http://www.moderntechno.de/index.php/meit/article/view/meit35-00-012
DOI: 10.30890/2567-5273.2024-35-00-012

UDC. 62-50

OPTIMIZATION OF THE ALGORITHM OF THE ROUTING PROCESS OF THE ELEVATOR COMPLEX FOR THE TRANSPORTATION OF GRAIN

ОПТИМІЗАЦІЯ АЛГОРИТМУ ПРОЦЕСУ МАРШРУТИЗАЦІЇ ЕЛЕВАТОРНОГО КОМПЛЕКСУ ДЛЯ ТРАНСПОРТУВАННЯ ЗЕРНА

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Annotation. *The article examines the issue of increasing the efficiency of elevators in the conditions of growing demand for agricultural products. Since high-quality storage and logistics of grain crops are important, the authors analyze changes in the management and technological equipment of elevator complexes. Particular attention is paid to the process of routing grain flows, the optimization of which can significantly reduce costs, increase processing speed and reduce downtime risks. The existing automated systems were studied, in particular the "Route" program, which helps to build optimal routes for transporting grain. It is proposed to use the traveling salesman method to determine the shortest paths, as well as to improve algorithms to minimize power consumption and mechanical damage to grain during transportation. The authors emphasize the importance of developing multi-criteria optimization, which allows simultaneous consideration of several aspects, such as grain quality, speed and route length. The article emphasizes the need to improve the existing methods of managing electromechanical complexes of elevators, which will contribute to increasing energy saving and product quality.*

Key words: *elevator, grain, logistics, routing, automation, energy saving, optimization, traveling salesman, mechanical damage, multi-criteria optimization.*

Introduction.

In conditions of constant growth in the demand for products of the agricultural sector, the efficiency of the operation of elevators becomes a key factor for increasing the productivity of the entire supply chain. With the increase in the development of the modern grain market, the task of ensuring high-quality storage and organization of grain logistics of grain crops, which in turn requires the development of the elevator industry [1], is becoming more and more relevant and important. In recent decades, elevator complexes have undergone significant changes, both in the management system and in the technological equipment, which significantly improved quality indicators. However, with the improvement of technologies, despite all the advantages, there are still factors that affect quality and productivity indicators. One of the important aspects of elevator complex management is the process of grain flow routing. Optimizing this process allows you to minimize costs, increase processing speed and reduce downtime risks. The use of well-defined criteria for routing is an important tool for achieving these goals [2]. Therefore, it is necessary to consider approaches to the optimization of the routing process of elevator complexes, in particular, the use of various criteria to increase the efficiency of their operation.

Analysis of previous studies.

Analyzing Internet resources, it can be noted that few companies are engaged in the implementation of automated control systems aimed at optimizing the routing process in elevator complexes. One of the examples is "INNOVINNPROM" LLC [3], which developed a unique system of automated design "Route". This software product, created on the basis of a personal computer, allows you to build optimal routes for transportation on elevators and granaries. The system chooses the best route from hundreds of possible options (according to the programmed criteria), taking into account the amount of equipment and the consumed electricity, which contributes to a more rational and efficient transportation of grain. The "Route" system automatically generates and runs the necessary routes based on the operator's command and selected movement coordinates, taking into account the state of the equipment involved in the process, which avoids mixing flows of different grain crops. That is, the system lays out a route from possible options depending on the coordinates of points A (start) and B (end) of the route. The system also provides the operator with information on the progress of transportation and controls the accuracy of the laid route according to the coordinates, controlling the equipment automatically (turning on, turning off, blocking), Figure. 1 [3].

