ZIVOJINOVIC, R., and VUJIC, S. Some problems in estimation of the optimum exploitation life of bucket wheel excavators. *Application of Computers and Operations Research in the Minerals Industries,* South African Institute of Mining and Metallurgy, 2003.

Some problems in estimation of the optimum exploitation life of bucket wheel excavators

R. ZIVOJINOVIC* and S. VUJIC†
**The Electric Power Industry of Serbia, Belgrade, Yugoslavia*
†Faculty of Mining and Geology, University of Belgrade, Yugoslavia

The structural age of the capital mining machinery, representing a part of the system of the Electric Power Industry of Serbia, has been dictated by the initiation and development of open pit coal mines. For example, the oldest bucket wheel excavators were installed some thirty-four years ago, and the average life of the relevant machinery exceeds twenty-two years. Operation of both capital equipment and machinery has direct effects on economic and business activities of open pit mines, and consequently forced us to make a decision and study thoroughly the problem of establishing the optimum exploitation life of capital mining equipment at the open pit coal mines of the Electric Power Industry of Serbia. The aim of this paper is to define and discuss the relative problems as well as to find out the possible solutions and establish the methodology for estimating the optimum exploitation life of machinery. The study was successfully carried out by a team of scientists engaged from and coordinated by the Department of Computer Science of the Faculty of Mining and Geology, University of Belgrade. This paper presents the key observations covering the subject problem.

Keywords: Mining, Opencast exploitation, Coal, Optimization, Exploitation life, Capital machinery, Electric power industry, Dynamic programming.

Introduction

This paper discusses the problem of determining the exploitation life of mining machinery from the aspect of selecting mathematical-modelling approaches and creation of a model for solving the subject problem. The excerpts presented in the paper represent a part of extensive exploration work the authors carried out for the requirements of the Electric Power Industry of Serbia and its mining equipment. As this equipment is very heterogeneous both in structure and age, the identification of the adequate approach, when solving the relevant problem, represented a highly demanding task. Namely, the orientation towards application of methods of dynamic programming only, could hardly offer a solution, having in mind the problem of input data validity indispensable for estimation of mining equipment exploitation life.

Thus, the second essential segment of the relevant study was to solve the manner and the procedure for overbridging this discrepancy. Further to this, an original procedure, presented herein, was suggested for the purpose of estimating the technical condition of mining equipment.

The period from 1992 to 2001 (sanctions imposed by the OUN and disintegration of Yugoslavia), was extremely difficult for the Yugoslav economy; significantly stopped its development trends, not excluding the mining industry as well. Over this period, the decrease in production volume was followed by deterioration of equipment condition, as, due to lack of financial means, it was neither renewed nor was quality maintenance carried out. The domestic production of machinery almost stopped.

Throughout the years of severe economic sanctions, the mining industry was brought to near extinction. The mines, generally left to themselves, gradually closed or were at the very margin of their existence and burdened with debts (the copper mine, Majdanpek and the mine basin, Bor). The exemptions are opencast coal mines that have succeeded in keeping production capacity and relatively high outputs.

Thus, unfortunately, both the technique and technology in our mines have been lagging far behind the world's modern trends in coal mines and mines with metallic and partly non-metallic mineral raw materials, while, in the past, the production effects reached in our mines could have been compared with the results obtained in the most developed mining countries.

The objective of this paper is to present the most powerful, most productive and most expensive mining machinery used in the mining facilities of the Electric Power Industry of Serbia, on the basis of which and the coal mined, the installed thermo capacities of 5170 MW realize an annual electric power production of 22 000 GWh.

Mining equipment of the Electric Power Industry of Serbia engaged in coal production

The installed annual capacities of coal opencast mining of the Electric Power Industry of Serbia amount to 43.4 million tons of coal and 93.5 million tons of overburden.

The biggest production of coal, amounting to 42.6 million tons, was reached in 1990, while the biggest production of overburden, amounting to 98.5 million tons was achieved in 1998.

