The influence of operational factors on the performance of buses of municipal routes of the city of Volzhsky

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Abstract. The article provides an analysis of MUE «Volzhskaya №1732 bus depot» premature buses removals with repair of components and parts. Scheduled maintenance and repair system implies the elimination of buses removals and repair works between MO1 (MO - Maintenance Operations) and MO2. The authors analyzed the malfunctions of the u-joint transmission, gearbox, clutch, engine. The article presents the results of researches of buses removals with different mileage. On the basis of many researches, it has been established that the resource of components and parts of the vehicles in kilometers of run, under proper operation, obeys the law of normal distribution. It is determined that premature buses removals are also possible with the influence of operating factors of the route network of the city of Volzhsky. Factors of delays of buses at traffic lights and pedestrian crossings are considered, the values of traffic flows are determined, the features of buses stopping at bus stops are identified. All these factors cause a change in speed, maneuvering of buses and, as a result, accelerated wear of the u-joint transmission, gearbox, clutch and engine. The article presents the results of researches of operational factors and recommendations for the exclusion or reduction of these factors on the performance of buses.

1. Introduction
The external operational factors affecting the trouble proof operation of components and parts of city buses include: large traffic flow, maneuvering in front of traffic lights, in front of pedestrian crossings, at bus stops, condition of the road network. In addition to the load of the road network affects the level of motorization, which in the Volzhsky city exceeds the requirements of building rules and regulations.

The organization of the buses on the routes should be aimed at the safe transportation of passengers, as well as warning of emergency removals due to adverse operational factors. Constant monitoring of the performance of buses and forecasting the state of the street-road network will make it possible to eliminate premature buses removals from the routes. The lack of places at the bus stops leads to the waiting and maneuvering of buses, which causes accelerated wear of components and parts. Besides the reducing traffic flow, it is necessary to ensure the safe setting of buses at bus stops and make separate lanes for public transport.

The purpose of the researches is to determine the external operational factors of the route network to reduce the impact on premature buses removal with repair.
2 Determination of quantitative characteristics of buses performance

2.1 Research method choice

In the municipal bus depot MUE «Volzhskaya №1732 bus depot» of the city of Volzhsky, 166 buses are operated: Volgabus-4298G8 - 8 units, Volgabus-5270G2 - 7 units, Volgabus-5270GH - 52 units, Volgabus-5285D0 - 1 units, Volzhinan-5270 - 60 units, Volzhinan-6270 - 23 units, Volzhinan-32901-4 units, Volzhinan-6216 - 1 unit. Until 2018, Icarus-280 buses also worked for operation on enterprises orders.

To provide the performance of vehicles, it is necessary to know the laws governing the changes in the technical state of vehicles under the influence of various factors during operation. Knowledge of these patterns is the basis for the development and effective application of scientifically based methods and standards for maintaining vehicles in a technically valid condition, i.e. management of their performance [1].

Determining the quantitative characteristics of the performance of components and parts of rolling stock is possible with the help of mathematical methods based on the generalization of the accumulated statistical data on their work in real operating conditions. For the development of recommendations for the rational technical operation, improvement of the design of cars, information about regularity of changes in their technical condition is needed. The most important regularities of technical operation include: changes in the technical condition of a vehicle, component, or parts by operating time (running time or mileage); the dispersion of the parameters of the technical state and other random variables that operate the technical operation, for example, the duration of the repair and maintenance work; the formation of the total flow of failures in vehicles (recovery process) [2].

To determine the performance of buses, removals due to ICE, clutch, gearbox, u-joint transmission are systemized. On the basis of many researches, it has been established that the resource of vehicles, as well as components and parts, under the correct operation, obeys the law of normal distribution.

"Operation of motor vehicles" chair of Volzhsky Polytechnic Institute constantly analyzes the performance of buses "Volzhnan", which consists in evaluation of removals with repair of components and parts with the determination of mileage from the moment of repair to the subsequent removal with repair. At the MUE «Volzhskaya №1732 bus depot» enterprise, there is an automated “1C: Enterprise 8. Motor Vehicle Management Standard” program, which allows you to receive statistical data on removals with repair and to determine mileage before the next removal.

