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The choice substantiation method of road construction equipment for mining enterprises

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Abstract. Selection of types and brands of road construction equipment for building quarry roads inside mining enterprises is an important task in a free market. In this case, the main criterion is the minimization of costs, which depend on the rational distribution of equipment among the work objects. Such a rational distribution is proposed in this technique, taking into account the operating conditions of the equipment.

1. Introduction

Design of mining enterprises, planning of their equipping with machines, mechanisms and equipment is inextricably linked with the substantiation of their presence, characteristics and optimization of their number, methods and techniques of application [1,2].

Road transport is one of the main ways of delivering minerals from quarries to mining and processing enterprises and places of loading into other modes of transport.

Road transport is usually used in quarries for the extraction of iron ores and non-ferrous metals, raw materials for the chemical industry, and building materials. The construction of quarries is aimed at exporting minerals to the place of storage, loading or processing, exporting waste rock, transporting material and technical means and technological equipment to the places of harvesting and vice versa. Career roads are built depending on the terms of operation and can be permanent and temporary.

Permanent type includes the main roads, which are subdivided into the ones connecting the quarry with the processing plant, a warehouse, a transshipment point, main ramps and rides to the quarry, main lines from the main ramps to the quarry to dumps, rides to dumps, roads on the surface of the dump connecting the row plots. Passages on ledges and rides to excavators may be temporary.

Thus, developing quarries include construction of many roads. During construction, a set of road-construction equipment of various types is involved in each of the facilities. At the same time, there is a need to complete a complex of road construction works: harvesting, loading and moving stone materials; profiling of roadbed and pavement; planning and strengthening of shoulders and slopes; drainage provision. Each of these work types can be performed by several types of road construction machines. The types of road construction equipment are shown in table 1.

Thus, each of the types of road equipment is capable of performing a complex of road construction works. In addition to road works, road construction equipment could be involved in overburden and quarry development, construction of loading and unloading areas, parking for equipment; maintenance of roads [3], sites and other works.



Table 1. The types of road construction equipment.

Types of road works	Types of road construction equipment				
	Excavator	Bulldozer	Scraper	Front loader	Motor grader
Preparation of stone materials	+	+	+	+	-
Loading stone materials	+	-	+	+	-
Moving stone materials	-	+	+	+	+
Construction of the subgrade	-	+	+	-	-
Subgrade profiling	-	+	+	-	+
Profiling pavement	-	+	-	-	+
Planning and strengthening of shoulders and slopes	-	+	-	-	+
Drainage	+	+	-	-	+

2. Materials and methods

Under these conditions, the substantiation of the selection of road-construction machines is associated with the formulation and solution of the problem of optimizing the costs of acquiring and maintaining the number of road construction equipment if it is necessary to perform a given amount of work [4]. The design of the work of the unit for the construction, repair and maintenance of roads at mining enterprises is based on the mathematical expression of the results of these processes through the cost of the work of all equipment and workers in physical terms or in monetary terms [5]. The methodology for designing the production structure of a road construction organization while minimizing the costs of its creation and operation is given in [5]. The optimization of the number of road construction equipment is carried out by solving the linear programming problem of finding the amount of work performed by sets of road construction equipment at construction sites [6].

3. The results of experimental studies and their discussion

In the general case, the problem of choosing and distributing road construction equipment is shown in figure 1; it can be represented mathematically as follows [7].

