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# Complex Characteristic Estimation of Vehicle Adaptability for Low Temperature Operation Conditions.

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**ABSTRACT**

Complex estimate of vehicle adaptability is offered for estimation of measure changes of singular operating characteristics of vehicles in severe conditions. It was regularity of low-temperature operation conditions influence on adaptability complex estimate is discovered; additive mathematical model of vehicle adaptability for low-temperature operation conditions complex exponent formation is developed. It was in complex characteristic of vehicle adaptability for low temperatures conditions that complex of five particular exponents is necessary: fuel economy, engine preheat time after parking in the open air, easiness of cold engine start, engine durability, driveline aggregates durability. Low-temperature operation conditions in moderately cold climate zone (representative point – Tyumen city), are characterized by four representative intervals, which severity varies from 3,4 *R* to 10,3 *R*. It corresponds surrounding air temperature from 0 to -40 ℃

**Keywords:** low temperature conditions, vehicle adaptability, severe operation conditions of vehicles.

## INTRODUCTION

Most countries are functioning in unstable economic conditions. These conditions dictate the most demanding requirements for resources saving. Demands on the vehicle performance efficiency are increasing. At the same time, severe low-temperature conditions [1,2,3,4,5,6,7,8] in which considerable part of Russian Motor Park is operated, affect vehicles negatively.

The influence of low temperatures on vehicle performance is considered by correcting norms of vehicle resources consumption, realization of different operating procedures etc. However, variable level of different brands and models vehicles adaptability for low temperatures is insufficiently taken into consideration [2,3,4,5,7,9,]. This leads to sufficient imprecisions in prescription of different vehicle operating standards, prevents objective planning, control and estimation of their efficiency and quality [10].

Demanding heavy expenses instrumental methods are widely used in estimation of measure changes of singular operating characteristics of vehicles in severe conditions. At the same time, it is possible to estimate comprehensively the adaptability on the ground of other methods, in particular expert ones, which provide essential resources saving in comparison with technical measurement instruments [11,12,13].

## METHODOLOGY

### The model of complex adaptability estimate

Estimation criterion is necessary for estimation of vehicles operation conditions severity for providing comparableness of different severe factors of operation. Taking into account multifactorness of vehicles operation conditions this criterion should be adaptable for using in integral exponent featuring comprehensively influence of combination of various factors. It should comply with the requirements of *generality, normalization, and comparability* [14,15]. Universal 12-grade scale of severity complies these requirements. Measuring unit of severity is exponent R. It corresponds 1/12 of possible maximum deviation of factor score from its standard score. In standard conditions, severity criterion is equal to *0* and in the most severe conditions it is equal to *12 R*. Therefore, severity scale *R* can be used for estimation of severity of low-temperature operation conditions representative intervals.

Changing of factors of vehicle’s separate operation characteristics under the influence of low temperature of surrounding air can serve as a characteristic of vehicle adaptability for winter operation conditions. Estimation of vehicle adaptability is a multiobjective problem [16]. Factors of vehicle operation characteristics serve as optimization criteria. Once noted criteria have various dimension and physical nature, optimization mechanism giving an opportunity to solve the multiobjective problem is necessary.

Investigation of multiobjective optimization methods led to the conclusion that almost all known methods of vector synthesis of optimal system directly or indirectly comes to scalar synthesis [17,18]. In other words particular criteria by some means combines into a complex criterion. Hereafter this criterion is maximized (or minimized) [19].

Complex estimate of vehicle adaptability foresees usage of complex (resumptive) coefficient of adaptability. Complex coefficient of vehicle adaptability *K* presents a function depending on singular exponents and can be found according to a formula [20]:

$$K = K_V \cdot \sum_{i=1}^{n} \lambda_i \cdot k_{ai}. \qquad (1)$$

*(1),* where

$_i$ – “weight” of i$^{th}$ exponent of vehicle adaptability;

$K_{ai}$ – adaptation coefficients taking into account vehicle adaptability for low-temperature operation conditions on various exponents of its operation peculiarities;

*n* – amount of vehicle adaptability exponents;

$K_V$ – coefficient "veto". It reduces to 0 when one of particular exponents of adaptability goes out of prescribed limits and it is equal to 1 in all other cases.

Complex coefficient of adaptability changes within 0 and 1.