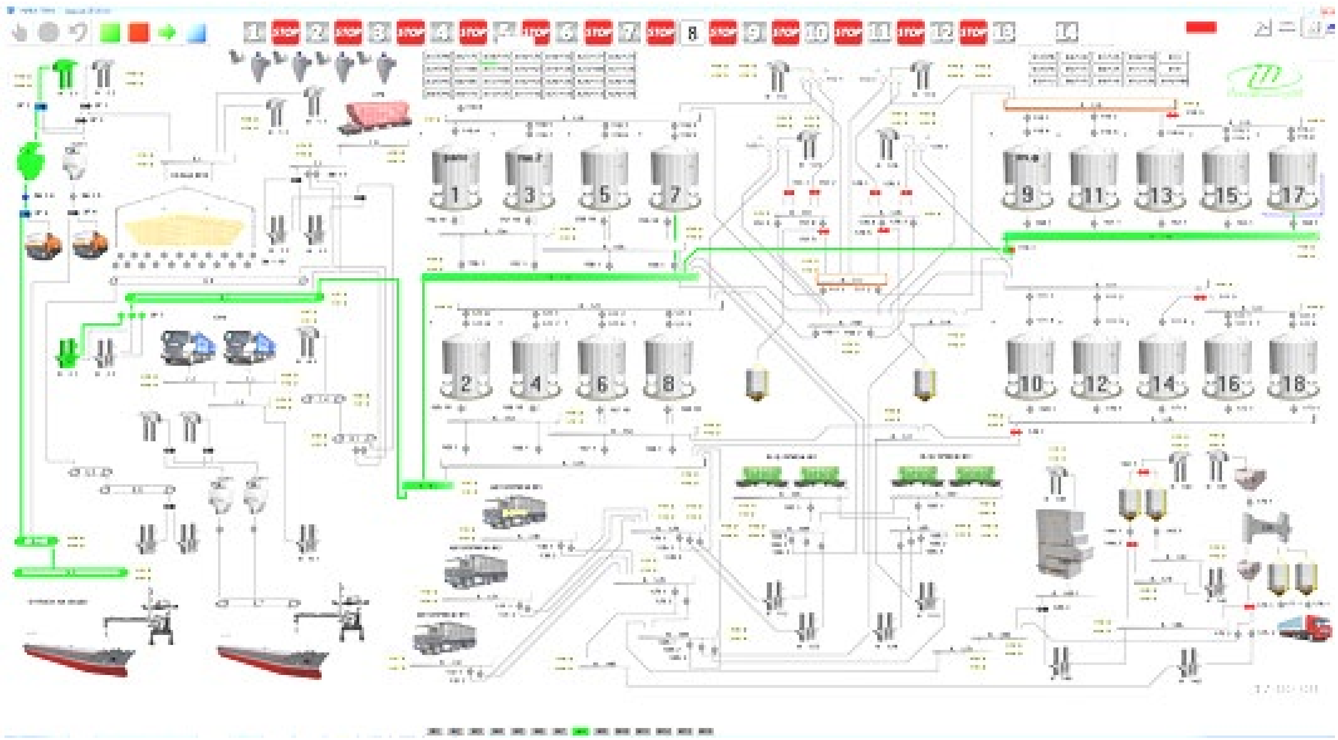

Figure 1 - Part of the technological route of grain transportation

A source: [3]

The process starts according to the principle of standard SCADA systems, where the operator sets the initial and final equipment of the route, and the system automatically configures all the necessary equipment for uninterrupted transportation of grain flows. An additional advantage of the system is the possibility of its adaptation for the elevator personnel through the "Editor" function, which allows you to change the elevator scheme and equipment parameters without the need for deep programming knowledge. This facilitates the process of making changes to the technological scheme of the complex and ensures more efficient operation of the system.

The considered system for providing technological routes is much more productive than all other existing route laying systems, however, as in other systems, this SCADA system uses a route database, that is, the "Route" system, like other SCADA systems, is based on pre-prepared routes, which requires their preliminary analysis, debugging and programming. Based on this, the task of automatically building transportation routes remains relevant.