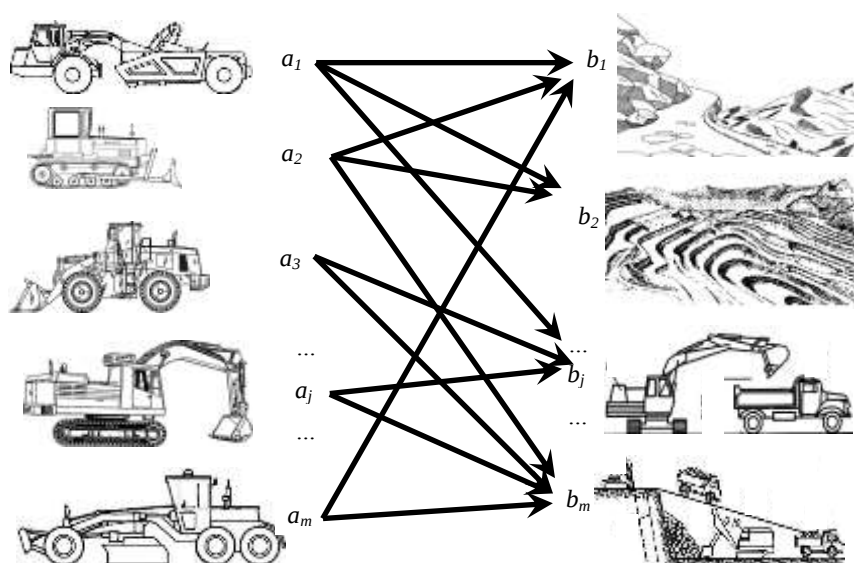


Figure 1. Scheme of task setting, substantiation of road construction equipment, its distribution.

There are n objects where work should be carried out at the same time by m sets of machines. The available total resources of machine hours (machine shifts) are limited and equal to $b_1, b_2, \dots, b_j, \dots, b_m$. The cost of machine hours (machine shifts) per unit volume of work at the i -th facility by the j -th technique is a_{ji} . It is required to distribute road construction machines between objects in such a way as to ensure the greatest productivity of the detachment of existing machines.

Let us denote the required volumes of work performed by sets of machines at the facilities, by $x_1, x_2, \dots, x_i, \dots, x_n$. Then the constraints in this problem can be written as follows:

[illegible]

where a_{ji} - the cost of machine hours (machine shifts) per unit volume of work when performing at the i -th facility by the j -th technique, $a_{ji} \geq 0$; $j = 1, 2, 3, \dots, m$; $i = 1, 2, 3, \dots, n$; x_i - volumes of work performed by sets of i -th machines at the facilities, $x_i \geq 0$; $i = 1, 2, 3, \dots, n$; b_j - maximum number of machine hours (machine shifts) spent on the j -th object $b_j \geq 0$; $j = 1, 2, 3, \dots, m$.

It is assumed that the productivity of a machine is inversely proportional to the cost of machine time per unit volume of work, therefore, instead of maximizing the objective function for productivity, it is possible to minimize the objective function of the cost of computer time

$$L = x_1 \sum_{i=1}^m a_j + x_2 \sum_{i=1}^m a_j + \dots + x_i \sum_{i=1}^m a_j + \dots + x_n \sum_{i=1}^m a_j \rightarrow \min, \quad (2)$$

where L - total cost of machine time, machine hours (machine shifts);
or minimize the objective function

$$L = \sum_{i=1}^n x_i \sum_{j=1}^m a_j \rightarrow \min \quad (3)$$

under constraints (1) and the condition of non-negativity $x_i \geq 0; \quad i = 1, 2, 3, \dots, n$

This problem in this formulation is a linear programming one, in particular, the so-called “transport problem”, and it can be solved by standard methods through the formation of an initial reference plan and its optimization by the potential method [8, 9]. However, the resulting solution can only show the ideal distribution of road construction equipment by production facilities and types of road works.

The cost of machine-hours per unit volume when performing work on the i -th facility with the j -th technique is dependent on the performance of the machine and the conditions of the road construction work and can be determined by the following formula [7]:

$$a_{ij} = \frac{1}{\Pi_{ij}} Ky_{ij}, \text{ machine hours/m}^3 \quad (4)$$

where Π_{ij} - productivity of j -th machines when performing work at the i -th object, m^3/h ; Ky_{ij} - coefficient of accounting for the conditions of road construction works, $0 < Ky_{ij} \leq 1$.