If *K* = 0, vehicle is absolutely inadaptive for these particular operation conditions. If *K* = 1, values of operation peculiarities exponents comply with nominal ones (given in the motor-book). According to accepted within the constraints of the research vehicles classification by adaptability, complex coefficient of adaptability *K* has three typical variation ranges: from 0 to 0,33 (*low* level of vehicle adaptability complies with this interval), from 0,33 to 0,66 (*middle* level of adaptability), from 0,66 to 1 (*high* level).

Complex coefficient of adaptability *K* changes in interspace of type forming vehicle operation peculiarities. It also changes depending on severity of low temperature of surrounding air. In the course of aprior research of vehicle adaptability complex coefficient's substantial content current hypothesis was formed. According to this hypothesis, searching for dependence of complex coefficient of adaptability *K* from severity of low-temperature operation conditions *h* should be done in class of functions corresponding typical additive model of adaptability.

$$K = K_o - s \cdot h^{\alpha},$$ (2), where

$K_o$ – optimal value of complex coefficient of vehicle adaptability;

*h* – severity of low-temperature operation conditions, *R*;

*s* – parameter of sensitivity to increase of severity of low-temperature operation conditions, reflects degree of line's curve, $^{o}C^{-1}$;

$\alpha$ – parameter of mathematical model, reflects degree of line's curve.

**Definition methods of adaptability complex coefficient values**

For definition of values of adaptability complex coefficient, it is necessary to form a list of the most informative in terms of its adaptability for low temperatures vehicle exit parameters. In addition, it is necessary to state "weight" of each of the exponents in complex characteristics, define values of particular adaptability coefficients for vehicles of different brands and models in specific low-temperature operation conditions.

It is established [20] that in conditions when characterizing different peculiarities of investigated object exponents are disparate and their values are not the same, the only one enough objective way of estimation of characteristics is defining between them relations of preferability which can be done with the help of expert evaluation method [13, 21,22].

On the ground of professional-theoretical analysis [20], procedures of experts' forward estimation are established: properties that are necessary and enough for specialists' participation in expertise are defined; list of questions is worked out. As a way of organization of expertise Delphi method [23] was chosen. Basic principles of this method are some rounds of questianary, anonymity, usage of "feedback" [13, 24,25]. These principles allow to increase empirically accuracy of expert questionary results. Interview method was used for expert qustianary. This method allows to individualize explanation of questions for experts, thereby almost excluding imprecisions resulting from their wrong interpretation.

On the ground of professional-theoretical analysis [20] primary list of vehicle operation peculiarities is established. These peculiarities can serve as characteristics of its adaptation for low-temperature conditions. Necessity for making up limited list of type forming exponents of vehicle operation peculiarities is established, since it is known that in conditions of deficit of sampled information including of less informative exponents into decision rule not only increase expenditures for information gathering, but also worsen average efficiency of classification.

## RESULTS

### The experts estimates results for establishing final list of particular adaptation exponents

For establishing final list of particular adaptation exponents on the ground of data gathered from preliminary questianary experts' selection is performed. As a method of alternatives ordering, exponents ranking method is used because it is the most corresponding expertise aims method. For achievement of requested level of estimates' coherence, three rounds of expert questionary were conducted, estimate of experts' competence (after the third round range of its variability worked out from 0,56 to 0,98) and expert estimates recalculation taking into account competence exponents was made. Calculation of pair correlation coefficient and coefficient of agreement for all possible pair correlations was performed. On the ground of calculation, interdependent peculiarities were aggregated [20].

Coherence of expert data is subject to analysis on three basic criteria: coefficient of variation *V* (its value for different characteristics after the third round corresponded from 0,18 to 0,02); remainder (*1 – [myu]$_j$*) (where *[myu]$_j$* – exponent of variation of $j^{th}$ peculiarity) as a measure of coherence on each characteristic (varies from 0,26 to 0,46); concordance coefficient *W* characterizing coherence of opinions on several peculiarities which influence one final result – vehicle adaptability (value of *W* after the third round of questionary corresponded 0,02). Importance of concordance coefficient is confirmed by criterion $[hi]^2$ ($[hi]^2_{fact} < [hi]^2_{table}$).