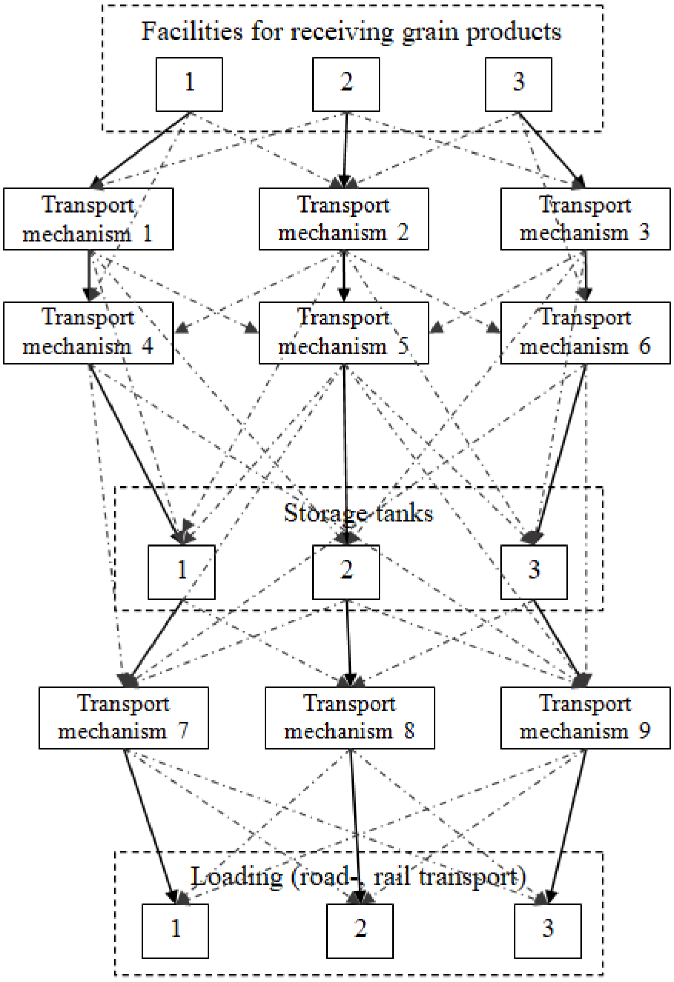

Figure 2 - Presentation of the technological scheme of grain transportation according to the task of the traveling salesman

To improve the automatic method of construction of the transportation route, it is necessary to take into account not only the optimization criteria, but also the correctness of its construction from the point of view of logistics. Since the main goal of transport logistics is to solve the problems of laying transportation routes that would ensure the minimum distance of transportation, the minimum time of involving equipment for the transportation process and minimizing the costs of moving products. One of the most effective methods for solving this problem is the traveling salesman method, which is widely used to optimize transport routes. The essence of the method is to find the shortest path between several points without crossing transport lines and forming loops, taking into account criteria such as transportation time, costs and distance [4]. Thus, the main task of routing is to reduce the time of product delivery from the initial point to the final point, which raises the issue of adapting the traveling salesman method (Figure. 2) for use in the transport processes of the elevator complex.

Considering this task, the question arises not of choosing the optimal route according to criteria from existing routes, but of constructing a route that is laid with the specified criteria of optimality immediately before transportation. Therefore, there is a task to optimize the modes and structural parameters of the control of the electromechanical complex of the elevator, due to the improvement of existing and development of new methods, software and technical means of operational intervention in the modes of operation of the electromechanical equipment of the elevator to increase energy saving and product quality.

The purpose of the study.

Development of an algorithm for optimized grain transportation routes in elevator complexes, taking into account the minimization of energy consumption and the reduction of mechanical damage to grain during transportation.

Laying out the main material.