Consideration of conditions is of great importance in the design of the road-building division of a mining enterprise, since the conditions for the production of road-building works significantly affect the productivity and cost of machine time for the performance of standard volumes of work.

Moreover, sometimes the cost of work in real conditions is several times higher than the normative [8,10].

To take into account the conditions for the production of road construction works when designing the road divisions of mining enterprises and the choice of road construction equipment, a technique for taking into account the real conditions of work is intended. The methodology provides for finding the mathematical expectation of $M(\Pi_{ij})$ productivity in fractions of productivity for the main type of work performed by the j -th type of equipment in optimal conditions.

The methodology involves the following steps [11]:

- determination of the list of φ -th conditions that are most often encountered when performing road works and affecting the performance of machines;
- clarification of the scope of work for each type of machine and determination of the k -th share of the type in the total amount of work performed by the j -th type of road construction equipment;
- the identification of patterns of change in the productivity of machines of the type when performing work of the type in optimal conditions;
- identification of patterns of change in machine performance for each of the k -th types of work in φ -th conditions using previously obtained data cited in a number of studies [12, 13] in special issues;
- calculation of the mathematical expectation of the productivity of machines of the j -th type on the k -th type of work under φ -th operating conditions.

First of all, it is necessary to clarify the lists of work for each j -th type of road construction equipment under consideration, which are given in [6, 13].

The share of the k -th type of work in the total volume, performed by the type of equipment, was determined taking into account the following considerations.

Graders are designed primarily for the production of planning works. Therefore, for machines of this type, such type of work as the layout of the top of the subgrade was adopted. In [10] it was established that the performance of motor graders is determined when planning the top of the subgrade with irregularities of up to 15 cm. With this in mind, the volumes (in m^3) of planning work on the site per day were calculated.

The main type of bulldozer work is soil development with movement up to 50 meters. The amount of work on leveling the delivered soil and stone materials was calculated from the condition that the bulk (up to 67% of the total volume of the brought soil) is carried out by bulldozers, and the rest - by graders. The volume of backfill is adopted in accordance with [7, 13]. The volume of planning of the subgrade and slopes was adopted taking into account the construction of new sections of roads.

The results of similar calculations for scrapers and excavators were obtained in [3, 13], which shows the shares of each k -th type of work in the total amount of work for each j -th type of equipment. In further calculations, these values can be taken as the probabilities of machines performing work of the k -th type.

The performance reduction factors for the listed conditions of the work were established by the authors of a number of works [6, 7, 10, 13, 14] quite accurately. The calculation of the coefficient of performance decline is a multiplicative convolution of private indicators of performance decline as a result of exposure to φ -th operating conditions. An example of a decrease in the performance of road construction machines is given in table 2.

Table 2. Decrease in productivity of road construction machines [13].

Type of road construction	The value of the coefficient of performance decline		
	By the difficulty of	By humidification	By both

machines	development	conditions	factors
Motor grader	0.9	0.8	0.72
Bulldozer	0.88	0.8	0.7
Scraper	0.9	0.8	0.72
Excavator	0.78	0.8	0.62
Front loader	0.74	0.8	0.59

To calculate the mathematical expectation of productivity of a technique of the j -th type at the k -th type of work in the φ -th operating conditions, the probability of the k -th type of work is specified. The probability of the main type of work is calculated as follows:

$$P_{och} = 1 - \sum_{k=1}^{t-1} P_k, \quad (5)$$

where P_{och} - probability of work of the main type; P_k - probability of k -th type of work.

Then, the mathematical expectation of the performance of road construction equipment in φ -th conditions for each k -th type of work is determined. Then the mathematical expectation of productivity of the j -th type of equipment is calculated under φ -th conditions taking into account k -th types of work $M(\Pi_{ij})$.

4. Conclusion

The proposed methodology will allow choosing a set of road construction equipment when designing quarry road construction units, as well as performing related works at mining enterprises. The choice is made taking into account the performance of brands of cars of various types by kinds of work, taking into account the operating conditions when optimizing the volume of work performed at various road construction sites.

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