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MODELING OF ECOLOGICALLY-ORIENTED CLOSED LOGISTICS CHAINS

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The article considers the issues of modeling ecologically-oriented logistics chains (supply chains) that meet the modern principles of the circular economy, which arose in response to the eco-destructive impact of the existing model of industrial economy on the environment. The concept of circular economy is characterized by taking into account the environmental aspects of logistics, which has led to the creation of closed logistics chains of reverse logistics, which originate and end in the natural environment and create reverse material flows.

Approaches to the creation of closed logistics chains are considered: organizational, flow and process. Each of the processes reflects one aspect of the essence of the logistics chain. Models of the ecological chain from the standpoint of each of the approaches are presented, which are based on the model of the circular economy proposed by the Ellen McArthur Foundation. The composition of the main participants of the closed logistics chain is determined from the standpoint of the organizational approach. A flow model is built, which takes into account direct and reverse, including rotary, material flows. The return flows are determined, and the logistic loops corresponding to them are constructed.

Introduction

The dynamic development of logistics as a science and the experience of practical implementation of the logistics approach have led to the assertion that logistics is strategically important in modern business. This is supported by the results of the use of logistics principles in the practice of management of Western companies: the cost of transportation and storage is reduced by 15-20%; the level of stocks decreases by 50%; the duration of the working cycle is reduced by 50–70% and the delivery of products to the consumer by 25–30%; 100% fulfillment of contractual obligations is ensured [1].

Logistics as a field of practice makes a negative contribution to the current state of the environment. The change of the worldview paradigm of mankind to

sustainable ecological-oriented development has led to the emergence of areas of logistics that meet the needs of today in creating a circular (closed) model of the economy.

The modern concept of logistics, which is actively developing and has recently been influenced by greening, is the management of supply chains (logistics chains) - Supply Chain Management [2; 3]. L.M. Zaretska, I.I. Mukhina, A.V. Smirnova, M.Yu. Grigorak, Yu.V. Varenko, J.-P. Rodrigue, B. Slack, C. Comtois, Su-Yol Lee, Robert D. Klassen reveal the application of an ecological approach to the management of logistics chains. Models of the logistics chain with reverse material flows are presented in the works of such authors as M.N. Grigoriev, O.P. Dolgov, S.O. Uvarov; S.S. Ali, D.A. Karkh, S.W. Potapova, C.A. Shakhnazaryan, A. Tambovtsev, T. Tambovtseva, K.O. Dzyubina, A.V. Dzyubina, V.A. Falovich and others.

Ideally, the formation of a circular economy model should lead to compliance with the principle of zero waste, which is possible through the introduction of mechanisms of reverse (reverse) logistics and the creation of environmentally-oriented closed logistics chains.

Presentation of the main material

1. Closed supply chains

In the general sense, the logistics chain - a system of business processes implemented in the system of relations of interacting partner companies, integrated in the direction of flow from the source of raw materials to the final consumer [4]. As an object of management, the logistics chain is a complex mesologistic system, which includes micrologistics systems of enterprises - participants in the chain, which are integrated with each other.

In accordance with the needs of greening logistics, it is necessary:

first, to extend the logistics chain from the initial supplier and the final consumer to the natural environment, where waste products that have no further

consumer value, even as secondary material or energy resources, must return with the least damage to the environment, and create a *complete logistics chain* [5];

secondly, take into account the return flows at each stage of the logistics chain from the extraction and processing of raw materials through the production and distribution of finished products to their final use or disposal, considering the *logistics chain as a feedback system* [6].

In this way, the logistics chain will change its linear structure and become an environmentally-oriented closed-loop supply chain, which is a complete supply chain with feedback. Management of such chains has different interpretations, but the ultimate goal is to reduce the eco-destructive impact on the environment (table 1).

Table 1

Interpretation of environmentally-oriented supply chain management

Ecological supply chain management
Green K., Morton B. and New S. [7] Innovative actions in the field of supply chain management and production supply, which can be considered in the context of environmental protection.
Green Supply Chain Management
Dan Bin, Liu Fei [8] Modern management concept, which comprehensively considers the impact of the supply chain on the environment and the efficiency of natural resources.
Godfrey R. [9] Practical actions to improve and control the ecological indicators of the supply chain.
Ali S.S. [6] A type of management that effectively takes into account all environmental aspects and resource utilization.
Srivastava Samir K. [10] Integrated thinking in the field of supply chain management, which takes into account the environmental impact factor and includes product design, search and selection of suppliers and materials for its manufacture, direct production process, distribution of finished products among customers, and product management after its end cycle.

