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Optimization of truck operation at gravel deposits

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Abstract. The paper considers the operating capacity issues for the *BelAz-7540* dump trucks operating at the gravel deposits of the Far North of Russia (*Mayat* mine case, *Almazy Anabara* joint stock company). Based on the statistical data analysis, the study has defined the influence of the surrounding air on the trucks' operating capacity, as well as the components limiting the trucks' reliability and operating efficiency. A method of optimizing the technical maintenance-and-repair schedule has been suggested for reasons of increasing the trucks' operating efficiency.

1. Introduction

There has been an increase in the mining output in the last decade due to the growth of the number of gravel deposits. This, combined with the fact that the deposits are characterized by extreme climatic conditions and that the mined rock is transported mostly by the *BelAz* rock handlers, accounts for the necessity of more research on the trucks' maintenance and reliability aspects.

Motor transport is an important link of the mining cycle, its operating capacity determining the enterprise' production capacity and the follow-up technological processes connected with the processing of the mineral raw materials. The mining transport operation in the extreme nature-and-climatic conditions shows that the number of the machine components' and assemblies' failures increases and the mean time to failure is reduced by a factor of 2-3.

Thus, research on the motor transport operating capacity as well as the influencing factors, with the purpose to develop the measures on increasing the trucks' operating efficiency in the conditions of the Far North gravel deposits is an important theoretical and practical task.

2. Materials and methods

In order to define the parameters characterizing the *BelAz-7540* trucks' operating capacity, the study has used the statistical failure, maintenance-and-repair data accumulated over the truck' operation time, as well as the records of the completed transport works.

The methods used in the study are: analysis of the published works on the transport equipment's reliability, statistical and regression analysis, and mathematical modeling by the cosinor method.

3. Research results and analysis

The study on the Far North quarry equipment shows that in the conditions of low temperature and significant temperature fluctuations over a short period of time, there is a double or triple decrease in the number of failures, which leads to the operating capacity decrease [1, 2, 3, 4, 5, 6, 7].



Figure 1 shows the failure number distribution by the components of the *BelAz-7540* trucks. The trucks' operating capacity is limited by the following components responsible for more than half of the failures: suspension, engine, driving axle, wheels and tires.

