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Methodology for Selecting Road Construction Equipment in Conditions of Insufficient Information

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ABSTRACT

The choice of the model is one of the determining factors within the concept of assessing the efficiency of equipment during its full life cycle.

The objective of this work is to justify the application of the methodology for assessing the competitiveness and quality of equipment as applied to road construction machines, improved by the authors and proposed for selecting machines under conditions of partial uncertainty and lack of information.

The article methodologically substantiates the information sets to assess the equipment at the selection stage, presents the results of studies of changes in the cost of road construction machines in the secondary market of the Russian Federation, offers assessment approaches to determining the quality and performance of products, and provides a final algorithm of an integral assessment based on individual competitiveness indicators. Methodologically, the proposed method may be of interest when assessing other types and classes of equipment under similar assessment conditions.

Keywords: *transport and technological machines, road construction equipment, quality assessment, competitiveness of machines.*

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INTRODUCTION

Modern domestic and foreign scientific research literature widely considers selected issues of assessing the quality, productivity and competitiveness of equipment in general and road construction machines (RCM) in particular.

The work [1] compares economic indicators of using hydraulic excavators and rope shovels at Russian mines. It was found that the cost of owning an EKG-12K rope shovel is lower than that of hydraulic excavators. The work [2] develops indicators of the efficiency of digging with a hydraulic excavator and software for their calculation. The work [3] studies a strategy for operating a group of machines to balance fuel consumption and productivity, determines optimal parameters for minimising operating costs. The paper [4] analyses the use of RCM for completion of large government projects, such as the Kaleswaram Lift irrigation system project and the Polavaram project. The results of monitoring of the operations of stone crushers and quarries, as well as an analysis of the technical characteristics of the machines, help to optimise marketing strategies for sale of excavators and loaders. The work [5] refers to selection of the most effective models of earthmoving machines for the soil conditions of the Republic of Kazakhstan. The study [6] analyses the evolution of methods for assessing the competitiveness of machines and equipment, identifying their applicability in modern market conditions.

The study [7] describes the expertise of PT Citra Mitra Sehati, an open pit mining company in Ulok Kupai district, Bengkulu, Indonesia. The equipment used, including a Dossan Dx 500 excavator and ten Hino 700 dump trucks, has a high wear rate, which reduces productivity and increases operating costs. The study aims to compare the use of old and new equipment considering economic parameters. The results show that the new equipment is more efficient in production, but there are significant differences in maintenance and production costs between the old and new equipment. The paper [8] discusses the importance of equipment condition diagnosis and life cycle management to minimise additional costs and time associated with unexpected breakdowns. The life cycle cost analysis of the 320C excavator from 2010 to 2017 helps determine the optimal equipment replacement time and the cost of its ownership.

The article [9] highlights the results of the analysis of the current state and directions of development of the road construction equipment sector in Russia at the turn of 2023. The study is based on the study of statistical information, as well as on the developments carried out by the Institute of Transport Problems of the Russian Academy of Sciences, the NTMT Scientific and Production Company and the Department of Highways of St. Petersburg State University of Architecture and Civil Engineering in various periods, supplemented by information obtained from the Internet. The article highlights that the key problem of the domestic road construction industry lies in the significant wear and tear of equipment, reaching 50 %, the main reason for which is the insufficiently high level of its renewal.

The authors of [10] discuss the importance of road machinery productivity as a criterion linking all stages of the life cycle of roads and machines. The study is aimed at determining the relationship between the volume of work and the performance of road machines used at sites. The objective of the article was to analyse the technical, operational and actual productivity of machines when operated at specific sites.

The article [11] considers the issue of the efficiency of road machinery operation, with the main emphasis on the technical operation system. It highlights as the main drawback of the current approach the lack of accounting for the volume of work performed when maintaining the technical condition of machines, which is considered necessary for more efficient operation of machines. The article [12] is aimed at identifying the relationship between the life cycles of machines and roads and discusses factors influencing the formation of road machine fleets, considering the specifics of operation and renewal of equipment. A new approach to the formation of machine fleets is proposed based on the feedback from the life cycle of the road and the machine, which can improve the efficiency and rationality of equipment use.

