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ORGANIZATIONAL, ECONOMIC AND TECHNOLOGICAL ASPECTS OF RECYCLING OF FLOW PROCESSES IN THE ROAD CONSTRUCTION

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The environmental safety of modern society reaches a critical level, which leads to the transition to the concept of a green economy. The problems of implementing green logistics and recycling in the flow processes in various sectors of the economy are of particular relevance. Road infrastructure is the most important infrastructure component of the transport complex, ensuring a balanced economic growth of the state. The article presents the results of research on the application of the logistics approach to the economic development *of the road sector in the field of improving the management of industry flow processes. The features of reverse logistics in the road sector and the structure of return material flows are highlighted. Their classification on the basis of origin has been clarified. The feasibility of involving waste in road construction processes was evaluated. The possibilities of using industrial waste in road construction are analyzed, and options for the formation of return material flows within the objects of work production within the boundaries of the micrologistic system of road construction are proposed. The results obtained allowed us to develop the theory of reverse logistics in the road sector, as well as to develop a system of scientific and practical recommendations for improving the recycling flow processes based on the formation of return material flows. Greater involvement of recycling processes in road construction, including through the use of innovative technologies, will reduce the estimated cost of construction by using cheap production waste and optimizing the transport component, preserve and, in some cases, improve the quality and durability of road structures, as well as improve the environmental situation.*

Key words: road construction, logistics system, return material flow, reverse logistics, supply objectives, production waste.

ОРГАНІЗАЦІЙНО-ЕКОНОМІЧНІ ТА ТЕХНОЛОГІЧНІ АСПЕКТИ РЕВЕРСИВНОЇ ЛОГІСТИКИ В ДОРОЖНЬОМУ ГОСПОДАРСТВІ

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В статті визначено, що застосування рециклінгу в потокових процесах будівництва автомобільних доріг вимагає створення умов для ефективного функціонування зворотних ланцюгів постачань на дорожніх об'єктах, що забезпечують не тільки відновлення якості матеріалів, які застосовуються, але і досягнення необхідного рівня якості готової дорожньої конструкції. У статті розкито особливості реверсивної логістики в дорожньому господарстві і визначено структуру зворотних матеріальних потоків.

Ключові слова: дорожнє будівництво, логістична система, зворотний матеріальний потік, реверсивна логістика, ланцюги постачань, відходи виробництва.

Introduction. The deterioration of the environmental situation and the constant impact on the environment of economic and other activities led to negative changes in natural systems. The environmental security of modern society reaches a critical level, which leads to a transition to the concept of a circular economy. The circular economy is understood by experts as an economy characterized by a restorative and concise character [1]. Initially, it had focused on environmental aspects, but over time it had acquired a pronounced economic character. At the same time, in order to improve public welfare, radical changes are taking place in the existing concept of management, the transformation of working economic models into fundamentally new business models, connected with the re-use of products and materials [2].

The circular economy was based on closed value chains that combined the technologically necessary production processes of the direct value chain with the inverse. Accounting for related processes allows you to form not only chains of rates along the entire path of moving the material flow from supplier to consumer, but also to extend them by combining production processes with the secondary use of resources

[3].

Analysis of recent researches. For the first time, the term «reverse logistics» was used by the trade organization Council of Logistics Management (CLM). J. R. Stock used the concept of «reverse logistics» to «designate the role of logistics in the processing, recycling and management of hazardous materials [4]. In a broader sense, reverse logic includes all issues related to aspects of logistics activities arising from waste reduction, rework, replacement, reuse of materials and recycling» R. J. Kopicky, M. J. Berg, L. Legg, V. Dasappa and C. Maggioni gave a similar characteristic to reverse logistics [5].

T. L. Pohlen and M. T. Farris in works understood the reverse logistics: "the movement of goods from consumer to producer back along the distribution channel" [6].

At the same time, D. S. Rogers and R. S. Tibben-Lembke, referring to the definition of CLM, described it as "the process of planning, organizing and controlling flows of raw materials and materials, unfinished production, finished products and related information from the place of consumption to the place of origin in order to restore value or destroy properly" [7].

