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Development of a repair technology for locomotive units on the basis of the theory of decision

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Abstract. The operative condition of locomotives is maintained by the existing repair system; it consists of the following elements: strategy, organization and technology. This repair technology for units and aggregates is based on disassembling and elimination of defects, and it can be inappropriate. The actual technical condition of the nodes requires an individual approach in determining the volume and content of technological impact during the repair process. Therefore, the purpose of this work is to research the task of developing a repair technology for locomotive units, depending on their actual technical condition. As far as probability distribution functions of the operating condition of units are known, a repair technology is chosen under risky conditions. Therefore, the decision-finding problem is framed in the theory of decision terms. The analysis of the decision tree of the choice of repair technology for fuel injectors of a diesel locomotive demonstrated that at least four variants of technologies (strategies) were possible. Operational costs were taken as the evaluation criterion for the technological process. The pay-off matrix obtained does not have a saddle point; therefore, the problem of choice of the technology cannot be solved only strategically. It substantiates a need to use flexible, adaptive repair technologies which consider the actual technical state of each unit. For a known distribution of states for fuel injectors, the greatest gain with minimum risks is the repair technology of dismantling and reseating the worn-out parts. Application of the described approach at locomotive repair enterprises will allow for improvement of the quality of repair and reduction of costs.

1. Introduction

The locomotive facility is one of the leading rail transport industries the key task of which is provision of the rail industry with sufficient amount of serviceable equipment and qualified personnel. The proper function of locomotives is maintained by the existing repair system; it consists of the following elements: strategy, organization and technology. Repair of machines and aggregates includes detection and elimination of trouble; it states the principal difference between the repair and machinery production facilities. The existing repair technology for units and aggregates of the rolling stock was formed before the active development and implementation of methods and tools to assess the technical condition of objects. It explains certain special features of the technological repair processes which require the disassembling of most units and aggregates to detect faults. Such a technology is unprofitable and sometimes unpractical.

The repair of units and aggregates of the rolling stock is characterized by a certain order of the key technological operations of cleaning, state controlling, disassembling, renewing, assembling and testing. Generally, these operations are carried out in a sequence [1-3]. Nowadays, the general technical deterioration of the rolling stock results in an increased number of panic repairs and



replacement of units and aggregates [4]. Consequently, even a scheduled repair of single-type units can considerably differ due to their technical conditions. Thus, the established repair technology for units of different technical conditions can be an unreasonably time- and resource-consuming procedure. Besides, it causes a considerable deterioration of some details due to consequent running-in wears after the assembly-disassembly procedure [5-7].

Thus, the situation necessitates the development and introduction of measures to improve the quality and decrease the cost of the locomotive unit repair. And one of the resource-saving approaches is the development of individual technological repair procedures for units in different technical conditions. It implies that out of all possible types and kinds of technological operations, there is one which stipulates such a content and consequence of operations that ensures the required quality at minimal costs. In production, such a task is successfully solved by the network modelling methods [8, 9]. However, for the repair facility such an approach does not yield favourable results, as the technical conditions of objects can considerably differ and thus demand various technological approaches. Therefore, the purpose of this work is to research the task of forming a repair technology for locomotive units, depending on their actual technical condition.

2. Methodology

As far as the probability distribution functions of the operating condition of units can be known, a repair technology is chosen under risky conditions. Therefore, the decision-finding problem is commonly framed in the theory of decision terms [10, 11].

As far as the repair technologies for various units differ, there is a need to use the actual data for modelling. The study used the information on the repair of fuel injectors for diesel locomotive engines as the initial data. The established repair technology included the following operations:

- cleaning and checking of the injectors on a test bench;
- disassembling;
- washing, blowing and examining;
- cleaning and replacing nozzles;
- monitoring of the spring condition;
- replacing faulty parts;
- reseating the surfaces of bodies of injector, sprayer and nozzle;
- reseating the needle to the sprayer body;
- checking the needle lift;
- washing and blowing components;
- assembling;
- checking and adjusting on a test bench.

Such a technology is reasonable for cases of limiting wear or damages in injector basic elements. The application of a complete repair technology for injectors with partial wear can lead to unreasonable costs and reduce the operational life of the elements.

