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THE OPTIMIZATION OF AUXILIARY MACHINERY IN OPEN-CAST LIGNITE MINES: A CASE STUDY OF BULLDOZERS

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Abstract: *One of the most important prerequisites for the successful operation of the open-cast lignite mine is to carry out all the auxiliary works timely with* the *necessary quality. The most important and most commonly used auxiliary machines are bulldozers. Engaging time of bulldozers use is in direct relation with the coefficients of the time and capacity utilization of the continuous system for the excavation of coal and tailings, which indicates their importance. More than 100 bulldozers have been hired on the open-cast lignite mines of Electric Power Industry of Serbia.* |The l*ife cycle of these machines is 5-10 years, so it is necessary to replace the complete equipment several times in the lifetime of the mine. The purchasing and the operational costs of auxiliary machines are high, and in the total cost of coal excavating mentioned cost are from about 1.5-2 €. All this points to the importance of choosing adequate type of bulldozer. Also, this paper defines the optimal bulldozer replacement period within the life cycle of that machine.*

Keywords: *Open-cast coal mine, auxiliary works, bulldozers, optimization, availability.*

1. INTRODUCTION

Dozers are most common auxiliary machines at open-cast coal mines, both by type and the scope of tasks these machines can be used for. In the open-cast lignite mines of Electric Power Industry of Serbia (hereinafter designation EPS), in daily operation are more than 50 bulldozers from 300 heavy duty auxiliary machines, while 113 are available. The average age of dozers is around 10 years and achieved 25,000 moto-hours (operating hours). Such structure of age and achieved operating hours is the reason for having more than twice as much available dozers in relation to operating ones.

It should be noted that dozers are generating 45 – 50% of all auxiliary equipment costs. This implies the necessity for detailed analysis of all parameters of these machines, including current and historic trends, as well as some technical capabilities. Such an analysis would enable better forecasting of their operation.

Dozer's life on the open-cast mines is related to numerous factors, where most important ones are machine's quality, operating conditions, maintenance quality, operating quality, and others. Empirical data shows that dozer's life on open-cast mines is 25-30,000 hours, i.e. around 10 years of operation. However, some data also shows that dozers after 6^{th} year of operation are having lesser efficiency which is indicated by reduced number of effective hours which these machines can achieve, higher consumption of fuel and spare parts and more stoppages (failures) (Figure 1).

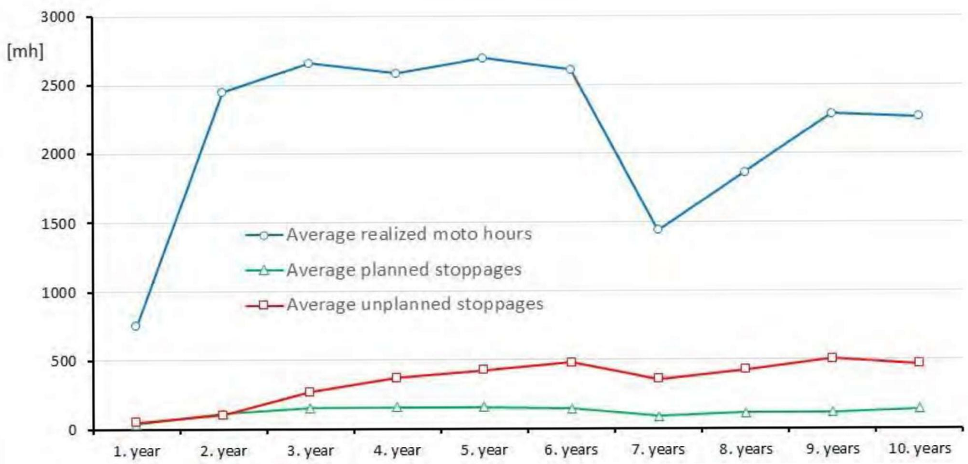

Figure 1. The average number of achieved moto hours in operation and stoppages of dozers for 10 years of operation

2. LIFE CYCLE OF DOZER

Life cycle of mechanization refers to its duration, i.e. it starts just after the designing stage and production stage. Hence, it is the period during which the mechanization is in functional condition, meaning it is used [2, 5].