In the modern practices of road machinery operation, many previous tasks have lost their scientific significance [13]. This is due to introduction of the latest regulations, development of CALS technologies, introduction of advanced monitoring systems and efforts to automate work processes. In this regard, there is a need to reassess and structure scientific issues related to the study of the life cycle of road machines using mathematical modelling, analysis of influencing factors and expert assessments for analysis. Industry methods and the ERA-GLONASS system are actively used in the field of road construction. The conducted study emphasises the key aspects of the modern system of the life cycle of road machinery and highlights the specifics of their study. Recommendations and implementation of tracking systems in road machinery contribute to scientific developments. The article proposes methods for solving current scientific problems, considering new trends in operation of road machinery, which contributes to a more accurate and reasonable formulation of scientific problems.

Article [14] examines changes in the consumer qualities of road construction machines from 1993 to 2018. The study based on expert assessments of various sources highlights that over the past 25 years, the requirements for machines have changed. At the beginning of the period under review, more valued were the characteristics related to formation of machine fleets and ensuring operability. As the market developed and with growing volumes of construction, qualities that determine the efficiency of machine operation became more important.

The article [15] discusses the need to assess the efficiency of vehicle operation in the agro-industrial complex (AIC) and proposes a multi-criteria model for this purpose. The main property of the model is credibility, which is achieved without the use of expert assessments. The article [16] also presents a decision tree for a vehicle quality assessment system, which helps to streamline the search for solutions.

The article [17] describes a new approach to determining consumer preferences when choosing road construction equipment among the options available on the market. This method is based on the application of one of the mathematical strategies for multi-criteria optimisation, which is the zoning method, and consists of analysing all possible combinations of priorities following assessment characteristics. The use of these techniques significantly improves the clarity and accuracy of the assessments. The effectiveness of the method is demonstrated using the example of analysing the technical features of bulldozers and comparing the obtained data with the assessments made using one of the classical approaches, expert cluster analysis based on significant operational characteristics.

In this regard, we set the following *objective* for the study: to propose an improved methodology for assessing RCM based on technical and economic indicators, suitable both for equipment with technical characteristics that are confusingly close, and in the case of partial or limited information on the results of operation (new or fresh models), also relatively free from subjective assessments of the decision maker.

RESULTS. SUGGESTED METHODOLOGY

The suggested methodology for assessing road construction machinery by technical and economic indicators was based on the methodological approaches for passenger cars, considered in the thesis work of P. I. Smirnov [18] and tested for logging and cargo equipment [19; 20]. The process of purchasing a road construction machine is similar to investing in production assets, which reflects the key interests of commercial structures aimed at acquiring RCM for their operational needs.

This approach allows us to consider the selection, acquisition and operation of RCM considering the economic principles and criteria that are usually used in assessing the effectiveness of investment projects. When determining the most suitable RCM model for specific operating conditions, the main attention is paid to the technical and economic parameters of the machines. This category includes technical characteristics that affect the efficiency of equipment operation, as well as indicators related to the costs of its operation.

During the initial phase of RCM assessment, these parameters are grouped according to criteria that allow them to be collected into a single analytical category (by type, purpose, availability of additional equipment and other characteristics).

When selecting a road construction machine for commercial use within an organisation, a critical aspect, along with compliance of technical parameters with established standards, is a comparison of the «useful effect of operation» with the costs of obtaining it throughout the entire life cycle (LC) of the equipment.

This principle is key to assessing the competitiveness of the RCM in terms of the set of technical and economic characteristics:

1. *Operation efficiency*: This refers to the ability of the machine to perform the required work with maximum productivity and minimum time costs.

2. *Operating costs*: Includes all costs for maintenance, repairs, lubricants and refuelling materials throughout the entire life cycle of the equipment.

3. *Dependability and durability*.

4. *Residual value*: This is an estimate of the value of the machine at the end of its operational period, which can significantly affect the overall economic benefit from its use.

5. *Convenience and safety of operation*: Includes an assessment of how convenient and safe it is to work with a given machine, which can also affect labour productivity and staff training costs.

The choice of RCM considering these parameters allows organisations to maximise the return on investment and ensure high competitiveness in the market.

This condition determines the assessment of the level of competitiveness based on technical and economic indicators:

$$E_{\Sigma} / C_{\Sigma} \rightarrow \max, \quad (1)$$

where E_{Σ} – beneficial effect of using RCM throughout the entire life cycle;

C_{Σ} – total costs of achieving a beneficial effect throughout the entire life cycle.

In the future, we will designate this ratio as an integral indicator of product quality based on technical and economic indicators – Q_{TEI}.

$$Q_{TEI} = E_{\Sigma}/ C_{\Sigma}. \quad (2)$$

To assess the economic benefit from using road construction machines, the methodology developed by S. V. Repin is used as a basis. This approach involves not only the use of an integral indicator for comparing RCM by their technical and economic characteristics, but also the calculation of specific costs for performing a certain amount of work. Such costs are expressed through specific costs per unit of transport work, designated as C_{sp}, with a preference for using the indicator in rubles per hour of machine operation.