Theoretically conducted research on this issue made it possible to establish that each of the authors took as a basis different aspects of reverse logistics. So, J. R. Stock, R. J. Kopicky and others point to the importance of reverse logistics in the context of environmental protection and waste disposal. While T. L. Pohlen and M. T. Farris drew attention to the direction of commodity flows in terms of supplier position and supply chain demand. Finally, D.S. Rogers and R. S. Tibben-Lembke see return material flows as flows closing the supply chain into a continuous single material flow cycle.

However, all three definitions have a common part, implying the formation of flows in order to use goods and materials returned to the place of production.

The most holistic definition is that given by M. Fleischmann, in which the management of reverse logistics is the process of "planning, organizing and controlling, entering the return material flow and accompanying information, in the opposite direction to direct flows in the supply chain, with the aim of restoring value or proper disposal" [8].

Speaking about the national scientific literature, it should be noted that during the time of the planned economy, research was carried out, recommendations were made on the management of return flows. However, full-fledged research by authors had not been carried out in the transition to a market economy. In general, scientific work was reduced to environmental problems or commodity expertise.

The fundamental works explore various facets of logistics as a science and a tool of business, its separate functional directions, but the issues of functioning of road facilities are not sufficiently reflected [9]. In the works of J. Coyle, M. Christopher, D. M. Lambert, V. V. Dybskaya, I. A. Elovoy, R. B. Ivut, S. I. Baranovsky, P. G. Nikitenko, S. A. Pelich, I. I. Poleshchuk and others formulated the main definitions of logistics [10–12].

Unexplored aspects of the issue. The adopted course on innovation in all areas of economy requires rethinking some basic concepts, reorientation of existing definitions in order to develop theoretical and practical foundations for the development of logistics systems in the road economy [9].

The purpose of the study is to develop the theoretical and methodological foundations of reverse logistics and to develop a system of scientific and practical recommendations for recycling flow processes based on the analysis of organizational, economic and technological features of road construction.

Main body of the study. The concept of the development of logistics systems in the road economy serves as the main basis for the formation and implementation of favorable organizational and economic conditions for ensuring the sustainable functioning of the economy, the growth of the country's competitive advantage in the world economic space by introducing a unified scientific approach to the definition of streaming processes for the construction, reconstruction, repair and maintenance of roads coordinated with current road operation processes implemented by various sectors of the economy [9].

The logistic approach to the development of road facilities sets a fundamentally new system vision of the processes of construction, re-construction, overhaul and operation of road horns throughout their life cycle [3]. The use of the "Product life extension" business model of the circular economy, meaning "extension of the product life cycle," ensures the preservation or improvement of the used product through its repair, modernization, reconstruction and restoration, which is especially relevant in the conditions of continuous operation of roads [13].

As shown above, reverse logistics involves the management of goods and materials whose use of consumer properties has been completed or has become impossible. From that point of view, the objective of reverse logistics was to maximize the economic benefits of restoring inventory and/or minimize the expenses of disposing of it. Assessment of the feasibility of the return is made taking into account the costs of transportation, cargo processing, restoration of consumer properties, storage costs, etc. The basis of the economic assessment of the rationality of the formation of return material flows is inequality (1):

$$CB - C3 > 0 \qquad (1)$$

where CB – total revenue from the use of refurbished materials;
C3 – Total cost of making materials commercially usable.

A striking example of the widespread use of technologies based on the reuse of materials obtained from disassembly of contiguous structures or in the course of associated mining is pre-mining. During the construction and repair of roads, the technologies of cold and hot regeneration of coatings, methods of milling and vibration resonance of their destruction with the possibility of further use of road structures as underlying layers of road clothing, re-use of material resources during work, as well as the preparation of other materials, etc. have become widespread [14]. The economic advantages of using modern technologies were evident in view of the technological need to remove the upper layers of road clothing during repair, in order to prevent the transition of old defects to newly worn layers. The use in the production of asphalt concrete mixtures and the construction of structural layers of the road of various additives obtained from waste from other industries allows not only to reduce the cost of construction, but also in many cases to improve the durability and quality of roads. In road science, the concepts of "recycling" and "re-cycling" are widely used to identify the above-mentioned processes, reflecting the essence of similar technological processes for the use of old asphalt concrete coating, which have a number of distinctive features. However, these are private cases of the formation of closed supply chains. Taking into account the process nature of the described processes, it is promising to apply a logistic approach to expanding the involvement of secondary material resources in the repeated economic turnover in order to increase the efficiency of road facilities [3].