Life cycle of a machine, facility or any other technical system has a complex structure, and it encompasses several distinctive but interrelated and timely adjusted groups of activities. Technical system is used only during one part of own life cycle, therefore, time it is used is shorter than time of its duration. Life cycle is defined by several stages:

- Concept / project requirements;
- Project concept;
- Main project – designing;
- Manufacturing;
- Application / operation and
- Decommissioning.

As shown in Figure 2, operation of the machine with the highest profit is just a short interval within the operational life. In this period profit is the highest due to low maintenance costs. Subsequent period has larger operational costs, but machine still generates profit, while finally, there is a period during which machine still can operate, but with large maintenance cost and declined reliability, meaning that we are not sure when machine will be available. At this time machine should be replaced [2].

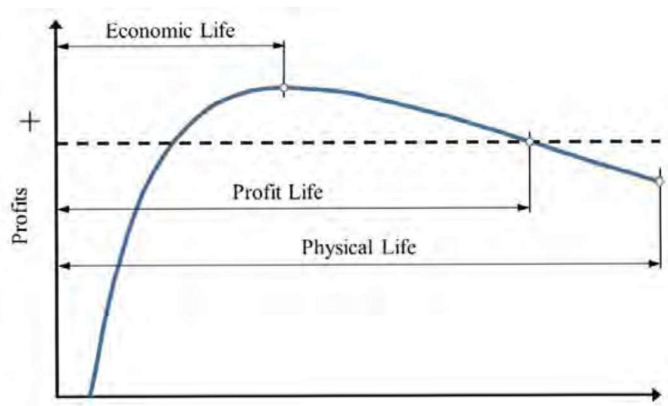

Figure 2. The relation between effective working time and total operating costs

Therefore, it can be said that economic life of the machine is defined by overall costs. However, it should be noted that any activity and each segment of life cycle requires investment of some kind. Life cycle costs can be classified as follows (Eq. 1):

- Ownership costs:
  - Acquisition cost, including transport, supply, insurance,
  - Administrative cost, including management, informatics.
- Operational costs, which are including labor, auxiliary facilities, installations required for work;
- Maintenance costs, which are including maintenance labor, spare parts, tools, devices and facilities for maintenance.

$$C_u = C_v + \int_0^T f(t)dt + C_k T, \tag{1}$$

where:
C_u – total life cycle costs,
C_v – ownership costs,
C_k – specific operational costs per time,
f(t) – function of mean time between failures,
T – time of machine application.

Optimal replacement time is at the moment with minimal cost (Figure 3). [2]

