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RATIONALIZATION OF ROAD TRANSPORT PARK FOR THE CARRIAGE OF MINING ROCKS IN THE OPEN MINES

Summary. The article investigates causes and conditions of downtime of automobile and excavator complex in iron ore open mines in the structure of the multi-type fleet of dump trucks. The formulas for determining the downtime trucks of different carrying capacity allocated to a single excavator. In this article will find out the regularities of formation wasting time waiting at the loading multi-type structure of the park trucks.

УСОВЕРШЕНСТВОВАНИЕ ПАРКА АВТОМОБИЛЬНОГО ТРАНСПОРТА ПРИ ПЕРЕВОЗКЕ ГОРНОРУДНОЙ МАССЫ В КАРЬЕРАХ

Аннотация. Рассмотрены причины и условия возникновения простоев автомобильно-экскаваторного комплекса в железорудных карьерах при разнотипной структуре парка самосвалов. Приведены расчетные формулы для определения простоев самосвалов разной грузоподъемности, направляемых к одному экскаватору. Установлены закономерности формирования потерь времени на ожидания погрузки при разнотипной структуре парка самосвалов.

1. INTRODUCTION

Transportation of mining rocks from the open mines - the single most important link in mining process. The main type of transport technology in open mining is road transport [1]. There is a large variety of quarry dump trucks that can run both individual vehicles as a part of automotive trains [2, 3]. The leading companies in the production of heavy trucks are Komatsu, Caterpillar, Hitachi, BelAZ, Terex, Liebherr and others. These cars may be different design, kind of engine, automation, transmission, environmental parameters and many other characteristics, but the main difference between them - is their capacity. For example, Komatsu offers in its catalogue dump trucks with a mechanical drive with capacities ranging from 40 to 158.9 tons [4]. Cars of this production with individual electric drive have even more capacity - from 200 to 360 tons. However, the leader in load capacity among vehicles of this class is the company BelAZ. The quarry dump trucks BelAZ 75710 can transport 496 tons of cargo [5].

Obviously, the easiest solution for the mining companies would be to have cars of the same type and the same capacity. Moreover, that a number of companies went the way of fully automated fleet of mining dump trucks [6]. However, in most cases, there is a situation that the cars were purchased at different times, have different characteristics, but need to work as a single complex. One possible solution is the use of ITS for the given car park. Here can be used the approach that is used for rail industrial transport [7]. The above situation is widespread for quarries of Kazakhstan. An attempt to develop methods to improve the functioning of career road transport was made in article [8].

However, the currently used methods for modelling and planning of mining dump trucks are based on the description of the process as a local object, and does not fully take into account the peculiarities of the vehicle fleet structure in modern mines. This leads to the loss of working time as the dump trucks, excavators, have a number of drawbacks. An integrated approach to the problem extends the possibilities of finding alternative solutions and ways to improve the efficiency of the transport of mining rocks from the mines. Therefore, the objective to improve the work of dump trucks in conjunction with the work of the excavator as a single auto-excavator complex, highly relevant and is of great scientific and economic value [9].

Improving the performance of mining dump trucks through their rational distribution of excavators with the influence of the various technical and operational factors and the structure of the park will increase the performance of career motor transport, and reduce downtime of automobile and excavator complex to increase the volume of transported mining mass and, as a consequence, reduce the cost of its transportation.

2. CAUSES OF DUMP TRUCKS DOWNTIME AT LOADING

Results of the statistical data analysis and studies show that the loss of time while waiting for a dump truck for excavator loading a single haul may vary over a wide range and up to 10 minutes per load and per year, on average, is 498 hours. As a result, downtime of machinery reduced the total volume of exported mining mass, which consequently leads to significant economic losses for the mining enterprise as a whole. Table 1 shows the annual economic losses caused due to a truck waiting for loading operations in the open mines of JSC SSGPO.

Table 1

Economic losses from dump truck downtime waiting loading

Parameter	Value of parameter
Unsatisfied traffic volumes for the year, thousand of tones	184,76
Annual losses from idle waiting for loading, ths. rub.	383,5
Economic losses from unshipped loading, ths. rub.	37 335,4

These losses are happening mainly due to the differences in movement modes of dump trucks of various types in a particular installation. They are not taken into account in the planning of road-excavation complexes, while fixing and determining the required number of dump trucks of various types of concrete excavated to ensure the smooth of its work [10]. This leads to deviations intervals movement, violation of the rhythm of the excavator downtime dump trucks and excavators in anticipation of the start of loading operations.

