economy, innovative ideas in the field of transport, which are indicators of trends in the development of transport systems, are considered. The attention is focused on the current trends of individualisation of vehicles, greening of transport and increasing traffic speeds. The aim of the study is to analyse specific examples of the implementation of these trends. The scientific novelty of the author's approach refers to the identification of "weak signals" in the analysis of transport innovations, indicating the emergence and development of promising trends.

The authors used actual materials devoted to transport innovations, Internet information sources, and scientific literature. Foresight methodology was applied.

Examples of innovative developments within the framework of the trends under consideration have been analysed. It is revealed that these trends are often combined with each other within the framework of specific transport vehicles and technologies, which generates synergistic effects important for the transport industry and the economy as a whole.

The analysis of transport innovations has shown that individualisation, greening and increasing vehicle speeds have become important conditions for the effective functioning and development of the transport industry. These trends exist both in isolation and in combination with each other. The combination of different trends in one vehicle or technology allows not only to bring the transport industry to a qualitatively higher level, to create new transport systems and products with the necessary consumer characteristics, but also to increase the economic efficiency of transport-related industries and the economy as a whole.

KEYWORDS: transport; innovation; foresight; individualisation of transport; greening; bionics; transport acceleration; economic efficiency

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Научная статья

Социально-экономические предпосылки и тенденции развития транспортных инноваций*

Д.А. Мачерет[1,2]✉, А.В. Кудрявцева[1,2]
[1] Научно-исследовательский институт железнодорожного транспорта (ВНИИЖТ); г. Москва, Россия;
[2] Российский университет транспорта (РУТ (МИИТ); г. Москва, Россия
[1] macheretda@rambler.ru✉
[2] anastasiya.izmaykova@mail.ru

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АННОТАЦИЯ В контексте инновационного развития современной экономики рассматриваются инновационные идеи в сфере транспорта, являющиеся индикаторами тенденций развития транспортных систем. Внимание сфокусировано на актуальных тенденциях индивидуализации транспортных средств, экологизации транспорта и повышения скоростей движения. Цель исследования — анализ конкретных примеров реализации указанных тенденций. Научная новизна авторского подхода состоит в выявлении при анализе транспортных инноваций «слабых сигналов», свидетельствующих о зарождении и развитии перспективных тенденций.

Использованы актуальные материалы, посвященные транспортным инновациям, информационных интернет-источников; научная литература. Применена методология форсайта.

Проанализированы примеры инновационных разработок в рамках рассматриваемых тенденций. Выявлено, что эти тенденции нередко сочетаются друг с другом в рамках конкретных транспортных средств и технологий, что генерирует синергетические эффекты, важные для транспортной отрасли и экономики в целом.

Проведенный анализ транспортных инноваций показал, что индивидуализация, экологизация и повышение скоростей транспортных средств стали важными условиями эффективного функционирования и развития транспортной отрасли. Данные тенденции существуют как обособленно, так и в сочетании друг с другом. Сочетание различных тенденций в одном транспортном средстве или технологии позволяет не только вывести транспортную отрасль на качественно более высокий уровень, создавать новые транспортные системы и продукты, обладающие необходимыми потребительскими характеристиками, но и повысить экономическую эффективность смежных с транспортом отраслей и экономики в целом.

КЛЮЧЕВЫЕ СЛОВА: транспорт; инновации; форсайт; индивидуализация транспорта; экологизация; бионика; ускорение перевозок; экономическая эффективность

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INTRODUCTION

Digitalisation is becoming the driving force of the new industrial revolution [1], changing not only production technologies, but also the system of social interaction and people's lifestyles [2]. The transition from mass to individualised production is beginning [3], and economic growth is combined with the growth of environmental friendliness within the paradigm of "green economy" [4, 5].

Transport, playing an active and very significant role in ensuring economic growth and increasing public welfare [6], stimulating innovative development and implementing industrial revolutions [7, 8], should be in line with these trends, and not just change following other spheres of activity, but be at the forefront of such changes. Already almost a century ago, economists who dealt with transport problems began to understand that for the successful development of the economy and society, transport must develop at an accelerated pace. *"Modern ways and means of transport <...> go far ahead of other branches of the national economy and facilitate their further movement. <...> First, new ways and means of transport are created, which open up the possibility of receiving and marketing in all directions, and only then production in turn can begin to be built on the basis of these new conditions"* [9, p. 43].

