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Fuzzy logic methods in assessing the transport and warehouse complexes functioning quality

Métodos de lógica difusa para evaluar la calidad de funcionamiento de los complejos de transporte y almacén

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ABSTRACT

In most sectors of the national economy, technical facilities are represented by unloading devices that extract bulk cargo from the freight rolling stock, store it for a certain time, and ship it to a similar or other type of transport. Objects intended for the implementation of the stages of loading, unloading, and various storage periods, including bulk cargos, are commonly referred to by the broad scientific community as transport and warehouse complexes (TWC). Most operations performed in the TWC are the movement of goods (internal movements, receiving or sending goods by various modes of transport. The authors clarified the concept of "transport and warehouse complex" - it is an element of the transport network of the region, providing communication of external transport systems of the regions and performing the functions of converting the cargo flow of the region into the cargo flow sent by the region. On the one hand, they perform functions of transshipment points in relation to deep (economic) warehouses, and on the other – the functions of storage facilities. Their primary purpose is determined and depends on a large number of factors, including: the size of the direct service area, the ratio of the design capacity of the warehouse to the volumes of deliveries and the use of bulk cargo, as well as the condition of roads in the serviced area, the uniformity of the receipt of bulk cargo and the availability of vehicles for their delivery to the consumer.

Keywords: Bin, Bulk Cargos; Comprehensive Quality Assessment; Transport and Ware-house Complex.

RESUMEN

En la mayoría de los sectores de la economía nacional, las instalaciones técnicas están representadas por dispositivos de descarga que extraen la carga a granel del material rodante de carga, la almacenan por un tiempo determinado y la envían a un medio de transporte similar u otro. Los objetos destinados a la implementación de las etapas de carga, descarga y varios períodos de almacenamiento, incluidas las cargas a granel, son comúnmente denominados por la amplia comunidad científica como complejos de transporte y almacenamiento (TWC). La mayoría de las operaciones que se realizan en la TWC son el movimiento de mercancías (movimientos internos, recepción o envío de mercancías por diversos modos

de transporte. Los autores aclararon el concepto de "complejo de transporte y almacén", que es un elemento de la red de transporte de la región. proporcionando comunicación de los sistemas de transporte externos de las regiones y realizando las funciones de convertir el flujo de carga de la región en el flujo de carga enviado por la región. Por un lado, realizan funciones de puntos de transbordo en relación a los almacenes profundos (económicos), y, por el otro, las funciones de las instalaciones de almacenamiento. Su propósito principal está determinado y depende de una gran cantidad de factores, entre ellos: el tamaño del área de servicio directo, la relación entre la capacidad de diseño del almacén y los volúmenes de entregas y el uso de carga a granel, así como el estado de las carreteras en el área de servicio, la uniformidad de la recepción de carga a granel y la disponibilidad de vehículos para su entrega al consumidor.

Palabras clave: Compartimiento, Cargas a granel; Evaluación integral de la calidad; Complejo de Transporte y Almacén.

1. INTRODUCTION

Ensuring a stable discharge of bulk cargo is largely due to a complex of factors of mutual influence of the set of material properties and parameters of the container intended for storage (Al Alaween, *et al.* 2020). The modern selection of geometric parameters of bins in the vast majority of cases is based on the previous work of the designer or the search for standard schemes of bulk storage with similar operating conditions is carried out, adapting them to the dimensions of specific industrial buildings. The set of individual properties of a certain bulk cargo, and, accordingly, the guarantees of uninterrupted unloading, are not fully taken into account in the design works on the bins. The current practice causes problems with performance and requires improvement in the design of the constructed bins intended for cargos with poor flowability.

The magistral and industrial transport of the regions is characterized by the creation of equal conditions for production, storage facilities, which is its feature (Rychkov, 2001). The origin of cargo flows from manufacturers occurs in the immediate vicinity of transport lines with high carrying capacity. The main link between transport routes is the hub center, which provides the regions with means of transportation for loading manufactured products or unloading and placing goods used as material for processing.

The transport and warehouse complex meets the following requirements:

- it has a transport system for the promotion of cargo traffic to (c) industrial enterprises;

- it has technical capabilities for storing, moving and converting cargo flows.

Features of increasing the importance of production were formulated by K. Marx, who noticed: "With the growth of the scale of production and with the increase in the productive power of labor through cooperation, division of labor, the use of machines, etc., the mass of raw materials, auxiliary materials, etc., that enter into the daily process of reproduction, also increases. Thus, the size of this stock, existing in the form of productive capital, absolutely increases.