End of the Table 1

Environmentally friendly supply chain management
Yan Zhang W. E. [11] Is a comprehensive method of environmental management, which would consider the entire life cycle of the product from the extraction of raw materials to the final consumer.
Closed-loop supply chain management
V. Daniel, R. Guide Jr. [12] Design, control and management of the logistics system in order to create the maximum added value of the product throughout its life cycle with the subsequent return of this value in different types and quantities over a period of time.
Supply chain management with feedback
Ali S.S. [6] An effective, efficient and economically optimal strategy aimed at supporting environmentally friendly methods of work in the industrial sector.

Eco-oriented management of logistics chains requires the use of modern approaches. Analysis of research by logistics specialists [3; 13-15] allowed us to identify the following approaches to modeling logistics chains: *organizational*, *flow*, *process*. The main difference between the approaches is the understanding of the essence of the chain and the elements that form it.

2. Organizational approach

The composition of the participants in the logistics chain may differ depending on the business area, product characteristics, logistics processes, functions and operations performed in the system, and so on. The following elements are offered as participants of the ecologically-oriented logistics chain:

– suppliers, manufacturing companies, warehouses, distribution centers, end users, collectors, repair companies, collapsible companies, recycling [16];

– suppliers, production, warehouse, distribution center, service center, consumer collection center, defective goods collection center, decomposition center, product recycling plant [17];

– enterprise-producer, enterprise-intermediary, consumer, enterprise-service center, enterprise-point of waste reception (returnable packaging), enterprise-processor of waste (returnable packaging) [18];

– production, wholesale intermediary, retail intermediary, consumers, enterprises for the collection of secondary raw materials, enterprises for the processing of secondary raw materials [19];

– suppliers, factories, warehouses of finished products, area of the "first buyer", collection centers, equipment points, utilization centers, zone of "second buyer" [6];

To create a closed-loop logistics chain with feedback, we use the participants and processes used in the circular economy model proposed by the Ellen McArthur Foundation [20]. According to this model, the main participants in the chain include: resource supplier, parts manufacturer, product manufacturer, service provider, consumer / user, collection center, repair center, disassembly center, recycling center.

Eco-oriented logistics chain consists of two chains: forward and reverse, depending on the direction of movement of the material flow. Participants in the direct chain may not be in the reverse, and vice versa. There are participants in both the direct and reverse chains. The conditional link that divides the complete chain into direct and reverse is the consumer/user of the product. The direct chain starts with the resource supplier and ends with the consumer/user of the product, the reverse chain begins with the consumer/user of the product and ends with the recycling center (fig. 1).

3. Flow approach

The flow approach determines the object of management in logistics material and related flows. The complete logistics chain considers the management of not only direct material flows, but also flows moving in the opposite direction to the direct material flow.