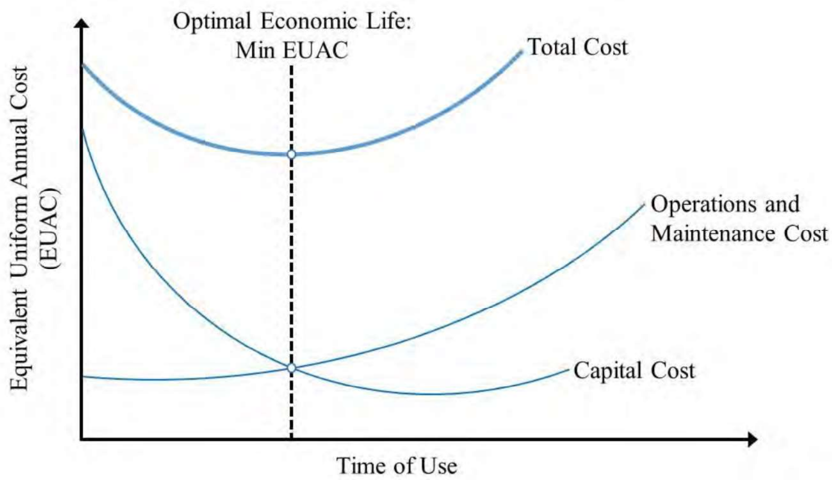

Figure 3. The economic life of the machine, based on the minimal cost method

Hourly ownership costs and operational costs for dozer could vary significantly. Parameters impacting these costs are: type of job performed, costs of fuel and lubricants, transportation cost from manufacturer, interest rates, etc. Analysis was performed according to recommended method for evaluation of hourly ownership and operational costs, including data on auxiliary machines (*Caterpillar* and *Komatsu* methods). Integration of this information with operational conditions will enable reliable evaluation.

Total costs, i.e. specific cost per moto hour is the sum of following costs:

TOTAL COSTS = OWNERSHIP COSTS + OPERATIONAL COSTS + COSTS OF OPERATOR

Following conclusions can be made on average costs for strong and very strong dozers operating on open-cast lignite mine:

- Average costs for strong dozers are 63.75 €/mh;
- Average costs for very strong dozers are 95.12 €/mh.

Limiting costs based on these values are defined for strong dozers at 70 €/mh and for very strong dozers at 100 €/mh.

Operating costs by years for CAT D8R and Dressta TD25M dozers in PE EPS are shown in Figure 4. Costs increasing trend is evident in this interpretation. In case of applying profit life criterion CAT D8R dozer should be replaced after 7 years of operation, or in this case after 22,000 working hours on average. On the other hand, Dressta TD25M dozer should be replaced after 3 years and 8,500 working hours. Limiting cost for all dozers is 70 €/mh [1].

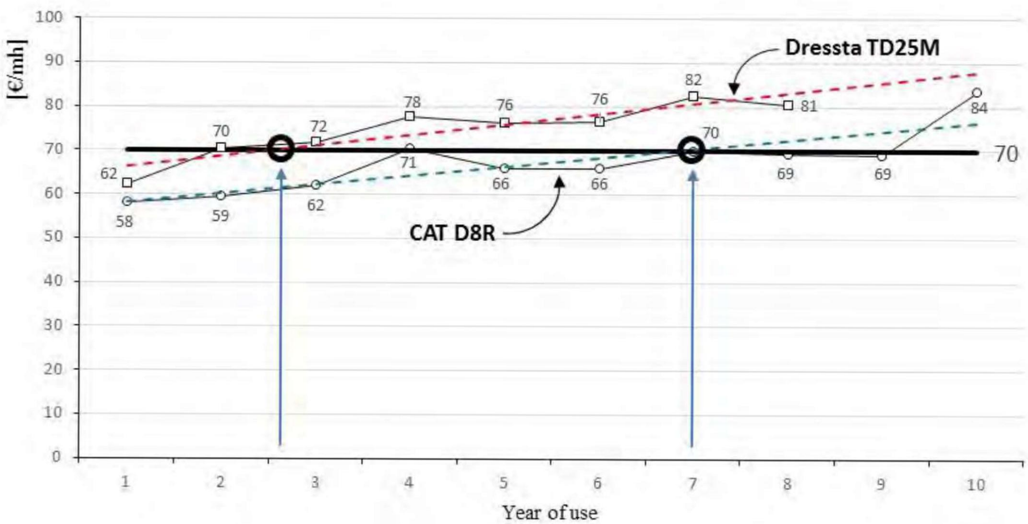

Figure 4. Diagram for determination of limiting costs value for CAT D8R and Dressta TD25M dozers

3. AVAILABILITY

Typical curve of failures, known as "bath tub" curve, is evident regarding dozers operating on open-cast mines. Failure is a condition when the machine completely or partially loses operating capability and it is unable to meet the task requirements and function, as established by the machine design and specifications. One of the most important reliability indicators is failure frequency, i.e. expected number of failures in certain time interval. Failure frequency distribution curve is afore mentioned "bath tub" curve, shown in Figure 5. Interpretation of this curve indicates that usually large number of failures occurs at the beginning of machine's service life, followed by the decline after this initial period. As machine approaches to the end of its life, curve enters the worn-out period with increasing rate of failures.