2. METHODOLOGY

The system of efficiency factors and the model of operation of bins for bulk cargos refer the considered object to a complex system with the task of evaluating the quality of work by many criteria. It is possible to consider the problem in a general form by dividing the system into the number of links that are finite, but the mathematical apparatus currently used does not allow to implement it. The difficult task of combining disparate parameters into a whole did not stop the authors, they chose the way of their

evaluation by a generalized complex indicator by means of single parameters of the quality of performance of the research object production functions (Azgaldov, 1982). The initial quality indicators of various kinds do not cause practical complexity in the considered case, and are solved with the use of nominal and maximum permissible quality results of functioning on the basis of the expert-statistical method of evaluation (Al Alaween, *et al.* 2020; Buonamico y Muller y Camargo, 2017; Lashin y Alrowais, 2020; Pragalath, *et al.* 2018; Rojek, *et al.* 2020).

Let's present an evaluation method that combines formal methods of mathematics and the results of the work of expert specialists. As a result, a theoretical or empirical model can be built by applying such methods, which in turn will allow to proceed to the construction of a mathematical model of a complex indicator of the quality of the object being evaluated.

For each specific case, it is necessary to develop empirical models based on the statistical relationships between individual and complex indicators, which is quite inconvenient.

Bin storage facilities for bulk cargos are considered by the authors as objects of modeling-which entails the search for solutions to problems: concretization of individual indicators (K_i) and finding the functional dependence (φ) to obtain a generalized indicator of the quality of the object (K):

$$K = \varphi(K_i), \tag{1}$$

where i=1, 2,..., n is the number of qualitative properties under consideration.

The quality indicator refers to relative values (K_i) and is a function of the ratio of the absolute indicators of the property – measured (x_i) and taken as the base one (x_i^b):

$$K_i = f\left(\frac{x_i}{x_i^b}\right). \tag{2}$$

The specific values of each property K_i depend on the base indicator x_i^bused, which makes the quality assessment correlated with the selected standard.

When obtaining the results of the quality assessment, depending on the values of the absolute x_i, the indicators of all the considered characteristics of the object should be combined. This result is achieved by translating them on the same methodological basis into a dimensionless scale.

The value of the indicator taken as the base x_i^b in the formula (1) is permanent for a number of properties (i) and is selected as the peak one for this evaluation object. Underestimating the range of variation in the spectrum of properties of the absolute indicator in the final can be a source of error (about 25%), because the value that characterizes the measurement property must be the actual absolute value of the i-th property (x_i^d). It is established that the addition in the value of individual indicators will cause a deterioration of the quality characteristics of the object of study.

3. LITERATURE REVIEW

As a professor, the Russian scientist Gjachev formulated the parameters characterized by the absence of the formation of arches in the bulk material (Gjachev, 1968). However, his proposed mathematical model for bulk cargos operates only with ideal conditions (particles in the shape of a ball, particles are absolutely solid, there is no external and internal friction). This limits the possibility of applying the obtained dependencies and can be used on loads with good flowability without additional transformations.

A scientist from the United States, Jenike implemented theoretical developments in the method of calculating linear and angular values of the discharge part of the bin with a guarantee of stable unloading of bulk cargos by the "expiration-no expiration" criterion developed by him (Jenike, 1968). The shear characteristics of bulk cargos are the basic values for the proposed method, it establishes: the instantaneous function of the movement of cargo particles, the time function of the movement of cargo particles (i.e., different storage periods are covered), the friction angles. The individual roughness of the proposed method includes the lack of a way to establish the significance of the remaining physical and mechanical properties on the flow process, the bin is considered without considering the mutual influence of its elements.

Researchers in large numbers, both domestic and foreign, put forward detailed classifications of bulk cargos according to the ability to move cargo particles.

Main list of bulk cargos Pogozhev, Anichkina, divided into three groups depending on the value of the initial shear resistance (Pogozhev y Anichkina, 1986):

- τ_0=0, the cargo demonstrates the properties of good flowability,

- $\tau_0 \leq$450 Pa, the cargo belongs to low-connectivity materials,

- τ_0>450 Pa, the cargo on the mobility of the particles is strongly connected.

Another direction of the development of the classification of bulk cargos is reflected in the works of Posemeynik, who chose the following features (Posemeynik, 1979):

- cargo with large particles (+0.5 mm) – the gravity of each of the particles is many times greater than the force of autohesional adhesion,

- weight with small particles (-0.5 +0.05 mm) – the gravity of each of the particles approximately corresponds to the force of autohesional adhesion,

- cargo with fine dispersion particles (-0.05 mm) – the gravity of each of the particles is significantly lower than the forces of autogesional adhesion, which is the reason for the formation of the aggregate state of bulk cargos.

