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Improving machine operation management efficiency via improving the vehicle park structure and using the production operation information database

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Abstract. The work represents the results of studying basic interconnected criteria of separate equipment units of the transport network machines fleet, depending on production and mining factors to improve the transport systems management. Justifying the selection of a control system necessitates employing new methodologies and models, augmented with stability and transport flow criteria, accounting for mining work development dynamics on mining sites. A necessary condition is the accounting of technical and operating parameters related to vehicle operation. Modern open pit mining dispatching systems must include such kinds of the information database. An algorithm forming a machine fleet is presented based on multi-variation task solution in connection with defining reasonable operating features of a machine working as a part of a complex. Proposals cited in the work may apply to mining machines (drilling equipment, excavators) and construction equipment (bulldozers, cranes, pile-drivers), city transport and other types of production activities using machine fleet.

1. Introduction

Nowadays, mining, construction and other works use more than half a million of various models of machines. The most efficient way of using them is via machine complexes (comprehensive mechanization demands) that are established in industries: the mining industry deals with excavator vehicles, cargo handling complexes on transport; the construction industry deals with various construction machines, depending on the particular work to carry out.

A complex includes various machines for different purposes to be grouped, depending on the amount of work, into machine marks with a varying amount of similar equipment (i.e. excavators, bulldozers, dump trucks, cranes etc.). The parks include machines with different characteristics (i.e. tonnage, capacity, productivity, parts implementation). Since machines are expensive, while production and technical operation is costly either, the park structure must meet the demand for efficient operation of the machines with required productivity, safety guaranteed in combination with reduced time waste and expenses.

A basic element in any control system is a controlled object. Regarding mining facilities transport systems, a controlled object may be equipment for a technological process and the technological process itself. Depending on the intended purpose, the controlled object may possess input and output parameters, i.e. material, power and information flows incoming and outgoing, as well as it may influence the object by deflecting output values compared to the specified one. Creating complex parameters allows the most efficient selection of a particular system automatically, with dispatching open-cut transport, justifying specific equipment unit selection and the number of units in the fleet.

2. Materials and methods

Let us consider open-pit mining using open-pit dump trucks as an example of opportunities to manage the dump trucks park structure (operating certain amount of dump trucks from different producers, different models from the same producer, with different ages) to guarantee an efficient use of machines, material and labor resources.

The amount of resources mined in Russia constantly grows, with most resources mined via open-pit mining to be transported by vehicles (up to 70%). Developing an open pit further results in deepening the location and increases the transportation distance.

Automation and dispatching systems nowadays used in open pit resource transportation allows monitoring the mining works and managing it via transport vehicle redistribution. For example, should some dump trucks or excavators be rendered inoperable, the traffic situation deteriorate, the resource mined volume to load change, the system software (and the dispatcher, if necessary) allow selecting the solution to maintain transportation efficiency. It is back in 2000s, when the systems from the companies Micromine Pty Ltd. (Western Australia), Wenco International Mining Systems Ltd. (Canada), Modular Mining Systems Inc. (USA), LLC VIST Group and CJSC NPO Sojuztechnocom (Russia) etc. were implemented in large open pit mining sites to allow accumulating much information on dump trucks operation.

The mining transport complex dispatching system is a complex of vehicle-borne, navigational and radio equipment allowing automated accounting of technical and operational parameters of vehicle operation, it has a dispatching center and vehicle-borne systems mounted on dump trucks. Those systems continuously collect information: about a vehicle location in the coordinate system, the distance covered, the dump truck speed, loaded weight, residual fuel in fuel tanks, the engine and other units operation time. All the information collected is transferred over the radio (GSM antenna) to the dispatching center for further processing and storing in the database on the working shift basis or daily, or monthly.

A dump truck is routed to minimize time waste and to maximize excavator productivity.

In turn, the volume of information (the amount of parameters and the information update frequency) is defined by the formulated tasks of managing the excavator and vehicle complex. Major factors for determining the operative management tasks are the rock mass volume which should be transported, total demand for loading/unloading equipment etc.

It is proposed to use the information to form the best dump truck park management structure via selecting the model and determining the best number of machines.

When the amount of work changes, it is virtually impossible to quickly change the park of machines and replace the models the machine park comprises. Increasing the number of machines to operate is costly and time consuming. Reducing the number of machines results in losing the productivity and time waste on machines unused, and that means financial losses. Practically, when scheduling mining works, determining the number of working machines is followed by determining the reservation factor to increase the number of dump trucks in a park 1.3 … 2 times.

Today, there are models [1] and methodologies [2, 7] developed to form dump truck parks by profitability criteria that use operation criteria related to various types of dump trucks throughout their entire service life. A park is formed with minimum operation, ownership and service costs according to statistics available for various types of dump trucks used in Russia and abroad.

An improvement also counts the park of machines to be used for 5-10 years and operated on constantly changing routs. It is necessary to finish the park formation with the following criteria taken into account: stability [6] and transport flow to compare transport vehicles [3-5] used.

