Modeling quality criteria for restoring parts of cars, vehicles and road-building machines

M Yu Kareлина1, A I Belyaev2, A V Terentev2, T Yu Cherepnina1

1Moscow Automobile and Road Construction State Technical University (MADI) Leningradsky Prospekt 64, Moscow, Russia
2Saint Petersburg State University of Architecture and Civil Engineering, 4 2nd Krasnoarmeyskaya str., Saint Petersburg, 190005, Russia

Abstract. The article analyzes the types, methods and techniques of parts processing at restoration and quality criteria of parts of cars, other vehicles and road-building machines in terms of efficiency. Correlations between the quality criteria and the functionality of the part have been established, for which the requirements for machine safety and reliability after the restoration of individual parts have been taken. A mathematical model has been developed in the form of an algorithm for selecting the best variant of the restoration technology for a functionally important part, based on a typical restoration technological process, which consists in the development of a multi-criteria problem, the initial postulates of which are matrices: W "wear resistance → durability"; S "safety → reliability"; F "part fragility → machine safety". New parameters in the form of coefficients describing roughness, hardness and riveting of a part have been proposed. In particular, the authors define the coefficient of technological isotropy of roughness, which evaluates the roughness parameters in the process of technological changes of a part; the coefficient of isotropy of hardness, which compares the hardness parameters on the surface of the part and in the core of it; the coefficient of intensity of hardness, which is a complex parameter and in which there is a change of hardness by the depth of the part and the value of hardness depth (riveting). The purpose of introducing these coefficients is consistent with the model being developed to select the optimal technology for restoring parts of cars, other vehicles and road-building machines.

1. Introduction
The modern development of economy leads to an increase in construction volume in general and roads in particular. Road network development leads to intensification of their maintenance. This is where modern road construction technologies and use of modern materials intervene. All these factors together create conditions for modern cars development, vehicles and road construction machines, both quantitatively and qualitatively. To provide intensive construction technologies, the use wide range of purposes technological equipment is required.

The main features of operation of cars, vehicles and road-building machines are: high operation intensity; high price; isolation from service bases and complication of machines repair and restoration process in connection with this.

Parts reuse for cars, vehicles and road construction machines is, in fact, a reserve from the economic approaches point of view. An example is economic experience of all countries of the world, especially
developed ones. As a specific example, we can name official data of the Tractor Parts Dealers Association (USA), on basis of which hundreds of enterprises carry out components and individual parts restoration that have gone out of service.

2. Research questions
Restoring parts technology typification for cars, vehicles and road-building machines. According to official statistics, 75% of the parts recognized as final marriage can in fact be restored [1]. Worn-out parts restoration, their double or even multiple use is economically feasible. Comparison of parts restoration with their new manufacture leads to the following conclusions: lower costs, lower labor intensity, high quality [2]. Rebuilding parts of cars, vehicles and road construction machinery is the best way to machines durability influence in general.

With the absolute correctness and relevance of these conclusions, it should be noted that issues related to restoring parts technology of cars, vehicles and road-building machines are not worked out. Each enterprise engaged in parts restoration solves technology issues independently, based on economic and material capabilities and considerations. At the same time, many questions in this area are well developed. According to the source, restoring parts technological process (TP) is a process that contains targeted actions to change a certain state of a part in order to restore its operational properties. But when organizing a production intended for restoring parts, it is recommended to use standard technological processes (STP). This makes it possible to reduce labor costs for technological process development, standardize parts nomenclature, and, as a result, make production more efficient from an economic point of view. It should be noted that the choice of the best route for specific part restoration of RBM depends on an understanding of various operations technological capabilities and their characteristic features.

Technological processes typification [3] raises technology level, reduces volume and shortens production preparation time.

Technological process schemes of restoring smooth shafts and axles are presented in the form of three most possible routes [4].

Technological processes typification implies the development of such technological process in which there would be a maximum number of operations varieties for a given type of parts.

A further algorithm for choosing the best technology option, based on the above STP, is to develop a multicriteria problem, the initial postulates of which are matrices: W "wear resistance → durability"; P "preservation → reliability"; F "part fragility → machine safety". A standard technological process is used to develop an optimal technological process with different objectives. Using multi-criteria dynamic programming and a typical technological process of part restoring, you can choose a sequence of operations that provide the best quality according to preferred criteria: either "durability" or "reliability" or "safety".

The authors [5] identified the main dependencies (three) for technological sequence choice for restoration of a car part or RBM part, where the difference was in different technological and, most importantly, economic indicators.

3. Methods and models
In most of the works devoted to this problem, criteria were used to select optimal technological process for cars parts restoring of vehicles or road construction or other machines, and mainly taking into account economic criteria.

To assess the choice of a method for part restoring, authors [6] proposed to select some evaluation criteria: shape, dimensions, coating thickness, surface hardness, part elements fatigue strength, and acting loads nature.

The author [6] proposes to solve the problem of choosing a method for part restoring that meets a complex technical and economic criterion, and technological process structure on the basis of a graph representation of possible options for combining technological operations that ensure objective function minimum value. Objective function value is put down at the top of graph.

The author [7] developed this system for choosing a method for recovering a detail by introducing
graph arcs lengths values are given in their discontinuities.