At the relevant open pit coal mines, a continuous technology of exploitation is used, including bucket wheel excavators for mining, belt conveyors for transportation and spreaders for stockpile loading.

The majority of open pit coal mines, within the Electric Power Industry of Serbia, have been operating for more than three decades, while the one opened most recently has been operating for six years. Successive opening of mines, starting exploitation and mining of coal was carried out with the introduction of huge bucket wheel excavators, the capacity of which ranges between 1,700 and 6,060 m^3/h and the weight between 493 t and 3,156 t.

In mine basins of the Electric Power Industry of Serbia, 54 excavators (age breakdown shown in Figure 1), varying in category and production with a total tonnage of approximately 60 000 t, operate mainly within the ECS system. As both spreaders and belt conveyors represent the constituent parts of the ECS system, the total number of this huge capital mining equipment amounts to 115 units, and the total weight is about 95 000 t. Figure 1 gives a review of the capital mining equipment age.

The majority of elements of the observed machinery shows a gradual decrease in operating efficiency, meaning, in practice, the application of a maintenance programme, while the registered stoppages, caused by failure of any element of the system, are also used for maintenance work. Such organization of maintenance increases the time of recovery of ECS system, but at the same time, the costs-made traces vanish except those primarily evidenced and connected with the element that caused a failure.

This paper discusses the capital mining equipment operating at open pit coal mines of the Electric Power Industry of Serbia.

Specifics determining the capital mining equipment exploitation life

A mathematical-modelling approach to determining the exploitation life of capital mining equipment should offer the possibility of recognizing the eventual prolongation of operational life representing a more realistic option for the present burdened with a difficult economic situation. With the estimation of the optimum exploitation life of auxiliary mechanization, the option of prolonging the life has no comparable equivalent and importance relating to capital equipment. Such a researching approach resulted from the extremely onerous financial situation in Yugoslavia: it is the only possible approach that, in accordance with the policy of the Electric Power Industry of Serbia, could improve reliability, safety and economy through the requirements of revitalization and the concomitant modernization and reconstruction of the basic equipment.

The term 'revitalization' understands the activities that are performed with the aim to prolong the working life of equipment, through the parameters warranted by both the supplier of equipment and the contractor, and under completely determined conditions or hypothetical conditions when, for any reason, a complete determination is not possible.

Today, the thirty-year experience in exploitation of machinery with complex continuous technologies at open pit mines of the Electric Power Industry of Serbia, strongly supports through professional circles, the process of revitalization the final goal of which is complete recovery of funds invested in this machinery. For this purpose, the possibilities are discussed on revitalization of old equipment that, when reconstructed and developed, would be more efficient and more reliable. Sophistication of equipment performances would provide longer utilization of the existing machinery without great investments in new ones.

Determination of a time span when revitalization is to be done, represents a demanding and a complex engineering problem while not being in collision with the estimation of the optimum machinery exploitation life and its replacement; on the contrary, their symbiosis is complete. By dividing the exploitation life into the period up to revitalization and the period that will determine the quality and volume of revitalization, respecting the length of optimum life of the first period—exploitation life, the subject problem is completely revealed.

When a decision on replacement or revitalization is based primarily on economic criteria, then the choice is also formed on the grounds of economic analysis, taking into consideration the costs of revitalization and future effects of the improved equipment characteristics. Accordingly, two aspects of revitalization exist:

- short-term prolongation of the working life—partial revitalization, and
- complete revitalization.