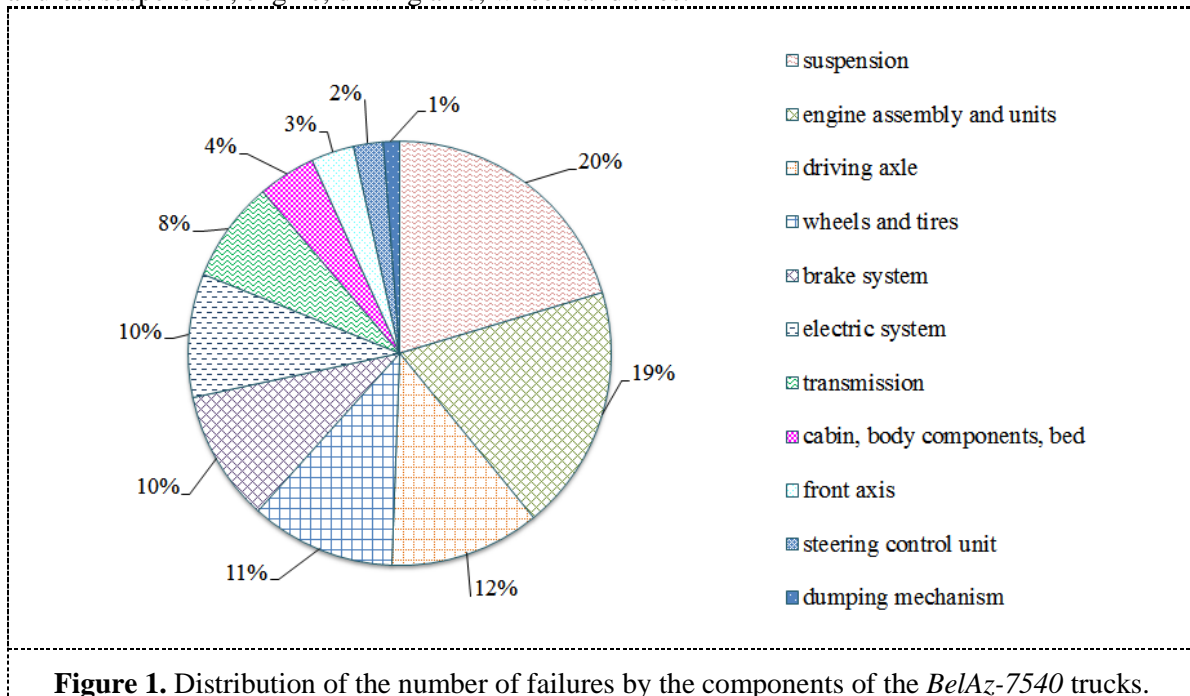


Figure 1. Distribution of the number of failures by the components of the *BelAz-7540* trucks.

In order to define the character and degree of the working conditions' influence on the trucks' operating capacity, the failure flux parameter has been defined. The calculation results are presented in Figure 2. The graph shows that in the cold period, the trucks' failure number increases. The increase of the failure flux parameter indicates that the maintenance conditions significantly influence the operating capacity of the trucks.