Analyzing the functional structure of transport route management [5,6], it is possible to determine a general approach to solving the task of optimizing transport routes. Particular attention should be paid to the structural component of the SCADA system, in particular to the programmable logic controller (PLC), which controls the equipment of the power board through a digital interface and the routing algorithm. The PLC is a key element of the automation of the elevator system, as it performs the main algorithms for controlling and protecting the equipment. Control algorithms are implemented using a system of logical equations that form control signals for executive mechanisms [7].

$$\begin{cases} Y1 = X7 \,\&\, X6 \,\&\, X5 \,\&\, X3 \,\&\, \left(X1 \,\&\, X2 \,\&\, X4 + \overline{X1} + X1 \,\&\, \overline{X2}\right) \\ Y2 = X7 \,\&\, X6 \,\&\, X5 \,\&\, \overline{X3} \,\&\, \left(X1 \,\&\, X2 \,\&\, X4 + \overline{X1} + X1 \,\&\, \overline{X2}\right) \end{cases}, \quad (1)$$

where $X1$, $X2$ - control of the current state of the object, $X3$ - the direction of forward movement is set, $X4$ - the speed of movement is satisfactory, $X5$ - movement corresponds to the given direction, $X6$ - mechanism overload, $X7$ - readiness of the next device to receive, $X8$ - power supply, $Y1$ - forward movement, $Y2$ - backward movement;

On the basis of the specified equations, it can be said that the signal formed from the control algorithm and logic equations is the main element during the control process. Therefore, the construction of the route directly depends on the correctly formed onessystems of logical equations, which in turn will describe the algorithm for laying and functioning of the route.

However, the considered algorithms for building the transportation route are not optimal for the technological process. The analysis of the routing of technological processes of the elevator made it possible to identify one of the optimization criteria, which contributes to the energy efficiency of the grain processing and grain storage complexes. This criterion is the minimization of electricity consumption during transportation (route electricity consumption). The energy intensity of transport and technological operations of the equipment is determined by the total amount of energy required to perform interconnected transport and technological operations. Therefore, the optimization criterion, namely the minimization of the electricity consumption of the route, can be defined as the sum of the capacities of the electric drives of technological installations and the drives of valves and valves performing technological operations, taking into account their participation in the transportation process.

$$C_{e.\min} = P_{e.dv}k_n + P_{e.cl.}k_n + P_{eg.}k_n + \ldots + P_i k_n, \quad (2)$$

where $P_{e.dv.}$- sum of capacities of electric drives of technological installations; $P_{e.cl.}$ - the sum of the capacities of the electric drives of the valves of technological installations; $P_{eg.}$ - the sum of the capacities of the electric actuators of the shutters of technological installations; k - is a coefficient that characterizes the element's involvement in the routing process (k = 0 - the element is used for transportation, k = 1 - the element is not used for transportation).

The application of this criterion during the development of the main or alternative transportation route can significantly increase the energy efficiency of the technological process in the elevator complex. This creates a need to improve the routing process of technological transportation operations. To determine the optimal route according to the specified criterion, you can use the method of dynamic programming. At the same time, the stages of conditional optimization of optimization for different combinations of loading and unloading points can be carried out a priori. And the stage of unconditional optimization of the grain transportation route, taking into account the current changes in the state of the equipment - according to the algorithm shown in Figure. 3.