It is also necessary to include the machines from at least two producers into the park to provide a better service and easier repairs and to reduce the cost of accessories and spare parts, and also repair workers' and drivers' skills are thus improved. A dump truck park formation algorithm (figure 1) for a mining enterprise takes the following technological and production parameters: productivity, dimensions, cost, reliability, operating costs etc.

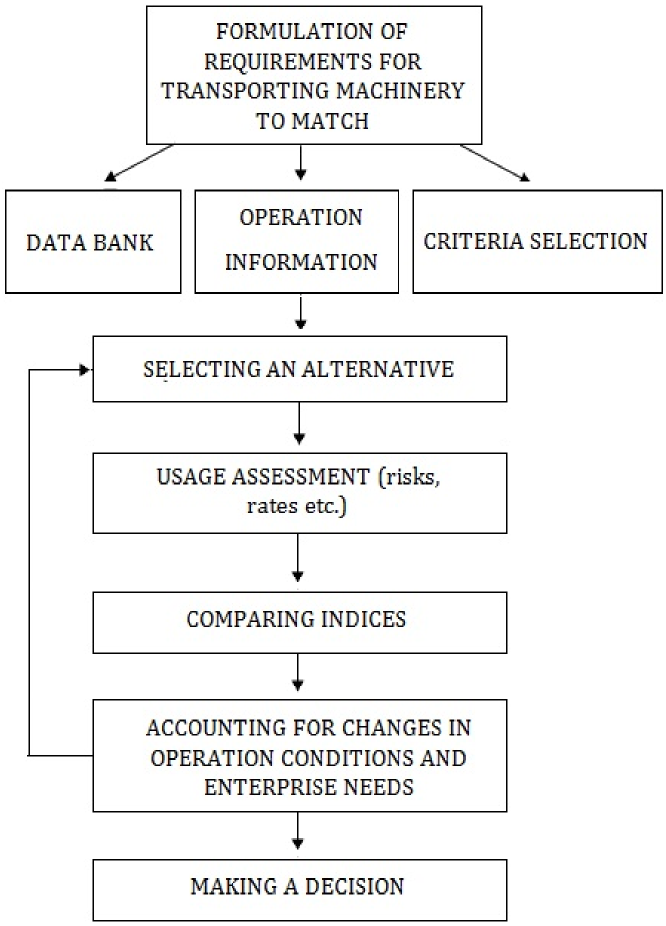

Figure 1. The dump truck park formation algorithm.

To improve production enterprise management efficiency at the level of the machine park structure, one needs, based on outsourcing, to establish centers of technics with a function of conducting technical operation and leasing service provision. The conditions that are favourable for launching these centers are present in mining clusters of Ural region, Yakut republic, Karelia, Krasnoyarsk region, Northwest region (Leningrad and Murmansk areas).

Cargo transportation from the production place (mining) to the delivery point (consumption or processing) is to be considered as a material flow motion within the space-time coordinate system. It has three characterizing parameters: volume Q[t], time T[h] and distance L[km]. And it is in one of 4 states: loading-transportation-unloading-storage. The value of transportation services represents the integral parameter, with the physical meaning of reflecting the value of the power spent by the transportation machine within the transportation time [8-10].

The total efficiency of the transportation service, Em, accounting for power spent, would be defined as the ratio between the transportation work carried out and the power spent:

$$Em = (Q \cdot L) / (Q \cdot L^2 T^{-3}) = T^3 / L. \quad (1)$$

And the ratio between the transportation service provided and the work, Ep, carried out is:

$$Ep = (Q \cdot L)(L \cdot T^{-1}) / (Q \cdot L^2 \cdot T^{-2}). \quad (2)$$

Bigger values of Em and Ep mean better usage of transportation machines. Calculation results for comparable conditions depending on inclination are represented in figure 2.

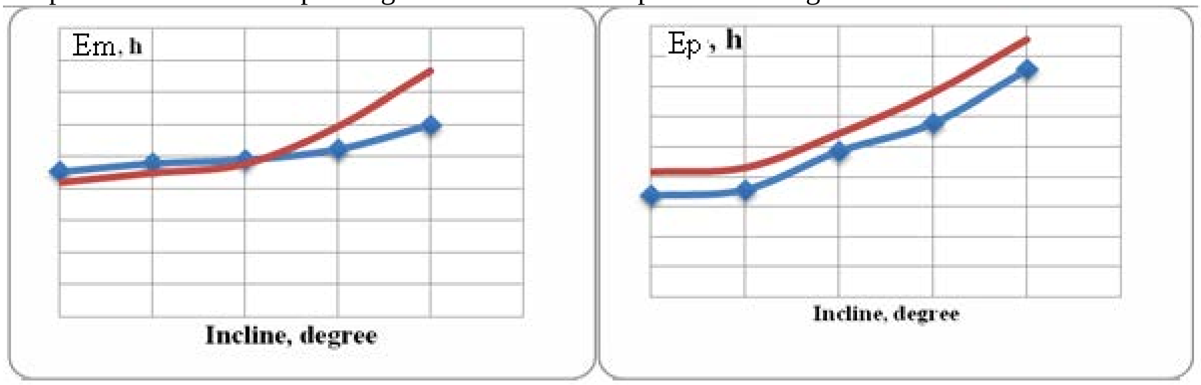

Figure 2. Changes in Em and Ep indicators depending on the angle of inclination: the red line for the dump trucks with load capacity of 55 120 tons; the blue line - railroad trains with dump cars, having load capacity of 60 and 120 tons.

