Designed gearbox reliability assessment techniques based on the real one

R.R. Yusupov, A.D. Yarzhemsky, A.V. Alexeyev, M.G. Korchazhkin, L.A. Berdnikov
Nizhny Novgorod State Technical University after R.Y. Alexeyev
E-mail: ro.iusupov@yandex.ru

Abstract. The paper shows the designed gearbox reliability assessment and analysis on the basis of the real one. The basic diagram has been analyzed as well as the units’ eventual failures. Based on the designed structural diagram of the SU gearbox reliability level has been estimated. The measures to raise the reliability level have been proposed.

Key words: unmanned vehicle, reliability calculation, failure quota, mean time between failures, gear box.

Research: “Gazon Next” gear box reliability calculation.
Research objective: estimate the reliability of the designed gear box on the basis of the real one and update to the required reliability level.

Introduction
Reliability is the property of objects to keep in time the values of all the parameters describing the ability to function as required by the preset modes and operating conditions.

Reliability is dependable on the following factors:

- Road operation conditions;
- Transport operation conditions;
- Natural and climatic conditions.

Road conditions determine the car units’ operation modes. They are determined by the road technical category, the type and quality of the roadway covering and the land topography (its altitude).

Transport operation conditions of the vehicle stock are determined by the traffic routing, cargo features, the real amount of load and others. All the above is determined by a number of basic rates and factors of vehicle operation conditions.

Natural and climatic conditions are characterized by the ambient temperature (a. t.), air humidity, dust level, precipitation intensity, wind load, solar radiation, seasonal fluctuations of operating conditions, environmental attacks, and altitude.

Car operation in urban and suburban areas causes time-varying modes of the ICE as well as intensive detrition of suspension, break gear and transmission rubbing parts, which are subject to heavy loads. [1]

At present non piloted vehicles are actively being developed. They require a high reliability level of their units and components. To achieve it computing and analyzing car units reliability level must be done, based on the obtained results, the reliability level must be raised to the goal, and new vehicle units must be designed.

“Gazon Next” gear box was chosen as the research object. “Reliability computing” and “updating to the goal” were made. Analysis was made based on the findings.

“Gazon Next” gear box reliability computing
Reliability computing plan
1. Gear box analysis.
2. Reliability structural diagram building.
3. Mean time to failure analysis.
4. System reliability computing.
5. System updating to reliability goal.

**System basic diagram analysis**

The general view of the basic diagram system is shown below (Fig. 1)

![Figure 1. General view of the system basic diagram](image)

1 – primary shaft; 2 – fifth gear; 3 – synchronizing sleeve; 4 – selector rod; 5 – third gear; 6 – second gear; 7 – first gear; 8 – gear shift fork; 9 – reverse gear; 10 – secondary shaft; 11 – sixth gear; 12 – intermediate shaft; 13 – fourth gear

**Building structural diagram of the system reliability**

Building is carried out with the following assumptions:

1) All the failures are independent;
2) In case a component fails, the system remains operative.

For building, let us subgroup the units based on their functionality:

1) gear shift knob
2) selector rod
3) gear shift fork
4) synchronizing sleeve
5) primary shaft
6) intermediate shaft
7) secondary shaft
8) gearwheel meshed

Let us make the system reliability model with the obtained units (Fig. 2)

![Figure 2. Air brake system reliability diagram](image)
As the reliability of some units in the diagram is increased the reliability model has been enlarged (Fig. 3).

![Image](image1.png)

**Figure 3.** Enlarged reliability diagram

**Mean time to failure analysis**

Initial data array has been obtained from the OAO GAZ dealer stations information about the failure mean time (table 1)

| Units   | Number of failures | Failure mean time km. | Reconditioning mean time norm/h. |
|---------|--------------------|-----------------------|----------------------------------|
| GSN     | 1                  | 94474                 | 0.44                             |
| SR      | 3                  | 51098                 | 6.2                              |
| GSF     | 4                  | 58544                 | 6.2                              |
| SS      | 10                 | 44996                 | 5.99                             |
| Prim. shaft | 3            | 51098                 | 6.2                              |
| Interm. shaft | 1         | 350                   | 4.2                              |
| Secondary shaft | 3    | 48522                 | 5.92                             |
| Gearwheel | 4              | 39699                 | 6.18                             |

Table 1 - Failure data

*Fig. 4 shows the gearbox failure quota*

![Image](image2.png)