The plan for the collection of operating data provides the definition of buses removals with repair of engine, clutch and gearbox with the calculation of mileage to removal with repair.

Evaluation of the parameters of the vehicle mileage distribution to removal with the components repair, performed according to the method of Gmurman V.E., presented in [3].

The source data for calculating the number of objects of observation N:

The following indicators are used:
- confidence probability q = 0.95;
- marginal relative error E = 0.05;
- the coefficient of variation $\nu = 0.20$.

With these values, the size of selection should be at least 45.

The coefficient of variation is equal:
- with normal distribution (Gaussian) $\nu = 0.3$;
- with Weibull distribution $\nu$ from 0.3 to 0.9;
- with exponential distribution $\nu$ from 0.9 to 1.1.

The calculation is performed according to the following formulas [3]:

\[
\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \cdot n_i
\]
standard deviation $\sigma$:
$$
\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2 \cdot n_i}
$$

(2)

the coefficient of variation $\nu$:
$$
\nu = \frac{\sigma}{x}
$$

(3)

certainty interval (interval value of mileage):
$$
\left( \bar{x} - \frac{t \cdot \sigma}{\sqrt{n}}; \bar{x} + \frac{t \cdot \sigma}{\sqrt{n}} \right),
$$

(4)

where $n$ – selection size; $t$ – Laplace function argument, $t = 1.96$ when $q = 0.95$; $\pm \frac{t \cdot \sigma}{\sqrt{n}}$ – measurement error.

Testing the hypothesis about the normal distribution is performed by the Pearson criterion [3].

As a criterion for testing hypothesis random value is taken $X^2$:
$$
X^2 = \sum \frac{(n_i - n'_i)^2}{n'_i},
$$

(5)

Where $n_i$ and $n'_i$ are empirical and theoretical frequencies.

The area of acceptance of the hypothesis is determined by the inequality: $X^2 \left( \chi^2_{\alpha}; k \right)$,

where $\alpha$ – level of statistical significance, $k$ – number of degrees of freedom.

The level of significance $\alpha$ in the calculations is $\alpha = 0.05$. Number of degrees of freedom $k$ defined by equation:

$k = s - 1 - r$,

where $s$ – number of selection groups; $r$ – the number of parameters of the intended distribution (for normal distribution $r = 2$), so $k = s - 3$.

**Rule.** In order, at a given level of significance, to test the hypothesis about the distribution of the population according to the normal law, it is necessary to calculate the theoretical frequencies, and then the observed value of the criterion $X^2$. According to the table of critical points of the distribution $X^2$, given level of significance $\alpha$ and number of degrees of freedom $k = s - 3$ find the critical point $X^2 (\alpha; k)$. If $X^2_{\text{observ}} < X^2_{\alpha}$, then the hypothesis is approved. If $X^2_{\text{observ}} > X^2_{\alpha}$, then the hypothesis is rejected.

### 2.2 Analysis of premature buses removals with repair

The analysis of removals with repair of components and parts has been carried out and the regularity of distribution of mileages to removals has been determined.

Analysis of removals with the malfunction of the u-joint transmission: the sixty “Volzhnin-5270” buses had 205 removals, the 16 buses “Volzhnin-6270” had 29 removals, the 41st bus “Ikarus-280” had 162 removals. The number of removals for each malfunction is shown in figure 1,2,3. During of the monitoring produced, the causes of buses breakages were identified. The main causes of breakages are the wear of the driveshaft slots; increased clearances (backlash) in the driveshaft joints; breakage of bolts of gearbox flanges and rear axle; high levels of driveshaft vibration; break of the driveshaft [4,5].
Since November 2017, 52 Volgabus-5270GH buses have been operated in the municipal bus depot №1732. As of the end of December 2018, the average mileage of buses is 52358.8 km. The maximum mileage is 62080 km at the bus with guar. №809; minimum mileage is 35301 km at the bus with guar №804. Mileages to maintenance are: 10,000 km to MO1 and 20,000 km to MO2. All buses are operated on the main city routes. The operational properties of rolling stock are determined by the technical characteristics of the bus "Volgabus-5270GH". The use of CNG motor fuel (methane) helps to improve the ecology of the city of Volzhsky. The number of the removals with repair of the engine is 201, with repair of the clutch is 53, with repair of the gearbox is 55.
The nature of the engine system malfunction: topping up antifreeze, does not develop speed, smoke check, cooling system branch pipe leak, antifreeze leak, the ICE does not start and heats up, the cooling fan, ICE does not work intermittently, no pressure, oil leaks and other removals [6].

