Simulation of optimal control of return flow of products from composite materials

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Abstract. This article discusses one of the possible approaches to modeling the process of controlling the return flows of composite materials products, taking into account the principle of low-waste production. During the simulation process, a model was developed that takes into account possible cost groups arising from the reverse logistics process. The developed model takes into account the requirements to minimize the cost of processes in the product recycling unit, as well as is aimed at determining the optimal volume of products from composite materials that are included in the return flow after the expiration of the assigned service life.

1. Introduction
In recent years, there has been a high rate of development of the composite materials industry. Modern composites are used in the implementation of engineering works, as well as the creation of many structural parts. The attractiveness of composites is related to their properties, which differ from those of traditional materials. Among them are: resistance to external influences, electrical insulation properties, high mechanical properties, etc. [8,9].

Speaking about the production of products from composite materials, it is necessary to note their characteristic features, such as high technical armament of labor, the need to use advanced technologies, the high share of technical training of production and special requirements for the qualification of engineering and scientific personnel. All this indicates the high capital intensity of the production process of products from composite materials [6,7].

In turn, the increase in the production and consumption of polymer composite materials leads to an increase in the amount of waste generated, which can appear during the production process, as well as after the end of the service life of the products. Related to this is the relevance of the topic of processing and recycling of polymer composite materials. As a strategic solution aimed at minimizing the amount of waste produced and ensuring the reuse of recycled polymer composite materials, a gradual transition to closed-loop industries involving the development of waste-free and low-waste technologies, as well as the development of recycling programs for products from composite materials, can be distinguished. This topic is also relevant from the point of view of resource savings: waste storage does not provide economic benefits from materials characterized by relatively high cost and energy consumption of production of initial components [2,3,5].

2. Research Method
To solve such problems, it is proposed to use the model of optimal control of return flows of products from composite materials [1,4].

When developing a mathematical model for processing return flows of products from composite materials, we will introduce the following assumptions:

- The cost of collecting and generating a return stream is known;
- The cost of transporting products from the consumer to the enterprise where the products from composite materials are recycled is known;
- Processing and storage capacity defined;
- Estimated proportion of components and parts that can be recycled and reused in production;
• The cost of carrying out all the processes of the recycling unit of products from composite materials is known: defects, processing, as well as the recycling process;
• Determined cost of processed products aimed at production for reuse.

The main task:
Optimize the management of return flows of polymer composite products based on the minimization of dedicated cost groups.

3. Results
For further modeling to determine the optimal volume of composite products included in the return flow, enter a number of symbols for the main processes.

| Name     | Characteristic                                                                 |
|----------|-------------------------------------------------------------------------------|
| \( X_i^t \) | The volume of the return flow of the \( i \)-th type of product at time \( t \) |
| \( c_i \)  | The cost of storage of the \( i \)-type of products upon arrival at the recycling facility and pending defects per unit of time |
| \( d_i \)  | Cost of \( i \)-type product defect identification process                      |
| \( p_i \)  | Cost of recycling of \( i \)-type of articles                                  |
| \( l_i \)  | Proportion of products and parts that can be turned into secondary resources   |
| \( u_i \)  | Cost of the \( i \)-type product disposaling process                           |

For further development of the mathematical model, you must also specify the following system parameters:

\( w_i \) - the cost of processed and melted products aimed at production for repeated use.

Thus, the cost minimization objective function will be as follows:

\[
\sum_{i=1}^{M} \sum_{t=0}^{T} c_i X_i^t + \sum_{i=0}^{T} \sum_{t=0}^{M} d_i X_i^t + \sum_{i=0}^{T} \sum_{t=0}^{M} p_i l_i X_i^t + \sum_{i=0}^{T} \sum_{t=0}^{M} u_i X_i(1 - l_i) - \sum_{i=0}^{T} \sum_{t=0}^{M} w_i l_j X_i \rightarrow \min, \quad (1)
\]

Where,

| Formula | Explanation                                                                 |
|---------|-----------------------------------------------------------------------------|
| \( \sum_{i=1}^{M} \sum_{t=0}^{T} c_i X_i^t \) | Storage costs due to the receipt of products included in the return flow to the plant warehouse |
| \( \sum_{i=0}^{T} \sum_{t=0}^{M} d_i X_i^t \) | Costs associated with performing the defects identification process |
\[
\sum_{i=0}^{M} \sum_{t=0}^{T} p_i X_i^t
\]

Costs associated with reprocessing items

\[
\sum_{i=0}^{M} \sum_{t=0}^{T} u_i X_i^t (1 - l_i)
\]

Costs associated with the disposal of the proportion of products included in the return flow that are not recyclable

\[
\sum_{i=0}^{M} \sum_{t=0}^{T} w_i l_i X_i^t
\]

The benefits in monetary value, obtained as a result of engaging in the re-circulation of recycled and remelted products

As assumptions imposed on this model, you can distinguish the following:

\[
\sum_{i=0}^{M} \sum_{t=0}^{T} X_i^t \leq V_1, \quad (2)
\]

\[
\forall i \in M, \quad \forall t \in T, \quad (3)
\]

Where \( V_1 \) is the maximum capacity of the material storage system coming to the recycling unit of products from composite materials.

4. Conclusion

Thus, the developed model is an affordable and effective tool that can be used by enterprises that aim or have already introduced into their activities the process of organizing and processing return flows of products from composite materials.

This model will allow you to determine the optimal volume of composite products that are included in the return flow after the expiration of the assigned service life, subject to the requirement of minimum costs for the defect identification, recycling, storage and disposal processes.

References

[1] Brom A E 2007 Supply chain management and global logistics University news. Engineering No. 4 pp 68-76
[2] GOST R 57702-2017 "Resource saving. Waste management. Requirements for low-waste technologies"
[3] Zueva O N, Shakhnazaryan S A 2014 Logistics of return flows of secondary resources Bulletin of the Baltic Federal University named after Kant No. 9 pp 140-147
[4] Zueva O N 2009 Reverse logistics in inventory management Izvestia of the Irkutsk State Economic Academy No. 1 (63) pp 107-111
[5] Rogers D S, Tibben-Lembke R S 1998 Going Backwards: Reverse Logistics Trends and Practices Reno: University of Nevada, Centre for Logistics Management 17 p
[6] Sidelnikov I, Brom A, Omelchenko I 2020 The influence of the use of composite materials on the rationing of material resources in mechanical engineering IOP Conference Series: Materials Science and Engineering 934(1) N 012008
[7] Brom A, Stoyanova M, Sidelnikov I 2019 Selection of the best available technology based on the Analytic Hierarchy Process IOP Conference Series: Materials Science and Engineering 934 N 012007

[8] Pozdnyakova E D, Maslennikova E V, Komshin A S, Orlova S R 2019 Measuring control of construction materials parameters in order to increase reliability of engineering objects IOP Conference Series: Materials Science and Engineering 489(1) N 012008

[9] Maung P P, Malysheva G V and Gusev S A 2016 A study of the effect of network angle of fabrics on kinetics of impregnation upon molding of articles made from carbon plastics Polymer Science Series D 9(4) pp 407-410