Current trends in the mining equipment and technology are consistent in increasing the carrying capacity of mining dump trucks and their performance. The structure of the rolling stock mining company presented several types of dump trucks with different technical parameters for load capacity ranging from 91 tons to 180 tons. To load the dump are also used different types of excavators with bucket capacity of 6.3 m^3 to 27 m^3 [11].

Organization of vehicular traffic in the open mines of the enterprise is carried out in a closed cycle, when the group, as a rule, different types of dump trucks assigned to specific excavator. In view of the technical readiness of the park there is a daily adjustment to secure dump for excavators. When redistributing dump between excavators differences are not considered technical and operational performance of different types of trucks. Simplified representation of the physical laws governing the flow of loading and transport processes in complex transport and technological systems, resulting in significant deviation of actual performance from the planned values and unproductive losses in the system.

Planning the work of road-excavation complexes by averaged parameters, without significant differences in the technical and operational performance-dump trucks and excavators, interacting as a road-excavator complex is simple to calculate the planned parameters, but does not provide a high-precision planning parameters of the automobile and excavator complex and it does not take into account the possible impact on the formation of the park structure the unproductive downtime of auto-excavator industry. Using the planning of additional parameters characterizing the mining and processing conditions of work and open mines structure of its transport fleet, enhances the quality planning road-excavator sector and to minimize unproductive downtime in the system.

A significant impact on the performance of different types of dump trucks and their technical and operational parameters have distance transportation of mining mass, the speed of the loaded truck and the time required to perform loading and unloading cars truck (entrance for loading, unloading, waiting for loading) [12].

In servicing the same type of excavator dump characterized by relatively minor downtime waiting time of loading, which are due to the random nature of the influence factors on the deviation of the actual values of dump parameters from the planned values. The impact of the same type of structure of the park while waiting in time t_{o2}^{a} for the dump is not revealed. With multi-type structure of the dump park losses anticipation of loading t_{o2}^{a}, first of all, reach significant values, and secondly, such losses are caused by deviation of the actual from the planned values of the parameters of the different types of dump trucks that have substantially different technical and operational parameters, and third, data loss They have a distinct non-linear dependence on the structure of the fleet assigned to the dredge dump.

3. DEFINITION OF DOWNTIME IN AUTO-EXCAVATOR COMPLEX AT PERFORMING LOADING OPERATIONS

In theory of organization freight traffic one of the main reasons of downtime waiting for loading dump trucks is a mismatch of the rhythm of excavator *R* by intervals of truck traffic *I*, whereby there any downtime of the rolling stock in anticipation of loading or excavators. Organization of automobile and smooth operation of the complex involves excavating to ensure uniform load of the excavator, the absence of delays in the process of maneuvering vehicles at the entrance to loading bays and exits and stable duration of loading.

Planned interval of dump traffic on the routes *I* is defined by the formula:

$$I = \frac{t_o}{A_m} = \frac{t_1 + t_2 + t_3 + t_4}{A_m}, \tag{1}$$

where: t_o – time of dump turnover by route, min; A_m – number of dumps on the route, units; t_1 – time of loading dump with excavator, min; t_2 – time of riding dump with the load by the route, min; t_3 – time of unloading dump, min; t_4 – time of empty work (without load) of a truck by the route, min.

This performance t_o, t_1, t_3 t_4 for each traffic route is a function of the combination of the above factors influencing the technical and operating characteristics of various types of dump trucks, and if they plan on the mean value, the deviations are inevitable in the system.

To ensure the smooth operation of the excavator dump intervals along the route *I* shall conform to the rhythm of the excavator *R:*

$$R = I. \tag{2}$$

It should be noted that the rhythm of R, which is actually specified by the value of the dump load time t_l, for any i-x type of dump A_{mi}, having different load q_i, will vary.

In order to satisfy the condition (2) in the planning of the trucks route should send the following number of machines A_m:

$$A_m = \frac{t_o}{I} = \frac{t_o}{R}. \qquad (3)$$

If there is a deviation of the actual interval truck motion I_f of the planned value I_{pl}, delays arise as a dump truck and excavator:

1) if $I_f < I_{pl}$ – excavator is waiting truck: $t_{o1}^{e} > 0$;

2) if $I_f > I_{pl}$ – truck is waiting under load $t_{o2}^{a} > 0$.