At this stage of improving the road economy, along with the development and implementation of progressive innovative technologies, due to the introduction of logistic principles into its work, it becomes impossible to clarify the applied logistic tools for managing production processes using WTO material resources. It is required to clarify the content of the return flow as an object of reverse logistics management in the transport sector, taking into account the performed value recovery operations used by the logistics channels of their movement [3].

The logistics approach to materials management in the construction and repair of roads provides for the integration of individual links of a structured material-conducting chain into a single system. It implies the need to solve a complex of problems in the field of technology, road construction equipment, economics and organization of production. The logistics production system involved the operation of return flows as an integral part of the mechanism of its operation. Reverse information and financial flows have been sufficiently investigated [15]. While the presence of return material flows is due to the peculiarities of the secondary material resources used. In any case, the return material flows are always opposite to the direct logistic flow and are obtained the beginning of the waste generation [3].

According to the Waste Classification of the Republic of Belarus (OCRB 021-2019), wastes include substances or objects formed in the course of carrying out economic activity, human life and do not have a certain purpose at the place of their formation or have lost, completely or partially, consumer properties. Substances recovered from waste, for which it was possible to reuse in the future or immediately, directly or after additional processing, a number of researchers referred to secondary material resources. At the same time, rework reused without additional treatment as raw materials in the production of the same products does not belong to them [16]. Thus, the same waste can be classified as a different category of rework streams depending on its purpose. Thus, asphalt concrete from the dismantling of asphalt surfaces refers, according to the above-mentioned classifier, to non-hazardous waste. When it is used again, the reverse current of secondary material resources is formed. In the case of the use of cold re-cycling technology, asphalt concrete passes into the category of rework when reused on the spot [3]. The characteristics of the formation of return material flows in the road economy are shown in Figure 1.