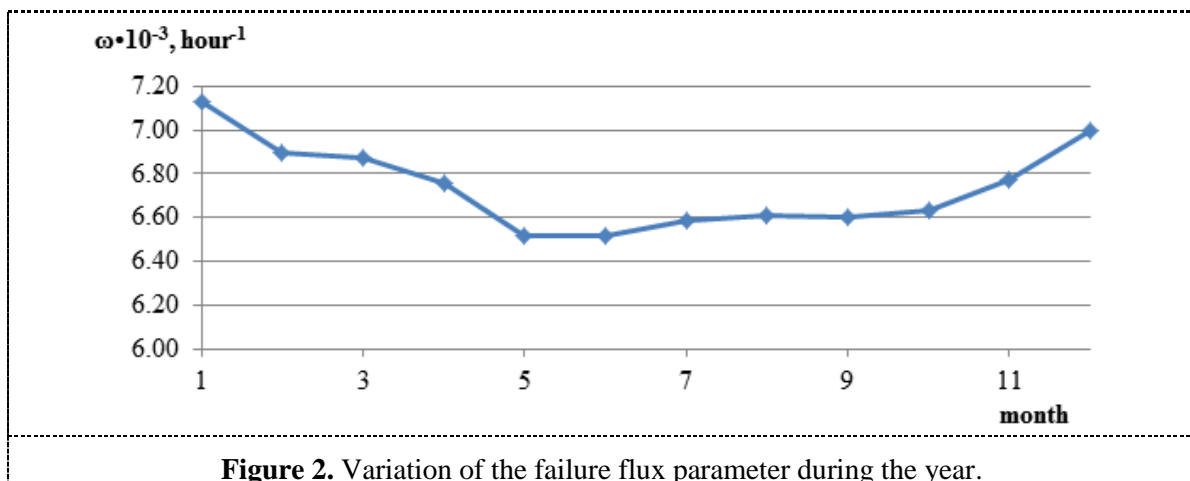
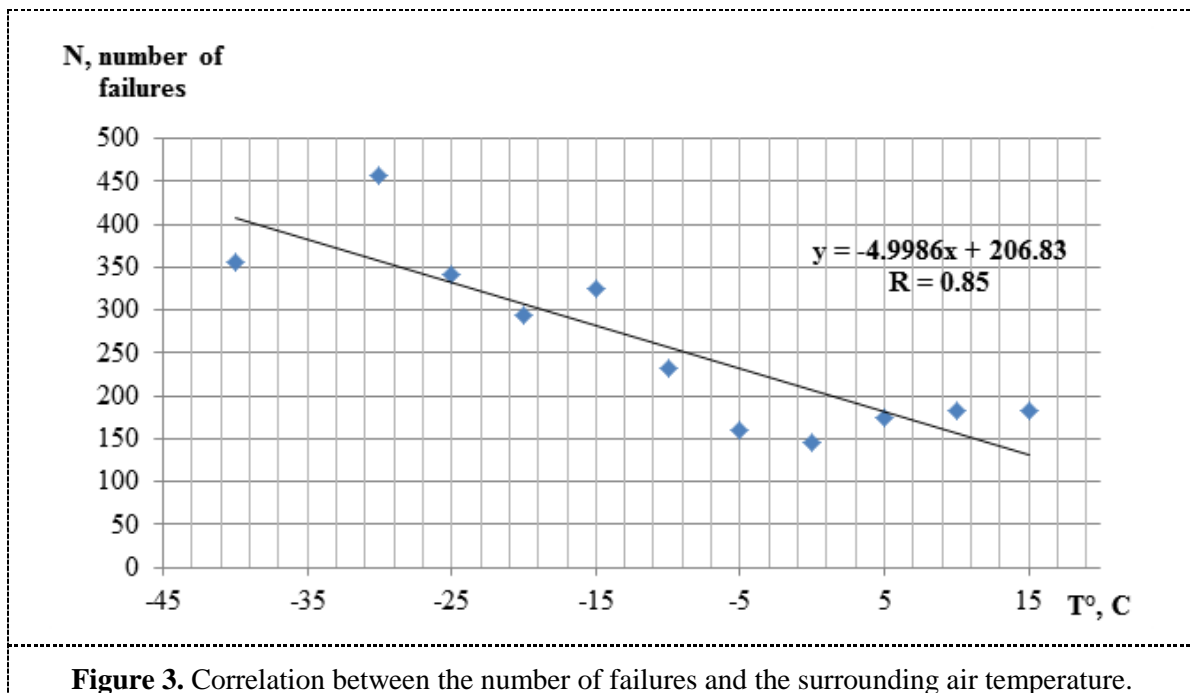
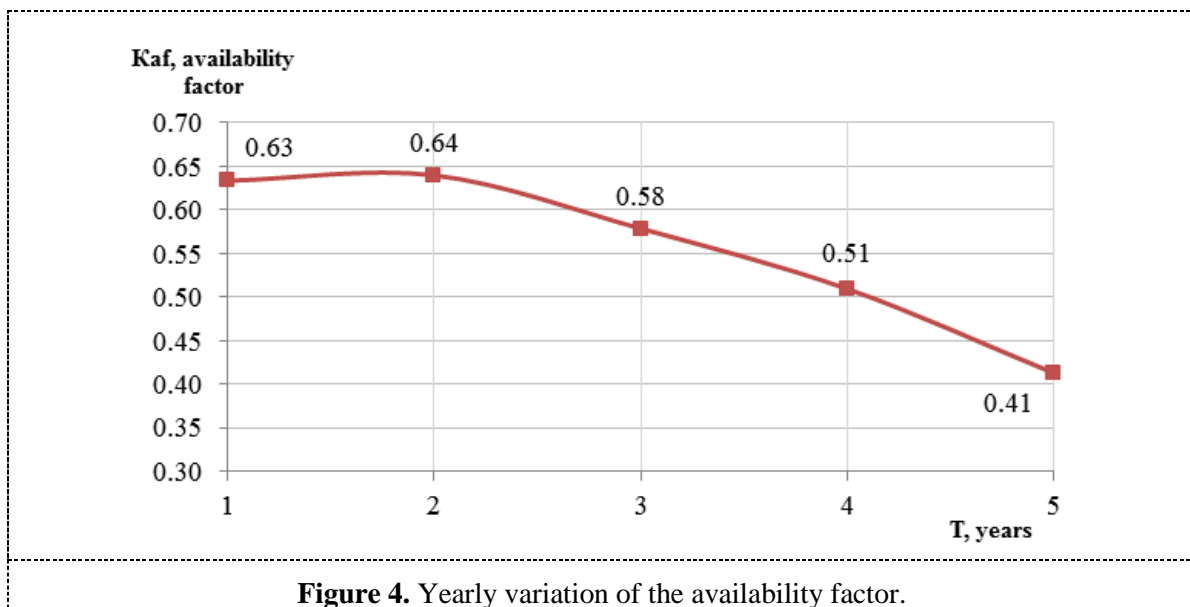