Further development of economic thought in the field of transport allowed to formalise this understanding in the form of the law of advanced development of transport infrastructure [10]. But it should be not only about quantitative advancement (creating reserves of throughput and carrying capacity for prospective transport flows), but also about qualitative. Transport should be one of the leaders of innovative development. In the early 19th century, railways, being an epochal innovation [11], played a key role in the realisation of the industrial revolution and the establishment of the era of modern economic growth [12, 13] (in synergy with the development of steamship traffic). *"From about the 1830s, railway construction and factory construction moved in tandem... The industrial revolution was by necessity also a revolution in transport"* [14, p. 181].

Now the emergence of numerous transport innovations may indicate the approach of a new "transport revolution", which will actively affect socio-economic changes [15].

It is important to identify trends in the development of railways [16, 17] and transport in general [18, 19] in a number of studies conducted and to determine, on this basis, the strategic directions of transport system development in the long term [20].

At the same time, along with the identification, analysis and forecasting of already emerging trends in transport development, it is important to identify, on the basis of the so-called "weak signals", only incipient trends, which is one of the elements of foresight [21]. Weak signals, according to I. Ansoff's definition, are vague early indications of upcoming important events [22]. Therefore, it is necessary to identify by weak signals the phenomena and processes that may dominate in the future [23]. Important indicators of weak signals are innovative ideas arising from scientists and inventors. Their identification can be carried out on the basis of such foresight methods as review of sources, scanning of sources, bibliographic analysis [24].

What innovative ideas in the field of transport engineering and technology can be considered weak signals of upcoming important events — those phenomena and processes that can have a significant impact in the future? In our opinion, these are the ideas and conceptual developments that meet the priority needs of people, and therefore will be demanded with a high probability.

Comparing the results of the analysis of transport innovations conducted over a number of years (some results of which are reflected in [5, 7, 15, 25, 26]) with the priority human needs allows us to identify important trends that should dominate the development of transport systems in the future. These are:

- individualisation of transport facilities and services;
- the greening of transport in the broad sense, understood not simply as a reduction of the burden on the environment ("green transport"), but as a harmonisation of transport systems and the natural environment;
- and, finally, the trend towards faster transport, which is not new but is becoming a priority.

Fig. 1. Citroën Skate

Fig. 2. Caravan NV350 Office Pod

INDIVIDUALISATION OF TRANSPORT

According to D.V. Dragunsky's apt remark, the development of culture is the development of privacy [27]. People's need for privacy, for individualisation of transport means and services, if sometimes it sometimes took a back seat to other important characteristics of transport, it never disappeared. It is worth remembering how the characters of N.S. Leskov, praising the railway for the speed of travelling compared to the horse-drawn railway (we are talking about the 1880s), *"found one thing better on horses, that you can ride in your own company and stop anywhere"* [28, p. 169]. That is, choosing to travel by rail because of the high speed, people retained the need for a more private, flexible, in a word, individualised transport. It is no coincidence that the bicycle, invented in the late 19th century, was in demand. *"The bicycle has become a mass means of transport, and the impact it has had on urban lifestyles is beyond all estimation. The bicycle in a sense paved the way for the car and motorbike, becoming a cheap and democratic, but still a personal vehicle"* [29, p. 207].

It is the need for private door-to-door travelling with the possibility of *"stopping anywhere"* that made cars so attractive, despite the high costs and serious problems associated with road "congestion" [30]. The solution to these problems must lie in new forms of individualisation of vehicles and transport services. Therefore, it can be assumed that the numerous ideas and concepts of such vehicles that are emerging will be in demand and are signals of emerging important trends in the evolution of transport.

For example, the French car manufacturer Citroën has presented an interesting mobility concept that combines several promising transport technologies into one universal vehicle, the Citroën Skate [31]. This is a platform for an unmanned electric vehicle that can be equipped with different interchangeable types of add-on modules depending on the work to be performed (*Fig. 1*).

Another major car manufacturer — the Japanese company Nissan, promptly responding to the new social challenge — remote work, has developed a new type of office space — Caravan NV350 Office Pod, which differs from typical designs of motorhomes in that it is an office [32]. The office, located in a retractable section, allows working outdoors in a very real sense (*Fig. 2*).

