Seasonal changes assessment of motor oil consumption by cars

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Annotation. In the article, the question of seasonal conditions influence on motor oil consumption by cars is considered. In the process of research, a hypothesis of a significant impact of seasonal conditions on motor oil consumption by cars is made. The hypothesis is verified by assessing the significance of oil consumption changes during the year. Harmonic analysis is used to solve this problem. The experiment was conducted for cars of six brands and models. The monthly variation of oil change quantity, oil refill numbers, and the amount of refilled oil were analyzed. As a result, it was found that for all the cases under consideration, all the indicators vary significantly over time. The results obtained can be used to improve the motor oil reserve management system.

1. Introduction

Motor oil plays an important role in ensuring durability and efficiency of cars. Engine operating life depends on oil quality and frequency of its change. Therefore, a correct selection and timely delivery of motor oil influence the cost of maintenance and repair [1].

The motor oil consumption planning system currently in use prescribes determination of the planned consumption as a proportion of the amount of fuel consumed. Along with the advantage of the system, which is its simplicity, it has a number of disadvantages. In particular, the impact of operating conditions on oil consumption is not sufficiently taken into account. In addition, some factors have different effects on fuel consumption and oil consumption. As a result, a calculated oil consumption determined by the current method may differ significantly from the actual one. This leads to an increase of oil reserves or their lack. Accordingly, oil acquisition and storage costs increase, or engine durability reduces and repair costs rise [2, 3].

Most of the Russian territory is characterized by a significant change of climatic conditions during the year. Thus, in Western Siberia, the air temperature can vary from – 60 °C to +35 °C [4]. It is established that the ambient temperature affects the coolant temperature and the oil temperature in the sump of the car engine, causing its viscosity change. These processes cause a significant variation of oil consumption rate. The results of this dependence study obtained by different authors are contradictory and sometimes mutually exclusive.

Planning of oil consumption for its change is carried out on the basis of the maintenance production program. It is not taken into account that due to the variation of the car operation rate during the year, the maintenance requirement flow varies over time, causing a change in oil demand.

Thus, there is an urgent problem of planning motor oil requirement, with the variation of operating conditions taken into account, and reducing the cost of revolving fund on that basis.

2. Research method

In the process of research, a hypothesis of a significant impact of seasonal conditions on motor oil consumption by cars is made. The hypothesis is verified by assessing the significance of oil consumption changes during the year, taking into account that operational conditions are changing during the year causing a change of motor oil consumption rate.
Indicators, the values of which change over time, can be represented as a dynamic series. The main hypothesis put forward in the study suggests that oil consumption varies significantly over time, respectively, the indicators characterizing it can be represented as follows [5]:

\[ Q = Q_C + Q_T + Q_P \]

where \( Q_C \) is a constant component; \( Q_T \) is a periodic component; \( Q_P \) is a random component.

The periodic component can be described by a harmonic model of the following type [5]:

\[ Q_T = \sum_{k=1}^{g} Q_k \cos(m(T_i - T_{0k})) \]

where \( k \) is a number of a harmonic; \( g \) is harmonic quantity; \( Q_k \) is an oscillation half amplitude of the \( k \)-th harmonic; \( T_i \) is the current time (months); \( m \) is the interval between \( T_i \) and \( T_{i+1} \) (degrees); \( T_{0k} \) is the initial oscillation phase (months).

To assess the significance of the seasonal variation of indicators characterizing motor oil consumption, the harmonic model of the periodic component is linearized by replacing the variables [5]. Then we will get:

\[ Q_T = \sum_{k=1}^{g} Q_k z_k \] where \( z_k = \cos(m(T_i - T_{0k})) \).

If we assume that the oscillation cycle of motor oil consumption has a 12-month periodicity, the condition of change significance consists in evaluation of the correlation coefficient significance for a linear one-factor equation of the following type

\[ Q_T = Q_1 z_1 \] where \( z_1 = \cos(30(T_i - T_{01})) \).

The condition of correlation coefficient significance \( r_{Q_1z} \) for the first harmonic is [5]:

\[ \frac{|r_{Q_1z}|}{\sqrt{1-r_{Q_1z}^2}} \sqrt{n-2} \geq t_P \]

where \( t_P \) is the table value of Student's criterion for confidence probability \( P \) and \( n-2 \) freedom degrees.

If the indicator change is estimated by monthly averages, then \( n=12 \) and \( \sqrt{n-2} \approx 3.16 \), therefore

\[ \frac{3.16 |r_{Q_1z}|}{\sqrt{1-r_{Q_1z}^2}} \geq t_P \]

Thus, the significance condition of seasonal changes of the indicators characterizing motor oil consumption is obtained.