Figure 2. Variation of the failure flux parameter during the year.

Figure 3 shows the correlation between the failure number and the surrounding air temperature. The dependence is of a linear character, the correlation coefficient being 0.85. It is to be seen that at a low temperature (-30° to -40°C) the failure number is 2-3 times higher than that at a temperature close to 0°C .



The dynamics of the availability factor represented in the graph below shows the operation process and its effectiveness (Figure 4): the availability factor gradually decreases indicating the ineffective truck operation.



The results of the study are as follows: it has been found that the surrounding air temperature has a significant influence on the trucks' operating capacity; the components limiting the truck reliability have been defined; the decreasing availability factor indicates ineffective trucks' operation.

4. Discussion

The trucks' operating capacity management is implemented with the means of the maintenance-and-repair systems that aim at preventing failures via timely fault clearance.

The preventive maintenance system makes provision for the trucks' stage-by-stage maintenance during the year, i.e. daily operations; first, second and third service routine; seasonal maintenance routines. For the purpose of restoring the trucks' operable condition, there are scheduled measures: routine repair, first and second scheduled repair, and general overhaul.

The drawback of the standard maintenance-and-repair system is that the preventive maintenance schedule is based on the 'standard' conditions defined for the identical machines and equipment, i.e. the technical maintenance is scheduled by the standard specifications of the base truck model.

As a consequence of the established standards of the maintenance conditions not being updated with the account of the operation conditions, either the capacity of the trucks' assemblies and components is not fully used or the trucks' mean time to failure and the scheduled operation time is reduced.

Development of the gravel deposits in the Far North regions is determined by the seasonal specifics, i.e. the transport equipment is intensively used in the flushing period, which leads to the high tear-and-wear of the trucks' assemblies and components. The failures accumulated by the beginning of the flushing period cannot be compensated with the seasonal maintenance measures and scheduled repairs, thus they influence the operation of the trucks during the intensive period.

Therefore, the current maintenance-and-repair system does not provide the required trucks' operating efficiency, which makes it necessary to develop a system that is adjusted to the operation conditions. The adjustment presupposes: updating the list of the maintenance-and-repair operations, their time interval and work content; introducing the typical and recurrent operations in the regulations.

Researchers suggest many methods to define the optimum maintenance time interval. Every method has its advantages and drawbacks, but their realization is limited because of the calculation complexity and also because the methods require processing a big pool of data on the truck operation in specific operation conditions. Besides, such data has to be collected and accumulated.

The analyzed methods [8, 9, 10, 11, 12, 13, 14] can be divided into two groups: analytical and graphical. The analytical group includes: methods defining the maintenance time interval by the allowable parameter values (i.e. hauling capacity, mileage, cycle index, etc.); methods based on the allowable failure-free time; performance-based methods; econometric methods.

However, the above methods have not yet been realized as the truck's operating capacity depends on the factors that are difficult to define in terms of the character and degree of their influence, not speaking about linking them in one complex. Thus, the above methods have a voluntary character.

Combination of the first and second scheduled repairs seems to be a most appropriate solution in terms of effectiveness and cost-saving. Inherently, the new scheduled maintenance measure would be a middle-term repair providing the truck's required operating capacity before the general overhaul.

