Requirement definition of passenger motor transport enterprises for spare parts by method of short-term combined forecasting

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Abstract. The article considers the method of short-term combined forecasting, which includes theoretical and experimental estimates of the need for details of units and assemblies, which allows obtaining the optimum number of spare parts necessary for rolling stock operation without downtime in repair areas.

1. Introduction
The problem of determining the optimum number of repair parts is especially relevant for the passenger motor transport enterprises (PMTE) incorporating several hundreds of buses. The forecasting of the necessary number of repair parts, in turn, influences the rolling stock work and its downtime duration in repair areas.

To increase the forecasting quality and the accuracy of the received results, let us use the combined forecast which includes the theoretical and experimental estimates and also promotes the reduction of results from two types of forecasting to a uniform conclusion.

2. Method of forecasting
For obtaining the combined forecast, let us carry out the forecasts analysis from the point of view of their possible sharing as long as they do not contradict each other. The forecasts consistency can be determined by Student’s criterion [1, 4]. In case of the forecast results discrepancy, it is necessary to analyze the reasons which have caused such results and to make changes to the forecasting technique, namely to the information base (fleet structure of the PMTE, operating conditions, etc.), and then to carry out the second forecasting. In case projections do not contradict each other, the average result of the forecasts received by theoretical and experimental methods taking into account their accuracy is defined.

The combined assessment of the forecast is received in the form of the theoretical and experimental forecasts sum:

\[ F^* (y_i) = \mu_1 * F(y_{mi}) + \mu_2 * F(y_{ei}) \]  

where \( F(y_{mi}) \) and \( F(y_{ei}) \) – the forecast value at the theoretical and practical methods; \( \mu_1, \mu_2 \) – weight of the i-th forecast, \( i = 1,2 \).
The values of the weight coefficients are determined by the formula:

$$\mu_i = \sigma_i^2 (\sigma_i^2 + \sigma_j^2)^{-1}. \quad (2)$$

When obtaining new data on the need for repair parts (the quantity change of the rolling stock units, the refusals frequency of units and assemblies details, etc.), the weight coefficients are calculated and they are equal to skilled probabilities of the first and the second versions of the forecast. Bayes’ theorem is used for the calculation. At the same time, two hypotheses are considered:

$$H_1 = \{\text{adaptive forecast of the financial indicator is implemented}\}, \quad (3)$$

$$H_2 = \{\text{adaptive forecast of the financial indicator is implemented}\}. \quad (4)$$

The hypotheses probabilities experimentally obtained are accepted equal by the calculation results of the distribution function of the first and the second versions of the forecast. When the passenger motor transport enterprise receives repair parts, one obtains new information on the financial state of the enterprise, i.e. there is an $A$ event.

The conditional probabilities of the $A$ event with $H_1$ and $H_2$ hypotheses are respectively equal:

$$P(A|H_1) \quad \text{and} \quad P(A|H_2).$$

Using Bayes’ theorem, let us find skilled probabilities of the hypotheses:

$$P(H_1|A) = \frac{[P(H_1) \cdot P(A|H_1)] \cdot [P(H_1) \cdot P(A|H_1) + P(H_2) \cdot P(A|H_2)]^{-1},} { (5)$$

$$P(H_2|A) = \frac{[P(H_2) \cdot P(A|H_2)] \cdot [P(H_1) \cdot P(A|H_1) + P(H_2) \cdot P(A|H_2)]^{-1}.} { (6)$$

The developed forecasting technique based on the forecasts sum received by the theoretical and experimental forecasting methods using Bayes’ estimates allows receiving short-term forecasts, which will be not only fast-updated, but also rather effective.

Besides the forecast value, the dispersion and the standard deviations are calculated by formulas:
- dispersion:

$$\sigma_i^2 = \sum_{i=1}^{N} (y_i^{fac} - y_i^{for})^2 \cdot (N - 1)^{-1}, \quad (7)$$

where $N$ – number of points of the dynamic series;

- the average quadratic deviation:

$$\sigma = (\sigma_i^2)^{1/2}. \quad (8)$$

The distribution law of operating time expressed by the function or the distribution density is the most general and exhaustive characteristic used for the calculation of the assemblies reliability.

The distribution laws are not just approximations of casual sets of operating time and reflect the formation regularities of these or those refusals during vehicle working.
Then it is necessary to calculate the values of the distribution function of the theoretical predicted level of the main \( F(y_{mi}) \) component provided that it submits to the normal law:

\[
F(y_{mi}) = (\sigma_{y,mi} (2\pi)^{1/2})^{-1} \exp\left(-\frac{(y_{i} - y_{mi})^2}{2\sigma_{y,mi}^2}\right)
\]

(9)

Taking into account the total score, the new ranged numbers are assigned to each i-value of the main component and the corresponding skilled \( F(y_{ei}) \) probabilities are calculated:

\[
F(y_{ei}) = \left(2 \ast (n - i + 1)\right) \ast (n(n + 2))^{-1}.
\]

(10)

The statistical parameters of the experimental forecast can be determined using the formulas for the average value:

\[
\bar{y}_e = \sum_{i=1}^{n} y_i \ast F(y_{ei})
\]

(11)

and the average quadratic deviation:

\[
\sigma_{y,e} = \left(\sum_{i=1}^{n} (y_i - \bar{y}_e) \ast F(y_{ei})\right)^{1/2}.
\]

(12)

Taking into account the received weight coefficients, it is possible to determine the statistical parameters of an indicator by the results of the theoretical and experimental forecasts:

- the average value:

\[
y^* = \mu_1 \ast \bar{y} + \mu_2 \ast \bar{y}_e;
\]

(13)

- the average quadratic deviation:

\[
\sigma_y^* = (\mu_1 \ast \sigma_y^2) + (\mu_2 \ast \sigma_{y,e}^2))^{1/2}.
\]

(14)

3. Experimental research

As scientists note [2, 3, 5-7, 10], the operation processes of the following assemblies submit to the normal law of distribution: an internal combustion engine (ICE), transmission, brake mechanisms, which contain the details that are under the influence of several destructive factors, such as, slips wear, friction clutches, inserts.

In figure 1 there are probability dependences of the approach of the assembly failures which operation submits to the normal law of distribution. The amount of malfunctions of the assembly in 5 years of operation of 43 buses is indicated on the X axis. The probability of the approach of the assembly failures is on the Y axis.
Figure 1. Probability dependences of the approach of the parts and assemblies failure which operation submits to the normal law of distribution: a - ICE; b - transmission; c - brake mechanisms.

By means of these schedules, it is possible to estimate the probability density of refusals, such as power steering, shock-absorbers, etc. [8, 9]. Laws of distribution also give an assessment to the buses operational reliability of the PAZ brand, the schedules of the distribution density show rather a total characteristic of refusals. It makes possible to estimate the reliability of the rolling stock and its separate assemblies and to reveal assemblies that are the most subject to refusals. Also with the help of the schedules, it is possible to determine the profitability of the bus operation and to predict the need for spare parts.

4. Conclusion
As the experiment can be made at any moment and under any conditions, in combination with the theoretical methods of forecasting, the developed technique provides the flexible version of the combined short-term forecast that for the passenger motor transport enterprises with the rolling stock in several hundreds will be optimum and above all will have the effective decision which will allow one to have the necessary nomenclature of spare parts without long idle times in repair areas. Therefore, the work quality of the whole PMTE increases that directly influences an economic component.

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