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ABSTRACT
The article considers one of the key characteristics of the new industrial revolution which is the increase in environmental friendliness of production or the «ecological imperative». Areas for improving environmental friendliness in the transport sector have been identified, and a number of inventions (innovative proposals) have been analyzed that contribute to the implementation of the ecological imperative. On the basis of the analysis, a matrix classification of innovations is presented, representing innovations significant for transport, primarily railway. Conclusions are drawn regarding the long-term development of rail transport in order to improve its environmental friendliness, an adequate response to the global challenges of the future.

Keywords: railway transport, ecological imperative, innovative development, economic growth, energy efficiency, bionics.

Background. The appearance of railways became one of the results of the industrial revolution of the beginning of the 19th century, which opened a new era in the economic history of mankind – the era of modern economic growth. All the further, almost two–centuries long, development of the railway industry occurred in close relationship with subsequent industrial revolutions, which are differently classified by different researchers, but under any classification it is obvious that they had impact on the development of railways. Indeed, that this development, in turn, contributed to the deployment of each subsequent industrial revolution and the formation of prerequisites for a new one [1].

There are the prospects of the railway industry and transport in general, trying now to prepare possible answers to probable future challenges, it is necessary to very carefully monitor new trends in economic development in order not to miss the start of another industrial revolution that will certainly generate both new requirements and new opportunities for transport.

Objective. The objective of the authors is to consider the «ecological imperative» and innovative development of transport.

Methods. The authors use general scientific methods, comparative analysis, evaluation approach, statistical analysis.

Results. According to Peter Marsh, a well-known British specialist, the new, fifth according to his classification, industrial revolution is unfolding now. It «began around 2005 and will last until about 2040, but it is possible that its full effect will only be manifested at the end of the century» [2, p. 363].

One of the key characteristics of the new industrial revolution, on which it is necessary to focus attention, is the increase in the ecological compatibility of production, or, in the terminology of Marsh, the «ecological imperative». The need should be noted for a balanced and careful attitude to the ecological aspect of development. Regardless of the obvious importance of environmental problems, many economists are skeptical about the «apocalyptic» conclusions of a number of environmental experts about the consequences of industrial production on the environment [3, p. 526–556] or even give negative assessments to some actions in favor of protection of the environment [4, p. 286].

From the economic point of view the approach of Dipak Lala is the most balanced. It is reinforced by the perspective of a large number of researchers, according to which the «ecological economy» in its correct interpretation boils down to the application of cost-benefit analysis based on the principles of the welfare economy [5, p. 39].

P. Marsh, while considering the environmental aspects of the new industrial revolution, although he does not declare such theoretical approaches, also links environmental compatibility and economy. And, accordingly, he does not oppose the preservation of the environment to economic growth, but shows the possibilities of realizing both. In his view, the new industrial revolution will be characterized by « economical management of resources and minimization of the impact on the environment … This will be a world in which the growth of the economy will continue, but production for the first time in history will reduce the impact on the environment instead of increasing this impact» [2, p. 211].

Achievement of such goals is seen at the expense of a combination of different thematic areas, such as consumption, energy consumption and water consumption, primarily – by improving the design of consuming devices;

– reducing the environmental load through the use of high-strength wear-resistant materials, which solves two problems at once – eliminates waste dumps and reduces the use of primary resources (minerals).

The latter direction can be most fully realized within the framework of the «closed cycle economy», which presupposes a «continuous cycle of processing materials that connects old and new products» [2, p. 224–225]. Thanks to this, a combination of environmental friendliness and profitability of production is possible. «If …» the effective operation of such a closed circulation of materials has been achieved, then the source materials in such a system, by definition, are extracted easily and very cheaply. Due to low costs, companies working on this principle can set themselves the task of achieving higher profit rates than their competitors …» [2, p. 225]. Thus, speaking of the «ecological imperative», Marsh does not resort to the general thesis «there are more important things than profits and competition», and shows, including a number of examples, how the ecological compatibility of the products increases the efficiency and competitiveness of the producer.