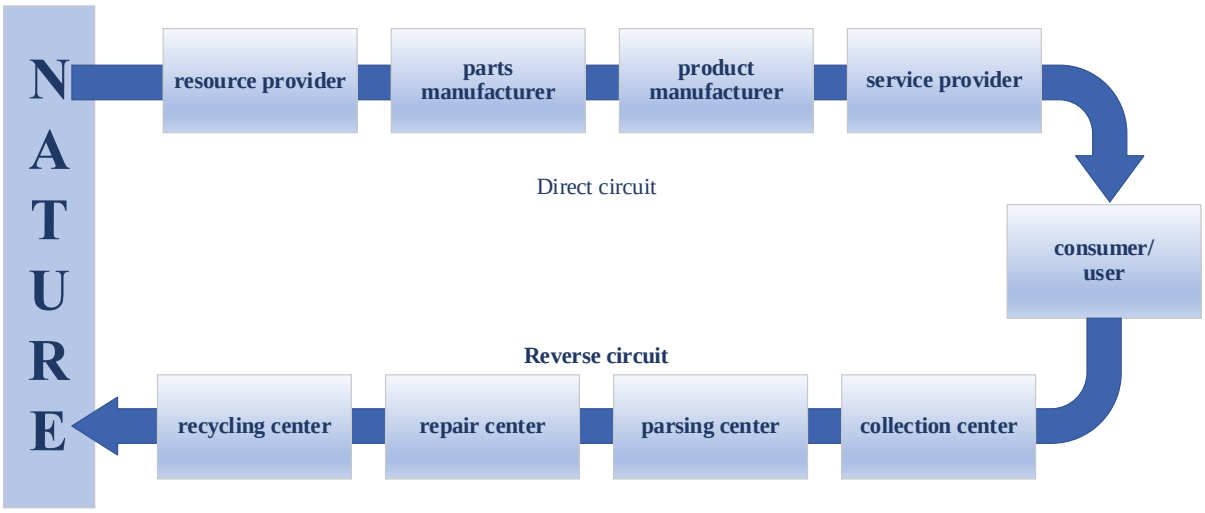


Fig. 1. Complete logistics chain

The need to take into account the movement of inventory in the opposite direction has led to the emergence of feedback and backward (reverse) material flows as an object of reverse logistics management [21; 22]. Reverse material flow is a set of inventory, attributed to a certain time interval and directed in the direction from the source of its consumption to the source of education in order to restore usefulness or withdrawal from circulation [18].

Reverse material flows may include raw materials, finished products, goods, packaging, reusable or damaged packaging, production and consumption waste, and so on. These may be products that have lost their marketable value, marketable form, which serve as material resources of processing organizations, i.e. secondary material resources.

There are also differences in the definition of the essence of return and return flows. Backward flows (from the word back) are directed in the direction opposite to the direct flow to the places of their processing for further involvement in economic circulation. Thus, for reverse flows, the direction of movement is opposite - the opposite of the direct.

Return material flows (from the word return) consist of returned goods, containers, packaging, etc. by one party to the other, to the address of the supplier, seller. Return flow is a commodity flow that is organized and sent by the recipient to

the address of the supplier at the agreed time, form of payment and quality of goods [23]. That is, in the process of spatial movement are goods of improper quality, defective, damaged, warranty, recalled by the manufacturer and so on. In the same form, or after recovery, they enter a new cycle of sales and realization.

Thus, there is a difference between return and reverse flows, which is expressed in the nature of their occurrence and purpose. As part of the reverse flows, in addition to the return flows, there are also material flows that are subject to recycling or disposal. It is proposed by analogy with [18] to call them recycling and recycling.

The flow model of the ecologistic system is shown in fig. 2.

