Methods of determining the correction coefficients of specific norms of spare parts consumption depending on fleet age

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Abstract. The article considers changes in requirements for spare parts for maintenance and ongoing repair of urban buses taking into account their mileage from the beginning of operation. The research was carried out with the purpose of development of a technique that would help one to determine coefficients of correction made to specific norms of consumption of spare parts for various age groups of buses on the basis of changes in their failure flow. Correction factors were calculated for the four selected age groups of buses. In addition, the article considers the issue of reducing the annual mileage of the public transit bus while increasing its service lifetime. The methodology was tested on taking LiAZ-529222 and LiAZ-621322 urban buses as an example, operated in Moscow. As a result of the performed calculations, values of coefficients of correcting the consumption of spare parts have been obtained for the considered modifications of buses in each age group.

1. Introduction
An integral part of the technical operation of motor transport is the planning for the necessary spare parts. The number of spare parts required can be effectively assessed based on reliability. Not only do the reliability indicators depend on the operating time but also on factors such as the operating environment (town, metropolis, intercity, etc.), natural and climatic conditions (e.g. dust, humidity, temperature, etc.), which may worsen or increase reliability. These factors must be taken into account in order to determine the exact requirements for spare parts [1, 2].

Applying the norms of spare part consumption established by the manufacturer to the conditions of a particular transport company is carried out by their adjustments of their correction with coefficients $K_1$, $K_2$, $K_3$, according with the Regulation on maintenance service and repair of a fleet of motor transport. Correction factor $K_1$ takes into account the influence of operating conditions, coefficient $K_2$ takes into account the type and modification of the vehicle, coefficient $K_3$ shows the climatic conditions influence [3].

During fleet operation its reliability constantly decreases. The probability of failure-free operation of units and assemblies is reduced, operating time intervals are reduced and the failure flow is increased which leads to an increase in the required number of spare parts. This leads to an increase in time required for ongoing repair, increasing fleet downtime and the spare parts and repair costs.
To sum up, it is required to correct norms of the consumption of spare parts by factor of correction $K_t$ taking into account fleet mileage when calculating consumption of spare parts for the transit agency operating urban buses.

2. Organization of research

This method is developed to determine the coefficient of correcting the norms of spare parts consumption depending on the fleet age.

This technique was developed on the basis of generalization of theoretical and experimental researches carried out on the basis of the SUE "Mosgortrans" and implemented on the LiAZ-529222 and LiAZ-621322 urban bus modifications.

The purpose of the research was to calculate and determine the coefficient of correcting the norms of spare parts consumption depending on the fleet age by the example of LiAZ-529222 and LiAZ-621322 buses.

The subject of the research is operational failures of LiAZ-529222 and LiAZ-621322 buses.

Definition of the normative framework is based on the statistical information of failures and calculated indicators of fleet reliability under the actual conditions of the technical base and specific fleet modification.

Collection of failures data and actual mileage of LiAZ-529222 and LiAZ-621322 buses were carried out on the basis of the branch of SUE "Mosgortrans" in Moscow.

The implementation of the method is realized in several stages:

• collection, processing and analysis of statistical data of failures on the example of LiAZ-529222 and LiAZ-621322 bus modifications;
• calculation of reliability of LiAZ-529222 and LiAZ-621322 buses;
• determining the coefficient of correction for the norms of spare parts consumption for the ongoing repair cases depending on the operating time since the beginning of the bus operation.

Maintenance and current repair of the controlled buses for the entire period of research are carried out in accordance with the requirements of the "Guidelines for maintenance and repair of buses", "Typical technologies for maintenance and repair of buses", recommendations of the "Regulations on maintenance and repair of buses" approved by the SUE "Mosgortrans".

The system of keeping the technical condition of the controlled buses in working order for the whole period of research did not contradict the recommendations of the manufacturer.

The controlled buses were refueled with fuel, oils and other technical fluids in accordance with the operating manual. The controlled buses operated as usual in the course of the studies.

The following restrictions were imposed on the collection of data of bus failures:

• all available LiAZ-529222 and LiAZ-621322 buses at the time of the survey were included in the sample;
• the sample did not take into account failures and repair operations performed by the manufacturer during the warranty period on these modification of buses.