3. Batch-continuous transport system parameters calculation

Designing transportation systems for transportation machine complexes with different principles of operation – batch and continuous ones – suggests that its logistics requires consideration of the transportation process in general. The complex operation efficiency is provided by the continuous transportation process implementing hopper storage devices [11].

For example, single-stall methods of mining potash utilize the complex of mining transportation equipment that includes a tunneling machine, a self-driving wagon, a reclaim hopper and a movable hopper (figure 1) [12]. The latter is not always used for unloading the wagon onto a drag-type conveyor. The complex consisting of a tunneling machine and a self-driving wagon only, is rarely used, mainly for short distances: during cutting, driving, short workings etc.

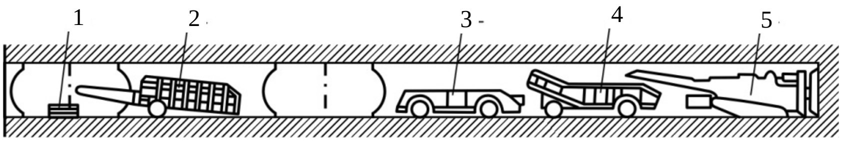

Figure 1. A tunneling complex for ore mining: 1 - a drag-type conveyor; 2 – a hopper; 3 – a self-driving wagon; 4 – a reclaim hopper; 5- a tunneling machine.

The main disadvantages of wagons is the impossibility to handle the ore in a chamber in case the mainstream transport fails, the performance depending on the delivery distance, and the presence of a cable that limits the transportation length [13, 14].

A distinctive feature of the discussed complex operation is the existence of the critical delivery distance, exceeding which results in the tunnel machine idle time waiting for a wagon, thus significantly compromising the performance of the complex. The critical delivery distance may be derived from comparing complex machine operation times during a single transportation cycle. The operation time of the reclaim hopper per cycle is:

$$A = t_{z.p} + t_{r.p}, \quad (1)$$

where $t_{z.p} = G_{b.p}/Q_k$ is the time of loading a reclaim hopper by the tunneling machine, in minutes; $G_{b.p}$ is the loading capacity of the reclaim hopper (the wagon), ton; $Q_к$ is the technical performance of the tunneling machine (in machine hours), t/min; $t_{r.p}$ is the unloading time of the reclaim hopper into the self-driving wagon per cycle, in minutes.

The hopper operating time is:

$$B = t_{z.v} + t_d + t_{r.v}, \quad (2)$$

where $t_{z.v}$ is the time of loading the wagon, in minutes; $t_d = 2L/\upsilon$ is the total time of motion for the loaded and empty wagon, in minutes; L is the delivery distance, in meters; υ is the equivalent speed of the wagon, m/min.; $t_{r.v}$ is the wagon unloading time, in minutes.

The equivalent speed of the wagon shall be:

$$\upsilon = \frac{2\upsilon_g \cdot \upsilon_p}{\upsilon_g + \upsilon_p}, \tag{3}$$

where υ_g , υ_p are the average speeds for the loaded and the empty wagons, correspondingly, m/min.

We take the reclaim hopper's and the wagon's operation time as equal during unloading, as the amount of the unloaded ore and the unloading method (by a bottom conveyor) is the same. Therefore, with accuracy good enough for calculations, we assume $t_{r.p} = t_{r.v} = t_r$. Then, believing that $t_{z.v} = t_{r.p}$, we have:

$$A = q/Q_к + t_p; \quad B = 2L/\upsilon + 2t_p. \tag{4}$$

If delivery distance L is such that $B < A$, then the wagon is idle waiting for the tunneling machine to fully load the reclaim hopper. If $B > A$, then the tunneling machine is idle, having finished with loading before the wagon arrives. Critical delivery distance L_{cr} is reached when $A = B$:

$$L_{cr} = \frac{\upsilon}{2}\left(\frac{q}{Q_к} - t_r\right). \tag{5}$$

The discussed methodology is applicable for other mining transportation complexes used in open and underground mining works to determine the required performance of batch and continuous operation machines establishing the complex, and to determine the capacity and the layout of accumulation tankages in combined transportation schemes.

4. Conclusion

Production transport network automation is complicated due to a vast range of technologies employed in production. It necessitates creating a flexible system with adjustable technologies, with the performance dependent on the abovementioned complex parameters of the transport unit types as well as operating features thereof, such as the total efficiency of the transportation service, Em; the operating time, B; the equivalent speed, v; the critical delivery distance, L_{cr}.

The proposals presented herein may be applied to mining machines (drilling machines, excavators) and road construction machines (bulldozers, cranes, pile driving machines), municipal public transport in cities, as well as other types of production activities that use vehicles and advanced dispatching systems.

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