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ECOLOGICAL SYSTEM IN THE CIRCULAR ECONOMY MODEL
ЕКОЛОГІСТИЧНА СИСТЕМА В МОДЕЛІ ЦИРКУЛЯРНОЇ ЕКОНОМІКИ

Abstract. *The purpose of the article is to model the ecological system in the circular economy model. To realize the goal, the method of mathematical modeling was used when creating models of the ecological system. It is proposed to understand under the ecological system the logistics system as a set of elements-links interconnected in the process of managing the movement of direct and reverse logistics flows, which takes into account the eco-destructive impact on the environment. An ecological system, like any system, has the following properties: integrity, divisibility, organization, structuredness, integrability, emergentity, purposefulness. In addition, the ecological system has properties typical for the logistics system: complexity, openness, stochasticity, heterogeneity and multifunctionality, dynamism and adaptability. The ecological system also has specific characteristics: environmental friendliness, closedness. The ecological system is considered at the micro, meso and macro levels. At the micro level, the elements of the ecological system are the functional units of the organization's logistics, including the unit responsible for reverse logistics. At the meso- and macro-levels, the ecological system is represented by the enterprises - participants of the logistics chain. The analysis of logistics specialists research allowed us to identify the following approaches to modeling the ecological chain: organizational, flow, process. The main difference between the approaches is the understanding of the essence of the chain and the elements that make it up. A necessary condition for the successful functioning of the ecological chain is the coordination 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 considered as an element of the value creation process. Ecological system modeling based on the use of the reverse logistics model was improved, which covers not only the collection and transportation of materials and goods, but also value-added activities such as testing, sorting, recovery, recycling and redistribution and is a major factor*

contributing to the expansion of implementation approaches to the circular economy in various branches of the national economy.

Анотація. *Метою статті є моделювання екологістичної системи в моделі циркулярної економіки. Для реалізації мети використано метод математичного моделювання при створенні моделей екологістичної системи. Удосконалено моделювання екологістичної системи на основі використання моделі зворотної логістики, яка охоплює не тільки збір та транспортування матеріалів та товарів, але й діяльність із доданою вартістю, таку як випробування, сортування, відновлення, переробка та перерозподіл та є основним фактором, що сприяє розширенню реалізації підходів до циркулярної економіки в різних галузях національного господарства.*

Key words: *ecological system, circular economy, modeling, ecology, logistics chain, reverse logistics model, process, sustainable development.*

Ключові слова: *екологістична система, циркулярна економіка, моделювання, екологістика, логістичний ланцюг, модель зворотної логістики, процес, сталий розвиток.*

Statement of the problem. With the strengthening of competition, certain restrictions on the supply of resources due to the pandemic and quarantine measures, increasing the propensity of most enterprises of the developed countries of the world to the greening of production and social responsibility acquires a significant importance in the application of methods and approaches of environmentalism. Sustainable development as a progressive direction of resource reproduction determines certain conditions for the functioning of enterprises, orienting them to the use of waste in the repeated creation of products and the establishment of closed-loop productions.

Analysis of the latest research and publication. The work of scientists such as: Kovtun T., Smokova T., Sumets O., Babenkova T., Krykavskoho E., Ellen Macarthur, Smrkovska V., Dzyubina K.O., Shapovalova I.M. are devoted to the problem of greening logistics activities. etc. Despite the significant number of scientific works on ecologically-oriented management in logistics that have appeared recently, due to the novelty of the direction, quite a few issues are unresolved and need to be studied. The application of the principles of the system approach in the study of ecological systems is relevant.

Purpose of the article. The purpose of the article is to model the ecological system in the circular economy model.

Results. The basic concept in logistics is the logistics system, which corresponds to the generally accepted definition of the system, since it consists of system-forming elements (subsystems, links) that are closely interconnected and interdependent, separated from the environment, with

which they also have connections [1]. A common property of the logistics system is its representation as a system characterized by a high degree of integration of its elements and processes with the aim of managing end-to-end material and accompanying flows. The elements of the logistics system form a certain structure with predetermined properties and defined goals. In addition, the logistics system is an element of a higher-level system - an economic system in the hierarchy of systems.