Average accuracy of expert estimates upon reaching coherence after the third round of questionary corresponds 0,85. As a result of analysis of expert data list consisting of 5 particular exponents of adaptability is formed, their weight coefficients are defined. Thus, complex coefficient of vehicle adaptability has the following form:

$$K = (k_{a_1} \cdot 0{,}33 + k_{a_2} \cdot 0{,}27 + k_{a_3} \cdot 0{,}2 + k_{a_4} \cdot 0{,}13 + k_{a_5} \cdot 0{,}07) \cdot K_V \text{, (3)}$$

where

$k_{a_1}$ – coefficient of vehicle adaptability on fuel economy;

$k_{a_2}$ – coefficient of vehicle adaptability on easiness of cold engine start;

$k_{a_3}$ – coefficient of vehicle adaptability on engine durability;

$k_{a4}$ – coefficient of vehicle adaptability on engine preheat time after parking in the open air;

$k_{a5}$ – coefficient of adaptability on driveline aggregates durability.

Experts assigned low ranks to *vehicle ecological compatibility* peculiarity markers. First, it can be explained by absence of experts' knowledge about change of values of surrounding air temperature fall ecological exponents.

**The experts estimates results for defining representative intervals of low-temperature operation conditions**

For defining representative intervals of low-temperature operation conditions, a group of specialists was formed as a result of preliminary questionary. To determine expert knowledge, as core method immediate interval estimate method is used.

Opinions, gathered as a result of questionary, have been met with statistical analysis on two directions: analysis of expert data about quantity and structure of representative intervals of surrounding air low temperatures [20]. For achievement of required level of coherence two rounds of questionary were needed. Calculation of variation and experts estimates' relative probabilities was done. For analysis of experts' opinions' distribution, distribution histograms were built separately for each control point of intervals. There is an example of histogram building for upper control point of representative intervals of low-temperature conditions.

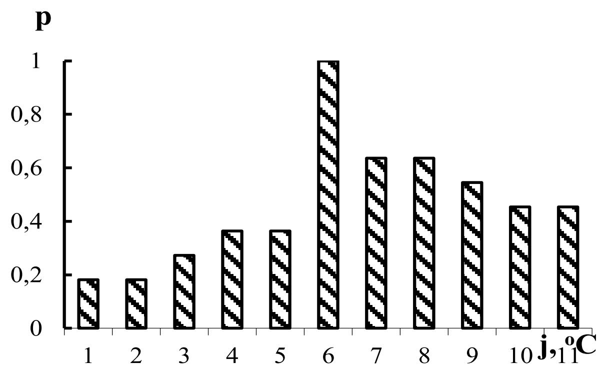



**Fig.1. Histogram of experts' opinions' distribution about value of upper control point of representative intervals of low-temperature vehicle operation conditions**

Histogram demonstrates high level of coherence in experts' answers about value of 0 °C. There are values of surrounding air temperature along axis of abscissa and exponent $p_j$, intended to be used for analysis of $j^{th}$ characteristic variation along axis of ordinates. Exponent $p_j$ presents relation of Hamming distance, serving for definition of reasonable discrete value in distribution of interval estimates, to number of experts in a group. Taking into account coordinated experts' group opinion, four representative intervals of low-temperature operation conditions were received. Their estimate in *R* is indicated in table 1.

**Table 1. Estimate of low-temperature operation conditions intervals**

| Interval | Interval limits defined by | |
|---|---|---|
| | Celsius scale, ℃ | Severity scale, *R* |
| 1. | [0 … -10] | [3,4 … 5,1] |
| 2. | (-10 … -20] | (5,1 … 6,9] |
| 3. | (-20 … -30] | (6,9 … 8,6] |
| 4. | (-30 … -40] | (8,6 … 10,3] |

**The experts estimates results for complex estimation of concrete brand and model vehicle adaptability**

For complex estimation of concrete brand and model vehicle adaptability, data gathered from ranges of expert questionaries (separately for each concrete brand and model) are used [20]. Each expert group membership after screening interview consisted of 10-15 people. All in all 173 specialists took part in expertise. They were defining adaptability of 12 different Russian brands and models vehicles: the VAZ-2105, the VAZ-2106, the VAZ-2107, the VAZ-2108, the VAZ-21099, the VAZ-21213, the GAZ-2410, the GAZ-31029, the KamAZ-5410, the KrAZ-6443, the "Moskvich"-412, the IG-2715. Questions to an expert supposed answers expressed in words and estimated by 4-grade order scale.

To check the coherence of expert data, the following coefficients were calculated: variation coefficients $V$, $\mu$, coefficient $K_M$ characterizing field containing the main part of experts' answers, and concordance coefficient $W$ (its value is defined by exponent $\chi^2$). Experts' competence analysis was carried out. Data were edited taking into account competence exponents. On the ground of data about coherence of expert estimates separately in each round of questionary, decision about realization of the next round was made (according to the Delphi method).