The nature of the clutch malfunctions: clutch adjustment, no clutch release, the clutch slips, the clutch does not engage, the clutch pedal does not work, the clutch does not disengage.

The nature of the malfunction of the gearbox: gearbox link/cable, leak oil from the gearbox, no gear transmission, gearbox noise, gearbox lever, no first gear, no second gear.

The number of the removals for each malfunction is presented on figure 4-6.

**Figure 4.** The number of the removals with engine malfunctions of bus “Volgabus-5270GH”.

**Figure 5.** The number of the removals with clutch malfunctions of bus “Volgabus-5270GH”.

Figure 6. The number of the removals with gearbox malfunctions of bus “Volgabus-5270GH”.

Calculation of the parameters of distribution of the mileage of buses to removals with repair of the components according to formulas 1-3 was carried out; results of the calculations are presented in Table 1. According to initial assumptions, distribution of mileage of the buses obeys the normal distribution law. Graphs of the distribution of the observed and theoretical mileages of buses to removals with repair are presented in figure 7-11.

As it can be seen from the graphs presented in figure 7 - 11, the distribution of the observed mileages obeys the exponential law, and the distribution of theoretical paths obeys the Weibull law. The exponential distribution of buses mileages before removals with malfunctions of u-joint transmission indicates possible violations in operation, repair and assembly technology, and design of u-joint transmission.

According to [7], failures (removals with repair) give a characteristic mainly of constructive reliability, as well as the quality of manufacture and assembly of vehicles and their components, and the subsequent ones characterize operational reliability taking into account the existing level of organization and production of maintenance and repair and spare parts supply.

Table 1. Mileages distribution parameters.

| Removal with repair | Mileages distribution parameters | Compliance with normal law |
|---------------------|---------------------------------|---------------------------|
|                     | $n$ | $\bar{x}$ | $\sigma$ | $\nu$ | $\chi^2_\nu / \chi^2_{max}$ | |
| “Volgabus-5270, -6270” buses, min. mileage 112 km, max. mileage 96456 km. | | |
| u-joint transmission | 138 | 26 | 26 | 0,98 | 27,6/16 | not complying |
| “Icarus-280” buses, min. mileage 100 km, max. mileage 95220 km. | | |
| u-joint transmission | 114 | 15,08 | 19,07 | 1,26 | 27,6/165,6 | not complying |
| “Volgabus-5270GH” buses, min. mileage 35301 km, max. mileage 62080 km. | | |
| engine | 201 | 6935 | 8120 | 1,17 | 15,5/69,68 | not complying |
| gearbox | 55 | 11382 | 12400 | 1,09 | 16,9/25,02 | |
| clutch | 53 | 11132 | 12800 | 1,14 | 16,9/18,01 | |

Figure 7. The graph of the distribution of the observed and theoretical mileages of the buses “Volgabus-5270” and “Volgabus-6270” to the removals with the u-joint transmission malfunction.

Figure 8. The graph of the distribution of the observed and theoretical mileages of the buses “Icarus-280” to the removals with the u-joint transmission malfunction.

Figure 9. Distribution of observable and theoretical mileages to the removals with engine repair of buses "Volgabus-5270GH".