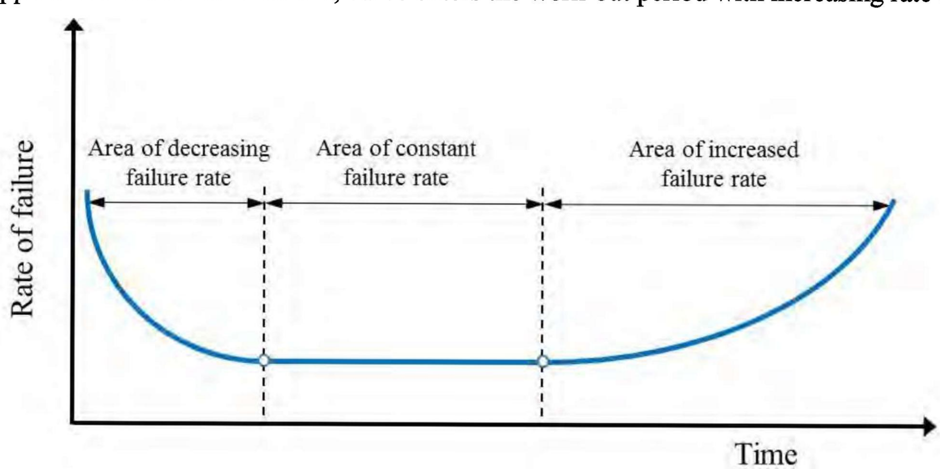

Figure 5. "Bath tub" curve, a relation of time and failure rate

Life cycle analysis of auxiliary machines operating on open-cast mines brings the question related to term which can be used to describe certain properties of this technical system most completely, in relation to performing their functions. In this context following terms are defined: Reliability, Maintainability, Efficiency, Maintenance support, Availability, Dependability, etc. All of these are used to describe behaviour of technical system during specific time of system's life.
Effectivity function is a comprehensive indicator, expressed as probability that specific system will start operation in required time and that it will successfully complete criteria function during designed interval and at given environmental conditions. It should be noted that operation of auxiliary machines are exposed to unexpected impacts, i.e. failures and other events during the life of technical system which are of stochastic nature. Definition of effectivity function is given by Eq 2.

$$E(t,\tau) = R(t) \times A(\tau) \times FP \tag{2}$$

R (t) – Reliability or probability to operate without failure during time t,
A (τ) – Availability or probability that system will be available at any given moment of calendar time τ, i.e. system will be capable to operate,
FP – Functional suitability or level for meeting functional demands, meaning adaptability to the environment or operating conditions.

Research presented in this paper implemented technical availability, i.e. term Coefficient of technical utilization. Coefficient of technical utilization of machine is calculated as given in Eq. 3.

$$k_T = \frac{\sum_{i=1}^{i=n} t_{r_i}}{\sum_{i=1}^{i=n} t_{r_i} + \sum_{i=1}^{i=n} t_{o_i} + \sum_{i=1}^{i=m} \theta_i} \tag{3}$$

where:
k_T – coefficient of technical utilization;
t_r – time in operation (at annual level),
t_o – time in failure (non-planned stoppages at annual level - repairs),
θ – time of planned stoppages caused by maintenance (preventive maintenance – services).

Accurate indicators on coefficient of technical availability of all types of dozers are obtained based on relevant data, median range, and least square method. It should be mentioned that the least square method is one of the most important methods for processing experimental data, which involves components of numerical mathematics and statistics. This method is used to acquire functional relationship of experimental data arrays. Based on the calculation, Figure 6 shows the technical availability coefficient for the CAT D8R bulldozer.