The influence of the «ecological imperative» on rail transport can be viewed in different aspects. Firstly, the reduction in the consumption of fossil sources of raw materials for the production of energy and materials will reduce (at least, relative to the volume of industrial production and GDP, and, possibly, absolutely) extraction of minerals, and, consequently, transportation of fossil resources. Given that these goods dominate in the structure of rail transportation, this will have a significant negative impact on their volumes. Increased transportation of recyclables, most likely, does not compensate for the decline in transportation of fossil resources. But even providing growth of transportation of secondary raw materials, railway men must take special measures. As unlike transportation of coal and ore, this sector of the market will be more competitive. Obviously, both new types of cars and new logistics of cargo delivery will be needed.

To an even greater extent than the total traffic volumes, their distribution by routes will change. Cargo flows from places of extraction of minerals to places of their processing or ports will be partially replaced by cargo flows from places of concentration of recyclables.
Classification of inventions (innovation proposals), corresponding to the «ecological» imperative and significant for transport

<table>
<thead>
<tr>
<th>Description</th>
<th>Inventions</th>
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<tbody>
<tr>
<td>Reduction of energy consumption and water consumption</td>
<td>Innovations implemented in railway transport, as well as on other modes of transport, allowing to ensure synergy with the development of railways</td>
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<tr>
<td>A unique wireless technology for engines is a sensor capable of wirelessly transmitting information about engine temperature, which allows to save vehicles from wires and reduce power consumption.</td>
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<td>The project of high-speed energy efficient maglev is a prototype of a pipe for magnetic trains, inside of which the air resistance is 10 times lower than the atmospheric pressure at sea level, which allows the magnetoplanes to move almost silently, thus spending an order of magnitude less energy.</td>
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<tr>
<td>Almost no energy consuming magnetic chip — a magnetic chip that consumes the minimum possible amount of energy for computing, almost equal to the Landauer limit, which is a million times smaller than the similar energy costs in modern processors.</td>
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<td>Energy-efficient temperature control in buildings — substitution of air conditioners with mirrors, redirecting excess heat to space.</td>
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<td>Reducing CO₂ emissions, development of renewable energy</td>
<td>Innovations implemented in railway transport, as well as on other modes of transport, allowing to ensure synergy with the development of railways</td>
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<td>Passenger express Solar Bullet is a special project of a high-speed passenger train with power supply from efficient solar batteries.</td>
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<td>Electric cars using graphene batteries — electric vehicles using the finest material — graphene, which makes it possible to make lightweight, durable batteries with huge capacity capable of charging from renewable energy sources.</td>
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<td>Stella is a solar-powered car — the world’s first solar-powered car, due to its low weight providing a long distance of mileage.</td>
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<td>Solar batteries that produce electricity during the rain are solar panels that can generate electricity in both sunny and rainy weather.</td>
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<td>A spray that converts any surface into a battery is a method to convert a traditional battery into a liquid, which can then be applied to any surface like paint from a can to create a power source.</td>
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<td>Remote acquisition of energy from bacteria is based on the ability of bacteria to release electrical charge from within the cell.</td>
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<td>Perovskite solar batteries — batteries made from a new material — perovskite, giving the opportunity to receive energy at a price of $2.7 per watt compared to $3.9 per watt for modern solar batteries.</td>
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<tr>
<td>Hybrid crystal is a black crystal on a perovskite matrix, with very low power consumption.</td>
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<td>An air vehicle is a car with a pneumatic engine, for which compressed air is used.</td>
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<td>The triboelectric generator is a device that generates electricity as a result of friction between two surfaces.</td>
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<td>A traction motor using the energy of microwaves is an engine that does not need fuel because it uses the energy of microwaves.</td>
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<td>The technology that allows to convert water and carbon dioxide in liquid fuel is a pilot plant that allows to convert water (H₂O) and carbon dioxide (CO₂) into liquid hydrocarbons, synthetic gasoline, kerosene and diesel fuel.</td>
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<td>There is no data in the sample used.</td>
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<td>The use of high-strength wear-resistant effective materials</td>
<td>Innovations implemented in railway transport, as well as on other modes of transport, allowing to ensure synergy with the development of railways</td>
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<td>Freighy cars on graphene supercapacitors — a new model of a lift-covered van with a pop-installed hybrid engine system, saving about 25% of fuel, and also reducing harmful emissions.</td>
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<td>Innovative tire repair technology uses a sealant for self-restoring tires.</td>
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<tr>
<td>Electric concrete, self-cleaning itself of snow and ice — concrete capable of heating itself and melting the accumulated snow and ice, while the coating is absolutely safe for human and any technique.</td>
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<tr>
<td>Accumulators on carbon batteries — accumulators on new, graphene batteries, withstand ing up to three thousand cycles of recharge without loss of capacity, against several hundred in modern lithium-ion batteries.</td>
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</table>
High-strength aluminum is as light as aluminum metal, but twenty-five times stronger.