Figure 10. Distribution of observable and theoretical mileages to the removals with clutch repair of buses "Volgabus-5270GH".
In this regard, we can conclude that since the mileage of the component or unit after its repair, failures appears as sudden and their distribution in most cases obeys an exponential law, although their physical nature is basically a collective manifestation of wear and fatigue components.

Using the methodology [7], we assume that in the initial period of buses operation, removals with repair were made due to the quality of manufacturing and assembly of vehicles and their components and their running-in. Considering that the maintenance of vehicles is carried out according to the standards of the manufacturer, we analyze the influence of operating factors of the route network on removals with repair.

3. Analysis of operational factors on the road network
Operational factors include road conditions (condition of the road surface), traffic conditions during heavy city traffic, the amount of traffic flow, the influence of bus operation modes - constant and variable, personnel qualifications, climatic conditions, quality and timeliness of maintenance [2].

Bus operating conditions on city routes can lead to the decreasing of life of engine, clutch, gearbox, u-joint transmission and accelerated wear of steering hinges and the failure of the braking system.

Road conditions on the routes of the city of Volzhsky are satisfactory. Asphalt surface determines the normal mode of operation of buses and the elimination of cases of buses removals with repair.

Natural and climatic conditions do not highly affect buses removals with a repair. However, in hot summer conditions, the temperature of the coolant may rise.

Buses maintenance is carried out in accordance with the requirements of manufacturers. Performance of the bus is also affected by the qualification of personnel. The higher is the qualification of driver, the closer to optimal mode the work of the buses is, that leads to the reduction of values of failures and increases the lifetime of components.

The article observes conditions of the buses during intensive city traffic by the traffic flow value, ensuring technical speed, delays on sections of routes, organization of buses stopping at bus stops.

Traffic conditions for public transport in the city of Volzhsky are unsatisfactory. The load of the city road network occurs due to the large motorization of citizens (474 cars per 1,000 inhabitants, with a SNiP norm of 247) and a large number of routed taxicabs — 512 city units and more than 300 suburban units, passing through the same streets as the buses routes. This can affect the decrease in buses speed, the frequency of maneuvering before bus stops, frequent gear changes, the increase friction of brake mechanisms, the frequency of maneuvering before bus stops, and an increase value of bus removals with malfunctions of engine, clutch, gearbox, brake and steering systems.

Driving mode of the bus is to be set by the driver, depending on the road conditions, his qualification and the technical condition of the vehicle. In the city, buses are operated in an alternating driving mode with multiple accelerations and decelerations, with frequent changes in road resistance and traffic conditions, which is a feature of intensive city traffic. With a variable mode of operation of the ve-
hicle, stability of the thermal mode and friction in the components and in the engine is disturbed. It increases the intensity of wearing of components and parts and fuel consumption.

Values of the calculated and actual traffic flows are presented in table 2 [8]. Research of the magnitude of traffic intensity on the streets of the city of Volzhsky, where public transport routes pass, showed, that the levels of traffic service defined by the industry document [9] mainly correspond to E and F levels in the areas, indicated in table 2. In these cases, the actual value of the traffic flow (vehicles/hour) is higher than calculated. This leads to a hard work of drivers, frequent maneuvering and variable bus operation mode, which can lead to a decrease in driving speed, increase of engine revolutions, wear of brake linings, high run on a curvilinear trajectory, a large number of transmission changes. Stability of the thermal regime and friction in the components and in the engine is disturbed. It increases the intensity of wear and fuel consumption.