The frequency of observations of the monitored buses is carried out daily.

The sample size for obtaining reliable material was determined by standard methods. In the case of the nonparametric method (when the type of distribution law is unknown), the sample size for the estimation of the unknown reliability law was determined by the following formula [4]:

$$N = \frac{\ln (1-\beta)}{\ln P(x)}$$

(1)

where $\beta$ is the confidence level;

$P(x)$ the required probability of failure-free operation during some operating time $x$.

In case of failure and malfunction of the bus, the driver filled out an application for current repair and submitted the bus to the area of current repair for inspection (diagnostics). During the repair the
foreman recorded the actual time of the beginning and the end of the repair, the list of repair operations, causes of malfunction, etc. in the observation report.

Subsequently, the statistics collected were entered into the SAP software database and presented in MS Office Excel spreadsheets. The spreadsheets contained structured information on the following key criteria:

- modification of the bus;
- garage number of the bus;
- date of failure and malfunction;
- mileage at the time of failure or malfunction;
- actual repair time;
- name of repair operations;
- mechanic’s conclusion, etc.

For the purpose of the further analysis and systematization of failures on certain intervals of operating time, the data were consolidated in the form of the table 1.

| Interval, thousand km | 0–50 | 50–100 | 100–150 | 150–200 | 200–250 | … | 750–800 |
|-----------------------|------|--------|---------|---------|---------|----|---------|
| \( N_t \) |       |        |         |         |         |    |         |
| \( \Sigma r_i \) |       |        |         |         |         |    |         |
| \( \omega(t) \) |       |        |         |         |         |    |         |

where \( \Delta t \) is the interval of operating time (mileage), thousand km;

\( N_t \) – number of observed buses in the interval, units;

\( \Sigma r_i \) – number of observed failures in the interval, units;

\( \omega(t) \) – estimated value of the failure flow parameter.

To specify the observations of the monitored buses and a more detailed study of changes in the failure flow under the conditions of compressed timing of observations it is advisable to break the intervals of operating time on the mileage \( \Delta t = 50 \) thousand km. It was taken into account that the necessary number of intervals should be within the range from 8 to 12 [4].

Based on mileage data, the number and distribution of observed buses were calculated and carried out in the specified intervals (\( \Delta t = 50 \) thousand km). The different number of controlled buses in the observation intervals is caused by the uneven age fleet structure.

Similarly, the distribution of failures within the specified intervals for observed buses was performed.

The failure flow is the ratio of the number of failures of the object being restored for a sufficiently small amount of its operating time to the value of this operating time [1, 5].

\[
\omega(t) = \frac{m(t+\Delta t) − m(t)}{\Delta t}
\]  \hspace{1cm} (2)

where \( \Delta t \) – operating time (mileage);

\( m(t) \) – the number of failures that occurred from the initial point of time before reaching the operating time \( t \);

the difference \( m(t+\Delta t) − m(t) \) is the number of failures on the operating time (mileage) \( \Delta t \).

Statistical evaluation of the failure flow parameter \( \omega(t) \) in each of the operating time intervals is determined by the formula 3, the data are entered in Table 1 separately for each of the bus modifications.

\[
\omega = \frac{\Sigma r_i}{N_t \times \Delta t}
\]  \hspace{1cm} (3)

where \( \Sigma r_i \) – the number of observed failures in the interval;

\( N_t \) – the number of buses observed in the interval;

\( \Delta t \) – operation time interval value.
In order to compare the operation of fleet in different conditions (different from the nominal ones), the standards of maintenance and repair of fleet are adjusted to the specific conditions of operation. The following types of correction are distinguished:

- resource (at the federal, sectoral and intrasectoral levels) – to create comparable working conditions for motor transport enterprises;
- operational (at the intra-industry and economic levels) – to ensure efficient use by the motor transport enterprise of its human and material resources.

Adjustments are made by changing:

- the quantitative value of the maintenance and current repair standards;
- list of maintenance operations;
- the ratio between maintenance and current repair work by including typical, frequently recurring current repair operations in maintenance.