Vanadium batteries – batteries that can work almost forever.

Wood glass is a sturdy, cheap, renewable and very pliable innovative wood-based material that has found its place in the market of abundant and valuable industrial materials.

StreetScooter C16 – a prototype of a small electric car, almost the whole body of which and most of the other parts were manufactured using an industrial three-dimensional printer capable of printing with several different materials.

There is no data in the sample used.

Airplanes with printed 3D details are a new method for producing metal parts of aircraft using 3D production stages.

StreetScooter C16 is an electric car made on a 3D printer. It is almost the whole body of which and most of the other parts were manufactured using an industrial three-dimensional printer capable of printing with several different materials.

There is no data in the sample used.

Unbreakable glass – a new technology for glass processing, thanks to which it was possible to significantly increase its strength, prompted by the properties of shellfish shells.

The technology of creating «live» cars is the technology of creating cars from biological materials that can change and adapt to the environment.

To assess the prospects and directions for the implementation of the «ecological imperative» in the transport sector, an analysis of a number of inventions (innovation proposals) has been carried out according to sources [8–43]. They are classified in the following areas:

- reduction of energy consumption and water consumption;
In addition, in the future, increased attention should be paid to innovations that ensure the recycling of secondary raw materials and to implementation of the principles of a non-waste economy of a «closed cycle» for transport.

In terms of applying these innovations to transport (with a focus on railways) or of their impact on transport, they can be divided into three categories:

- innovations implemented in railway transport, as well as in other modes of transport, allowing to ensure synergy with the development of railways;
- innovations implemented in other modes of transport that can give them a competitive advantage in the transportation market;
- innovations in other, non-transport, industries, the absorption of which by rail and other modes of transport opens up new opportunities to improve the efficiency of transport companies.

(Such a grouping is a modification of the classification of innovations that are significant for rail transport, proposed in [44]).

The resulting matrix classification of innovations corresponding to the «ecological imperative» and significant for transport, especially the railway, is shown in Table 1.

**Conclusion.** Based on the analysis of inventions (innovations) formed within the framework of the ecological paradigm and significant for the long-term development of transport, a number of significant conclusions can be drawn.

- Five identified areas of implementation of the ecological paradigm, the most actively developing direction is associated with the reduction of CO₂ emissions and the use of renewable energy. In this case, most of the inventions and innovations both in this area and in general are carried out in non-transport industries (which are in a more natural state).
- To improve the environmental friendliness of railway and other modes of transport, target absorption is required, and then diffusion of such innovations.

Regarding modes of transport (air and road) competing with the railways one can take note of a number of promising inventions that can give them a competitive advantage in terms of environmental friendliness. This requires the railway men to react adequately.

Most innovations directly affecting rail transport are associated with innovative transport systems that have the potential for synergy with the development of railways. To realize this potential, a purposeful scientific, technical and economic policy is needed. It is necessary to radically intensify developments in the field of new high-strength wear-resistant effective materials for a railway transport (as well as diffusion of developments available in other industries) and in the development of new technologies that reduce the number of production stages.

We should pay attention to the lack of activity in the sphere of radical innovations, which reduce energy consumption and water consumption in railway transport. In the industry, the diffusion of previously created innovations (such as the Elbrus system in Russia) takes place, but new innovations are needed that would allow dynamic increase in energy efficiency of railways in a strategic perspective.

Innovations require great efforts and support in the framework of various transport systems and technologies. They serve as a basis for harmonizing the interaction of various transport systems and technologies, such as symbiosis, which can concern not only the use of properties of specific objects of wildlife, but also the mechanisms of interaction between them, such as symbiosis, which can serve as a basis for harmonizing the interaction of various transport systems and technologies.

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