### Table 2. Traffic flows on the main streets of the city of Volzhsky.

| Street                  | Area                        | Traffic flow value, vehicles per hour | Maintenance level |
|------------------------|-----------------------------|--------------------------------------|------------------|
|                        |                             | calculated                          | actual           |
| Lenina avenue          | Stroitelei square - Fontannaya st. | 2078                                | 2199             | EF               |
|                        | Fontannaya st.- Sverdlova square | 2625                                | 2648             | E                |
|                        | Sverdlova square-Lenina square | 1969                                | 2070             | EF               |
|                        | Lenina square-Molodogvarheitsev st. | 1903                                | 1949             | EF               |
|                        | Molodogvarheitsev st.- Aleksandrova st. | 2581                                | 2618             | EF               |
| Mira                   | Aleksandrova st.-Olomoutskaia st. | 2603                                | 2646             | EF               |
| Engelsa                |                            | maximum values                      | 1778             | 1950             | EF               |
| Pushkina               | Aleksandrova st.-Olomoutskaia st. | 1516                                | 1609             | F                |
| Druzhby                | Aleksandrova st.-Olomoutskaia st. | 538                                 | 632              | F                |
| Olomoutskaia           | Karbysheva st.- Lenina av.          | 1398                                | 1410             | E                |
| Aleksandrova           | Lenina av.- Karbysheva st.       | 1138                                | 1215             | F                |
|                        | Karbysheva st.- Druzhby st.       | 1260                                | 1325             | F                |
| Karbysheva             | Karbysheva square ring-Korolyova st. | 1859                                | 2056             | E                |
|                        | Korolyova st.- Profsoyuzov boulevard | 1659                                | 1902             | F                |
|                        | Profsoyuzov boulevard - Pionerskaya st. | 1859                                | 1806             | F                |
|                        | Pionerskaya st.-Aleksandrova st. | 1990                                | 2008             | F                |
|                        | Aleksandrova st.-Olomoutskaia st. | 1836                                | 1648             | E                |
|                        | Olomotskaia st. -40 let Pobedy | 1090                                | 966              | E                |
|                        | 40 let Pobedy st.-87 Gv. Divizii st. | 901                                  | 780              | F                |

Due to the large traffic flow on Mira street and Lenin avenue, where about 20 public transport routes pass, delays up to 60 seconds occur at traffic lights and pedestrian crossings.

The authors determined dependence on the provision of technical speed of buses on the traffic flow on Mira street in the form of regression equation [10]. The technical speed was determined on route №14 by the counters on the «Volzhanin-6270» and GAZelle buses, and the traffic flow was determined by the counters on 5 certain stations along Mira street of the city of Volzhsky starting from the 37th microdistrict. The maximum values of the traffic flow for the settlement period of 1 hour at “rush hour” on sections of Mira street on a working day are presented in Table 3. The speed stated in the schedule for the «Volzhanin-6270» and «GAZelle» buses on route 14 is 24.9 km/h and 31.2 km/h, respectively, which is provided by a traffic flow equal to or less than 760 vehicles/h (fig. 12) and equal to or less than 938 vehicles/h (figure 13). The maximum traffic flow reaches 1407 vehicles per hour,
which also leads to traffic delays and maneuvering of buses. Provision of technical speed by buses is possible only by relief of Mira street due to reduction of traffic flows, making of a separate lane for public transport.

Table 3. Summary table of regression equations.

| Bus model | Observation day | Traffic flow value, vehicles/hour | Number of observations | Regression equation |
|-----------|----------------|----------------------------------|------------------------|--------------------|
| Volzhanin | Wednesday      | 1407                             | 96                     | $Y = 3652.68 / X + 20.1$ |
| Volzhanin | Sunday         |                                  | 128                    | $Y = 1969.04 / X + 22.6$ |
| GAZelle   | Wednesday      |                                  | 144                    | $Y = 2812.5 / X + 28.2$ |
| GAZelle   | Sunday         |                                  | 160                    | $Y = 4298.5 / X + 26.4$ |

Figure 12. The dependence of the technical speed of the «Volzhanin-6270» bus on the intensity of the traffic flow on Mira st. on a working day.

Figure 13. Dependence of the technical speed of the «GAZelle» bus from traffic intensity on the Mira st. on a working day.
Of the 54 surveyed bus stops, 22 ones with the existing organization of passenger transportation do not provide simultaneous safe stopping of buses at bus stops [11]. The approach of buses to bus stops is carried out with waiting for a place, maneuvering, which also affects the performance of buses. The load of one of the bus stops is shown in figure 14. Simultaneously at the bus stop can stop 5 buses. In 10 minutes, 36 buses approached the bus stop, in 3 cases the buses could not stop without waiting and maneuvering.