The first aspect of revitalization is carried out on old-fashioned and worn-out equipment or under realization of lack of the required finance, thus temporarily prolonging the working life of this equipment. Complete revitalization, requiring significantly greater investments, gives back the

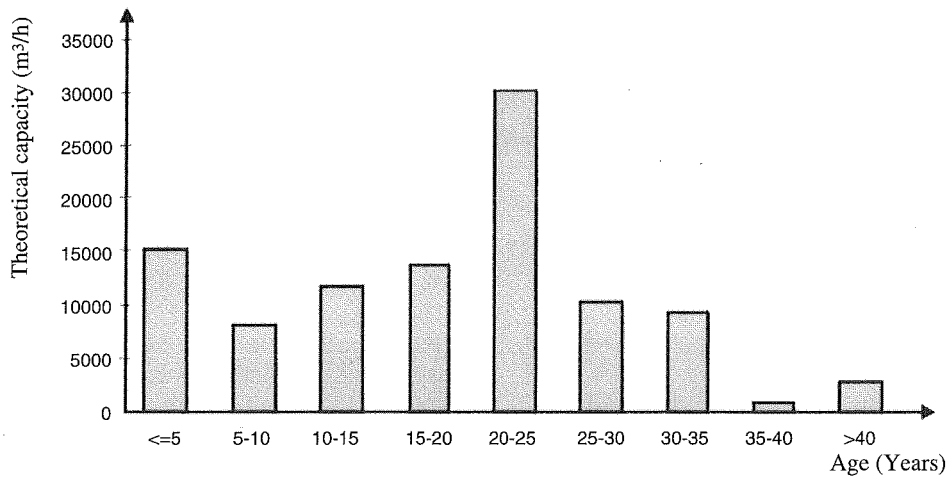

Figure 1. The age of capital mining equipment in the Electric Power Industry of Serbia

working vitality to old-fashioned and worn-out equipment, significantly prolonging its working life.

At the time when large bucket wheel excavators, as well as other capital mining equipment was bought and put into operation (belt conveyors, spreaders, track transporters) at open pit mines within the system of Electric Power Industry of Serbia, the administration issued high amortization rates. Such acts undertaken by the legislator and the state were based on the arguments for establishment of great accumulation that would provide replacement of old machinery and purchase of new, technologically modern and productive, more efficient equipment. This amortization fund was exclusively used for purchase of technology. Large investment funds of mines, created from accumulation, resulted from these legal regulations.

However, complex social conditions occurring after 1999, inexorably degraded this practice so that the mining equipment that paid off itself, could not be replaced but was permanently exploited.

Today, the major part of this mining equipment, in fact all the machinery older than 10 years, has been amortized in bookkeeping.

The paper also presents a model for determination of exploitation life, namely the most represented 'amortized' mining equipment. The model establishes the beginning of activities that prolong the working life of a bucket wheel excavator.

Overhauling of machinery, in order to reach a certain degree of modernization and reconstruction through revitalization, is based on estimation of machinery technical status (for each machine separately) as well as on precise economic estimation.

The open pit mines where coal is mined for the requirements of thermo-electric plants of the Electric Power Industry of Serbia are unified into a functional and technological entity. Considered from that aspect, a decision on removing an excavator and the accompanying ECS system out of working use in order to carry out lengthy overhaul activities for the purpose of prolonging the working life, requires a serious and complete analysis of causal-consequential implications.

How to establish the machinery/overhauling order ?

As the weight of each machine is up to 3,000 t, the spatial model of which contains 2,500 knots, 2,300 poles and 2,400 elements, their dimensions and structural complexity is enormous. Diagnostic methods for determination of the 'technical status' of these machines are very expensive, the process itself requires a long time and also includes a partial disassembling and removal from the operational process. Therefore diagnostic processes, even if costs are acceptable, cannot be applied simultaneously to several machines. This certainly would cause great disturbances in the production process if not a complete collapse.

A logical question is evident; how to rank machinery overhauling priorities when several machines are ranked as equivalent, at the same time, according to criteria of machinery age and status. Besides, the additional condition to be respected is that production at open pit mines should not be compromised.

If borne in mind that duration of operation (number of years/hours) could be the only measure for the status of the excavator, the other indications having an effect on the general technical condition of machinery should be considered. It means that several potential 'candidates' are involved to undergo revitalization. And, as the number of 'candidates' determines funds as well as the time of absence of the excavator from the operating process, a systematic engineering analysis and the solution offering the least disturbance in production and the best post-overhauling effects are required.