**Figure 4.** Units failure distribution

**System reliability computing**

Reliability computing algorithm is shown [2]. The reliability of this system is estimated:

\[ P = P_1 \cdot P_2 \cdot P_3 \cdot P_4 \cdot P_5 \cdot P_6 \cdot P_7 \cdot P_8 \]
where $P_1$ – Gear shift knob (0,96)
$P_2$ – Selector rod (0,89)
$P_3$ – Gear shift fork (0,86)
$P_4$ – Synchronizing sleeve (0,64)
$P_5$ – Primary shaft (0,89)
$P_6$ – Intermediate shaft (0,96)
$P_7$ – Secondary shaft (0,89)
$P_8$ – Gearwheels meshed (0,86)

Probability of no-failure operation according to experimental data of the system failures is:
$$P = P_1 \cdot P_2 \cdot P_3 \cdot P_4 \cdot P_5 \cdot P_6 \cdot P_7 \cdot P_8 = 0.96 \cdot 0.89 \cdot 0.86 \cdot 0.64 \cdot 0.89 \cdot 0.96 \cdot 0.89 \cdot 0.86 = 0.31$$

As is seen from the computation the lowest failure-free operation is in:
- Synchronizing sleeve
- Gear shift fork
- Gearwheels meshed

Let us increase the above units’ reliability to 95% and calculate:
$$P = P_1 \cdot P_2 \cdot P_3 \cdot P_4 \cdot P_5 \cdot P_6 \cdot P_7 \cdot P_8 = 0.96 \cdot 0.89 \cdot 0.95 \cdot 0.89 \cdot 0.96 \cdot 0.89 \cdot 0.95 = 0.56$$

### System updating to the required level

Units’ reliability rate must be redistributed for the whole system reliability to be $P^{TP} = 0.47$

**Solution:**

The whole system reliability is
$$P = 0.31$$

To update the system let us consider the units in the reliability ascending sequence

| Symbol | $P_i$ |
|--------|-------|
| $i_1$  | 0.64  |
| $i_2$  | 0.86  |
| $i_3$  | 0.89  |
| $i_4$  | 0.89  |
| $i_5$  | 0.89  |
| $i_6$  | 0.89  |
| $i_7$  | 0.96  |
| $i_8$  | 0.96  |

Assign the relevant numbers.

Value the rank:

$$r_1 = \left( \frac{P_1}{P_2 \cdot P_3 \cdot P_4 \cdot P_5 \cdot P_6 \cdot P_7 \cdot P_8} \right)^{1/7} = \left( \frac{0.47}{0.86 \cdot 0.89 \cdot 0.89 \cdot 0.89 \cdot 0.96 \cdot 0.96} \right)^{1/7} = 0.98$$ (2)

$$r_2 = \left( \frac{P_1}{P_2 \cdot P_3 \cdot P_4 \cdot P_5 \cdot P_6 \cdot P_7 \cdot P_8} \right)^{1/7} = \left( \frac{0.47}{0.86 \cdot 0.89 \cdot 0.89 \cdot 0.89 \cdot 0.96 \cdot 0.96} \right)^{1/7} = 0.92$$ (3)

$$r_3 = \left( \frac{P_1}{P_2 \cdot P_3 \cdot P_4 \cdot P_5 \cdot P_6 \cdot P_7 \cdot P_8} \right)^{1/7} = \left( \frac{0.47}{0.89 \cdot 0.89 \cdot 0.96 \cdot 0.96} \right)^{1/7} = 0.9$$ (4)

$$r_4 = \left( \frac{P_1}{P_2 \cdot P_3 \cdot P_4 \cdot P_5 \cdot P_6 \cdot P_7 \cdot P_8} \right)^{1/7} = \left( \frac{0.47}{0.89 \cdot 0.96 \cdot 0.96} \right)^{1/7} = 0.89$$ (5)

$$r_5 = \left( \frac{P_1}{P_2 \cdot P_3 \cdot P_4 \cdot P_5 \cdot P_6 \cdot P_7 \cdot P_8} \right)^{1/7} = \left( \frac{0.47}{0.96 \cdot 0.96} \right)^{1/7} = 0.89$$ (6)

$$r_6 = \left( \frac{P_1}{P_2 \cdot P_3 \cdot P_4 \cdot P_5} \right)^{1/7} = \left( \frac{0.47}{0.96 \cdot 0.96} \right)^{1/7} = 0.894$$ (7)

$$r_7 = \left( \frac{P_1}{P_2 \cdot P_3} \right)^{1/7} = \left( \frac{0.47}{0.96} \right)^{1/7} = 0.9$$ (8)

$$r_8 = \left( \frac{P_1}{P_2} \right)^{1/7} = \left( \frac{0.47}{1} \right)^{1/7} = 0.91$$ (9)