In general, the classifications presented in the analysis use, as a rule, one of the indicators of physical and mechanical properties and do not consider the influence and mutual influence of others. The division into groups according to one of the characteristics is decisive and, with a high degree of probability, does not reflect the full range of states, since it is reliably known that individual properties of cargos change during storage.

The initial works in the field of complex assessment of the properties of bulk cargos includes the Carr classification, which considers the five most important indicators, according to the author: the coefficients of compaction, friction and inhomogeneity of the cargo particles size distribution, the angles of collapse, and the natural slope (Carr, 1965). In the classification, each property of the cargo is assigned scores from 1 to 25 points, which are then summed up. Accordingly, the cargo approaching the ideal bulk state is characterized by 100 points, the cargos of increased connectivity are assigned a lower value in points. The lack of accountability of the weight value of individual indicators and their impact on the complex criterion of cargo flowability is the main disadvantage of the considered classification.

4. RESULTS

The difficulty of solving the problem of dividing cargos by the ability to expire is due to the versatility of the parameters for assessing the share of the impact of individual properties on the process of arching. The probability of developing a universal container capable of meeting the requirements of the technological process for storing and unloading cargos with a wide range of physical and mechanical properties almost tends to zero. The study and accounting of the properties of cargos for work, with which the bulk storage of bulk cargos is designed, is necessary to justify their geometric parameters.

The quality characteristics of the storage facility for bulk cargos should be used in the development, production and operation for the implementation of tasks:

- planning and forecasting the quality characteristics of the bin operation,
- performing design and experimental designing,
- development of options for upgrading existing equipment,
- to check the quality characteristics of the bin operation,
- development of technologies for storage and unloading of bulk cargos.

Using research materials, the authors created a mathematical model of a complex indicator for assessing the quality of bin storage facilities, justified individual criteria for the design parameters of bin-type storage facilities, taking into account the physical and mechanical properties of bulk cargos, and proposed a method for a comprehensive assessment of the operation of bins (Goryushinsky, *et al.* 2003; Tretyakov, *et al.* 2010).

The parametric model of the bin operation, implemented on the results basis of the conducted quality assessment, directly affects the choice of parameters of the bin-type storage facilities according to Fig. 1.

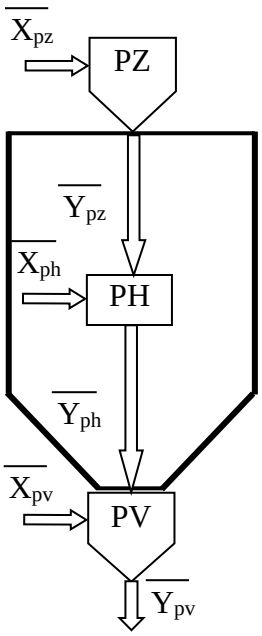

Figure 1. Parametric model of a bin operation

The operating parameters of bulk storage of bulk cargos in transport and warehouse complexes in a generalized form include three interrelated blocks for their functional purpose: loading the bin with bulk material (PZ), storing it (PX), and releasing the cargo (PV). In a parametric model of the bin (silo), functions of external and internal influences are represented by the following symbols (Fig. 1): $\bar{X}_{pz}$ the vector function characterizing load conditions (characteristics of the means of load);$\bar{Y}_{pz}$– the vector function of the influence of the load options on the process of storage and release of goods; $\bar{X}_{px}$ – the vector function of the influence of the environment and the capacity settings on the storage process; $\bar{Y}_{px}$ – the vector function of the influence of the storage parameters on the process of unload (storage characteristics, changing the properties of the cargo); $\bar{X}_{pz}$ – the vector function describing the parameters of the bin and features of the cargo; $\bar{Y}_{pv}$ the vector function of the influence of the issue parameters on the result of the work of the bunker.

The vector function of the disturbance of the release process can be represented as a functional:

$$\bar{X}_{pv} = \bar{X}\{x_{1v}, x_{2v}, x_{3v}, x_{4v}, x_{5v}, x_{6v}, x_{7v}, x_{8v}, x_{9v}, x_{10v}, x_{11v}, x_{12v}\}, \quad (3)$$

where x_{1v} – capacity configuration indicator; x_{2v} – exhaust funnel configuration indicator; x_{3v} – parameters of outlet configuration; x_{4v} – the location of the outlet; x_{5v} – angle of inclination of the walls of the emptying funnel; x_{6v} – area ratio of the outlet and capacity; x_{7v} – the height of the bin; x_{8v} – the indicator of the angle of cargo collapse; x_{9v} – coefficient of internal friction of the cargo;

Based on the proposed evaluation structure (Fig. 1), the values of x_i are represented as the initial values of the property for a comprehensive assessment of the functioning of storage facilities in transport and warehouse complexes: the design characteristics and the physical and mechanical characteristics of bulk cargos.