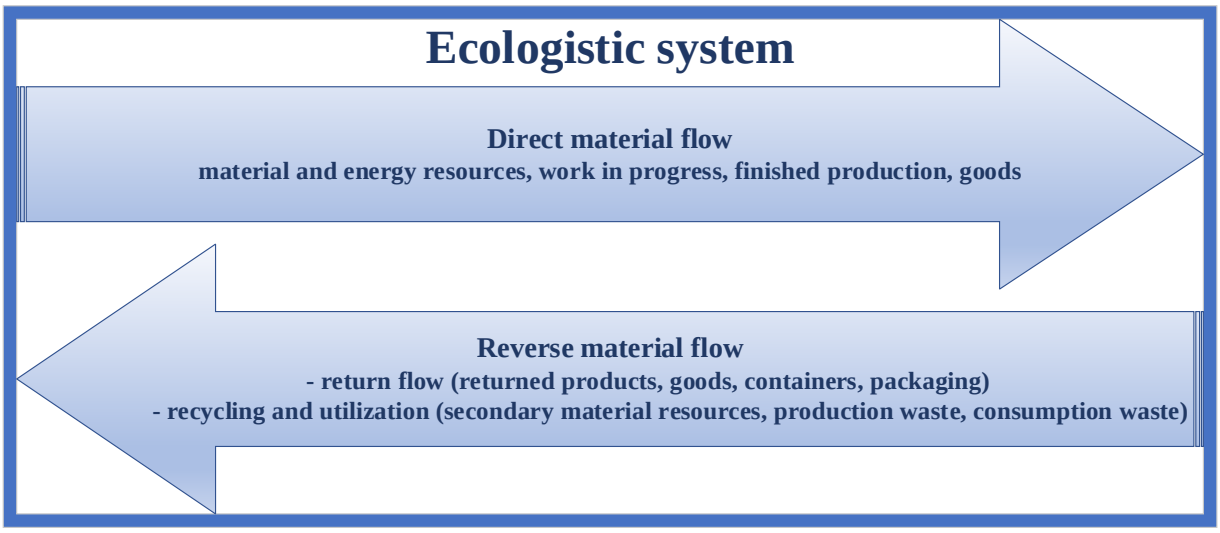


Fig. 2. Material flows of the ecologistic system

4. Process approach

The basis of the circular economy is formed by closed (complete with feedback) supply chains that provide an integrated environmental and economic effect throughout the life cycle of the product by restoring the value of products, materials and resources. The object of management in a closed logistics chain in the process approach are logistics business processes at the level of micro-, meso- and macro-logistics systems).

Logistic organization of business is based on the integration of individual production and commercial functions into a single system of material movement, strengthening coordination and cooperation of individual entities in the process of achieving a common goal - ensuring maximum economic efficiency, which is achieved through system-wide optimization of business processes [24].

The system of business processes of the logistics chain is a sequence of interconnected processes carried out by different companies - members of the chain [24]. A necessary condition for the successful operation of the logistics chain is the harmonization of the principles of process and flow approaches. It is proposed to form chains of processes according to the direction of flow. In this case, the logistics process is seen as an element of the value creation process. The boundaries of the process are determined by the possibility and feasibility of measuring the result of the process [4] and may be limited to the logistics system of an individual enterprise or extend to other participants in the logistics chain.

The introduction of the circular economy model, which requires the closure of the logistics chain by creating a feedback system, has led to the use of processes that are not typical of linear logistics chains. The development of the concept of circular economy has led to the formation of frameworks ("3R", "4R", "6R", "9R"), which include processes that close the logistics chain:

– *recover* (recovery, return) - the process of collecting products and components at the end of use, disassembly, sorting and cleaning for use in subsequent life cycles [25];

– *recycle* (recycling, recycling) - the process of returning waste, discharges and emissions into the processes of techno genesis [26], reuse of waste for the same purpose, as well as the return of waste after appropriate treatment in the production cycle [20];

– *refurbish* (renewal, repair) - restoration and renewal of an old but serviceable product [27];

– *remanufacture* (update, modification) - the process of restoring the product to bring it into working order by replacing or repairing major components or components [28];

– *repurpose* - reorientation, use of a failed product and its parts in a new product with a second purpose [29];

– *repair* (repair, correction) - repair and maintenance of a defective product for use in accordance with the original purpose [30];

– *reuse* implies that a product is reused for original or new purposes in its original form or with some changes and minor improvements [31];

– *reduce* (reduction, decrease) involves the reduction of the use of resources and energy at the stages of planning and production of the product, and the reduction of emissions and waste at the stage of its use [30];

– *rethink* (rethinking) - increasing the intensity of product use (e.g., sharing) [27].