After it was established that gathered data are characterized by above-average coherence, generalized experts' opinion was figured out; value of complex coefficient of adaptability of presented brands and models vehicles in each representative interval of low-temperature operation conditions severity was calculated.

In possible interval, characterizing temperature of the coldest period in moderately cold climate zone (representative point – Tyumen city), researched brands and models of vehicles are distributed in accordance with adaptability level in the following way:

**Table 2: Vehicles adaptability levels in severity interval of low-temperature operation conditions from 6,9 *R* to 8,6 *R***

| High<br>$K$ = (0,66 … 1,00] | Medium<br>$K$ = (0,33 … 0,66] | Low<br>$K$ = [0 … 0,33] |
|---|---|---|
| VAZ-2108<br>VAZ-21099 | VAZ-2105<br>VAZ-2106<br>VAZ-2107<br>VAZ-21213<br>KamAZ-5410<br>KrAZ-6443 | GAZ-24-10<br>GAZ-31029<br>Moskvich-412<br>IG-2715 |

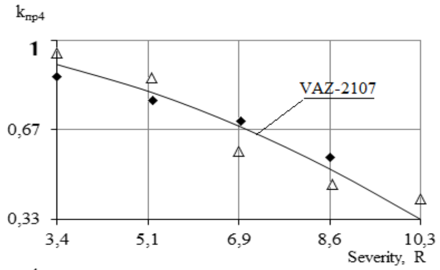
For approval of adaptability complex coefficient's dependence from surrounding air temperature, we used data of expert questionary for three different brands and models vehicles: the VAZ-21099, the VAZ-2107 and the IG-2715. It was done in order to provide the representativeness of selection characterized by low, medium and high level of adaptability correspondingly. Experts' answers were measured by *10*-grade order scale. Requested coherence was achieved after the second round of questionary. On this stage changing range of variation coefficient $V$ corresponded from 0 to 0,24 (average coherence is achieved at $V \leq 0{,}24$), concordance coefficient corresponded from 0,61 to 0,74 at $\chi^2_{факт} < \chi^2_{табл}$ (which is evidence of existence of non-random coherence in experts' opinions).

**The control measurements results to check experts estimations**

For constructing requested dependence, expert data validity was verified. For these purposes control measurements of engine preheat time for the following vehicles were performed: the IG-2715, the VAZ-2107. Methodologies developed and tested in Tyumen State Oil and Gas University, "Vehicle Operation" department were used. To perform control measurements, plan of experiment was worked out. This methodology foresaw performing measurements of engine preheat time at the following surrounding air temperatures: +20, 0, -10, -

20, -30 °C. After vehicle's long-term parking in the open air multimeter MAS-838 connected to coolant temperature sensor. After that engine start was performed. Upon reaching the temperature of engine +20 °C stopwatch started. Preheat was performing until temperature of 60 °C. In each presented temperature value 4-7 measurements were performed. Imprecision of the measurements was 3,3 %. It was established that experiment data distribution follows normal law.

For comparison, coefficient of vehicle adaptability on engine preheat ($k_{a4}$) defined as a result of marking estimation in expert questionary. And using results of control measurements this coefficient is equal to relation of engine preheat time in standard conditions (+20 °C) to preheat time at defined low air temperature. Experiments' results, expert questionary data in comparison with theoretical curve displaying change of vehicle adaptability coefficient on engine preheat time at surrounding air temperature fall are shown in fig. 2 and fig. 3.



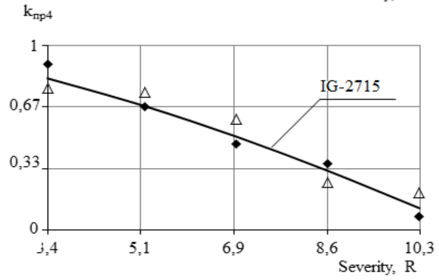




**Fig.2. Severity influence on value of adaptability coefficient on engine preheat time: - on the results of control measurements; - on experts questionary data;**

**Fig.3. Severity influence on value of adaptability coefficient on engine preheat time: - on the results of control measurements; - on experts questionary data;**

As a result of received data computing it was established that dependence of changes of adaptability complex coefficient *V* value under the influence of surrounding air low temperature severity is described by typical additive model of adaptability. Statistical analysis results by the example of such vehicles as the IG-2715 (characterized by low level of adaptability), the VAZ-2107 (medium level of adaptability) and the VAZ-21099 (high level) are shown in table 3.