This paper also suggests the application of multi-attributive estimation, namely the appraisal of referent indicators of status. By introducing the preferences according to the given indicators and summarizing the scores, the number of scores will determine the first unit on the rank list that will enter the subject procedure (Figure 2).

A global algorithm of multi-attributive ranking of excavators for the purpose of carrying out overhaul-revitalization operations is presented in Figure 3.

The importance and the originality of establishing the 'priority' process for the excavator that undergoes revitalization will shortly be described according to the method based on the operations research experience (multi-attributive decision-making, multi-purpose decision-making). The following estimation indicators are suggested:

Age of equipment (preference 0.80)	*Estimation*
• from 15 to 20 years	0.35
• from 20 to 25 years	0.50
• from 25 to 30 years	0.75
• over 30 years	1.00

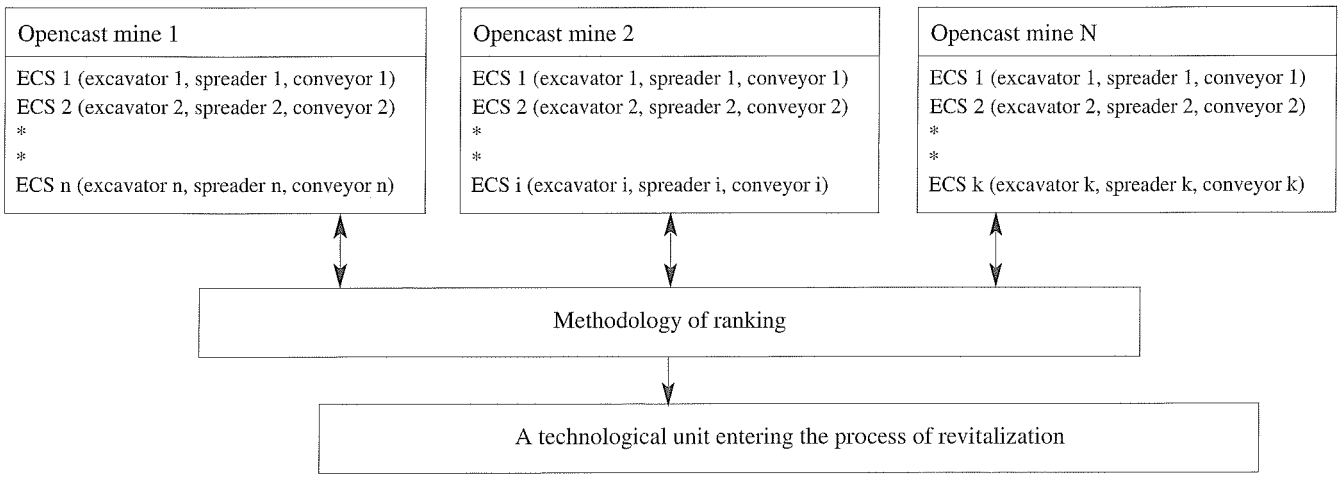

Figure 2. A concept of multi-attributive estimation for the purpose of priority ranking of excavators revitalization