Until now, there is no unambiguous interpretation of the meaning of the concept of logistics system. Despite the large number of definitions of the logistics system, which are refined with the development of logistics as a science, only some of them reflect the connection of its elements with the external environment [2; 3].Definition of a logistics system that takes into account the connection with the environment:

- an adapted (self-adjusting and self-organized) system with feedback, which performs logistics functions and logistics operations and usually consists of several systems and has developed connections with the external environment;

- the system is an ordered structure in which the planning and implementation of the movement and development of the aggregate resource potential, organized in the form of a logistic flow, starting with the alienation of resources from the environment and ending with the realization of final products, is carried out;

- a complex, dynamic, open for interaction with the external environment, orderly system of management of end-to-end economic flows, created for the purpose of optimizing the resources used in the flow;

- an adaptive system with feedback that performs one or another logistic function, consisting, as a rule, of several subsystems and having developed connections with the external environment;

- an adaptive system with feedback, which performs certain logistic functions and operations, mainly consists of several subsystems and has sufficiently developed connections with the external environment.

Of the given definitions, the most ecologically oriented is the definition that takes into account the fact of the alienation of resources from the environment, but does not indicate the need to return the used product and materials to nature with the least eco-destructive impact.

Taking into account the ecological aspect in logistics led to the emergence of a new concept of ecologically oriented logistics system or ecological system.Under the ecological system, we propose to understand the logistics system as a set of elements-links interconnected in the process of managing the movement of direct and reverse logistics flows,

which takes into account the eco-destructive impact on the environment.

An ecological system, like any system, has the following properties: integrity, divisibility, organization, structuredness, integrability, emergentity, purposefulness. In addition, the ecological system has properties typical for the logistics system: complexity, openness, stochasticity, heterogeneity and multifunctionality, dynamism and adaptability. The ecological system also has specific characteristics, namely: environmental friendliness, closedness. General system properties:

- integrity and divisibility. An ecological system is a complete set of elements (links, subsystems) that interact with each other to achieve a common goal and differ depending on the level: micro-, meso-, macro-logistic systems. At the micro level, the elements of the ecological system are the functional units of the organization's logistics, including the unit responsible for reverse logistics. At the meso- and macro-levels, the ecological system is represented by enterprises - participants in the logistics chain.

- organization and structure. The elements of the ecological system are organized and structured in a certain order, which allows the promotion of material (direct and reverse) and accompanying flows.

- integrability and emergency. The elements of the ecological system are characterized by a high degree of integration, which allows obtaining new qualities that are not inherent to individual elements of the system. For example, to organize a closed logistics chain (hereinafter - LC) with the participation of reverse material flows.

- purposefulness.Each component of the ecological system is oriented towards the achievement of the general goal - the promotion of material flows in compliance with the "rules of ecology".

Typical properties of the logistics system:

- complexity. An ecological system consists of a large number of participants, between whom complex connections are established, which allow the creation of closed logistics chains.

- openness. The boundaries of the ecological system are almost permeable to material, energy and information flows.

- stochasticity. The parameters of the ecological system are probabilistic in nature.

- heterogeneity and multifunctionality. The elements of the ecological system have heterogeneous properties and perform various logistical functions.

- dynamism and adaptability. Over time, ecological systems can change their qualitative and quantitative state, adapting to changes in the environment.

- availability of streams. The goal of creating an ecological system is to ensure the movement of material (direct and reverse) and accompanying flows.

Specific properties of the ecological system:

- environmental friendliness and closedness. The functioning of the ecological system is aimed at reducing the eco-destructive impact on the environment by reducing the consumption of primary natural resources and increasing secondary material resources that participate in the reverse processes of the circular economy.

The ecological system is characterized by certain classification characteristics, the identification of which allows a deeper understanding of the essence of this type of system (table 1). The ecological system at the micro level should be considered as a subsystem of enterprise management, which includes functional logistics subsystems: main - purchasing (supply), production, distribution (sales) and auxiliary - warehouse, transport and reverse.