The contours of future urban mobility are gradually taking shape. It is likely to include vehicle types such as "flying cars", "flying taxis" and "flying motorbikes". With regard to the development of flying motorbikes, mention should be made, for example, of the French company Lazareth. The American firm JetPack Aviation has already successfully tested its Speeder

Fig. 3. Speeder motorbike

Fig. 4. XTurismo Limited Edition flying motorbike

motorbike (*Fig. 3*), which is based on the operation of a vertical take-off and landing (VTOL) aircraft. It is expected to have a top speed of 96 km/h and a range of 15 minutes. The second variation of the flying motorbike has a speed of 240 km/h and a flight time of 10 to 22 minutes [33].

Japanese startup A.L.I. Technologies has launched the XTurismo Limited Edition flying motorbike (*Fig. 4*), which has six propellers powered by a conventional engine and four electric motors. The motorbike weighs 300 kg and can fly at 100 km/h for about 40 minutes [34].

When it comes to urban mobility and the customisation of vehicles, the modernised wingsuit is not to be overlooked[1] with an electric motor, on which Austrian stuntman Peter Salzmann made the first flight in history (*Fig. 5*).

The speed after switching on the engines was more than 300 km/h. For the first time in history, a person in a wingsuit flew not only downwards but also upwards, achieving an unprecedented freedom of flight [35].

Mobility is a major challenge in Africa where transport infrastructure is underdeveloped. This was the starting point for Phractyl engineers to develop the Macrobat, a uniquely shaped flying machine. Thanks to its wings and two "legs", this device shares common features with birds, thus the device performs an almost vertical take-off and landing (*Fig. 6*). This feature is in great demand today by all those who are trying to create compact flying machines [36].

One of the visible trends of emerging innovations is the combination of several weak signals (development trends). For example, modern transport is becoming both personalised and environmentally friendly. A good example is the Eximus IV rail vehicle, which has become the most fuel-efficient vehicle in the world (*Fig. 7*) [37].

Fig. 5. Austrian stuntman Peter Salzmann flying in a motorised wingsuit

Fig. 6. Macrobat aircraft

Fig. 7. Rail vehicle Eximus IV

[1] Wingsuit ("wing" + "suit") — a special suit-wing, the design of which allows the rushing air flow filling the wings between the legs, arms and body of the pilot, thus creating an aerodynamic profile. This makes it possible to perform gliding flights.

Fig. 8. A "solar-powered" electric car Aptera

Fig. 9. A car made of recycled rubbish called "Luca"

Fig. 10. Roadster electrotrike

Combining individualisation and environmental friendliness are electric cars with ultra-aerodynamic shapes and ultra-light weight, for which a solar panel located on the roof can provide a range comparable to the average daily mileage of a typical city dweller's car.

For example, the American electric car Aptera, which has 180 solar panel modules on its roof and bonnet, with a total area of just over three-square metres, has adapted this idea for the consumer class (*Fig. 8*). The Aptera car's solar panels are capable of generating enough energy for 72 kilometres of driving under ideal conditions. The car's two-seater body has an air resistance coefficient of 0.13 (for comparison, the very low resistance coefficient of the Volkswagen ID Space Vizzion is 0.24) [38].

Another example of an eco-friendly individual vehicle is Project Luca (*Fig. 9*), created by a team of enthusiasts from the Eindhoven University of Technology in the Netherlands, which consists almost entirely of skilfully recycled rubbish.

The car has an electric drivetrain and two electric motors, and since it is very light, it can accelerate up to 90 km/h. The energy reserve is enough for 220 kilometres. The car is designed for two passengers [39].

American company Arcimoto has developed a new version of the electrotrike[2] Roadster (*Fig. 10*), with a top speed of 120 kilometres per hour [40].

The trend towards individualisation of vehicles covers various modes of transport, including air and even rail, and is often combined with greening. Of course, the trend towards greening transport goes beyond individualised vehicles and requires special consideration.

TRANSPORT GREENING

The development of transport has played an important role in shaping the ecological component of human consciousness. *"…"Reverence for nature," as Aldous Huxley noted, "resulted from good means of communication. In the seventeenth century no sane man loved wilderness." The change came when the French began to pave roads over the Roman roads, so that nobles could travel and 'gaze upon the wilderness with comfort and without serious risk'…"* [41, p. 9].

When analysing the prospects of transport greening, attention should be paid to a wide range of innovations that ensure both the reduction of transport load on the environment and harmonious "embedding" of vehicles and objects into the natural environment.

