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RESULTS OF SIMULATION STUDIES OF THE TRANSPORT AND PRODUCTION SYSTEM OF WASTE RECYCLING IN THE CONDITIONS OF A METALLURGICAL ENTERPRISE

The article conducts simulation studies of the transport and production system of waste recycling at a metallurgical enterprise. To date, the method of simulation modelling is one of the most powerful and effective methods for studying processes and production systems. The object of research is the processes of managing freight transport on technological routes for the transport of metallurgical waste. In this study, the transport and production system of waste recycling of a metallurgical enterprise is considered as a complex system that includes a certain number of subsystems, namely: "Raw material supply", "Raw material processing", "Raw material sales", the elements of which are technologically interconnected.

The subsystem "Raw material processing" was selected for simulation studies. The aim of the study is to develop software that will simulate the situation on the technological routes of transport and production systems, taking into account the specified criteria, and obtain a set of values of the number of rational type trucks, taking into account their carrying capacity and time factors, a set of values of the total queue time, and the time spent in the queue of trucks. The random nature of the time for unloading trucks associated with the operation of crushing and screening equipment was revealed. At the same time, neither the intensity of raw material supply to the receiving devices of the DSC nor the variability of the time parameters of transport service cycles are taken into account. The software makes it possible to model any situation on the technological routes of the structural units of a coal enterprise and obtain a variety of values for the total queuing time, vehicle queuing time, downtime and repair rates for a group of vehicles with a given carrying capacity. This enables the operation department to correctly select and deploy rolling stock on routes to ensure the highest system performance.

Key words: *dump truck, recycling, technological route, crushing and screening complex, transport costs.*

Formulation of the problem. The current methodology for calculating the required amount of RS on the technological routes of domestic metallurgical enterprises is related to the volume of continuous production, the value of which is planned for a long-term period. In other words, there is a planned amount of raw materials to be transported over a certain period of time (shift, month, year). At the same time, neither the intensity of raw material supply to the receiving devices of crushing and screening equipment nor the variability of the time parameters of transport service cycles are taken into account.

Analysis of recent research and publications. The efficient functioning of transport and production systems of mining and quarrying enterprises largely depends on the effective organization of the transportation process, which involves the timely delivery of goods in accordance with the technology and production needs at minimal cost. The transport and production systems for the transportation of metallurgical slag are no exception, where the organization of freight transport is associated with extremely difficult operating conditions for trucks and with ensuring continuous technological processes for recycling waste from the main production process. The use of dump trucks is driven by the advantages of this transport: the relatively low cost of this transport compared to other vehicles, manoeuvrability, use of diesel fuel (independence from the power grid), mobility, which makes it possible to use them atany horizons in the quarry, a greater slope overcome by dump trucks when lifting, simplification of the process of creating quarry roads, small work sites, etc. [1].

A number of works have been devoted to the study of transport and production systems [2–5]. In today's environment, enterprises are faced with the task of increasing profits and improving the efficiency of managing production processes, including transportation. For the sustainable development of transport and production systems, a new approach to research is needed that will allow to promptly take into account environmental changes, adequately respond to the changing behaviour of transport consumers, and effectively influence supply and demand [6, 7].

Transportation of goods in transport and production systems Slag transportation is carried out in changing environmental conditions and is associated with random processes that occur during the transportation of goods, as a result, abnormal time occurs during cargo operations, which leads to a decrease in the efficiency of the system as a whole. Therefore, it is extremely important to take into account the stochastic nature of rolling stock downtime when selecting rolling stock.

The types of vehicles and the need for them are determined on the basis of a study of intra-plant cargo flows, i.e. the amount of cargo moved in a certain period of time in a certain direction between loading and unloading points [8]. The rational allocation of different types of rolling stock for different tasks is referred to as a distribution problem. If the demand for transportation is deterministic, and the effect of using rolling stock is proportional to its number, then such distribution is carried out using linear programming methods [9]. The authors of [10] propose to take into account the following factors when selecting rolling stock: transport, road, natural and climatic, structural, operational qualities, and economic criteria. Paper [11] provides an analysis of methods for assessing and selecting a rational type of rolling stock, including the following: depending on the nature of transportation and type of cargo, technical, operational and consumer properties. The authors [12] suggest choosing rolling stock based on performance, namely, using various indicators – weight and volume of cargo, specific fuel consumption, transportation distance. Higher load capacity and utilization ratio (lower unladen weight) as well as lower fuel consumption (low rolling and air resistance) can maximize efficiency at a given speed and distance. The work [13] considers the algorithm for choosing the most rational mode of transport according to the conditions of specific transportation. In order to substantiate the economic feasibility of using one or another type of transport, it is necessary to take into account the geography of production and consumption of goods, the volume of cargo flows, the presence and condition of rolling stock, the seasonality and rhythm of work on transport and at manufacturers of goods, the system of organizing the transportation process.