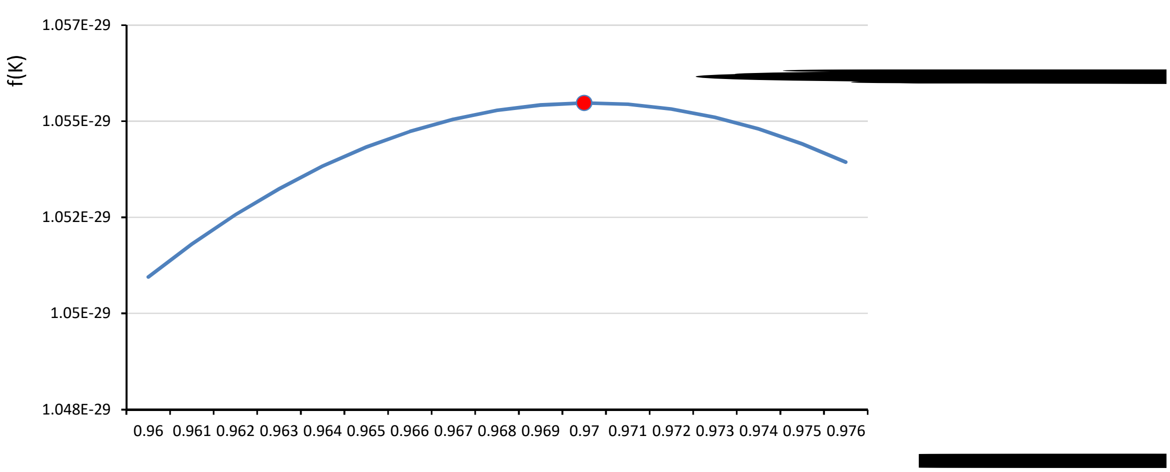

Figure 6. Coefficient of technical availability of bulldozer CAT D8R in Kolubara basin for 1st year of operation

Described procedure was performed for all ten years. Decreasing trend of technical availability coefficient for dozers CAT D8R in Kolubara basin for ten years of operation, only relating to dozers of similar performances (internal marks C3 to C17) is presented in Figure 7.

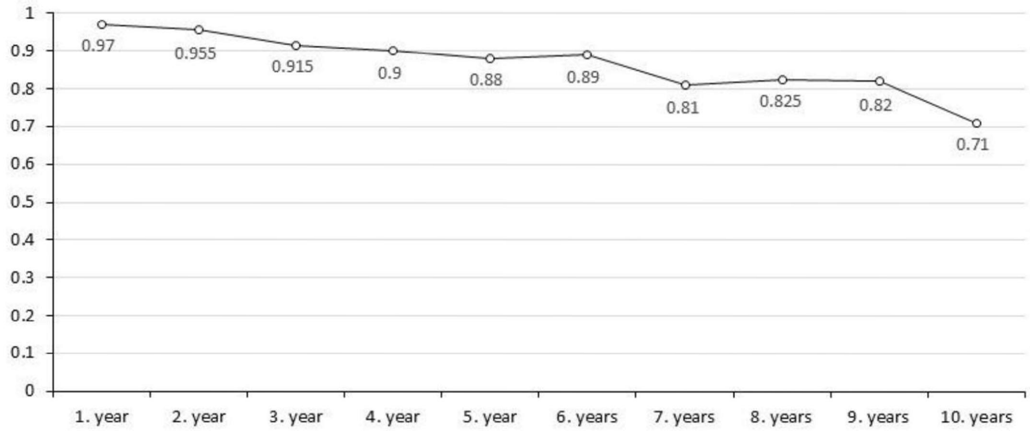

Figure 7. Declining trend of technical availability coefficient of bulldozer CAT D8R in Kolubara basin during first ten years of operation

This diagram (Figure 7) is used for further analysis related to optimal replacement time.