An important component of greening is the reduction of noise pollution. Trailing edge noise is the strongest source of sound from rotating aircraft and gas turbine engines used in aeroplanes, unmanned aerial vehicles and wind turbines, and its suppression is an important task. One of its solutions becomes the use of the characteristics of extremely quiet owl wings to determine the design of airfoils. Interestingly, the use of asymmetrical teeth (similar to the tips of owl feath-

[2] Electrotrikes (electric tricycles) are three-wheeled vehicles with an electric motor that are designed for personal journeys but can also be used to transport goods or passengers on commercial sites, parks, businesses or private farms.

Fig. 11. High-speed electric train with distributed traction KTX-Eum

Fig. 12. Train with hybrid propulsion system of HC85 series

ers) reduces noise more than conventional symmetrical teeth. This is a prime example of using bionics[3] for transport innovations [42].

Bionics is a promising direction of transport innovations, which allows increasing not only the environmental friendliness but also the efficiency of transport systems [43]. Along with the application of bionics principles for individual innovations in the field of transport equipment and technologies, they can also be used to effectively harmonise the interaction and development of different modes of transport, following the example of mutual positive interactions between different biological species and their symbiogenesis [44].

Despite the fact that the railway is the most environmentally friendly mode of transport, there are projects aimed at further increasing its environmental friendliness.

For example, the Canadian National (CN) railway and Progress Rail (part of Caterpillar Corporation) have begun working with biodiesel producer Renewable Energy Group (REG) to test fuel blends that include both biodiesel and diesel from renewable components. The tests conducted and the results obtained were an important step in reducing harmful emissions from the operating locomotive fleet [45].

The government of the Republic of Korea plans to completely eliminate diesel trains by 2029. They will be replaced by high-speed electric trains with distributed traction KTX-Eum (*Fig. 11*). Replacing diesel traction with electric traction will reduce greenhouse gas emissions by 70 thousand tonnes, which is equivalent to planting 10 million coniferous trees [46].

Hydrogen-fuelled locomotives are a promising alternative to diesel-powered rolling stock. The Republic of Korea Railway Research Institute (KRRI) is developing a hydrogen fuel cell traction system that can run 600 km on a single charge at a speed of 110 km/h [47].

It should be noted that developments on the use of hydrogen fuel for train traction are underway in a number of other countries, including Russia [48, 49].

The Japanese railway company JR Central has completed tests of a train with a hybrid propulsion system. The new HC85 series trains developed by Nippon Sharyo are designed to run at a speed of 120 km/h (*Fig. 12*).

The HC85 train is equipped with a 145 kW diesel generator set and a 40 kWh battery pack. The use of battery packs during acceleration and braking of the train reduces the level of harmful emissions into the atmosphere. When the diesel engine is idling at the station, the fuel supply system switches it off. Compared to the 85 series diesel train, the new train's fuel consumption is reduced by 35 %, CO_2 emissions by 30 % and NOx emissions by 40 % [50].

The American company Progress Rail will build a shunting locomotive with traction batteries for the Pacific Harbor Line railway. The six-axle locomotive with an output of 3200 hp is equipped with new generation lithium-ion batteries and asynchronous traction drive. The capacity of the EMD Joule traction battery pack is 2.4 MWh, the duration of operation without recharging depends on the mode of locomotive use and can reach 24 h [51].

If electrification is a traditional tool for improving environmental friendliness in railway transport, and only in recent years the search for alternative solutions has intensified, then in motor transport the use of electric energy is a serious reserve of greening.

It should be noted that electric vehicles are relatively expensive. However, this problem is being actively addressed. An example is the electric car Wuling by a Chinese manufacturer (*Fig. 13*) [52], which managed to reduce its price to 4.3 thousand dollars. In China, it overtook the American company Tesla Model 3 electric car in sales.

[3] Bionics — applied science of application of principles of organisation, properties, functions and structures of living nature in technical devices and systems.

Fig. 13. Wuling Mini EV in GameBoy configuration in Russia (photo by Aleksey Shvaikov)

Fig. 14. Zero Labs

Fig. 15. "Green" Aframax class tanker "Vladimir Monomakh"

It is likely that it is China that will become the dominant player in the growing global electric vehicle market. China already controls a significant part of the global electric car supply chain, starting with the processing of critical minerals. In doing so, China is the leading electric vehicle market in the world. The Chinese government predicts that by 2025, electric vehicle sales will account for up to 25 per cent of all car sales [53].