At the same time, it is important to take into account the availability of reliable information of failures and costs of current repairs and preventive maintenance.

Determination of correction coefficients, in accordance with the recommendations of the "Regulations" [3], is carried out for the enlarged groups of fleet with a mileage interval of 0.25 \( L_R \) (0-200 thousand km) to the service life:

- Age group 1 – mileage from the beginning of operation from 0 to 200000 km;
- Age group 2 – mileage from the beginning of operation from 200001 to 400000 km;
- Age group 3 – mileage from the beginning of operation from 400001 to 600000 km;
- Age group 4 – mileage from the beginning of operation from 600001 to 800000 km.

\( L_R \) is a mileage of units before to resource depletion (Table 2), determined on the basis of experience in the operation of LiAZ buses in the Russian Federation [3, 5–8]. The resources of the bus units may be achieved submitted that the frequency of maintenance is observed, with the use of fuels and lubricants and operating materials recommended by the manufacturer.

### Table 2. Unit mileage rates before resource depletion LiAZ-529222 and LiAZ-621322 buses, thousand km

| Category of operating conditions | Engine, MAN D0836 LOH | Transmission, ZF Ecomat 4 6HP504C | Front axle RL-85A ZF | Rear axle AV-132/87, AV-132 II /87 ZF |
|---------------------------------|-----------------------|-----------------------------------|----------------------|-------------------------------------|
| III                             | 800                   | 800                               | 800                  | 800                                 |

![Figure 1. Histogram of the effect of the service life on the annual average mileage of LiAZ buses](image-url)
The correction coefficient of specific norms of spare parts consumption defines increases in mathematical expectation of number of expected failures and corresponding quantity of spare parts in the considered interval of mileage \((0.25 \ L_R)\) since the beginning of operation.

The mileage-correction factor is calculated in relation to the average value of the failure flow at the middle of the interval \((0.25 \ L_R)\), relatively the first group. The value of the failure flow for the first age group is taken as 1.

Calculation of correction coefficients depending on the fleet age is based on the average annual mileage by year of operation.

Histogram (Figure 1) shows the effect of the service life (year of operation) on the annual average mileage of the LiAZ-529222 and LiAZ-621322 bus modifications.

### 3. Processing and analysis results

All LiAZ-529222 and LiAZ-621322 buses, which are on the balance of the company, were under observation during the period of statistical data collection from 01.08.2017 to 31.12.2018.

In the conducted studies, the sample volume for LiAZ-529222 buses was 107 units, and for LiAZ-621322 – 32 units which meets the specified conditions (see the formula (1)).

During the observation period, the statistics of failures of LiAZ-529222 and LiAZ-621322 buses were obtained in the amounts of 1148 and 319, respectively.

In accordance with Formula 1, a sample size of at least 28 shall be used to study the reliability characteristics of the safety-related components and assemblies (maximum reliability level).

The sample size for obtaining reliable material was determined by standard methods, according with the formula (1).

\[
N = \frac{\ln (1 - 0.95)}{\ln 0.9} = 28
\]

where 0.95 is the confidence level (in the field of road transport operation is in the range from 0.8 to 0.95);

0.9 – the required probability of failure-free operation during some operating time (in the field of road transport operation it is usually assumed to be 0.9).

Tables 2 and 3 buses included data on the number of observed buses in the operating time interval and the number of failures for the LiAZ-529222 and LiAZ-621322.

Further, the calculation of the failure flow for each of the intervals operation was performed according to the formula 3. For example, for the interval of 350-400 thousand km for the LiAZ-529222 bus modification:

\[
\omega(t) = \frac{\sum r_i}{N_t \cdot dt} = \frac{315}{73} = 0.086
\]

where 315 – the number of recorded failures in the interval of 350–400 thousand km for the modification of the LiAZ-529222 bus;

73 – the number of observed LiAZ-529222 buses in the interval of 350–400 thousand km;

50 – operating time interval.

Similarly, calculations are performed for other intervals.