Streamlining the work of automobile and excavator complex should be aimed at reducing the total unproductive downtime associated with waiting for loading T_o, for all involved in the number on the open mine A_{mi} dumps of i type (i= 1, 2 … n) and the quantity A_{ej} of excavators with j type A_{ej} (j= 1, 2 … m):

$$T_o = \sum_{i=1}^{n} t_{oi}^{a} + \sum_{j=1}^{m} t_{oj}^{e} \longrightarrow \min, \qquad (4)$$

where: $\sum_{i=1}^{n} t_{oi}^{a}$ – Total waiting time of loading dump, min; $\sum_{j=1}^{m} t_{oj}^{e}$ – total idle time of excavator waiting for loading, min.

The priority is to reduce the losses of excavator downtime for loading since only with continuous their work can get the maximum profit of the mining sector as a result of the largest export, processing and marketing of the mining mass.

When the same type of park structure for dump their load time t_l is the same for all machines and meets the rhythm of the excavator and the interval of their movement:

$$t_l = R = I. \qquad (5)$$

With multi-type structure of the dump park A_{mi} has different load q_i and accordingly, various download time t_{li}. In this case, the rhythm of a second excavator, to ensure the continuity of its work, shall be appointed at the lower time of loading $t_{1ij}^{\min}$ of the possible values for all exploited with the type of dredge dump:

$$R_{\min j} = t_{1ij}^{\min} = \min_i(\{t_{1ij}\}). \qquad (6)$$

However, to provide the rhythm of the j excavator according to (6), it is also necessary to schedule the smallest interval of movement

$$R_{plj} = I_{plj} = R_{\min j} = I_{\min j} = t_{1ij}^{\min}, \qquad (7)$$

and as a result, according to (3) on the route to the j-excavators must be produced the highest number of machines:

$$A_{mj}(R_{\min}) = \frac{t_o}{I_{\min j}} = \frac{t_o}{R_{\min j}}. \qquad (8)$$

With multi-type structure of the fleet of dump trucks A_{mi} each i-type machines turnaround time t_{oi} will be different. Therefore, to determine the planned number of cars that will provide fulfillment of the condition (6) in view of (8) in calculating $A_{mj}(R_{\min})$ should use the highest possible value of the turnover time of dump trucks on the j route determined for all the exploited with the excavator types of dump:

$$t_{oij}^{\max} = \arg\max(\{t_{oij}\}) \qquad (9)$$

Then the formula (8) we will show as follows:

$$A_{mj}(R_{\min}) = \frac{t_{oij}^{\max}}{R_{\min j}} = \frac{t_{oij}^{\max}}{t_{1ij}^{\min}}. \quad (10)$$

The ratio of the park structure is characterized by η_m index, which reflects the proportion of heavy trucks $A_{mi}^{\max}$ in the total number of machines:

$$\eta_m = \frac{A_{mi}^{\max}}{\sum_{i=1}^{n} A_{mi}}. \quad (11)$$

Taking into account that planning to work on the route of different dump types in the quantity A_{mi} ($R_{\min}$), having different time of turnover, and perhaps downtime waiting of excavators for the loading

Since the loading of heavy dump trucks $t_{1i}^{\max}$ will be more used to calculate the rhythm of the excavator loading time: $t_{1i}^{\max} > t_{1i}^{\min}$ then it means that the next dump arriving after the I_{pl} interval will wait in the line for t_{o2i}^{a} time, which is calculated by:

$$t_{o2i}^{a} = \left| t_{1i}^{\max} - I_{pl} \right| = \left| t_{1i}^{\max} - t_{1i}^{\min} \right|. \quad (12)$$

The total sum of trucks waiting for the shift will be:

$$T_o^a = \sum_{i=1}^{n} A_{mi} t_{o2i}^{a} n_{ei}, \quad (13)$$

where: n_{ei} – number of trips of i type dump truck for the shift, units.

To study the dependence of time loss of auto-excavation complexes waiting for loading from the park structure we carried out simulations complex work, in which were investigated the regularities of formation wasting time at the loading multi-type structure of the park trucks. Simulation results are consistent with evidence downtime tippers.