The calculation of specific costs per unit of work can be carried out based on the actual life cycle of the machine, or on a conditional LC, provided that there are no operational data, for example, assuming 10000 hours of machine operation. This approach allows for a more objective comparison of different models of road construction machines and making informed decisions when choosing the most suitable equipment, considering its long-term economic efficiency.

Our approach to the analysis of road construction machines at the stage of comparing them by technical and economic indicators includes the possibility of using an additional analytical module. This module is designed for a detailed assessment with individual specific criteria that may be critically important in certain operating conditions or for specific consumer preferences. Such criteria include, for example, engine parameters, traction characteristics, features of the working area, lifting capacity, level of convenience and ergonomics of the operator's workplace, as well as the specifications of individual important machine components.

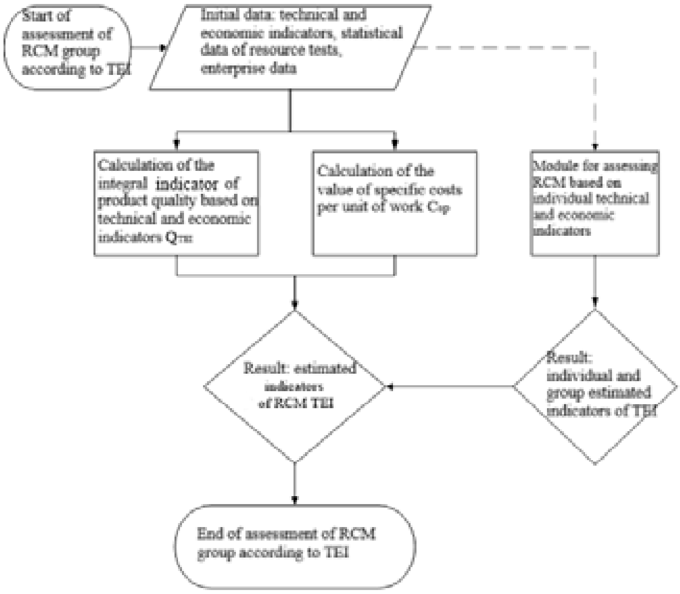
Assessments using these criteria are formed based on a comparative analysis of available RCM options. For objective comparison and selection of the best option in the presence of several similar alternatives and in conditions of limited information or uncertainty, it is proposed to use the zoning method. This method was further improved by A. V. Terentyev [21] and allows for the effective solution of multi-criteria selection problems, optimising the decision-making process in complex conditions.

The introduction of such an additional module allows for an in-depth analysis of each aspect of the proposed equipment, considering the unique requirements and preferences of the consumer, which makes the process of selecting road construction machinery more targeted and rationale.

The inclusion of additional evaluation criteria and the use of mathematical methods to integrate these results into a common integral indicator is a significant step forward in the methodology for analysing and selecting road construction machinery. This approach not only reduces the subjectivity that often accompanies the evaluation process but also increases the credibility and reliability in determining the competitiveness of various RCM models.

The integral technical and economic indicator of product quality, designated as Q_{TEI}, plays a key role in this process, as it summarises various aspects of the efficiency of machine operation into a single generalised numerical expression. This allows consumers and organisations to make an informed choice based on a comparison of the maximum return on investment.

However, like any comprehensive method, the proposed approach requires access to extensive and accurate data on technical parameters, operating costs and potential income from equipment operation, as well as the ability



Pic. 1. Flow chart for assessing analysed RCM according to TEI [developed by the authors].

to correctly interpret this information in the context of specific operating conditions. This may pose some challenge, especially for new models of RCM, for which there may not be sufficient operational data.

The flow chart of the proposed method for assessing RCM based on technical and economic indicators is shown in Pic. 1, the algorithm for calculating Q_{TEI} and C_{sp} for assessing RCM at the stage of decision-making on acquisition is given below.

*Step one***.** Creation of a database for the studied group of road construction machines based on information from Internet resources and on experimental data obtained from users and operators.

