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DETERMINATION OF THE QUALITY INDEX OF CARS

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Summary. This article presents theoretical studies of methods for assessing car quality indicators in the operation stage. Important criteria for determining the quality indicators of cars during the operation phase are the following: functional stability, ecology, comfort, technical solutions, and traffic safety. The problem of converting a multicriteria quality assessment to a single criterion is proposed to be solved by the method of determining a quality index. The methodology for the practical and actual implementation of this research is based on the evaluation of the quality index established on the average vehicle speed then the basic methodological principles are formulated. The quality index of a car is significantly dependent on the operating conditions. This article presents the correction coefficients for the quality index of base, hybrid, and electric vehicles, depending on the operating conditions. The studies and the proposed car quality index provide timely information on the characteristics of operating conditions, creating the necessary conditions and opportunities for automakers to improve the design of cars, promote the image of car brands, and increase sales.
Keywords: car, electric car, hybrid car, quality, method, technique

1. INTRODUCTION

To date, the choice of a car is complicated by the fact that it is carried out in conditions of a lack of information by the closure of operational failures by service enterprises; the limited and, to a large extent, advertising nature provided by manufacturers; the lack of a centralized bank containing objective information on the actual indicators of technical and operational properties of cars; the complexity of comparing information obtained from various sources, etc. It should be borne in mind that cars with specific purposes have different properties depending on the external conditions in which they are used [1-5].

The presence of specific properties of cars allows them to be used in conditions where the use of a different car model is less appropriate. The determination of the technical and operational properties and quality of automobiles as a whole allows choosing the one that best suits the user's requirements for these operating conditions and makes it possible to develop optimal methods for supporting the operation of the properties inherent in the design and manufacture of automobiles [6]. This context is especially important when choosing or purchasing a car for operation in Ukraine [7].

One of the major causes for the low vehicle competition in Ukraine is the lack of high-quality made-in-Ukraine vehicles. Car quality depends on several different indicators that describe not only the weight and overall parameters but also performance, reliability, fuel economy, maneuverability, safety, cost, etc. Therefore, the issue of evaluating and selecting a car during the operation phase by its user is not fully solved, justifying the relevance of the research topic [8-11].

The purpose of this work is to increase the efficiency of evaluating car quality indicators by quantifying them at the operational stage.

From an analysis of sources from the literature, it was established that the current state of the market and the updating of the structure of passenger cars at the operational stage require an integrated approach to the assessment of quality indicators with the goal of a better alternative [12-13, 27]. For the degree of compliance of passenger cars with operating conditions and consumer expectations, it is necessary to consider the large list of technical and operational properties displayed by the totality and quality of parameters. A review of existing studies on the analysis of methods for assessing the quality of automobiles was carried out, although it does not allow full objective consideration of the totality of indicators that require their improvement [14, 26, 30].

2. RESEARCH AND METHODS OF THE QUALITY INDEX RESULTS

The object of this research is the process of determining the quality indicators of cars at the operational stage.

The solution to the task is provided by the use of a systematic approach and a rational combination of theoretical and experimental studies, generalization and analysis of known scientific results, as well as the use of mathematical modeling, and mathematical statistics of the first developed special techniques. Road test methods were applied to assess the quality parameters of passenger cars. An urgent scientific and applied problem was solved, creating conditions for the efficient use of vehicles by improving the method for assessing the quality indicators of vehicles at the operational stage.

To evaluate the car quality index, performance indicators were studied and developed in this research. Important criteria for determining the quality indicators of cars during the operation phase are the following: functional stability, ecology, comfort, technical solutions, and traffic safety. The quality of the car, considering its level of functional stability and energy intensity during the operation phase, is evaluated from the position of the frequency of technical impacts, energy consumption and the cost of maintenance and repair. A criterion that evaluates the functional stability of quality indicators is as follows:

- base car

$$K_Q = \frac{0.079 N_{max} \cdot g_{emin} \cdot C_T \cdot L_{GVM}}{C_{auth} \cdot \rho_T \cdot V_a} = \frac{A}{V_a}, \tag{1}$$

$$A = \frac{0.079 N_{max} \cdot g_{emin} \cdot C_T \cdot L_{GVM}}{C_{auth} \cdot \rho_T}, \tag{2}$$

- hybrid car

$$K_H = \frac{20 N_{max} \cdot g_{emin} \cdot C_T \cdot L_{GVM}}{C_{auth} \cdot \rho_T \cdot V_{max} \cdot V_a} = \frac{C}{V_a}, \tag{3}$$

$$C = \frac{20 N_{max} \cdot g_{emin} \cdot C_T \cdot L_{GVM}}{C_{auth} \cdot \rho_T \cdot V_{max}}, \tag{4}$$

- electric car

$$K_H^e = \frac{2.7 E_{ACB} \cdot C_c \cdot L_{GVM} \cdot V_{max}}{C_{auth} \cdot L_e \cdot V_a} = \frac{B}{V_a}, \tag{5}$$

$$B = \frac{2.7 E_{ACB} \cdot C_c \cdot L_{GVM} \cdot V_{max}}{C_{auth} \cdot L_e}, \tag{6}$$

where:

N_{max} – maximum engine power, kW;

g_{emin} – minimum value of specific fuel consumption, g/kW • h;

C_T – the cost of one liter of fuel, UAH;

L_{GVM} – guaranteed vehicle mileage, km;

C_{auth} – the cost of a new car, UAH;
ρ_T – specific gravity of fuel, kg/l;
V_a – speed, km/h;
E_{ACB} – battery capacity, kW • h;
C_c – the cost of one kW • h, UAH;
L_e – electric range, km;
V_{max} – maximum speed, km/h.