During the repair process, it should be possible to take successive solutions regarding the technological impact on the object in repair. Thus, it is reasonable to use a graphic method, the tree of decision, which allows for connection of the decision points, feasible strategies A_i , their consequences with possible factors and environmental conditions. The decision tree begins with an earlier decision, moves to possible events with their consequences, transfers to another decision (choice of the operation line), etc. until all logical consequences of the results are used up.

The required volume of technological impacts for injectors in different technical conditions was determined in building the decision tree (figure 1).

The analysis of the decision tree demonstrated that repair of fuel injectors might require at least four technological variants (strategies) according to the condition of the injectors: A_1 – disassemble, repair with replacement parts; A_2 – disassemble, repair with machined parts; A_3 – do not disassemble, adjustment; A_4 – do not disassemble, cleaning.

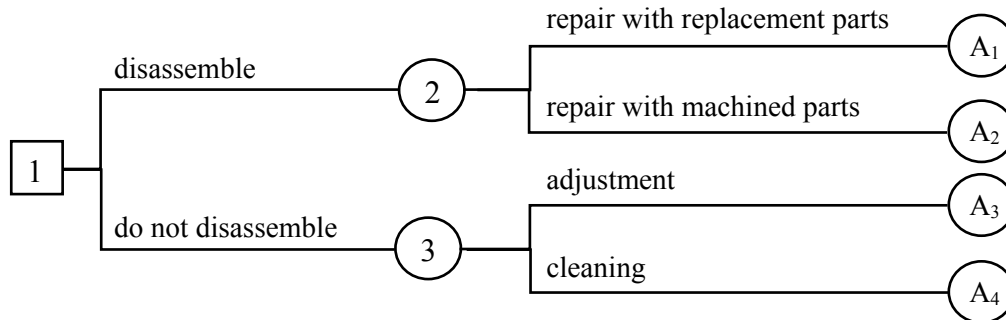


Figure 1. Decision tree of choice of a repair technology for the fuel injector of a diesel locomotive engine.

Here, the determining criteria are the general operative state and misalignment of the injector, and faults in certain parts. Probabilities of these states were determined from the statistical data on failures in the injectors collected by the repair facility of a locomotive depot (Table 1).

Table 1. Distribution of failures in fuel injectors of diesel locomotives under repair.

Type of failure in an injector	Number of injectors with faults	State probability
Damages and failures of certain components	654	0.26
Loss of tightness	830	0.33
Failures of adjustment	578	0.23
Dirty vents in a sprayer	453	0.18
Total	2515	1.0

As far as one of the assessment criteria for technological processes is the operational cost, it is crucially important to determine faults for the locomotive industry. The basic expenditure for a technological operation in the repair process of a locomotive unit can be determined according to:

$$C^{TO} = W + E_C + T_C + P_C \tag{1}$$

where: W is wages and salaries; E_C – operation and depreciation costs; T_C – costs of tool and equipment usage; P_C – costs of spare parts and materials.

If a technological repair process consists of k operations, the cost model of the process with consideration of (1) looks as:

$$C^{TP} = \sum_{k=1}^K C_k^{TO} \tag{2}$$

Calculations according to (2) make it possible to build an appropriate pay-off matrix in relative units. The rows of the matrix are the possible variants of the repair technology A_i (figure 1), and the columns are the possible conditions of the injectors (Table 1):

$$A = \begin{pmatrix} 122 & -7 & -953 & -1025 \\ -250 & 1072 & 1037 & 1055 \\ -156 & -1200 & 1166 & 1149 \\ -138 & -1088 & -1182 & 1184 \end{pmatrix} \tag{3}$$

On determining the strategies and building the matrix of gains and risks, the formalization of the problem is considered to be completed.

3. Results and discussion

The analysis of the pay-off matrix made it possible to determine a guaranteed gain, with the lower value of game $a = \max(a_i) = -250$ and the upper value of game $b = \min(b_j) = 122$. As $a \neq b$, the saddle point was absent, and the game value was within a range of $-250 \leq y \leq 122$. Therefore, the problem set did not have decisions in pure strategies. It was also determined, that no pure strategy was either dominating, or dominated. The technology currently used (strategy A_1) is characterized by the higher cost and is only appropriate for one condition of the injectors - with damage and parts failure. Considering that injectors with different technical conditions (Table 1) can come in for repair, it is rational to use flexible, adaptive repair technologies.