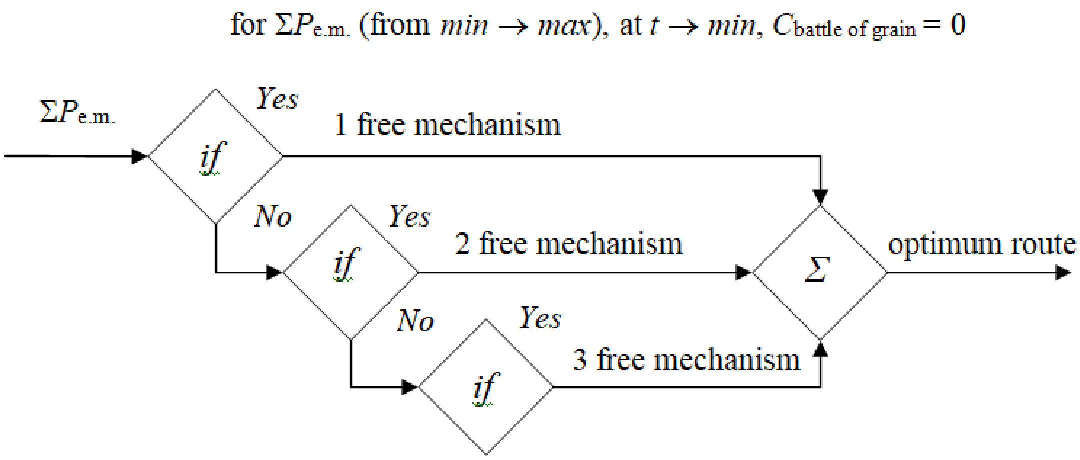

Figure 3 - Algorithm for selecting a route according to the min energy consumption criterion

According to this algorithm, the laying of the transportation route will take place from the minimum to the maximum value, depending on the sum of the capacities of the electric drives of all technological installations. In other words, to transport grain from point A to point B, the system will choose a route based on the results of conditional optimization and checking the availability of routes. If the route is free, it will be selected based on the sum of the capacities of its elements.

Based on this algorithm, the system will be able to lay a route not from existing options, but directly form it, using data from conditional optimization and technical characteristics of electrical equipment involved in the transportation process. Such data include the purpose of transport elements, their necessity in the process of movement and their capacity.

The application of this criterion adds another transportation condition - time minimization, i.e., when electricity consumption is reduced, the optimal length of the route and the number of technological installations involved are ensured, which positively affects the transportation speed, however, losses of grain products are not taken into account.

Another important criterion that allows to reduce grain losses is the minimization of its damage during transportation.

Damage to crops during elevator transportation and storage in containers are factors to be considered. All grain crops experience varying degrees of mechanical damage, starting from the field during harvest and continuing in the granaries. One of the factors that lead to grain damage and a decrease in its quality in the elevator complex is the loading of grain into containers for storage and processing [8]. As a rule, the first tens or even hundreds of tons of grain that fall into empty metal and concrete containers are subject to damage and crushing. This, in turn, worsens grain quality and increases the number of unwanted impurities.

Another factor of grain mass damage is its movement during the technological process, which is carried out with the help of elevator equipment (transporters, noria). Mechanical damage to grain during transportation occurs due to the variety of grain crops with which the elevator works, and more precisely, due to their different physical characteristics. In order to achieve the necessary quality indicators, it is necessary to create suitable conditions for different types or compatible grain crops.

Thus, to increase the reliability and efficiency of the transportation process, backup transport branches (additional vertical or horizontal conveyors) can be used. To improve production indicators, it is advisable to introduce additional transport lines and grain processing machines, which allow simultaneous reception or unloading of products on several cars or wagons [9].

Therefore, during the transportation of grain products, there can be many routes by which the grain moves from one technological point to another. One of these routes is usually chosen by the operator manually, since modern software and logic complexes for controlling technological equipment do not provide automatic search for grain tracking routes.

As mentioned earlier, taking into account the criterion of minimization of grain losses will reduce mechanical damage to the grain mass during transportation, which, in turn, will increase the productivity and quality of the technological process in the elevator complex.

The application of the optimization criterion of minimization of the grain fight at the stage of unconditional optimization can be implemented with the help of a programmable logic controller that takes into account the state of the technological equipment and the possibilities of branching. This determines all possible routes for grain movement from the starting point to the final point, after which the optimal one is selected from the selected routes. Using the principle of optimality and taking into account the influence of transport equipment on the quality of grain, the controller issues commands for the preparation of valves and valves that are part of the technological equipment of the optimal route with the criterion of minimizing the growth of the grain fight during transportation.