![Figure 14. Load of a "Rynok Valentina" bus stop in the time interval from 8-15 to 8-25.](image)

4. Findings
1. Considered the nature of the buses removals with malfunctions of u-joint transmission, gearbox, clutch, engine.
2. Analysis of operational factors on the route network of the city of Volzhsky showed that deterioration in the performance of buses, causing premature removals with repair, is possible due to the high traffic flow, delays and maneuvering before traffic lights and pedestrian crossings, delays and maneuvering before stopping at the bus stop due to waiting for free space.
3. All the factors considered lead to frequent maneuvering and variable bus operation, leading to a constant change in driving speed, an increase in engine speed, wear of brake linings, a large run during a curvilinear trajectory of movement, a large number of gear changes. In the components and in the engine, the stability of the thermal regime and friction is disturbed.
4. In the "Volgabus-5270GH" bus a manual gearbox is used, the reduction of the resource of which is possible due to frequent gear changes at bus stops.
5. The effects of premature removals due to untimely and poor-quality maintenance have not been determined in this work and are separate researches. In the MUE «Volzhskaya №1732 bus depot», buses maintenance is serviced according to mileages, specified by manufacturers.

5. Suggestions
Researches have identified the need to consider operational factors to ensure the performance of buses. To increase the performance of buses, it is necessary to reduce the influence of operational factors on the route network. To do this, it is necessary to reduce the traffic flow by redistribution of transit vehicles to other streets, making a separate lane for public transport, increasing the length of bus stops and
the making of individual places for buses of medium and large capacity of MUE «Volzhskaya №1732 bus depot».

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References

[1] Atapin V G 2006 Fundamentals of technical systems performance. Automobile transport (Novosibirsk: NSTU publisher) p 192
[2] Isaenko P V 2014 Fundamentals of technical systems performance: in 2 parts (Tomsk: TSUAB publisher) p 324
[3] Gmurman V E 2003 Probability Theory and Mathematical Statistics: Tutorial for universities - 9th ed p 479
[4] Chernova G A and Popov Al V 2013 Analysis of the possible reasons for the low operational reliability of u-joint transmissions of "Volzhanin" buses Automotive industry 6 pp 26-28
[5] Chernova G A and Popov Al V 2010 Investigation of the causes of premature failure of the "Volzhanin" buses u-joint transmissions Modern science: theory and practice: mater. I I tern. scientific-practical conf. vol 12 (Stavropol: Natural and technical sciences / GOU VPO "NorthCaucasus STU") pp 326-329
[6] Chernova G A and Pimenov E A 2019 Evaluation of the quantitative characteristics of the performance of the buses "Volga-bass-5270GH" transmission Internauka: scientific journal 6 (88) Part 1 - M. «Internauka» publisher pp 78-83
[7] Abaimov R V and Malaschuk P A 2007 Fundamentals of technical systems performance. Syk. Fo est univ. - ed. second, revised (Syktyv-kar: SFU0) p 92
[8] Popov A V and Chernova G A 2018 The urban traffic flow and its impact on the intensity of work of drivers on the example of the city of Volzh-sky. monograph VPI (branch) (VolgSTU. Volgograd) p 223
[9] ODM (guidance doc.) 218.2.020-2012 Guidelines for evaluating the capacity of highways
[10] Chernova G A, Svetlichnaya V B and Velikanova M V 2014 The use of mathematical statistics in the organization of transportation of passengers by public transport. News of VolgSTU: intercollege. comp. of scientific articles 19 (146) VolgGTU Volgograd p 108 (“Land Transport Systems” series Issue 9 pp 77-81)
[11] Chernova G A, Velikanova M V 2013 Evaluation of the safe operation of the passenger-forming bus stop in the city of Volzhsky. Modern problems of the transport department of Russia 3 pp 71-81