Based on the mentioned-above, the formula for complex property estimation is written as:

$$K_i = \frac{x_i^{max} - x_i^{д}}{x_i^{max} - x_i^{min}}, 0 \le K_i \le 1 \quad (4)$$

where x_i^{max} is the highest value (unacceptable value);

x_i^{min} is the lowest value (acceptable value).

By mathematical methods, the complex properties estimation is transformed into a weighted arithmetic average (Carr, 1965). In this case, the formula (1) will be written:

$$K = \sum_{i=1}^{n} g_i K_i, \ (i = 1,...,n), \text{ all } g_i \ge 0, \quad (5)$$

where g_i is the significance coefficient of the i-th individual characteristic of the quality criterion.

Mathematical model of complex properties estimation:

$$K = \sum_{i=1}^{n} \frac{x_i^{max} - x_i^{д}}{x_i^{max} - x_i^{min}} \frac{\frac{1}{K_i^{max} - K_i^{min}}}{\sum_{i=1}^{n} \frac{1}{K_i^{max} - K_i^{min}}}. \quad (6)$$

In order to determine the qualitative characteristics of research objects, the method of statistical processing of populations was used.

A comprehensive assessment of the properties of bulk cargo bins is implemented by reducing the estimate of an acceptable value to an unacceptable value meaning.

A comprehensive assessment of the properties was carried out in two stages:

Evaluation of structural elements of storage facilities for bulk cargos in compliance with the condition of guaranteed unloading according to the method of expert assessments.

Comprehensive assessment of the physical and mechanical properties of cargos by the degree of flowability.

The result was 45 expert assessments of the structural elements of storage facilities for bulk cargos according to Table 1.

Table 1. Expert assessments of the shape of storage facilities for bulk cargo indicators

№	Bin shape		The shape of the lower part			Location of the outlet	
	Longitudinal section	Cross-section	Longitudinal section	Cross-section			
				Upper part	Outlet	Bin bottom	Side wall
	1	2	3	4	5	6	7
1	Curvilinear (0.95)	Round (0.95)	Curvilinear (0.75)	Round (0.95)	Slotted (0.95)	Axially symmetric (0.5)	Around the perimeter (0.95)
2	Top-down trapezoid (0.5)	Polygonal (0.75)	Top-down trapezoid (0.5)	Polygonal (0.75)	Round (0.75)	Asymmetric (0.75)	Local (0.5)
3	Top-up trapezoid (0.95)	Rectangular (0.75)	No funnel (0.95)	Rectangular (0.75)	Polygonal (0.75)		
4	Rectangular (0.75)				Rectangular (0.25)		

The analysis allows to determine an acceptable value for the conditions presented above: the curvilinear shape of the bin, the trapezoid with the top up, the score is 0.95; the rectangular shape and the trapezoid with the top down, respectively, are 0.75 and 0.5. The best option is a cylindrical shape.

The absolute parameters of storage facilities for bulk cargos are presented in Table 2. Acceptable values were taken with a result of 0.95.

Table 2. Absolute parameters of storage facilities for bulk cargos

Ratio of areas S_{emk}/S_{otv}	Angle of inclination of the hopper α, degree	Storage facility height H, m
100% (0,95)	90 (0,95)	H≤5 (0.95)
75% (0,75)	70 (0,75)	H>5 (0.5)
50%(0,5)	50 (0,5)	
25% (0,25)	30 (0,25)	

5. CONCLUSION

The results obtained made it possible to develop a software product for the implementation of a comprehensive assessment of the properties of bulk cargo bins during their operation.

This method allows evaluating storage facilities with a gravitational expiration of cargo, at the same time, transport and warehouse systems are used for storing and processing a large volume of cargos with a low degree of flowability. In this case, performance is achieved by using storages with impelling devices.

The patented author's technical developments include various technical means of direct and indirect influence on the content of storage facilities for bulk cargos, as a result of which guaranteed unloading is achieved. These include designs of mechanical rippers, arch breakers, feeders, distributors of the flow of bulk cargo.

Based on the above-mentioned, a comprehensive assessment of the properties of storage facilities provides predicted indicators of the process of bulk cargos expiration. The results will be used in the development of design and technological documentation of bins in transport and warehouse complexes, modernization of existing equipment with low energy consumption with small investments.

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