Therefore, mechanical damage to grain during transport and technological operations can be described as the sum of the effects of elements of transport equipment, valves and latches on the technological route. At the same time, it is necessary to take into account the coefficient of influence of each previous element of the transport equipment in the next element, thus the optimality criterion for minimizing the grain fight can be presented in the form:

$$C_{б.з.\min} = K_{b.e1}k_n + (K_{b.e1} + K_{b.e2})k_n + (K_{b.e1} + K_{b.e2} + K_{b.e3})k_n + \ldots + \sum K_{b.e.n+1}k_n, \quad (3)$$

where K_b - coefficientinfluence of elements of transport equipment, valves and valves of the technological route; k - the coefficient characterizing the involvement of the element in the routing process ($k = 0$ - the element is used for transportation, $k = 1$ - the element is not used for transportation).

The implementation of the specified criterion when forming the main or alternative transportation route can lead to a reduction in mechanical damage to the grain mass during transportation, which, in turn, will increase the efficiency and quality of technological processes in the elevator complex. In addition, for companies focused on international consumer markets, grain quality indicators are important, which in some cases can be improved by building optimal grain transportation routes based on criteria defined by the operator.

The algorithm for building the optimal route (Figure. 4) according to this criterion is similar to the one shown in Figure. 3.

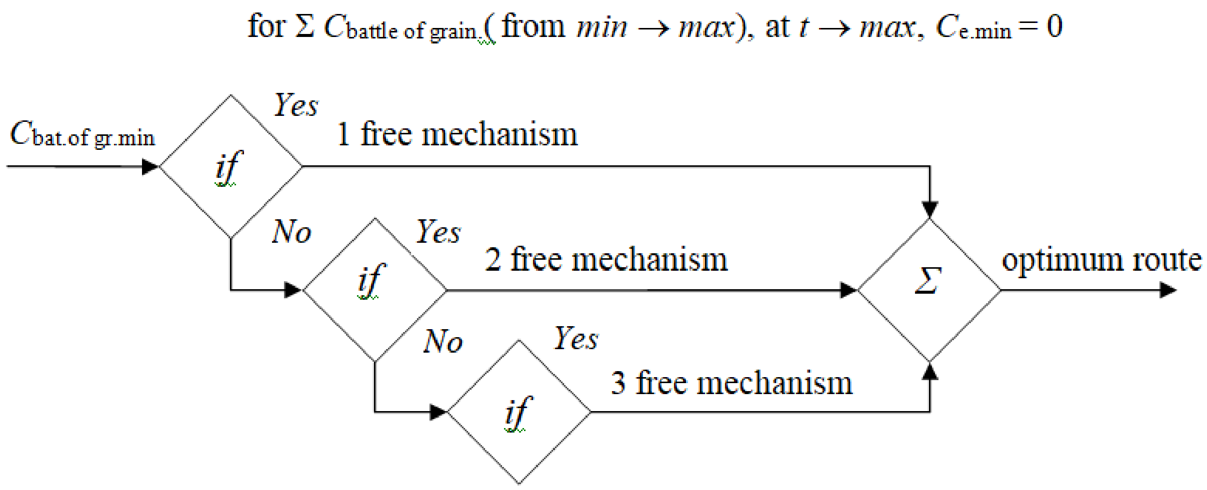

Figure 4 - Algorithm of laying the route according to the criterion of min battle of grain

It can be seen from this algorithm that, as in the previous case, the laying of the transportation route will be carried out from the minimum to the maximum value, depending on the sum of the coefficients of the influence of the elements of transport equipment, valves and valves on grain crops. In other words, for the transportation of grain products from point A to point B, it is necessary to save as much of the product as possible. The system will lay out a route, checking the possible options and the load of these routes. If the route is free, it will be laid based on the results of the sum of the coefficients of influence on the mechanical damage of the grain.