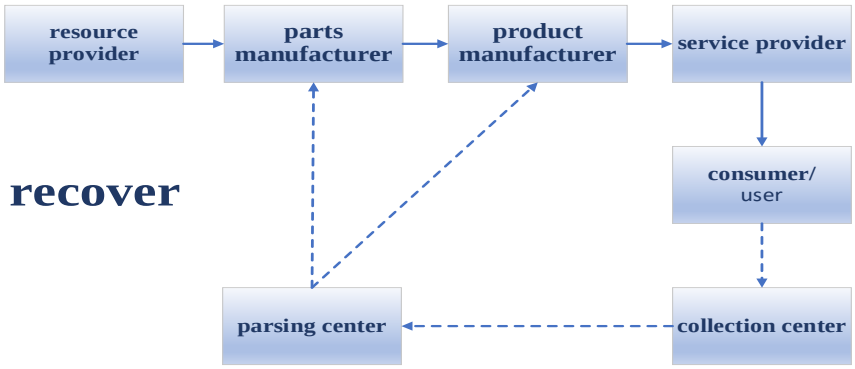
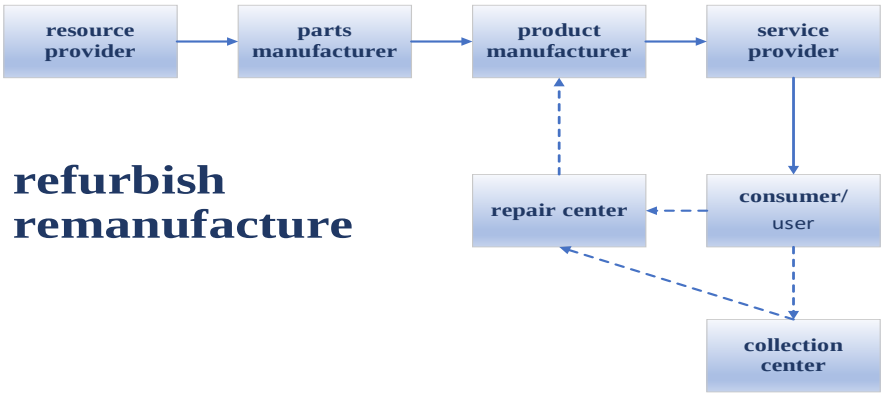
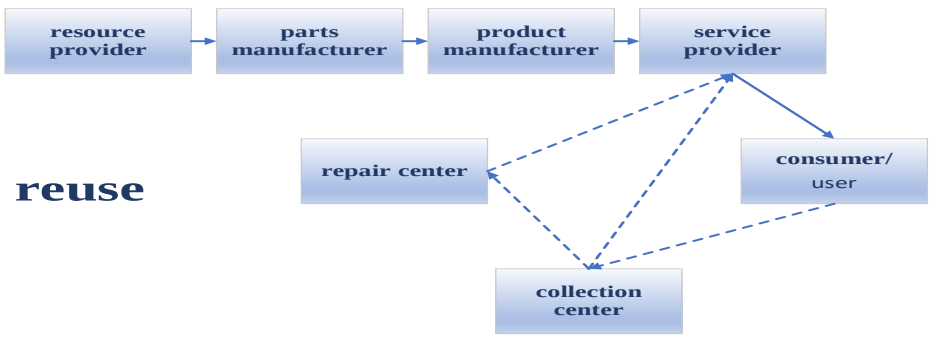
– *refuse* - reduction of excessive consumption of products due to the complete abandonment of their functionality by transferring their functionality to other products [27];

– *redesign* - the process of developing next-generation products that use components, materials and resources extracted from the previous life cycle or previous-generation products (redesign to use as many extracted components and parts as possible without losing functionality) [27].

Among the presented processes of the circular economy should be noted the processes related to reverse logistics and involved in the organization of reverse flows to create feedback in a closed logistics chain. Such processes include *recover, recycle, refurbish, remanufacture, repurpose, repair, reuse*. Due to these processes, which can be called circular, there are logistic loops between the participants in the logistics chain, providing feedback in closed logistics chains (table 2).