Lower limit of availability for dozer replacement is 0.80. This is limit value for linear correlation of time categories – time in operation, time of planned and non-planned stoppages. It the availability is lower than this value than should be more of the machines in the fleet of the open cast mine, thus increasing the costs. On the other hand, insufficient number of machines (dozers) will result in reduced execution of auxiliary operations, with influence on efficiency of continuous systems. Below is an example with CAT D8R and *Shangai* PD320Y-1. Optimal replacement time is established, based on diagrams of availability of these dozers (declining trend of technical availability coefficient of bulldozers in Kolubara basin for first ten years of operation) and limiting availability of 0.80. This diagram is shown in Figure 8 [1].

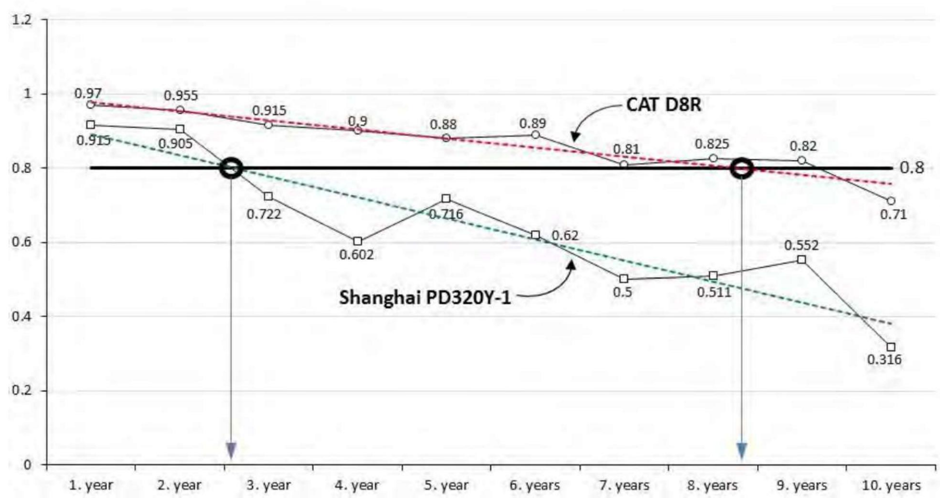

Figure 8. Optimal replacement of dozers CAT D8R and Shanghai PD320Y-1 according to availability

Therefore, CAT D8R dozer, in conditions of Kolubara open-cast mines, should be planned for replacement after 8th year of operation, while Shanghai PD320Y-1 dozer after 3rd year of operation.

4. CONCLUSION

Analysis showed that profit life (economical life) of dozer CAT D8R operating on open-cast mines of EPS is around 7 years, while optimal operating time from the aspect of availability is 8 years. Considering other types of bulldozers operating on open-cast mines of EPS (TD25M, TD25H, 752 / 754, PD320Y-1, SD32W) operational life is around 8 years, excluding model TD 25 M, which exceeded the costs of 70 €/mh during 3rd year of operation [1].

Regarding availability, dozer CAT D8R reaches 80% on 8th year, while availability of remaining dozers is reduced to this value between 3rd and 5th year.

Fact that open-cast mines are having sufficient number auxiliary machines (namely dozers) should be included into determination of their life cycle. These machines will complete all planned tasks and create optimal conditions for operation of main mining machines (bucket wheel excavators, belt conveyors and stackers). It also should be noted that one hour of bucket wheel excavator – belt conveyor – stacker system operation is valued at several thousands of euros, and that value on one hour of dozer operation is below 100 €. Hence, it is more important that open-cast mine has sufficient number of available dozers [1, 4, 6].

Therefore, benefits emerging from this attitude on auxiliary machines selection, including savings and improvements, can be achieved by these activities:

- In-time replacement of auxiliary machines and vehicles;
- Usage of proven and quality machines with implemented unification as much as possible;
- Improvement of maintenance system;
- Implement modern and improved technologies in machine operation.

Execution of these activities or just part of them will reduce the operational and maintenance costs, increase the volume of auxiliary works and create conditions for maximal utilization of Excavator – Conveyor – Stacker and Excavator – Conveyor – Crusher systems. In another word, these activities will increase time utilization and production rate utilization coefficients, at reduced costs.

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