Existing approaches to the choice of a restoring parts method for cars, vehicles and road-building machines inevitably face the need to solve problems in a multi-criteria formulation. In this case, as a rule, widespread methods of reducing multi-criteria problems to single-criteria ones (methods of using composite criteria) are used [8, 9]. This approach has a significant drawback: when using composite criteria, the deficiency in one criterion is compensated for by another [10]. The most complete picture of possible solutions is provided by the method of effective plans set finding (Pareto set), since the use of this method allows you to compare all competitive options between each other [11]. The final choice of a solution from the set of Pareto sets can be carried out using the zoning method according to the principle of observing the hierarchical ratio of research environment possible states probabilities [12, 13].

When passing from a multicriteria problem to problems of probability theory, the probabilities of research environment states $p_j$ are, in their meaning, adequate to criteria relative importance coefficients $c_j$, i.e. $p_j \equiv c_j$.

Analytical solution is given in [12-11].

$$c_j = \begin{cases} \frac{1}{k}, & \text{if } j = k \\ \lambda \frac{1}{k}, & \text{if } j < k, \text{ where } \lambda = \frac{n-1}{n} \\ 1 - \frac{1}{n-k}, & \text{if } j > k \end{cases}$$

where index $k$ is determined from condition $\alpha_{kj} = \max_j a_{ij}$.

Fundamental difference between developed method is formalized relationship absence between relative importance coefficients according to individual criteria, which makes it possible to determine the values of solutions relative importance coefficients in multicriteria problems in accordance with the real conditions of system functioning under study.

4. Results and discussion

Consider machine durability in terms of the part properties. Durability is machine property to have the same performance for some time. Knowing the operating conditions, it is possible to determine the operability [13, 14]. Surface microrelief and correct lubricants are important [15]. According to other sources, the main reasons limiting reliability (and they are associated with increasing durability methods), in addition to surface wear, include the breakdown of the part itself, surface integrity violation due to contact stresses or work hardening, or corrosion [16].

Conclusion - machines durability is primarily manifested in the form of particular part function - wear. Here the relationship "wear resistance $\rightarrow$ durability" is established.

Reliability is determined by part property, while maintaining its characteristics, to perform specified functions. This occurs during the part running time period [17]. It can be concluded that relationship between durability and safety of the machine as a whole is obvious. This is where the «persistence $\rightarrow$ reliability» relationship is established.

Let us consider operation safety of cars, vehicles and road-building machines from the part properties point of view. It is possible to reduce cracking possibility by applying surface plastic deformation methods [18]. If safety indicators do not meet the requirements, then this can lead to catastrophic consequences in the field of life, human health, ecology and economic factors, and ultimately reduces machine efficiency to a minimum [19]. Here the link "part fragility $\rightarrow$ machine safety" is established. A multicriteria dynamic model has been developed for choosing the best option for part restoring technological process, depending on priorities set in advance.

Surface layer of part has important characteristics, such as roughness, hardness (in the form of work hardening or heat treatment) and, as a result, residual stresses.

Roughness. Roughness is a very important and diverse quality criterion. This ambiguity, complexity and variety of relationships leads to the need to introduce a new parameter describing the roughness. It is proposed to introduce roughness technological isotropy coefficient for the part $K_{RTI}$. 


Roughness parameters comparison in process of technological changes in part, that is, roughness comparison before and after operation, and will be desired value $K_{RTI} = \frac{RT_{before}}{RT_{after}}$, where $RT_{before}$ – roughness parameter before any operation.

*Hardness*. It is proposed to introduce hardness isotropy coefficient for part $K_{HIS}$. Then hardness parameters comparison precisely on part surface $H_{SUR}$ and hardness of part core $H_{CORE}$ and will be the required value $K_{HIS}: K_{HIS} = \frac{H_{sur}}{H_{core}}$.

*Depth of hardness (work hardening)*. Surface hardness of part is changed not only by thermal or chemical-thermal treatment, but also by surface-plastic deformation methods. Enter hardness intensity factor for part $K_{Hil}$. This is complex parameter comparison, in which there is a change in hardness along the depth of part and value of hardness depth (work hardening). For hardness, this is $K_{HIS} = H_{SUR}/H_{CORE}$.

5. **Conclusion**

After analyzing various indicators of hardness depth or work hardening, we came to conclusion that it is more preferable to evaluate hard layer depth during thermal or chemical-thermal treatment, during blade processing, or during SPD in absolute terms - in millimeters.

In general, proposed indicators: roughness technological isotropy coefficient, hardness isotropy coefficient and hardness intensity coefficient, can be summarized as integral quality indicators.

A mathematical model has been developed using dynamic programming method to obtain optimal trajectory of part movement from the initial state to the final state, based on the Bellman principle.

6. **Recommendations**

These integral quality indicators greatly simplify and facilitate the optimal selection process modeling of the best variant of technological process. Achieving maximum efficiency in technological process design of restoring parts of cars, vehicles and road-building machines according to the selected justified criteria (durability, reliability, safety) is possible by integrating zoning method using observing principle of probabilities ratio of research environment possible states into solving dynamic programming problem.

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