**Table 3: Numerical values of parameters and statistical characteristics of model (2)**

| Parameters | Values for a vehicle with adaptability level | | |
|---|---|---|---|
| | low | medium | high |
| s·10-3 | 10,03 | 2,81 | 1,07 |
| $\alpha$ | 1,97 | 2,39 | 2,69 |
| F-Fisher's criterion fact., $F_{fact}$ | 82,9 | 16,6 | 110,03 |
| Average approximation error $\varepsilon$, % | 3,45 | 6,75 | 2,06 |
| Level of adequacy | 0,95 | 0,95 | 0,95 |

Statistical characteristics indicated in table 3 point at high adequacy of received model. Graphically indicated dependence for vehicles with low, medium and high adaptability level is shown in fig.. 4.

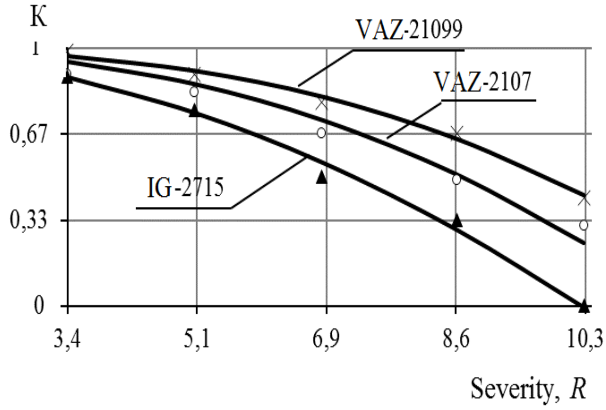



**Fig.4. Results of defining dependence of adaptability complex coefficient *K* value under the influence of low-temperature operation conditions**

## DISCUSSION

Outcomes of comparative analysis of engines preheat time measurements and results of expert questionary using such vehicles as the VAZ-2107 and the IG-2715 as an example showed that the difference between expert questionary data and control measurements results is not more than 15%. Thus, expert questionary data can be used for establishing of regularity of surrounding air low temperatures severity influence on vehicles adaptability complex coefficient.

Statistical characteristics obtained (indicated in table 3) point at high adequacy of received model. Thus, received results confirm the primary hypothesis.

There are some questions for discussion:

- the application limits of expert’ and expert-statistical methods for technical problems;
- the adaptability estimate for modern vehicles of different models;
- the estimate of severity of climatic factors, road factors etc.;
- investigation of operation efficiency for vehicles with different adaptability level.

These are area of future investigations.

## CONCLUSION

On the ground of basic principles of expert analysis transformation with respect to vehicles adaptability, development and testing of absent methods of expert analysis within the constraints of the research methodology of expert estimate of vehicle adaptability for low-temperature operation conditions was developed. Recommendations for recognition and exploitation of expert judgements are mathematically formalized. For simplicity of practical application methodological guidelines with detailed description of methodology are worked out. Procedures of expert estimates computing and analysis are realized on PC.

Methodology of motor-vehicles rational choice for particular severe operation conditions is worked out. Boundaries of low-temperature conditions, when certain brand and model vehicle operation can be considered to be effective, are indicated. Limits of vehicles use are recommended.

Complex of recommendations for different brands and models vehicles is worked out to improve their adaptability for low temperatures of surrounding air. This complex is differentiated by adaptability levels.

On the ground of elaboration of vehicle adaptability complex estimate methodology of differentiated fuel consumption rate is established.

Thus, resulting from the research [20]:

- applied research task of recognition and exploitation of regularity of low-temperature operation conditions influence on adaptability complex estimate is solved;
- additive mathematical model of vehicle adaptability for low-temperature operation conditions complex exponent formation is developed;
- it was established that for complex characteristic of vehicle adaptability for surrounding air low temperatures complex of five particular exponents is necessary: fuel economy, engine preheat time after parking in the open air, easiness of cold engine start, engine durability, driveline aggregates durability;
- low-temperature operation conditions in moderately cold climate zone (representative point – Tyumen city), are characterized by four representative intervals, which severity varies from 3,4 *R* to 10,3 *R*. It corresponds surrounding air temperature from 0 to -40 ℃;
- regularity of vehicle adaptability complex coefficient value change under the influence of surrounding air low temperatures is characterized by typical additive model of adaptability;
- methodology of expert estimate of vehicles adaptability for low-temperature operation conditions is worked out. This methodology represents particular modification of expert analysis basic principles.

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