In addition to assessing the significance, it is necessary to assess the magnitude of changes. For this purpose, the value of the first harmonic oscillation half-amplitude can be used. In addition to it, there is one more dimensionless indicator, which is unevenness factor \( K_U \) that shows the ratio of the maximum indicator value in the average annual [5].

3. Experimental research

Data collection on the parameters of the motor oil consumption process was carried out in transport enterprises of OJSC "Surgutneftegaz". The corporate database was used as a source of information. First, cars were selected from the database by brands and models, then the considered technical effects were selected.

To process the database, a program was developed. It allows sorting technical impacts by month, as well as presenting results in a graphical form.

The experiment provides assessment of motor oil consumption for each month during the year. Since the plan matrix is determined by the experiment task, planning is reduced only to assessment of the required number of measurements at each point of the plan, that is, for each month. The minimum required number of measurements \( N \) for the normal distribution law of values is determined by the expression [5]:

\[ N = t_\alpha^2 V_s^2 / \Delta^2. \]
where $t_2$ is Student’s statistics corresponding to probability $P$; $V_Q$ is variation coefficient; $\Delta$ is relative error.

The results of the calculations carried out using the latest formula are given in table 1.

| $\Delta$ | $N$ at $P=0.95$ and various $V_Q$ values |
|----------|----------------------------------------|
| 0.10     | 9                                      |
|          | 15                                     |
|          | 24                                     |
|          | 35                                     |
| 0.05     | 35                                     |
|          | 61                                     |
|          | 96                                     |
|          | 138                                    |

When choosing the number of measurements, it is necessary to test the hypothesis of the distribution normality of the measured values, as well as to determine the value of variation coefficient.

For that purpose, a preliminary experiment was carried out, which consists in selecting from the database the values of the amount of refilled oil for each month. The obtained samples were processed. Verification of the empirical distribution compliance with the normal law was tested by Pearson's criterion [5].

Data were obtained for cars KAMAZ-43118, Ural-4320, GAZ-3302, GAZ-2705, UAZ-3909, Volkswagen Multivan.

The values of variation coefficient vary from 0.15 to 0.24. Accordingly, to ensure relative error of no more than 0.10 with no less than 0.95 probability, it is necessary to carry out minimum 9 ... 24 measurements, and for 0.05 relative error, it is necessary to carry out 35 ... 96 measurements. Calculations show that all empirical distributions are adequately approximated by the normal law with no less than 0.95 probability.

4. Results

The experiment involved cars of six brands and models: Ural-4320 – 111 units, KAMAZ-43118 – 33 units, GAZ-3302 – 129 units, GAZ-2705 – 282 units, UAZ-3909 – 332 units, Volkswagen Multivan – 159 units.

The experiment can be described as passive, consisting in collecting information about the actual values of the indicators that form motor oil requirement.

The experiment consisted in processing the database of OJSC "Surgutneftegaz" by selecting information about the moments of the technical impacts on the cars of the above brands and models, including oil refills into the engines.

When processing the experimental data, the average monthly values of the maintenance number, the number of refills, as well as the amount of the refilled oil were calculated. To ensure the possibility of their comparative analysis, the values are translated into relative values (as a proportion of the average monthly values for the year). The results are shown in a graphical form in fig. 1.

Next, a harmonic analysis of time series of values of indicators that form motor oil consumption by cars is performed. A fragment of the results is given in table 2. Consolidated results for the first harmonics are presented in table 3.

The indicators presented in the latest table allow estimating the value and frequency of oscillations of oil consumption for refilling:

$Q_k$ is oscillation half amplitude that shows the maximum relative deviation from the mean value, with the period depending on the harmonic number: one year for the first harmonic; $\frac{1}{2}$ year for the second harmonic; ...;

$T_i$ is initial phase which is time in months corresponding to the maximum harmonic value;

$r^2$ is determination coefficient for the linearized harmonic, showing the influence share of this
harmonic in the change of the considered indicator;

$r$ is correlation coefficient for the linearized harmonic characterizing the closeness of the linear relationship of time and changes in the considered parameter with the periodicity corresponding to the harmonic number;

$t_r$ is Student's statistics for correlation coefficient;

$t_{0.95}$ is the table value of Student’s statistics for 0.95 probability and 10 freedom degrees.