Table 1

Classification affiliation of the ecological system

Classification sign	***Types of systems***	***Type of ecological system***
- according to the method of formation	*natural, artificial, mixed*	*mixed ecological and economic*
- by the objectivity of existence	*real, abstract*	*real (anthropogenic)*
- by structure	*simple, complex*	*difficult*
- in essence	*biological, technical, social, economic, ecological, etc.*	*ecological and economic*
- by the nature of the system's connections with the environment	*closed, open, combined*	*open*
- by the nature of functions	*specialized, multifunctional*	*multifunctional*
- by the nature of development	*stable, evolving*	*that are developing*
- according to the degree of organization	*well organized poorly organized*	*well organized*
- by the nature of the connections between the elements	*deterministic, stochastic*	*stochastic*
- according to the management structure	*centralized, decentralized*	*centralized*
- by size	*one-dimensional, multidimensional*	*multidimensional*
- by homogeneity and diversity of elements	*homogeneous, heterogeneous*	*heterogeneous*
- by the ability to determine the target	*casual, purposeful*	*purposeful*

From the standpoint of the system approach, it is worth considering the integral impact of the ecological system on the environment as the sum of the impact of each element or each functional subsystem of logistics. One of the ways of greening the micro-ecological system can be considered the implementation of greening measures in its separate functional areas.

Purchasing logistics (supply):

- environmental audit of suppliers;
- procurement of resources with the possibility of secondary use and processing;
- procurement of resources with assessment of environmental

characteristics of supplies (volumes and procurement system).

Production logistics:

- application of ecological equipment in the production process;
- minimization of resource-, energy-, and material-intensiveness of the technological process of product production;
- minimization of production waste;
- ensuring environmentally safe working conditions.

Sales (distribution) logistics:

- use of environmentally safe packaging;
- organization of a distribution network with minimal impact on the environment;
- organization of environmental service;
- application of eco-labeling.

Warehouse logistics:

- spatial organization and construction of warehouse infrastructure taking into account the ecological impact on the environment;
- use of resource- and energy-saving technologies in the operation of warehouses;
- ensuring environmentally safe conditions for the placement and preservation of stocks, finished products, and waste;
- selection of environmentally safe methods and means of loading and unloading operations.

Transport logistics:

- giving priority to ecological modes of transport, mode of communication, means of transport;
- optimization of transportation routes taking into account the minimum impact on the environment;
-use of ecological fuels and lubricants.

Reverse logistics:

- organization of return and reverse material flow channels;
- organization of the process of returning packaging material and products for reuse;
- organization of secondary use of production waste; organization of the waste disposal system.

At the meso- and macro-level, the ecological system consists of subsystems - members of the LC, participating in the promotion of direct and reverse material flows, as well as accompanying flows [4; 5].

An ecological system, like any other system, exists in the external environment, which includes objects external to it that affect the state of the system (directly or indirectly), since this system cannot be indifferent to the external environment. If the conditions of the external environment are favorable, the system functions successfully, if not, it can slow down its development, almost to the point of ceasing to exist.

If we are talking about a micro-ecological system, then the external environment of direct influence can be divided into two contact levels:

- the first level - includes other subsystems of the parent enterprise, the elements of which come into direct contact with the elements of the ecological system: production,

financial, marketing, organizational, ecological subsystems of the enterprise;
- the second level includes direct contacts that have an impact on the functioning of the ecological system: suppliers, customers, competitors, regulatory bodies, public bodies, etc. For the meso- and macro-ecological system, the external environment of direct influence includes:
- the first level - participants of the economic system, which includes the ecological system, who do not participate in the formation of LC, but enter into connections (contractual relations) with the elements of the system: financial institutions, insurance companies, brokerage companies, etc.;
- the second level - participants of other logistics systems operating in the same market: suppliers, manufacturers, transport companies, warehouse complexes, logistics operators, etc.

The external environment of indirect influence for the micro-, meso- and macro-ecological system includes the following factors of influence: political, economic, social, ecological, technological, demographic, scientific and technical, etc.

An ecological system, like any open system, receives matter, energy and information from the external environment to ensure its vital activity, as well as development and improvement.

Environmentally-oriented management of the logistics system requires the use of modern approaches. The analysis of research by logistics specialists allowed us to identify the following approaches to modeling the ecological chain: organizational, flow, process. The main difference between the approaches is the understanding of the essence of the chain and the elements that make it up.