Based on the results of simulation plotted idle graphics of trucks downtime wasting for different types of machines allocated to a single excavator, as well as a graph of the total downtime for multi-type truck fleet structure for different values t_{o2}^{a} of the proportion of heavy trucks η_m (Fig. 1).

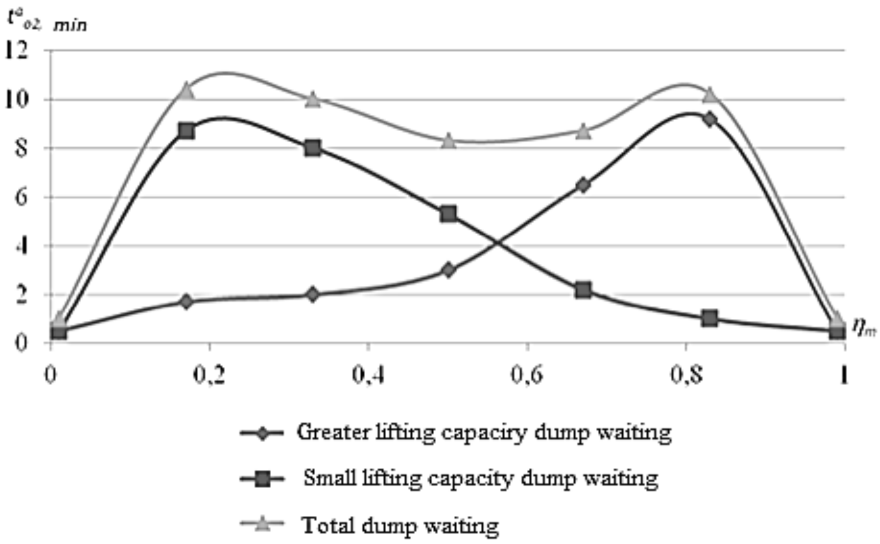

Fig. 1. Dependence of the total dump waiting t_{o2}^{a} from the coefficient of ratio of fleet structure η_m

Рис. 1. Зависимость суммарного простоя самосвалов t_{o2}^{a} от коэффициента соотношение структуры парка η_m

4. RESULTS AND CONCLUSIONS

Analyzing the data graphs in Fig. 1 we can draw the following conclusions: first, the loss of trucks waiting for loading t_{o2}^{a} tend to zero η_m = 0 and η_m = 1, that is, the same type of park structure; secondly, in the real values of η_m from 0 till 1, there exists a rational ratio of different types of dump trucks in which they work with a particular type of excavator is characterized by the lowest total losses of all dump trucks t_{o2}^{a} in anticipation of loading.

We write in general model of the optimal fixing dump trucks of different carrying capacity of the excavator:

$$s(t_{o2}^{a}) = \{A_m, \eta_m\} \longrightarrow Opt, \tag{14}$$

where: $s(t_{o2}^{a})$ – vector of optimal parameters for fixing dump by excavator, providing minimum loss of time t_{o2}^{a}.

However, the optimal solution of (14) is not always possible in practice as well as the required number of trucks of each type may not be available at the enterprise. Therefore, the problem (14) may have restrictions on the structure of the park, and is reduced to finding rational fixing trucks for excavators in order to minimize T_{o}^{a}.

The task of securing a rational available number A_{mij} of dumps of various i types for j excavators is formulated as follows: to find a vector s^* from the set of relations of truck fleet park structure S, for the value of the aggregate loss of time waiting for the loading of dump excavator T_{o}^{*a} = F (s^*, t_{o}^{a} (s^*)), was less, than T_{o}^{a} = F (s, t_{o}^{a} (s)) for any other $s \in S$:

$$T_{o}^{*a} = F(s^*, t_{o2}^{a}(s^*)) \longrightarrow \min, \qquad \text{when} \sum_{j=1}^{n} A_{mij} \le A_{mi}. \tag{15}$$