The pay-off matrix did not always reflect all existing conditions for taking decisions. Therefore, the model analysis should certainly include indications of “good” and “failed” choices of the strategy for each state of nature. The ease of state of nature Q_i is determined as the biggest gain at a given state, i.e. the largest element of the j -th column:

$$\beta_j = \max_i a_{ij}, \quad j = \overline{1, n} \quad (4)$$

The utility value of nature is used for determining risk r_{ij} , the characteristics of the utility for a player to use the strategy A_i for the state of nature Q_i :

$$r_{ij} = \beta_j - a_{ij} \quad (5)$$

According to (5) and the data on pay-off matrix (3) the risk matrix was obtained:

$$A = \begin{pmatrix} 0 & 1078 & 2118 & 2208 \\ 372 & 0 & 128 & 128 \\ 278 & 2272 & 0 & 34 \\ 260 & 2160 & 2348 & 0 \end{pmatrix} \quad (6)$$

Analysis of the risk matrix made it possible to reveal certain features of the model obtained. Thus, elements a_{22} , a_{23} , a_{24} were characterized by virtually equal gains in the pay-off matrix for strategy A_2 . As for the risks, these elements were far from equal. For states Q_3 and Q_4 the risk was 128, and for the state Q_2 it was 0.

The decision-making techniques under risks use the choice theory called the utility theory. According to this theory, strategy A_i is chosen from the combination A_i ($i = 1 \dots n$) if it maximizes the expected cost of its utility function [11, 12]. The expected value for each alternative is determined as the average weighted gain $\overline{a_c}$ with consideration of probabilities w_i of all possible states of nature Q_j :

$$\overline{a_c} = w_1 a_{i,1} + w_2 a_{i,2} + \dots + w_s a_{i,s} = \sum_{j=1}^s w_j a_{i,j} \quad (7)$$

The strategy with the maximum average weighted gain is optimal.

The average weighted risk was used for assessment of risk strategies.

$$\overline{r_c} = w_1 r_{i,1} + w_2 r_{i,2} + \dots + w_s r_{i,s} = \sum_{j=1}^s w_j r_{i,j} \quad (8)$$

By comparing criteria $\overline{a_c}$ and $\overline{r_c}$ for strategies A_{1-4} it was possible to determine a practical value in using these strategies for researched state probabilities (figure 2 (a)).