The use of the specified criterion creates additional conditions for transportation, making it possible to draw up the necessary technical task and make adjustments to the management program for the formation of grain movement routes. This enables the elevator to adjust the quality of grain for export and provide additional profit. However, the application of this criterion may lead to a decrease in the speed and cost-effectiveness of the transportation process.

Thus, the application of the specified principle in the formation of technological routes can help in solving the problem of creating an optimal transportation route (Figure. 5).

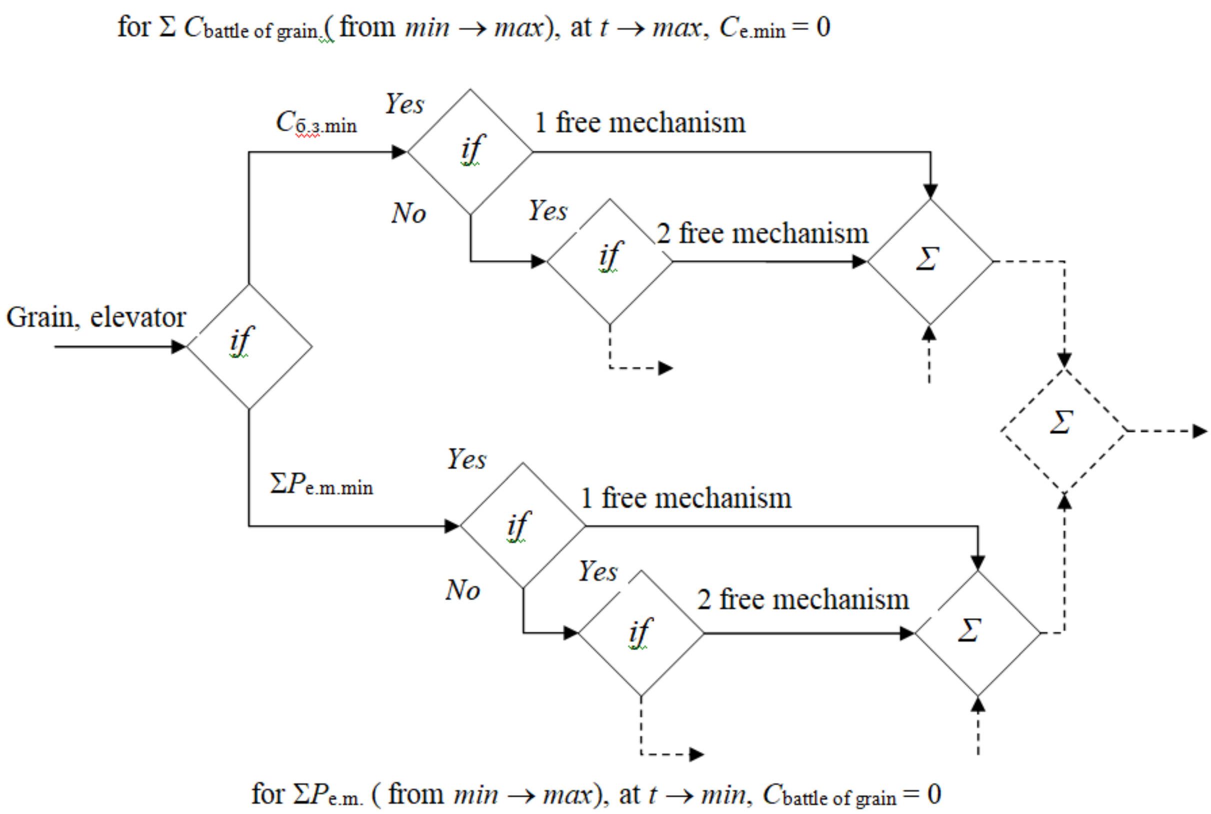

Figure 5 - Algorithm for choosing a route based on the specific needs and goals of the enterprise

Both criteria are of great importance in the construction of optimal transportation routes in elevator complexes. The choice of a specific criterion may depend on the specific needs and goals of the enterprise.