Estimated values of the failure flow of LiAZ-529222 and LiAZ-621322 buses for all intervals are presented in Table 3 and 4.

| Table 3. The value of the LiAZ-529222 bus failure flow according to specified operating time intervals |
|------------------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Mileage interval, thousand km            | 150    | 200    | 250    | 300    | 350    | 400    | 450    | 500    | 550    |
| \(N_t\)                                 | 2      | 2      | 12     | 44     | 73     | 82     | 51     | 20     | 3      |
| \(\sum r_i\)                            | 6      | 6      | 41     | 120    | 315    | 396    | 254    | 105    | 13     |
| \(\omega(t)\)                           | 0.060  | 0.060  | 0.068  | 0.054  | 0.086  | 0.086  | 0.096  | 0.099  | 0.105  | 0.086  |
Table 4. The value of the LiAZ-621322 bus failure flow according to specified operating time intervals

| Mileage interval, thousand km | 150  | 200  | 250  | 300  | 350  | 400  | 450  | 500  | 550  |
|------------------------------|------|------|------|------|------|------|------|------|------|
| \( N_t \)                    | 7    | 17   | 26   | 22   | 16   | 7    | 4    | 1    |      |
| \( \sum r_t \)               | 19   | 46   | 64   | 76   | 59   | 32   | 20   | 3    |      |
| \( \omega(t) \)              | 0.054| 0.054| 0.051| 0.073| 0.076| 0.091| 0.100| 0.060|      |

The correction coefficient of spare part consumption norms depending on age was calculated on average value of failure flow at the middle of an interval from the beginning of operation with a step of operating time of 0.25 \( L_R \) (0–200 thousand km). The data were entered in Table 5.

Based on the lack of statistical data on failures for the 4 age groups (mileage from the beginning of operation from 600 thousand km to 800 thousand km), the value of the coefficient was forecasted by the already known values of the coefficient for the three previous groups.

Calculation of correction coefficients depending on the age of the fleet is based on the average annual mileage by year of operation (Table 6, Figure 2).

Table 5. Values of the correction coefficient of specific norms of spare parts consumption (\( K_4 \)) depending on the mileage from the beginning of bus operation

| Bus modification | Mileage interval, thousand km | 0-200 | 200-400 | 400-600 | 600-800 |
|------------------|-------------------------------|-------|---------|---------|---------|
| LiAZ-529222      | 1.00                          | 1.12  | 1.62    | 2.05    |
| LiAZ-621322      | 1.00                          | 1.20  | 1.58    | 1.99    |

Table 6. Values of the correction coefficient of specific norms of spare part consumption (\( K_4 \)) depending on the age of the buses

| Bus modification | The age of buses, years |
|------------------|------------------------|
| LiAZ-529222      | 1 0.85 0.94 1.02 1.11 1.21 1.30 1.37 |
| LiAZ-621322      | 0.87 0.96 1.05 1.14 1.23 1.32 1.38 |

Figure 2. Histogram of correction coefficient values of specific norms of spare part consumption (\( K_4 \)) depending on the age of buses
4. Conclusion
As a result of the research, the technique of experimental determination of correction coefficient of specific norms of spare part consumption ($K_4$) depending on mileage from the beginning of operation has been offered. Figure 3 shows a graph for comparing the values of the correction coefficient of specific norms of spare parts consumption according to various methods and regulatory approved documents [3, 8] for the class of LiAZ buses.

![Figure 3. Values of the correction coefficient $K_4$ according to different methods](image)

Technique testing is performed in real conditions of the operating branch of the SUE "Mosgortrans" by the example of buses LiAZ-529222 and LiAZ-621322, representing a significant share of the fleet of the company.

As a result of the performed calculations, the values of the correction coefficient of specific norms of spare parts consumption ($K_4$) depending on mileage and time from the beginning of operation have been received, taking into account the dynamics of change of average annual mileage of the considered modifications of buses at the enterprise of SUE "Mosgortrans".

It is necessary to adhere to a single rational system of management and planning of spare parts and materials consumption in order to increase the level of fleet reliability, improve the system of supply in the branches of SUE "Mosgortrans".

The obtained values of the correction factors are currently applied within the framework of the developed unified management and planning system of spare part consumption in the bus branches of SUE "Mosgortrans".

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