The composition of participants in the logistics chain may differ depending on the field of business, product characteristics, logistics processes, functions and operations carried out in the system, etc. To create a model of a closed logistics system (a logistic system with feedback), which includes closed, complete LCs, we will use the participants and processes used in the circular economy model proposed by the Ellen MacArthur Foundation [6]. According to this model, the main participants of closed LCs include: resource provider (RP), detail manufacturer (DM), product manufacturer (PM), service provider (SP), consumer/user (consumer/user, CU), collection center (CC), repair center (RC), sorting center (SC), utilization center (UC) [7; 8].

The ecological chain consists of two chains: forward and reverse, depending on the direction of movement of the material flow. The conditional link that divides the complete chain into direct and reverse is the consumer/user of products.

The flow approach defines the object of management in logistics as material and accompanying flows. In a complete, closed ecological chain, the management of not only direct material flows, but also flows moving in the

opposite direction to the direct material flow is considered.

The need to take into account the movement of goods and material values in the reverse direction led to the emergence of feedback and reverse (reverse) material flows as an object of reverse logistics management. The return material flow is a set of commodity and material values, attributed to a certain time interval and directed in the direction from the source of its consumption to the source of formation with the purpose of restoring usefulness or removing it from circulation [9].

There are also differences in the definition of the essence of return and return flows. Return flows (from the word reverse) are directed in the direction opposite to the direct flow to the places of their processing for further involvement in economic circulation. Therefore, for reverse flows, the direction of movement is decisive - opposite to the direct one. Return flow is a flow of goods that is organized and sent by the recipient to the address of the supplier according to the terms agreed with him, the form of payments and the quality of the goods. Return material flows (from the word to return) consist of returned goods, containers, packaging, etc. from one side to another, to the address of the supplier, seller. As part of return flows, in addition to return flows, there are also material flows subject to recycling or disposal, so-called recycling-utilization flows [9; 10].

The basis of the circular economy is formed by complete, closed logistics chains that provide an integrated ecological and economic effect during the entire life cycle of the product thanks to the recovery of the value of products, materials, and resources. The object of management in a closed logistics chain with a process approach is logistics business processes at the level of micro-, meso- and macro-ecological systems.

The logistics organization of the business is based on the integration of individual production and commercial functions into a single system of material movement, strengthening the coordination and cooperation of individual economic entities in the process of achieving a common goal - ensuring the maximum economic efficiency of economic activity, which is achieved due to the system-wide optimization of business processes [11].

A necessary condition for the successful functioning of the ecological chain is the coordination 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 considered as an element of the value creation process. The implementation of the concept of a circular economy, which is based on the creation of closed ecological systems, which requires the closure of logistics systems by creating systems with feedback, has led to the application of processes that are not

characteristic of linear LCs. Among the processes of the circular economy, it is worth highlighting the processes related to reverse logistics and participating in the organization of reversible flows to create feedback in a closed ecological chain: recover, recycle, refurbish, remanufacture, repurpose, repair, reuse [12]. Thanks to these processes, which can be called circular, logistic loops arise between the participants of ecological chains, which provide feedback in closed ecological chains [13].

The largest number of logistics loops is created by the recycle process - ten loops. The process of returning waste, discharges and emissions to the production cycle can be carried out by almost all elements of the ecological chain.

The repair process (repair, maintenance) creates one logistics loop, since the repair and maintenance of a defective product for use according to its original purpose requires the participation of a repair center.

The process of repurpose (reorientation) creates three logistics loops, as the path of the failed product to the product manufacturer is through the collection center or the collection center and the repair center, and the parts of the product move through the disassembly center.

The recover process creates two loops in the logistics chain, because after the products are disassembled, the products and their components can go to parts manufacturers and product manufacturers.

Refurbish and remanufacture processes create two loops, as products from consumers can go to the repair center through the collection center or directly.

The process of reuse (repeated use) creates two loops, because it involves the reuse of a product for original or new purposes in its original form or with some changes and minor improvements.

In addition to the reverse processes in the model of the circular economy, there is a utilization process, which is aimed at the safe processing of waste that cannot be used in another, more efficient way.

Conclusions. Improved ecological system modeling based on the use of the reverse logistics model, which covers not only the collection and transportation of materials and goods, but also value-added activities such as testing, sorting, recovery, recycling and redistribution and is a major factor contributing to the expansion of implementation approaches to the circular economy in various branches of the national economy.

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