Step two. To calculate and determine the total operating costs of road construction machines throughout their entire life cycle, it is necessary to calculate the following component items to determine the total costs C_{total}:

C_{RCM} – cost of equipment in rubles;

$C_{one\text{-}time}$ – initial acquisition costs, in rubles;

$C_{const.annual}$ – conditionally constant annual costs, in rubles per year;

T_{use} – number of years of use within the life cycle under consideration, in years;

C_M – maintenance costs, in rubles;

N_{FC} – average fuel consumption rate, in litres per hour of operation;

C_{fuel} – fuel cost, in rubles per liter;

C_{loan} – loan payments, lease payments, in rubles;

L_{total} – the value of the expected operating time or the value equal to the operating time within the conditional life cycle.

*Step three***.** We determine the final total costs for operation of RCM throughout the entire life cycle:

$$C_{const.annual} \times T_{use} + C_M + \frac{N_{FC} \times L_{total} \times C_{fuel}}{100} + C_{loan}, \text{ rub.} \quad (3)$$

*Step four***.** Calculation of specific costs:

$$C_{sp} = C_{total} / L_{total}, \text{ rub/hour.} \quad (4)$$

*Step five***.** Calculation of the beneficial effect from operation of RCM throughout the entire life cycle of E_{Σ}. As the latter, one of the following values in rubles/hour is taken:

$I_{com.oper}$ – the specific value of the expected income from commercial operation is determined in rubles per hour of work.

I_{alt} – specific alternative income is defined as the difference between the cost of services for providing the organisation with RCM for rent and the projected costs of its own machines, reduced to one hour of RCM operation.

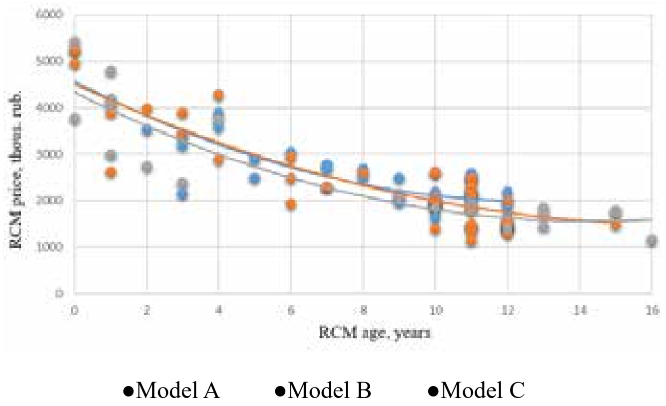
The value of the latter is determined by solving the system (5):

$$\begin{cases} I_{alt} = \sum Q_{rent}(t) - \sum Q_{own}(t) \\ I_{alt} > 0, if\ t \in \left[t_{payback} \ldots t_{service}\right] \\ \quad t_{payback} < t_{service} \end{cases}. \quad (5)$$

Step six. Calculation of individual components of costs for achieving a beneficial effect throughout the entire life cycle of RCM C_{Σ}:

C_l – labour costs;

C_{fuel} – fuel costs;



Pic. 2. Regression models of changes in the cost of 3-ton loaders [performed by the authors].

C_{spare} – purchase of spare parts and tires;
C_{cons} – costs of consumables;
C_{mr} – maintenance and repair costs;
C_{ov} – overhead costs;
C_{loan} – loan payments, lease payments;
I_{sale} – the price of selling RCM, when used to the limit state, can be taken as equal to the liquidation value or considering the application of the mathematical model of changes in the residual value, given below.

Step seven. Calculation of total costs for achieving a beneficial effect throughout the entire life cycle of RCM E_Σ:

$E_\Sigma = C_l + C_{fuel} + C_{spare} + C_{oper} + C_{mr} + C_{ov} + C_{loan} - I_{sale}$, rub. (6)

Step eight. Calculation of the integral indicator for TEI Q_{TEI}:

$Q_{TEI} = (E_\Sigma \times L_{total}) / C_\Sigma$. (7)

Step nine. Recording the calculated values of C_{sp} rub/hour and Q_{TEI} in the final table of RCM assessment. If necessary, one should proceed to assessing the next RCM from the analysed group (transition to *Step two*).

In the above method, the value of I_{sale} is of particular interest which is the cost of selling RCM, when used to the limit state, which can be taken as equal to the liquidation value or calculated using the obtained mathematical models. To find them, an analysis of statistical data was performed. For the calculation, data from such ad aggregators as Avito, excavator.ru, Avto.ru were used. Offers for the sale of three front end wheel loaders of manufacturers from the PRC with a lifting capacity of 3–5 tons were analysed, from newly manufactured to the oldest ones, while the price and operating time in engine hours (if available) were recorded.