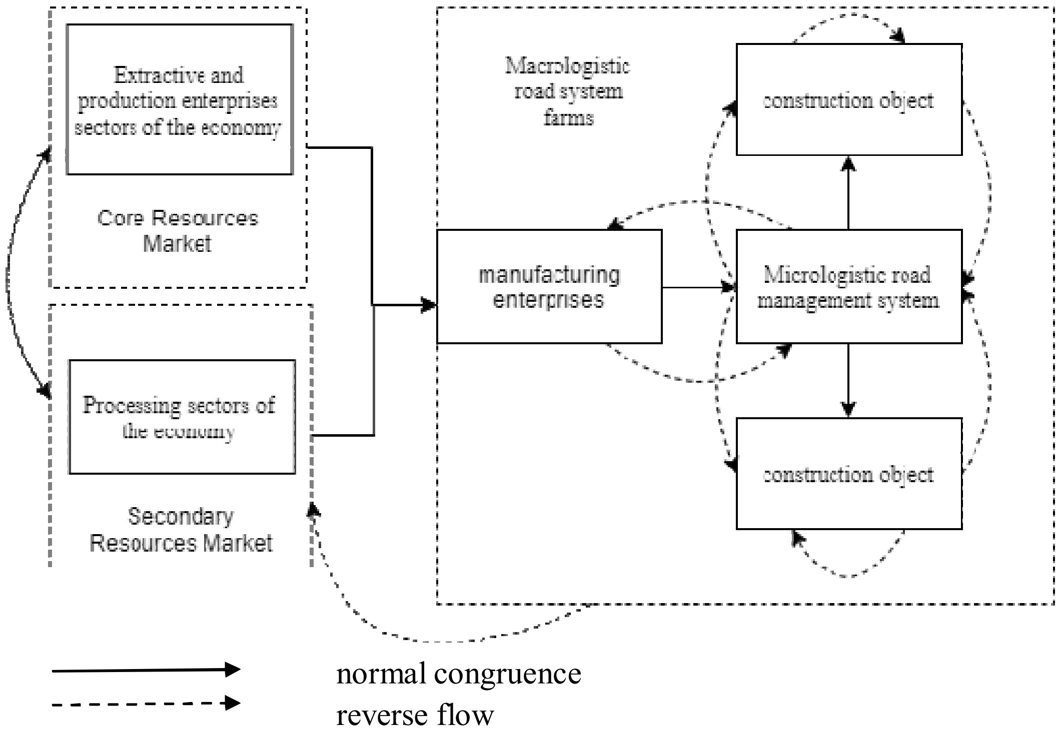

Fig. 1. Peculiarities of formation and movement of material flows in road economy

The use of this theoretical basis makes it possible to develop a system of practical recommendations for the formation of return material flows in the road economy on the basis of the use of co-temporary innovative technologies. Let us consider the most promising and available directions in this field.

The issue of recycling car tires has not been finally resolved even in the most advanced countries. Often they are simply stored. Belarus also has such "reserves," according to various estimates, amounting to about 65 thousand tons. The transition to a green economy was increasing the impact of research on their reuse. The protsess of tire processing consists in grinding into small components and sorting. The main product of processing from tires is a rubber-new crumb.

The demand for rubber crumbs increases annually. At the moment, the volume of sales has been increased by 10% compared to last year. The main market is the Russian Federation. 80% of manufactured products are exported. In addition, rubber crumbs are used in the production of roofing materials, pre-roofing, in the construction of bridges and even for the preservation of oil wells.

The most promising area of its use in road construction is the use of asphalt concrete mixture as one of the components. 2% of the rubber crumb in the composition of the asfalt concrete mixture not only significantly improves the quality of the pre-rope coating, but also increases its service life. It has been found that the use of rubber crumbs as a "thickener" of bitumen is economically more advantageous compared to polymers or whole-lulose fiber [17].

Galvanic sludge occurs at electrochemical production at application of metallized coatings (galvanic). At the financial stage of the process, soluble and insoluble sediments arise, which have different degrees of danger to the environment. Industrial enterprises were faced with the need to remove sludge from the process of production. It is undesirable to take such waste to landfills because the compounds react with a slightly acidic atmosphere. As a result, the likelihood of environmental pollution increases.

Galvanic sludges differ from ordinary ones in that they contain heavy metals in the form of cations. The ingress of these salts leads to severe diseases. The metals in the sludges are present as compounds, so for further use it is necessary to remove these elements in the form of simple substances. Recycling takes away a lot of energy and finance, so it is possible only for a large content of non-ferrous metals. But usually in galvanic sludges, non-ferrous metals are present in very small amounts. Under such conditions, it was relevant to use waste for construction and road materials as an additive.

Thus, an additive to concrete mixtures is developed, which is a galvanic sludge with a content of potassium bichromate of about 60%. The op-optimal amount of the additive is 0.5-1.5% of the cement consumption. Thanks to the plasticizing effect, it allows to reduce the quantity of the closure water by 10%, increase the density and strength of the be-tone by 20 and 30%, respectively. Also, one of the options for forming return streams of galvanic sludge is the use of them in the production of asphalt concrete mixtures. The maximum slurry addition is 20%. Tests of a road route with asphalt concrete pavement containing sludge carried out under rayon conditions showed that the concentration of heavy metal ions in the soil on roadside sections slightly exceeds their concentration in sections far from the road. In that connection, it was recommended that asphalt concrete mixtures prepared with sludge additives should be used in the construction of country route coatings.

The main problem of electroplating sludge was the storage of compounds. Initially, enterprises cleaned waste water from impurities of heavy metals, releasing dry residues. They were disposed of by the method of burial at landfills of household waste outside the city.