The environmental benefits of electric cars are undeniable. But not everyone is ready to part with classic cars and replace them with compact, quiet electric vehicles. Companies such as Zero Labs are working specifically for them, which seeks to convert an existing car to an electric chassis. Zero Labs offers a ready-made electric platform on which all that is required is to mount the desired body and connect the controls (*Fig. 14*). In fact, by contacting the company, the customer buys a ready-made electric car, but retains complete freedom to choose how it will look like [54].

Concepts and innovations aimed at maintaining the industry's environmental friendliness are also appearing in water transport. An example of such environmental innovations is the first Aframax-class "green" tanker in Russia, the Vladimir Monomakh, built at the Zvezda shipbuilding complex (*Fig. 15*). This liquefied natural gas (LNG)-powered vessel is designed to transport oil in an unlimited navigation area and meets high standards of environmental safety. The tanker can be powered by LNG, which minimises harm to the environment [55].

In Tatarstan, where work is underway to expand the use of LNG as a motor fuel in transport and industry, the Zelenodolsk plant is building LNG-powered passenger vessels of the Chaika type (*Fig. 16*). Passenger capacity of the vessel is 170 people. The range of navigation on fuel reserves is 400 km, autonomy — 24 hours [56].

An interesting trend in the greening of water transport is the use of sails. The French company Airseas has installed the first Seawing kite-sail with an area of 500 square metres on the 154-metre cargo vessel Ville de Bordeaux (*Fig. 17*), which will save about 20 % of

Fig. 16. The reduced-gas-fuelled passenger ship "Chaika" on the Neva River in Saint Petersburg

Fig. 17. Seawing sail on a cargo ship Ville de Bordeaux

fuel and reduce the amount of harmful emissions by a corresponding amount [57].

As for the aspect of greening transport, such as the harmonisation of transport systems and the natural environment, it is related to the aforementioned bionics. Illustrative examples are innovative proposals such as the chameleon design of high-speed trains, allowing them to blend in with their surroundings, or the technology of creating cars from biological materials capable of adapting to the environment [5]. Examples of the use of bionics in innovations in transport and related fields are numerous and deserve to be systematised and analysed.

INCREASING VEHICLE SPEEDS

A key human need fulfilled by transport is to reduce the time taken to cover distances. Increasing travelling speeds have played a key role in the development of human society [58]. The logical prediction made two decades ago about the priority of increasing speeds in transport [59] is confirmed by practice. Nevertheless, increasing the speed efficiency of transport systems remains an urgent task [60]. Therefore, the emerging ideas of creating fundamentally new vehicles that can dramatically increase the speeds of people and goods deserve increased attention as signals of future changes in transport systems.

Researchers in China have built and tested a prototype hypersonic TSV X-plane (*Fig. 18*). Unlike most hypersonic aircraft concepts with an engine on the lower hull, the TSV X-plane has two separate engines on each side. At lower speeds, they operate as conventional turbojet engines. This configuration gives the aircraft the ability to quickly switch to high-speed mode. The aircraft can accelerate to speeds up to five times the speed of sound. This means that the TSV X-plane can fly around the planet in a few hours [61].

Fig. 18. A model of Chinese aeroplane TSV X-plane

An interesting project is the Super Sub, a new high-speed submarine with a long plumage and advanced wing design, which is the most hydrodynamic submarine on the market (*Fig. 19*). It was developed by U-Boat Worx, a Dutch submarine manufacturer.

Fig. 19. Mini submarine Super Sub

The submarine has a best-in-class propulsion system with four powerful thrusters, allowing it to travel at eight knots underwater. This is two knots faster than the maximum cruising speed of a dolphin-aphaline and five knots faster than the average speed of similar submarines. The Super Sub's 62 kWh battery has enough capacity to operate underwater for up to eight hours without recharging, and if something goes wrong, the life support system will last for at least 96 hours. The new submarine can carry a captain and two passengers [62].

Fig. 20. Snoek velomobile

The Dutch company Velomobiel has presented an innovative development that combines answers to two modern trends at once — increasing speed and individualisation. It has developed a racing velomobile[4] Snoek (*Fig. 20*).

[4] A velomobile is a tricycle with an aerodynamic body, which the rider controls from a recumbent position. It is not particularly off-road, especially on rough terrain, but thanks to its streamlining on a good road it can be driven at a relatively high speed with less effort.

Fig. 21. Spirit of Innovation aircraft

It is purely foot-powered, with Sturmey Archer drum brakes. Snoek can accelerate up to 60 km/h [63].