The authors of [12] propose to select rolling stock by performance, namely, using various indicators – weight and volume of cargo, specific fuel consumption, and transportation distance. Higher carrying capacity and utilisation rate (lower unladen weight), as well as lower fuel consumption (low rolling and air resistance) can maximise efficiency at a given speed and distance. Paper [13] discusses an algorithm for selecting the most rational mode of transport for a particular transportation. To substantiate the economic feasibility of using a particular mode of transport, it is necessary to take into account the geography of production and consumption of goods, the volume of cargo flows, the availability and condition of rolling stock, the seasonality and rhythm of work in transport and at manufacturers of goods, and the system of organising the transportation process. The authors of [14] present the results of solving the problem of choosing the number and type of vehicles, which was achieved by determining the specialisation and selection of the carrying capacity of rolling stock, which would lead to a reduction in the cost of transportation. According to the authors in their study [4], the task of choosing a rational rolling stock is to allocate available resources to fulfil known orders. If we are talking about a long planning period (season, year, several years), then another task arises – the formation of a rational fleet structure.

Existing studies, when choosing a rational truck fleet, do not take into account the specifics of truck operation and the stochastic nature of rolling stock downtime when transporting metallurgical slag.

Task statement. Conduct simulation studies to develop software that will simulate the situation on the technological routes of transport and production systems, taking into account the specified criteria, and obtain a set of values for the number of rational trucks, taking into account their carrying capacity and time factors, a set of values for the total queue time, and the time spent in the queue by the trucks.

Outline of the main material of the study. In this study, the transport and production system of waste recycling of a metallurgical enterprise is considered as a complex system that includes a certain number of subsystems, namely: "Receipt of raw materials", "Processing of raw materials", "Sales of raw materials" [15].

For simulation studies, the subsystem "Raw material processing" was selected, with technological routes Б, В.

The study of routes B, C will significantly complicate further research, so for further analysis, the share of each route in the total number of trips within the subsystem was considered (Table 1) [16].

Table 1

Share of routes in the total number of trips

Route	Share of routes in the total number of trips, %.
Subsystem "Processing of raw materials"	
Route Б	3
Route В	97

Given the insignificant share in the total number of trips, it is advisable to exclude route Б from the study.

The selected route has a length of 1.05 km, the productivity of the crushing and screening equipment is 300 t/h, the duration of the crushing and screening equipment per 1 shift is 10.5 hours, the average vehicle travel time is 7.99 minutes, the average time of unloading and loading operations is 6.29 minutes, the average waiting time in the queue is 5.97 minutes, the average number of riders per shift is 30 ~ 31. The productivity of the crushing and screening complex on this route is 300 t/h, the shift time of which is 12 hours, the useful time is 10.5 hours (excluding the time for the operator's lunch of 0.5 hours, 0.5 hours for cleaning the equipment – 0.5 hours, 1 hour – time for acceptance/delivery of the shift).

According to the costing of trucks and the specifics of transportation, four types of dump trucks are most appropriate for servicing technological routes (Table 2).

To service the technological route B, BelAZ dump trucks with a capacity of 33 tonnes and 42 tonnes are used, some of which are periodically idle for certain technological reasons. As can be seen from Table 2, the highest tariff is for a BelAZ-7523 dump truck, and the lowest tariff is for a BelAZ-7522 dump truck. However, BelAZ-75404 and BelAZ-7540B dump trucks are also used on technological routes. In this regard, in order to reduce transport costs, the task of selecting a rational dump truck fleet is being addressed. Using the developed methods and models, it is possible to quickly determine the rational type of rolling stock on technological routes at the lowest cost.

Under such conditions, the route, taking into account the bulk cargo weight, should be serviced by 4 BelAZ-7522 (BelAZ-7523) vehicles with a carrying capacity of 30 tonnes or 3 BelAZ-75404 (7540B) vehicles with a carrying capacity of 40 tonnes, with the number of vehicles varying depending on the technical condition of the rolling stock, the operational situation of production processes, and the physical condition of the drivers.