It has been redeployed of dumps for Kachar Open Mine of "Sokolov-Sarbai Ore-Dressing Production Association" (Kazakhstan) in the open mine with road trucks work 8 different types of excavators (EKG-8, SAT-993K, Hitachi 3600, Hitachi 5500); park consists of 35 dump trucks of various types (BelAZ-7513, BelAZ-7514, CAT 777 and Hitachi EH 3500), which carry ore rocks into two transshipment warehouse with a range of different transport. The planned range of movement I_{pl} was set as value t_I for CAT-777. We calculated all the figures and found a rational solution to fixing trucks for excavators. The resulting solution is rational of the valid, but its implementation is related to the possible cumulative downtime trucks in the amount of 11.1 minutes per cycle of turnover of cars. Also we found that the resulting solution for the existing structure of dump park allows the periodic occurrence of downtime due to lack of excavating machines. To eliminate downtime excavators is recommended to increase the number of trucks in the open mine for CAT-777 to 15 units. According to estimates in the article was made overall economic effect by reducing downtime while waiting for loading and reduce economic losses from not unloaded weight of the mining enterprises of JSC "Sokolov-Sarbai Ore-Dressing Production Association" for 40,666.9 thousand of rubles per year.

References

1. Васильев, М.В. & Смирнов, В.П. & Кулешов, А.А. *Эксплуатация карьерного автотранспорта*. Москва: Недра. 1979. 280 с. [In Russian: Vasilyev, M.V. & Smirnov, P.V. & Kuleshov, A.A. *Operation of quarry vehicles.* Moscow: Nedra. 1979. 280 p].
2. *Innovative mining haul train.* Available at: http://www.etftrucks.eu/Haul-Trains/
3. *BAS Mining truck – Vechicles.* Available at: http://www.basminingtrucks.com/en/mining-concept/vehicles.aspx
4. *Komatsu. Mechanical tracks*. Available at: http://www.komatsuamerica.com/equipment/trucks

5. *The world's biggest mining dump trucks.* Available at: http://www.mining-technology.com/features/feature-the-worlds-biggest-mining-dump-trucks/
6. *Mining company Rio Tinto now has a full fleet of huge, self-driving trucks.* Available at: http://www.sciencealert.com/mining-company-rio-tinto-now-has-a-full-fleet-of-huge-self-driving-trucks
7. Rakhmangulov, A. & Sładkowski, A. & Osintsev, N. Design of an ITS for Industrial Enterprises. In: *Sładkowski, A. & Pamuła, W. (eds.) Intelligent Transportation Systems – Problems and Perspectives. Studies in Systems, Decision and Control 32.* Cham, Heidelberg, New York, Dordrecht, London: Springer. 2015. P. 161-215. ISBN 978-3-319-19149-2.
8. Mahambetov, D. & Rakishev, B. & Samenov, G. & Sładkowski, A. Efficient using of automobile transport for the deep open-pit mines. In: *V Int. Sci. Conf. & II Int. Symposium of Young Researches „Transport Problems'2013". Conference Proceedings*. Katowice: Silesian University of Technology, Faculty of Transport. 2013. P. 287-293. ISBN 978-83-935232-1-4.
9. Дадонов, М.В. Повышение эффективности работы карьерного автомобильного *транспорта методами и средствами оперативного управления*. Дис. ... канд. техн. наук Кемерово. 1999. 189 с. [In Russian: Dadonov, M. V. Improving the effectiveness of career road transport methods and means of operational management. Dis. ... cand. tech. sci. Kemerovo. 1999. 189 p].
10. Chanda, E.K. & Gardiner, S. A comparative study of truck cycle time prediction methods in open-pit mining. *Engineering, Construction and Architectural Management*. 2010. Vol. 17. No. 5. P. 446-460.
11. Вуейкова, О.Н. & Ларин, О.Н. Вопросы повышения эффективности работы карьерного автотранспорта. *Вестник ОГУ*. 2011. №10 (129). С. 20–25. [In Russian: Vuyeykova, O.N. & Laryn, O.N. The issues of enhancing the effectiveness of career vehicles. *Bulletin of OSU.* 2011. No. 10 (129). P. 20-25].
12. Ларин, О.Н. & Вуейкова, О.Н. Факторный анализ производительности карьерного автотранспорта Сарбайского карьера. *Транспорт: наука, техника, управление.* 2011. No 1. С. 29-32. [In Russian: Larin, O.N. & Vuyeykova, O.N. Factor analysis of the performance career of transport Sarbai quarry. *Transport: science, technique, management*. 2011. No. 1. P. 29-32].

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