It is suggested that the maintenance-and-repair time interval is established with the account of the correction coefficient that is defined as follows (1):

$$K_c = \omega_{\text{mod}} \times (\omega_{\text{cold}})^{-1} \quad (1)$$

where $\omega_{\text{mod}} = N_{\text{mod}} \times (T_1)^{-1}$ is the failure flux parameter for the 'moderate' period,

$\omega_{\text{cold}} = N_{\text{cold}} \times (T_2)^{-1}$ is the failure flux parameter for the 'cold' period;

N_{mod} is the expected number of failures for the 'moderate' period,

N_{cold} is the expected number of failures for the 'cold' period [15];

T_1 , T_2 are scheduled time-to-failure values for the 'moderate' and 'cold' period, correspondingly.

The 'moderate' period includes the months of May to September, the other months belonging to the 'cold' period. The scheduled time to failure values for the studied trucks are based on the mining-maintenance works data and are as follows: $T_1 = 255,000$ hours, $T_2 = 165,000$ hours. The calculated correction coefficient K_c is 0.86 based on the conventional non-failure operating time values.

The established maintenance-and-repair time interval by the types of maintenance and repair with the above correction coefficient applied is shown in Table 1.

Table 1. Maintenance-and-repair time interval.

Type of measure	Standard (hours)	Suggested (hour)
SR-1	250	215
SR-2	500	430
SR-3	1 000	860
PR-1	5 000	4730
PR-2	8 000	
GO	11 000	9480

Where SR stands for maintenance *service routine*; PR stands for *planned repair*; GO stands for *general overhaul*.

The time interval reduction leads to a decrease in number of the emergency failures [2, 3, 5, 6, 7]

The increase in the operating efficiency can be also achieved through the increase in the service operations' work content and the time released due to the combination of the scheduled repairs. The calculation of the work content does not account the seasonal maintenance measures as the number of the measures does not change and the measures are realized when preparing for the spring-summer and autumn-winter operation periods; besides, they are combined with the next scheduled maintenance measure.

Table 2. Work content of the repair cycle operations.

Works type	Standard		Suggested	
	Work content, (person/hour)	Amount	Work content, (person/hour)	Amount
SR-1	13	22	15	22
SR-2	32	11	36	11
SR-3	49	8	55	8
PR-1	230	1	403	1
PR-2	492	1		
GO	720	1	720	1
Total work content	2,472		2,289	

Replacing two preventive repair measures with one reduces the repair costs. The suggested repair structure is a complete repair cycle adjusted to the operation conditions.

5. Conclusion

The expected effect of introducing the suggested maintenance-and-repair measures with an optimum maintenance-and-repair time interval is determined by the increase in the non-failure (productive) operating time.

The non-failure operating time is defined as a time difference between the scheduled time assigned for maintenance and repair, and the time based on the suggested maintenance-and-repair structure:

$$T_{pr} = T_{sched} - T_{sugg} \quad (2)$$

where T_{sched} , T_{sugg} are the total work content values of the maintenance-and-repair operations by the scheduled and suggested structure, correspondingly, person/hour.

The expected productivity with the account of the increased non-failure time is calculated as follows:

$$Q_{add} = N_{tr} \times T_{pr.op.} \times Q_{prod} \quad (3)$$

where N_{tr} is the number of the dump trucks; $T_{pr.op.}$ is the non-failure operating time, hours; Q_{prod} is the truck productivity, m³/h.

Table 3. Calculation of the expected productivity for BelAz-7540 trucks.

Parameters	Measurement unit	Parameter value
Number of trucks	units	10
Expected non-failure operating time	hour	183
Hourly truck productivity	m ³ /hour	9
Expected productivity	m ³	16.470

The results of the calculation by formulas 2 and 3 for the expected productivity over a four-year period (for 10 dump trucks) are presented in Table 3.

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