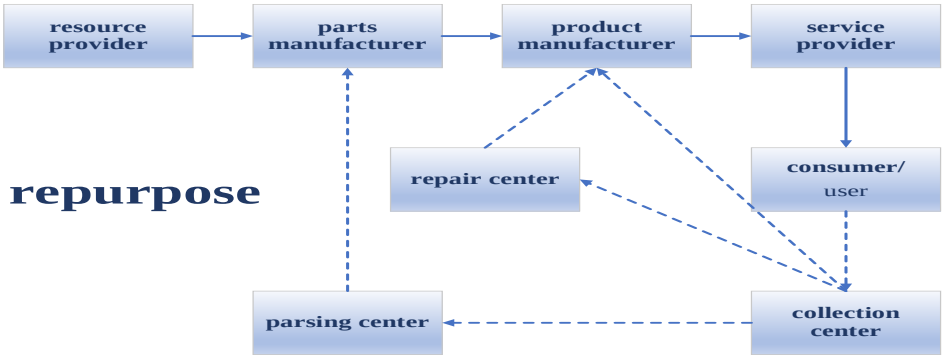
Table 2

Reverse processes of a closed logistics chain

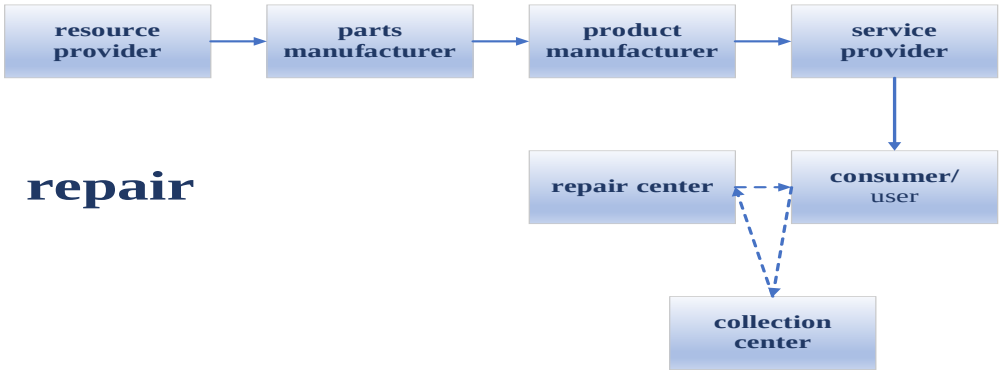
Logistic chain of the circular process
The *recover* process creates two loops in the logistics chain, because after disassembling the products, the products and their components can go to the parts manufacturers and product manufacturers. 
The processes of *refurbish* (update, repair) and remanufacture (update, modification) create two loops, as products from consumers can come both to the repair center through the collection center and directly. 
The *reuse* process creates two loops because it involves reusing the product for original or new purposes in its original form or with some changes and minor improvements. 

End of the Table 2

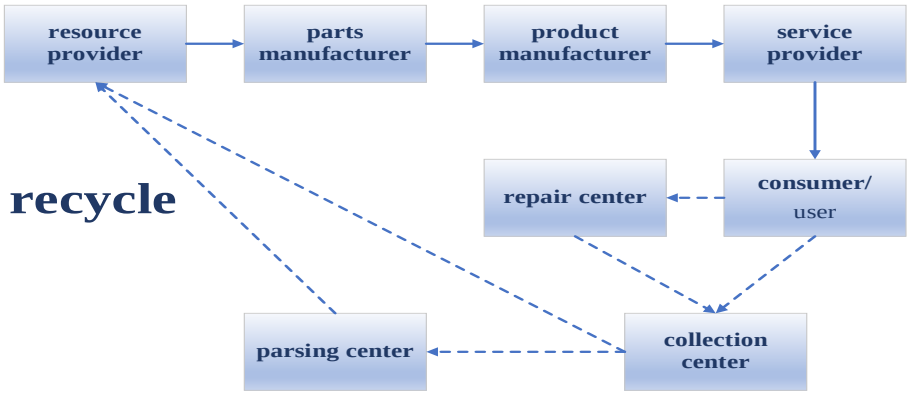
The *repurpose* process creates three logistic loops, as the path of the failed product to the manufacturer goes through the collection center or collection center and repair center, and parts of the product move through the disassembly center.



The *repair* process (repair, maintenance) creates a single logistical loop, as the repair and maintenance of a faulty product for use in accordance with the original purpose requires the participation of the repair center.



The largest number of logistics loops creates the process of *recycle* (recycling, remaking) - ten loops. The process of returning waste, discharges and emissions into the production cycle can be carried out by almost all elements of the environmental chain.



In addition to the reverse processes in the circular economy model, there are two processes: *energy recovery* and *landfill*, which are recyclable and aimed at the safe recycling of waste that cannot be used in another, more efficient way.

Conclusions

The ecological chain as an object of management is a complex system based on the integration of individual links - the micrologistic systems of the participating companies that form the chain. Integration into a single system of participants in the environmental chain is carried out by promoting material flows in both forward and reverse directions. Thus, the linear model of the logistics chain becomes irrelevant, it is replaced by a closed model, in which not only direct but also feedback between the participants of the chain is possible. The closed logistics chain is complete because it begins at the place of receipt of natural resources and ends at the place of their utilization and disposal.

The application of organizational, flow and process approaches to modeling allows to take into account the peculiarities of the essence of the chain and the elements that create it. The integration of these approaches leads to the creation of a logistics chain that takes into account aspects of the modern vision of the circular economic model and reduces the negative impact on the environment.

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