Under these conditions, the transport costs per shift for the first variant using four units of BelAZ-7522 dump truck will amount to ~ UAH 34362, and for the second variant using four units of BelAZ-7523 dump truck ~ UAH 36776. For the second variant, when using three units of BelAZ-75404 or BelAZ-7540B dump trucks, the cost will be ~ UAH 27166.

Accordingly, the transport costs for one month for the first variant when using four units of BelAZ-7522 dump truck will be ~ 1065222 UAH, when using four units of BelAZ-7523 dump truck ~ 1140056 UAH. For the second variant, when using three units of BelAZ-75404 or BelAZ-7540V dump trucks, the cost will be ~ UAH 842146.

Based on the timekeeping of transport service cycles for technological route B, the random nature of the time for unloading vehicles associated with the operation of crushing and screening equipment was revealed. At the same time, neither the intensity of raw material supply to the receiving devices of the DSC nor the variability of the time parameters of transport service cycles are taken into account.

In particular, the load intensity of the crushing and screening complex is a random variable I_{CSC}, which is determined by the time of unloading vehicles, the carrying capacity of the vehicle, and the time of movement on the routes. On the routes, during any

Table 2

Estimates for transport services by car brand, UAH

Calculation item	BelAZ 7522	БеЛАЗ 7523	БеЛАЗ 75404	БеЛАЗ 7540В
Fuel	308,90	367,74	349,31	349,31
Salary	177,85	177,85	177,85	177,85
Social security contributions	38,82	38,82	38,82	38,82
Replaceable equipment	0	0	0	0
Current repairs	7,02	7,02	7,02	7,02
Maintenance	45,98	45,98	45,98	45,98
Transport costs	0	0	0	0
Depreciation of property, plant and equipment	52,02	52,02	52,02	52,02
Other workshop expenses	1,12	1,12	1,12	1,12
General production costs	108,94	108,94	108,94	108,94
Labour protection	6,34	6,34	6,34	6,34
Total costs for 1 hour.	746,99	799,49	787,40	787,40

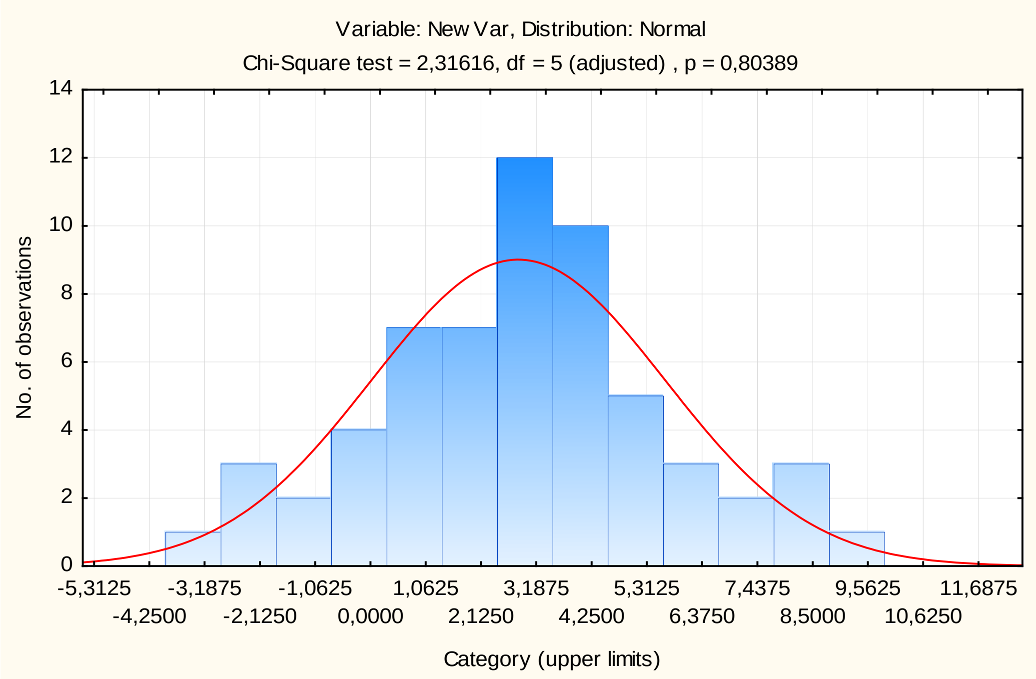

Fig. 1. Histogram of the distribution of values Δt_{CSC}

shift, a situation may arise of uneven arrival of vehicles for unloading, uneven unloading, uneven departure from the unloading fronts. In this case, there are two possible situations for the time of departure from unloading in front of a moving vehicle t_{dis} and the time of arrival for unloading of the vehicle following it t_{arriv}. The first case involved a delay in unloading a vehicle $t_{dis} > t_{arriv}$, and, as a result, the formation of a queue. The second case involved the detention of a car following in the queue $t_{dis} < t_{arriv}$, which leads to a gradual reduction in the residual amount of raw materials in the crushing and screening complex.