When it comes to increasing the speed efficiency of vehicles, Rolls-Royce's Spirit of Innovation electric aircraft meets two trends at once: increasing speeds and environmental friendliness (*Fig. 21*).

The Spirit of Innovation is powered by a 400 kW electric propulsion system, which is supplied by a battery system that has the highest energy storage density of any aerospace system. The aircraft reached a maximum flight speed of 623 km/h, making it the world's fastest all-electric aircraft [64].

Another interesting concept of the Vox aircraft combines high flight performance with the ability to land on almost any helipad. At the same time, its speed is three times higher than that of a helicopter, and fuel consumption is half that of a helicopter, i.e. acceleration is combined with increased energy efficiency and, therefore, environmental friendliness [65].

In the modern world, most of the population lives in cities, and the most important task is to accelerate urban transport, primarily in megacities and agglomerations, where the speed of cars and public transport is limited due to "traffic jams" [66]. An interesting approach to solving this problem is the development of air transport ("helicopter taxi") in megacities and agglomerations [67].

Thus, innovative solutions aimed at accelerating the movement of both passengers and freight appear in different modes of transport, while other trends of individualisation and greening are often implemented.

CONCLUSION

Global trends always emerge from the aggregate of many micro-trends. These, in turn, are based on breakthrough ideas and "weak signals" of upcoming important events. For sustainable economic development, it is strategically important for the transport industry to be well oriented in the ongoing changes, to meet the existing socio-economic challenges and human needs, as well as to competently forecast the upcoming significant changes. To do this, it is necessary to timely identify "weak signals", as well as to know the "rules" of formation of "microtrends" [67].

The analysis of transport innovations has shown that individualisation, greening and increasing vehicle speeds have become not just trends, but important and even necessary conditions for the effective functioning of the industry. Their transition from "weak signals" to "necessary conditions" for further development is taking place rather quickly.

These trends exist both in isolation and in combination with each other. This conclusion seems important because the combination of different trends in one transport vehicle or technology generates synergetic effects, which allows not only to bring the transport industry to a qualitatively higher level, to create new transport systems and products with the necessary consumer characteristics, but also to increase the economic efficiency of transport-related industries, and thus of the economy as a whole.

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Bionotes

Dmitry A. Macheret — Dr. Sci. (Econ.), Professor, First Deputy Chairman of the Joint Academic Council of JSC Russian Railways; **Scientific Research Institute of Railway Transport (VNIIZHT)**; 10 3rd Mytishchinskaya st., Moscow, 107996, Russian Federation; Professor; **Russian University of Transport (RUT (MIIT))**; build. 9, 9 Obraztsova st., Moscow, 127994, Russian Federation; macheretda@rambler.ru;

Anastasia V. Kudryavtseva — Cand. Sci. (Econ.), research assistance of the apparatus of the Joint Academic Council of JSC Russian Railways; **Scientific Research Institute of Railway Transport (VNIIZHT)**; 10 3rd Mytishchinskaya st., Moscow, 107996, Russian Federation; Associate Professor of the Department of Innovation Management in Transport; **Russian University of Transport (RUT (MIIT))**; build. 9, 9 Obraztsova st., Moscow, 127994, Russian Federation; anastasiya.izmaykova@mail.ru.

Об авторах

Дмитрий Александрович Мачерет — доктор экономических наук, профессор, первый заместитель председателя Объединенного ученого совета ОАО «РЖД»; **Научно-исследовательский институт железнодорожного транспорта (ВНИИЖТ)**; 107996, г. Москва, 3-я Мытищинская ул., д. 10; профессор; **Российский университет транспорта РУТ (МИИТ)**; 127994, г. Москва, ул. Образцова, д. 9, стр. 9; macheretda@rambler.ru;

Анастасия Валерьевна Кудрявцева — кандидат экономических наук, научный сотрудник аппарата Объединенного ученого совета ОАО «РЖД»; **Научно-исследовательский институт железнодорожного транспорта (ВНИИЖТ)**; 107996, г. Москва, 3-я Мытищинская ул., д. 10; доцент кафедры «Управление инновациями на транспорте»; **Российский университет транспорта (РУТ (МИИТ))**; 127994, г. Москва, ул. Образцова, д. 9, стр. 9; anastasiya.izmaykova@mail.ru.

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Corresponding author: Dmitry A. Macheret, macheretda@rambler.ru.
Автор, ответственный за переписку: Дмитрий Александрович Мачерет, macheretda@rambler.ru.

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