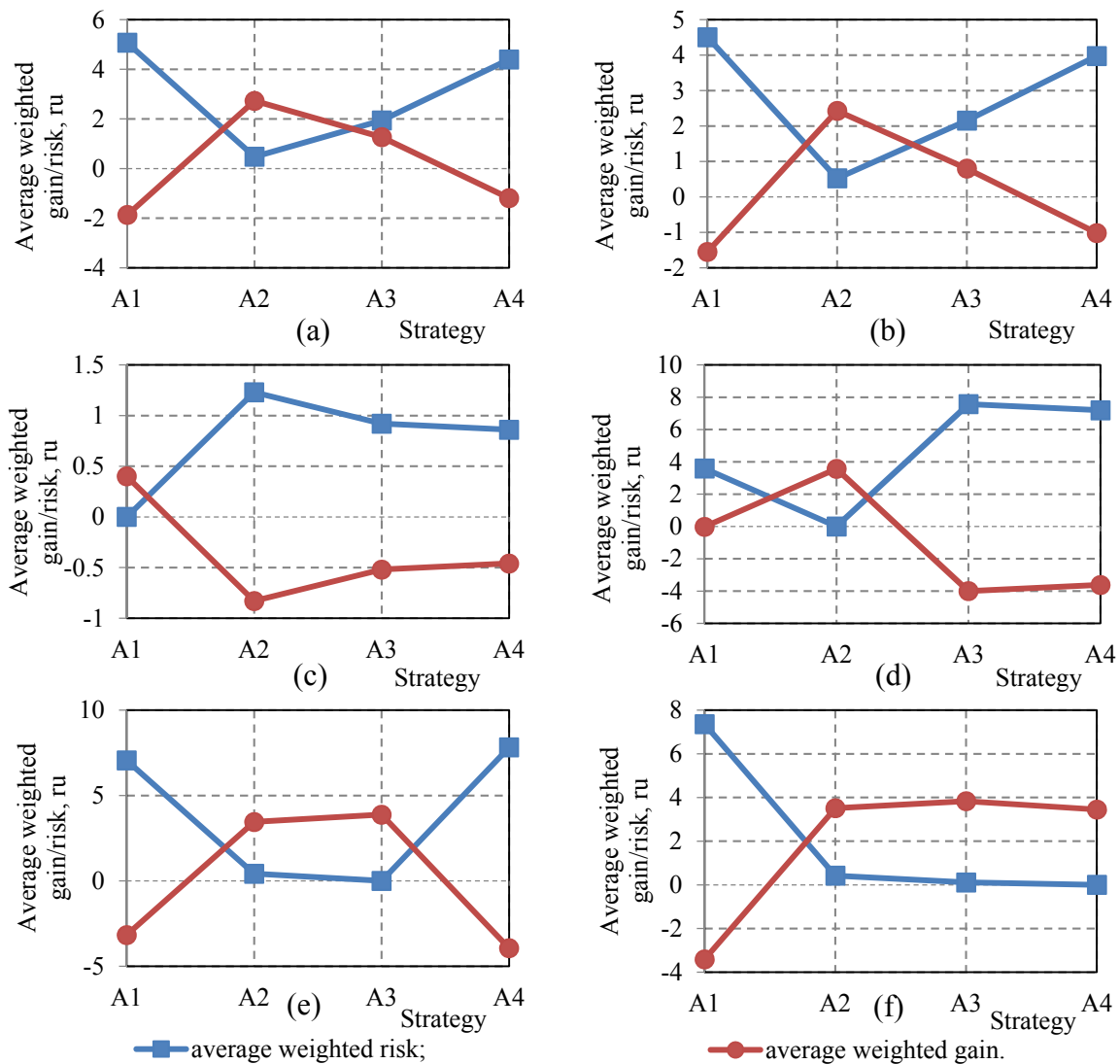


Figure 2. Comparison of the criteria $\overline{a_c}$ and $\overline{r_c}$ for the strategies A_{1-4} . (a) according to statistical data; (b) injector conditions probabilities are equal; (c) dominance of condition “Damages and failures of certain components”; (d) dominance of condition “Loss of tightness”; (e) dominance of condition “Failures of adjustment”; (f) dominance of condition “Dirty vents in a sprayer”.

Strategy A_2 was characterized by the maximum average weighted gain (2.72) and, accordingly, by the minimal average weighted risk (0.47). By using the result to the problem, it should be mentioned that for a given distribution of state probabilities for fuel injectors, the biggest gain with minimal risks is a repair technology of disassembling and reseating worn-out parts. A simulation of the situation with equal probabilities of injector conditions showed a similar result (figure 2 (b)). Analysis of the simulation results for the cases of dominance of different injector conditions shows the maximum gain and the minimum risk of the most appropriate repair technology (figure 2 (c, d, e, f)). It confirms the need for an individual approach in determining the repair technology of injectors.

4. Conclusions

The authors proposed a model for development of a repair technology for locomotive units. The examples of fuel injectors made it possible to determine a guaranteed gain, with the lower value of game $a = \max(a_i) = -250$ and the upper value of game $b = \min(b_j) = 122$. Since $a \neq b$, the saddle point

is absent, and the game value is within a range of $-250 \leq y \leq 122$. Therefore, the set problem does not have decisions in pure strategies.

The technology currently used (strategy A_1) is characterized by higher cost and is only appropriate for one condition of the injectors - damage and parts failure. Considering that injectors with different technical conditions can come in for repair, it is rational to use flexible, adaptive repair technologies.

For the considered probability distribution of the condition of the fuel injectors, the implementation of the repair technology with disassembly and grinding of worn parts will bring the greatest gain 2.72, with a minimum risk of 0.47.

Simulation of situations of dominance of different conditions of the injectors shows the maximum gain and the minimum risk of the most appropriate repair technology. It confirms the need for an individual approach in determining the repair technology of injectors.

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