Fig. 1 shows the results of processing the values Δt_{CSC} for 312 vehicle trips on the routes Б, В. with parameters for the route Б – $\bar{x} = 5,515$; $\sigma = 0,107$, for the route В – $\bar{x} = 3,199$; $\sigma = 0,091$. The resulting sample at the 0.95 significance level follows a normal distribution law with parameters $\bar{x} = 2,842$; $\sigma = 0,364$, та has ranges of negative values Δt_{CSC} for transport service cycles. This proves that there is a possibility of trucks being late for loading. The data obtained and the ranges of negative values make it clear that the amount of raw materials in the crushing and screening complex is decreasing, which ultimately leads to a shutdown of the crushing and screening complex. The solution in this case is to involve backup vehicles, the number of which will depend on the time of delay of the vehicles for unloading.

However, an increase in the number of vehicles on the route can lead to a queue in front of the crushing and screening complex, so it is advisable to develop special software that would take into account these simulation studies.

Conclusions. The software makes it possible to model any situation on the technological routes of the structural units of a coal enterprise and obtain a variety of values for the total queue time, vehicle queue time, downtime and repair rates for a group of vehicles with a given carrying capacity. This enables the operation department to correctly select and deploy rolling stock on routes to ensure maximum productivity.

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Муковська Д.Я. РЕЗУЛЬТАТИ ІМІТАЦІЙНИХ ДОСЛІДЖЕНЬ ТРАНСПОРТНО-ВИРОБНИЧОЇ СИСТЕМИ РЕЦИКЛІНГУ ВІДХОДІВ В УМОВАХ МЕТАЛУРГІЙНОГО ПІДПРИЄМСТВА

У статті проведено імітаційні дослідження транспортно-виробничої система рециклінгу відходів металургійного підприємства. На сьогоднішній день саме метод імітаційного моделювання є одним із найпотужніших та найефективніших методів дослідження процесів та виробничих систем. Об'єктом дослідження є процеси управління вантажним автотранспортом на технологічних маршрутах перевезення відходів металургійного виробництва. У даному дослідженні транспортно-виробнича система рециклінгу відходів металургійного підприємства розглядається як складна система, що містить у своєму складі певну кількість підсистем, а саме: «Надходження сировини», «Переробка сировини», «Збут сировини», елементи яких технологічно пов'язані між собою.

Для проведення імітаційних досліджень була обрана підсистема «Переробка сировини». Метою дослідження є розробка програмного забезпечення, що дозволить імітувати ситуацію на технологічних маршрутах транспортно-виробничих систем з урахуванням заданих критеріїв і отримувати безліч значень кількості вантажних автомобілів раціонального типу з урахуванням їхньої вантажопідйомності та часових факторів, множину значень сумарного часу перебування в черзі, часу перебування в черзі автомобілів. Було виявлено випадковий характер часу розвантаження автомобілів, пов'язаний з роботою дробильно-сортувального устаткування. При цьому ні яким чином не враховуються ні інтенсивність подачі сировини до приймальних пристроїв ДСК, ні мінливість часових параметрів циклів транспортного обслуговування. Використання програмного забезпечення дає можливість моделювати будь-яку ситуацію на технологічних маршрутах структурних підрозділів вугільного підприємства й отримувати безліч значень сумарного часу перебування в черзі, часу перебування в черзі автомобілів, коефіцієнтів простою та коефіцієнтів ремонту для групи автомобілів із заданою вантажопідйомністю. Це робить можливим співробітникам відділу експлуатації правильно здійснювати підбір і розстановку рухомого складу за маршрутами для забезпечення найбільшої продуктивності функціонування системи.

Ключові слова: *самоскид, рециклинг, технологічний маршрут,дробильно-сортувальний комплекс, транспортні витрати.*