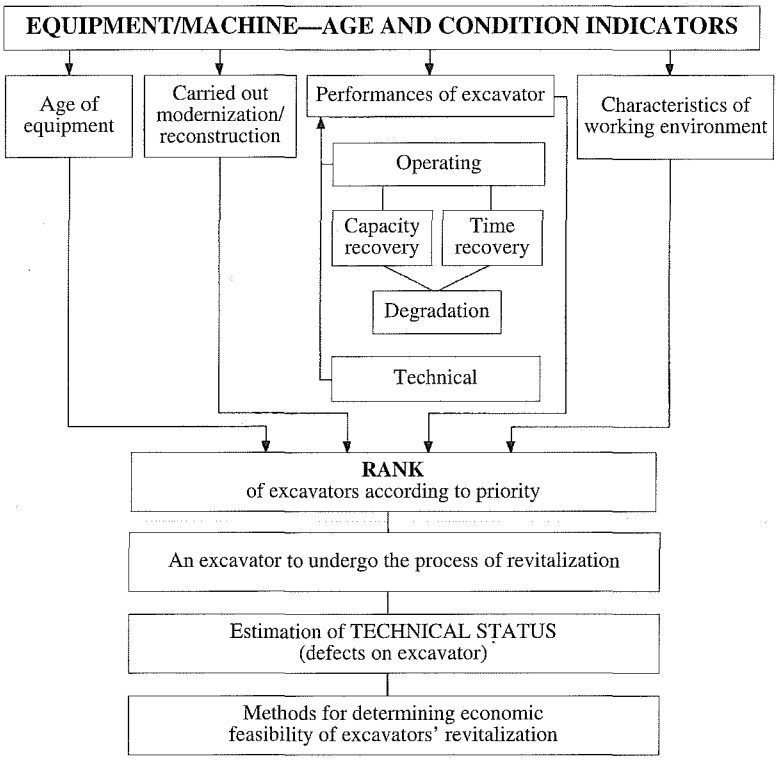

Figure 3. A concept of selecting the excavator

Performed modernization (preference 0.60)

- the equipment underwent modernization 0.60
- the equipment underwent reconstruction process 0.70
- the equipment underwent a partial reconstruction 0.80

Operating performances (preference 0.40) should be established on the basis of the conditions of their operating and technical parameters. Operating performances would be determined on the basis of the realized capacity and time recovery coefficients of the excavator.

The following ranges* are suggested for

Capacity recovery *Estimation*

- up to 30 (%) of guaranteed excavator capacity 0.10
- from 30 to 35 (%) of guaranteed excavator capacity 0.35
- over 50 (%) of the guaranteed excavator capacity 0.50

Time recovery

- up to 30 (%) of annual idle time 0.10
- from 30 to 50 (%) of annual idle time 0.35
- over 50 (%) of the annual idle time 0.50

Degradation of basic parameters of excavator†

- capacity recovery over 30 (%) 0.15
- time recovery over 30 (%) 0.15

Technical performances (preference 0.55)

- number of investment repairs carried out at excavator up to 1990 nx0.02
- number of dates required for investment repairs up to 1990 nx0.02
- number of investment repairs carried out from 1990 to 2000 nx0.01
- number of dates required for investment repairs from 1990 to 2000 nx0.01

Working environment (preference 0.25)

- specific cutting force 0.05–0.015
- moisture of the working environment 0.01–0.10
- size of mined material 0.03–0.12

The final ranking list of priorities is formed after cyclic-process treatment of all machinery representing the objective of multi-attributive analysis.

Conclusions

The author of this paper discusses the model for establishing the exploitation life of the 'amortized' continuous mining equipment, as due to the characteristics of total economic and technical environment, the equipment operates in, the prolongation of exploitation life of the same is the most realistic option. It is also emphasized in this paper that the estimation of the remaining exploitation life of equipment cannot directly result from defects, but the defects precede equipment status estimation and indicate the directions in decision-making (which parts and components of the equipment should be replaced) in order to provide further required safety of functioning. Finally, expected working life of large equipment—bucket wheel excavators—will be determined by economic parameters.

References

ZIVOJINOVIC, R. Mathematical-modelling approach to determination of the optimum exploitation life of equipment at mines, FMG Belgrade, 2002., Doctoral thesis, Belgrade.

VUJIC, S. *et.al.* The Study on Establishing the Exploitation Life of Capital Mining Equipment at Coal Open Pit Mines of the Electric Power Industry of Serbia, FMG Belgrade, 2002., p.138, Belgrade.

TANASKOVIC, T. *et al.* A proposal for determination of exploitation life of excavators by a modified model of replacement, SYM-OP-IS 2000, 2000., Belgrade.

*These parameters would be calculated for the exploitation life of excavators (equipment)

†These values would be established only for the period after excavator's bookkeeping write-off