Environmental organizations began to pay attention to the fact that the frequency of acid rain in the burial areas of galvanic garbage is higher than in other areas. In the ground, sludge dissolves with precipitation, penetrates into the soil, groundwater. As a result, nature is contaminated with heavy metals, which negatively affects humans, flora and fauna.

Then it was decided to place galvanic sludge in pits, walls and the bottom prevent the spread of hazardous compounds into the environment.

The development of production had led to a decline in the number of potential burial sites. Today, recycling methods were coming to the fore to produce raw materials available for use in construction.

The technology of reusing asphalt granulate in asphalt concrete layers made it possible to achieve a closed cycle, in which the need for scarce and expensive new materials was minimized, which was very relevant in existing economic conditions. The introduction of asphalt granulate has a significant impact on the physical and mechanical properties and durability of the asphalt tone. Hot asphalt concrete prepared using asphalt granulate has high shear resistance compared to traditional dense asphalt concrete. [18]. The most effective method of using asphalt granulate is its use as part of asphalt concrete mixtures prepared in stationary asphalt mixing plants. Asphalt granulate can be used for preparation of dense mixtures of grades II and III, porous and highly porous mixtures according to STB 1033.

For the preparation of asphalt concrete mixtures, it is necessary to use active asphalt granulate with a maximum grain size of less than 20 mm. The aspholtogranulate may be conveyed to a hot elevator, hot stone silo, weighing silo, or directly to an asphalt mixer. The content of asphalt granulate in an amount of not more than 20% of the weight of the asphalt-ton mixture ensures the normal operation of the drying ba-raban. The required characteristics of the asphalt concrete mixture are ensured by the content of asphalt granulate in the mixture up to 20% by weight. When 20% of asphalt granulate is added to the mixture, the energy consumption for the asphalt concrete coating device is reduced by 10%. The economic effect of using asphalt granulate is about 11% of the cost of asphalt concrete mixture [19].

Conclusions and prospects for the further research. The system-structural approach proposed in the work to explain the essence and content of return material flows in the industry is based on the fact that the increase in the efficiency of investment road projects occurs in the process of transforming the traditional resources of the logistics system by involving both intra-industry and external return material flows. This approach increases the usefulness of resources.

A single coordinating centre was required to regulate the entire system, balance the interests of all its participants and be responsible for the implementation of the objectives of the logistics system. Its formation is possible, both on the basis of the current service of road customers, and as a separate structure that implements the entire set of organizational and management decisions. In that case, it becomes possible:

- agreement on the timing of road works, which will help to optimize the costs of road users;
- optimization of material and associated flows during the construction, reconstruction and overhaul of roads, which will ultimately lead to a decrease in the cost of construction and installation work, reducing costs under the items "materials" and "transportation costs";
- rational use of production capacity of construction organizations, which will contribute to increasing the utilization rates of road equipment, and increase the possibility of its renewal.

Then the logistics system of the road economy is formed by a set of regular links, united among themselves for optimal planning, organization and management of the logistics flow during the implementation of construction, reconstruction, repair and maintenance of roads based on logistics technology. These systems ensure the entry of the logistic flow into the internal environment of the unified management system and the integral in-formation field, the passage and exit from it in the form of a ready-made product (roads) that implements functions. The novelty of this definition lies in the interpretation of the concept of "logistics road management system" from the point of view of the process approach, aimed at studying the links of the system on the movement of logistics flow based on the integrated management of this process.

In view of the above, reverse logistics in road management is an independent component of the management of reverse waste flows, as well as the accompanying information and financial flows in time and space from the moment of their formation to the place of repeated production consumption in order to achieve the greatest economic effect while complying with environmental requirements. Back flows of secondary material resources are generated in the logistics system. At the "input" to the system, material streams consist of waste, the production process extracts secondary material resources from them, providing at the "output" a material stream of secondary raw materials, which can later be used in production.

Taking into account the identified features of reverse logistics in the industry and the structure of the reverse material flow, it was established that the efficiency of the logistics system depended on the degree of use of its logistical capabilities: capacity, time and expenses associated with the movement of flows.

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