Table 1

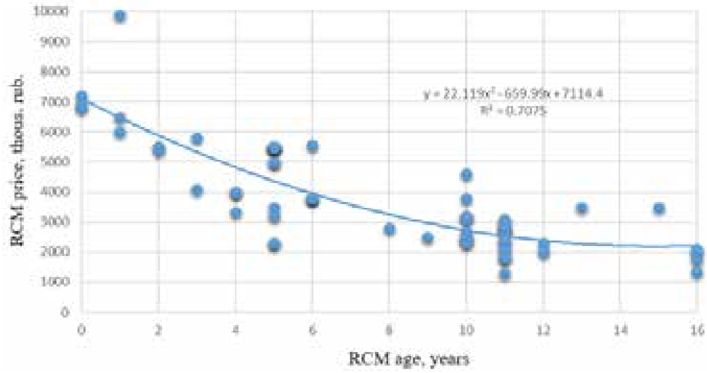
Mathematical models of changes in the cost of RCM

Model	Regression equation	Coefficient of determination
A	$y = 15.794x^2 - 404.68x + 4576.9$	$R^2 = 0.7117$
B	$y = 10.492x^2 - 356.58x + 4512.4$	$R^2 = 0.7606$
C	$y = 13.598x^2 - 388.92x + 4337.8$	$R^2 = 0.8171$

Based on the collected data, statistical dependencies of the cost of RCM in the secondary market from their age were obtained, shown in Pic. 2. Herewith, there is a clear understanding that the price announced on portals of advertisements for sale of equipment and the real price of equipment on the secondary market can often differ significantly. At the same time, this is partly compensated by both the volume of collected records and the peculiarity of the excavator.ru advertisement portal, in which records on sold equipment go to the archive allowing their further viewing. Records from the archive, as a rule, consider the decrease in the price declared by the seller in the process of displaying the advertisement on the site and therefore are much closer to the real cost of selling equipment on the secondary market. In the total share of statistical information, the share of such advertisements is about 34 %.

Regression models were calculated for the obtained statistical data on the cost of equipment (see Table 1), for which sufficiently significant coefficients of determination R^2 were obtained. The highest value $R^2 = 0.8171$ was obtained for the data on the cost of loaders of model B with a lifting capacity of three tons due to the largest volume of collected data.

A similar model was constructed for the loaders of the company «C» with a lifting



Pic. 3. Regression model of change in the cost of 5-ton loaders [performed by the authors].

capacity of five tons, shown in Pic. 3. The regression model has the form: y = 22.119x2– 659.99x + 7114.4 with a coefficient of determination $R^2 = 0.7075$.

In addition, during data collection, records of equipment operating time were recorded, which allowed us to obtain additional rather interesting results. Thus, for loaders with a lifting capacity of 3–5 tons of the company «C», the average operating time in engine hours per year of operation was 921 engine hours/year, for model «B» – 780 engine hours/year and for model «A» – 674 engine hours/year.

DISCUSSION AND CONCLUSIONS

As the analysis of statistical data on the cost of RCM on the example of loaders of different brands manufactured in the PRC has shown, the nature of the change in their cost is similar and does not show a significant difference irrespective of a specific manufacturer either model. The curves and models constructed in this case are similar to those obtained by S. V. Repin for RCM of European and American manufacturers [21].

At the same time, if several years ago in similar studies conducted by the authors, equipment manufactured in the PRC compared to RCM of European and American manufacturers greatly lost in value on the secondary market starting from the first year, now we do not find this.

At the same time, despite the absence of differences in the dynamics of the decrease in the cost of RCM on the secondary market between loaders of different PRC manufacture companies, it was found that the average operating time in engine hours/year of loaders of one of the brands is 15 and 27 % higher than that of loaders of two other companies. In our opinion, the latter may indicate a potential opportunity to operate the equipment more intensively, as well as shorter delivery times for spare parts and possibly potentially higher quality of the equipment.

The suggested calculation technique can be used to assess RCM of manufacturers regarding whose products there is still few information on the service life of units and assemblies, and on the entire maintainability and repairability.

Thus, the methodology we propose, the essence of which is shown in Pic. 1 and described in the algorithm above, comprising the application of the results of statistical studies on the cost of equipment on the secondary market, can be used to select RCM for purchase, considering the existing uncertainty and the lack of operating data and data on the resource and service life of equipment. The set of information for assessing the cost and availability of spare parts for equipment deserves special attention, which will be considered by the authors in a separate study.

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