Let us estimate the “K” number (Table 2)

| №  | $P_i$  | $r_i$  | Symbol |
|----|--------|--------|--------|
| 1  | 0.64   | 0.98   | <      |
| 2  | 0.86   | 0.92   | <      |
To update the system to goal the reliability of «K=6» units must be raised. Their reliability is raised to the level $P_{TR} = 0.894$. The system reliability is estimated:

$$P = \left( P_0^{TPR} \right)^K \cdot \prod_{i=k+1}^{n+1} P_i = \left( P_0^{TPR} \right)^6 \cdot P_7 \cdot P_8 \cdot P_9 = (0.894)^6 \cdot 0.96 \cdot 0.96 \cdot 1 = 0.47$$

To update the system the following must be done: the reliability of the first unit is 0.96; the reliability of the second unit must be raised from 0.89 to 0.894; the reliability of the third unit must be increased from 0.86 to 0.894; the reliability of the fourth unit must be raised from 0.64 to 0.894; the reliability of the fifth unit must be raised from 0.89 to 0.894; the reliability of the sixth unit is 0.96; the reliability of the seventh unit must be increased from 0.89 to 0.894; the reliability of the eighth unit must be raised from 0.86 to 0.894.

Review
The reliability probability of the rest car SU is $P_{J} = 0.85 - 0.9$. The reliability probability based on experimental data and after updating the system to the required level is $P = 0.31$, $P_{mp} = 0.47$. In comparing the obtained results of reliability probability with the acceptable value margin we can see that the obtained results do not enter the range. It cannot be stated that SU of the gear box must be updated to the acceptable reliability level as the failure data are insufficient. It makes it possible to conclude that failure data are not enough.

Conclusion
In this research an analysis of “GASon Next” gear box was made. Based on it, the reliability structural diagram was made. The obtained data enable us to make a histogram of average trouble-free life which shows the main units subject to risk. In calculating gear box SU reliability the permissible reliability level is lower than failure-free operation probability of the other car SU which do not respond to traffic safety. One can conclude that it is necessary to increase reliability of the gear box units, particularly synchronizing sleeves, gear shift forks and gearwheels meshed.

Acknowledgements
This research done with the financial support from Ministry of Education and Science of the Russian Federation in the frame of the complex project “The establishment of the high-tech manufacturing of safe and export-oriented GAZ vehicles with autonomous control systems and the possibility of integration with the electric platform on the base of components of Russian production” under the contract №03.G25.31.0270 from 29.05.2017 (Governmental Regulation №218 from 09.04.2010). The experimental research was conducted with the use of measurement equipment of the NNSTU Centre of collective using “Transport Systems”.

Bibliography
[1] Kuzmin N.A., Borisov G.V. “Car working capacity change laws” – NNSTU, - N. Novgorod, 2014.
[2] Berdnikov L.A., Suvorov I.A., Vilkov N.A. Comprehensive approach to examining the factors which determine the reliability of turbochargers of car ICE. Collected Papers of 12 International Young People’s Scientific and Technical Conference “The Future of Technical Science”, Nizhny Novgorod, NNSTU, - 2013. Pp. 195-196.
[3] Korczakhin M.G., Khoryayev E.A. Research of fuel system reliability of car diesel engines. Collected Papers of the 94 International Scientific and Technical Conference of the Association of car engineers “Non-piloted vehicles: problems and prospects”. Nizhny Novgorod, NNSTU – 2016, pp. 240-245.
[4] Korczakhin A.V., Solovyev S.S. Functional reliability features of car automatic transmission. Papers of NNSTU after R.Y. Alexeev – 2013, № 4 (101). Nizhny Novgorod, 2013, pp. 66-71.
[5] Tokarev A.V., Berdnikov L.A. Diagnostic specificity of brake systems in checkup. Transport Systems – 2017, №3. Nizhny Novgorod, 2017, pp. 21-26.

[6] Korchazhkin M.G. Increasing functional reliability of city bus engines when operating in a high heat load mode / M.G. Korchazhkin // Thesis for a candidate of technical sciences, 2005.

[7] Kustikov A.D. City bus transmission reliability problems / A.D. Kustikov, N.A. Kuzmin, M.G. Korchazhkin // Papers of NNSTU after R.Y. Alexeev – 2013, №4 (101). Pp. 18-26.

[8] L. A. Berdnikov, A. A. Pikulkin, M.G. Korchazhkin, P. I. Bazhan and L. A. Zakharov. Study of factors affecting the reliability of turbochargers/ IOP Conference Series: Materials Science -and Engineering, Volume 386, conference 1