Figure 1. Change of the indicators forming oil consumption by cars KAMAZ-43118 during the year:
Nm is maintenance number; Nr is number of operations performed to refill motor oil; Qr is refilled oil amount

Table 2. The harmonic analysis results of consumption changes of oil for refilling the engines of cars KAMAZ-43118 during the year

| Harmonic number | $Q_r$ | $T_1$, months | $r^2$ | $r$   | $t_r$ | $t_{0.95}$ |
|-----------------|-------|---------------|-------|-------|-------|------------|
| 1               | 0.30  | 2.96          | 0.8037| 0.8965| 6.39  | 2.23       |
| 2               | 0.02  | 3.75          | 0.0044| 0.0663| 0.21  | 2.23       |
| 3               | 0.08  | 2.36          | 0.0526| 0.2293| 0.74  | 2.23       |
| 4               | 0.10  | 0.97          | 0.0932| 0.3053| 1.01  | 2.23       |
| 5               | 0.06  | 3.18          | 0.0331| 0.1819| 0.58  | 2.23       |

Table 3. Parameters numerical values and statistical characteristics of the first harmonic linear model of oil consumption changes for refilling the car engines during the year

| Car brand and model | $Q_r$ | $T_1$, months | $r^2$ | $r$   | $t_r$ | $t_{0.95}$ |
|---------------------|-------|---------------|-------|-------|-------|------------|
| Ural-4320           | 0.14  | 0.38          | 0.414 | 0.6434| 2.66  | 2.23       |
| KAMAZ-43118         | 0.30  | 2.96          | 0.8037| 0.8965| 6.39  | 2.23       |
| GAZ-3302            | 0.43  | 1.91          | 0.7538| 0.8682| 5.53  | 2.23       |
| GAZ-2705            | 0.19  | 2.77          | 0.5697| 0.7548| 3.64  | 2.23       |
| UAZ-3909            | 0.22  | 0.98          | 0.5671| 0.7531| 3.62  | 2.23       |
| Volkswagen Multivan | 0.16  | 3.87          | 0.4794| 0.6924| 3.03  | 2.23       |

Graphs of the linearized harmonics and a graph of the harmonic model are shown in fig. 2.

Analysis of the data from the table 2 indicates that for all the cases considered, Student’s $t$-statistic exceeds the table value for 0.95 probability. For example, for cars Ural-4320, correlation coefficient for the first harmonic is 0.6434, $t$-statistics 2.66 exceeds the table value 2.23 for 0.95 probability.
Similarly, for cars Volkswagen Multivan, \( r = 0.6924, t_r = 3.03 > t_{0.95} = 2.23 \).

![Graphical view of linearized first harmonic of the model of oil consumption change for refilling the engines of cars KAMAZ-43118 over the year](image)

**Figure 2.** Graphical view of linearized first harmonic of the model of oil consumption change for refilling the engines of cars KAMAZ-43118 over the year

Thus, the hypothesis of a significant change of motor oil consumption during the year is confirmed. The next issue to be solved in this experiment is determination of the maximum deviation value of the considered parameters from the mean values. For this purpose, for each of the three indicators under consideration, unevenness coefficient equal to the ratio of the maximum value for the year to the average annual value was calculated. The calculation results are given in table 4.

**Table 4.** Unevenness coefficient values of indicators forming motor oil consumption by cars

| Car brand a model | Unevenness coefficient values | Unevenness coefficient values | Unevenness coefficient values |
|-------------------|-------------------------------|-------------------------------|-------------------------------|
|                   | for oil change number         | for oil refills number        | for refilled oil amount       |
| Ural-4320         | 1.54                          | 1.12                          | 1.29                          |
| KAMAZ-43118       | 1.31                          | 1.41                          | 1.44                          |
| GAZ-3302          | 1.27                          | 1.62                          | 1.99                          |
| GAZ-2705          | 1.21                          | 1.36                          | 1.51                          |
| UAZ-3909          | 1.21                          | 1.55                          | 1.74                          |
| Volkswagen Multivan| 1.23                          | 1.56                          | 1.59                          |

Analysis of the results shows that for the number of changes of oil in the engine, unevenness coefficient varies from 1.21 (GAZ-2705 и UAZ-3909) to 1.54 (Ural-4320).
5. Inference
The hypothesis of a significant change of motor oil consumption during the year is confirmed.

Analysis of the obtained results shows that for the number of changes of oil in the engine, unevenness coefficient varies from 1.21 to 1.54, for the number of refills, it varies from 1.12 to 1.62, and for the amount of the refilled oil, it varies from 1.29 to 1.99.

6. Conclusion
On the basis of the data on the actual motor oil consumption, the statistical significance of the seasonal variation of indicators that form motor oil requirement for cars of six brands and models is proved.

The results obtained can be used to improve the motor oil reserve management system.

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