The next stage of optimization of the routing process can be the creation of a multi-criteria optimization algorithm.In this algorithm, not only the previously mentioned criteria of optimality are taken into account, but also the criteria of length and time of transportation, which will contribute to increasing the loading of the enterprise. The fast process of modeling the optimal route also increases the loading speed of transport equipment, which, in turn, improves the efficiency of work while maintaining the same capacities. However, solving this problem is possible only through the development of a multi-criteria optimization algorithm. Using a multi-criteria approach when determining the grain transportation route to the elevator makes it possible to take into account and optimize several criteria at the same time, and not just one aspect. This approach allows you to balance various factors, such as export quality of grain, minimization of losses, route length and others, in order to achieve an optimal result when planning and choosing a transportation route.

But multi-criteria optimization generates uncertainty in making the optimal decision, since its result is a set of alternative routes competing according to different criteria (Pareto set) [10]. This poses the additional problem of choosing a single compromise route from the Pareto set. Solving such a problem requires the introduction of additional conditions and criteria. Or the operator can choose a route from the Pareto set using additional operational information about the progress of technological processes. Of course, multi-criteria optimization will be more effective, the larger the elevator farm.

Conclusion.

Analyzing modern grain transportation routes, it can be noted that the existing algorithms for their laying do not provide a full-fledged process and do not realize the full potential of automation. There is insufficient attention to the quality of the routes in terms of their efficiency, productivity, economy and logistics. These transportation algorithms do not take into account optimization criteria, the application of which could significantly improve the automated control system, providing more efficient technological transportation processes.

Optimization means the construction of a shorter and more productive transportation path, as well as the possibility of creating an alternative route that will allow bypassing equipment that is overloaded or out of order. Route optimization can be achieved by minimizing electricity consumption and mechanical damage to grain during transportation. Two main optimization criteria - reduction of electricity consumption and minimization of grain losses - must be integrated into the routing algorithm. This will make it possible to create more efficient routes that take into account the technical characteristics of the equipment and its condition, as well as contribute to increasing the productivity and quality of the technological process.

An important stage of further optimization is the implementation of a multi-criteria approach, which allows you to take into account several criteria at the same time, such as grain quality, transportation speed and route length. As a result, one of the directions for improving the technological process at the elevator was determined by improving control algorithms with an emphasis on optimization according to various criteria. This creates the need to optimize the modes and structural parameters of the elevator's electromechanical complex control through the improvement of existing and the development of new methods and software and technical tools for prompt intervention in the operation of electromechanical equipment, which will contribute to increasing energy saving and product quality.

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Анотація. *У статті розглядаються питання підвищення ефективності функціонування елеваторів в умовах зростання попиту на аграрну продукцію. Оскільки якісне зберігання та логістика зернових культур є важливими, автори аналізують зміни в управлінні та технологічному обладнанні елеваторних комплексів. Окрема увага приділяється процесу маршрутизації зернових потоків, оптимізація якого може суттєво зменшити витрати, підвищити швидкість обробки і знизити ризики простоїв. Досліджено існуючі автоматизовані системи, зокрема програму «Маршрут», яка допомагає будувати оптимальні маршрути для транспортування зерна. Запропоновано застосування методу комівояжера для визначення найкоротших шляхів, а також удосконалення алгоритмів для мінімізації електроспоживання та механічних пошкоджень зерна під час транспортування. Автори підкреслюють важливість розробки багатокритеріальної оптимізації, яка дозволяє одночасно враховувати кілька аспектів, таких як якість зерна, швидкість та довжина маршруту. Стаття акцентує на необхідності вдосконалення існуючих методів управління електромеханічними комплексами елеваторів, що сприятиме підвищенню енергозбереження та якості продукції.*

Ключові слова. *елеватор, зерно, логістика, маршрутизація, автоматизація, енергозбереження, оптимізація, комівояжер, механічні пошкодження, багатокритеріальна оптимізація.*