From the equations described above, it follows that for a given car, the criterion of functional stability of the quality assessment indicators will not achieve a constant value.

During the dynamic growth of the intensely competitive automobile market, the level of comfort of a driver and passengers is continuously increasing. The reason for this may be an improvement of the car design, which includes not only the dimensions of the passenger compartment, trunk, wheel path, and wheelbase but also the noise and temperature in the passenger compartment. So, the criterion of indicators of the quality of comfort can be determined from the following equation:

$$K_C = \frac{L_b \cdot K_K \cdot Y_n}{128 L_w}, \quad (7)$$

where:
L_b, L_w – the base and track of the wheels of the car, respectively, m;
K_K – coefficient considering the availability of air conditioning, $K_K = 0.9$,
coefficient considering the climate control, $K_K = 0.8$;
Y_n – noise level in the cabin when driving a car, $Y_n = z + \zeta \cdot V_a$- for vehicles with engine z = 40 db, and for electric vehicles and hybrid z = 30 db, constant coefficient ζ = 022 db· year/km.

Figure 1 shows the change in the criteria for assessing the quality of the functional stability (K_K) and the comfort (K_C) for a base car, a hybrid and an electric car, based on the average speed.

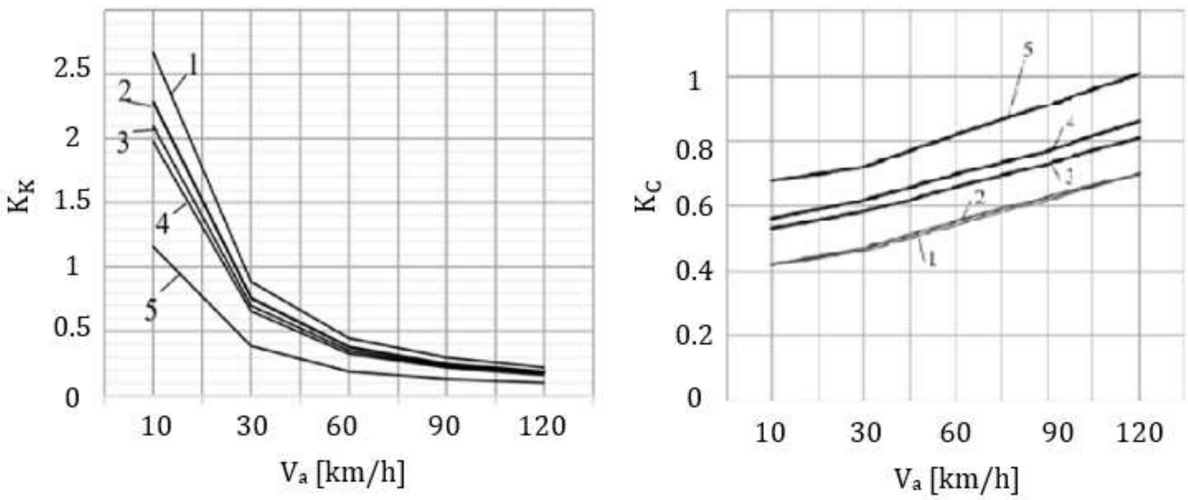


Fig. 1. Change of the functional stability (K_K) and the comfort (K_C) criteria for a base car, a hybrid and an electric car depending on the speed, where: 1 – Lanos Sens; 2 – Mitsubishi Lancer; 3 – Chevrolet Aveo; 4 – Toyota Prius; 5 – Nissan Leaf

The environmental safety of vehicles can be evaluated by comprehensively analyzing several technical and economic issues, including the laws governing the formation of toxic and carcinogenic substances, technogenic atmosphere pollution, fuel and environmental performance of engine studies, and many others. The total toxicity criterion can be defined as a multidimensional vector that is hard to express in a single number. Therefore, assessing the environmental safety quality of a car can be greatly simplified if nitric oxide (NOx) of 0.06 g/km for the gasoline engine and 0.08 g/km for the diesel engine is taken as the base standard of the standard (Euro 6), and fuel consumption is taken as minimal. Then, the calculated expressions for determining the quality of environmental safety can be expressed both for cars with an internal combustion engine (ICE) (7) and hybrid cars (8):

$$K_e = \frac{0.0033 H_{l.min} \cdot V_{max}}{K_{NO_x} \cdot V_a}, \tag{8}$$

where:
K_{NOx} – permissible norm of nitric oxide according to the standard (Euro-6), g/km;
$H_{l.min}$ – minimum fuel consumption by car, l 100 km.

$$K_e^g = \frac{0.0275 H_{l.min} \cdot N_e \cdot V_a}{K_{NO_x} \cdot V_{max} \cdot N_{max}}, \tag{9}$$

where:
N_e – electric motor power, kW;
N_{max} – engine power, kW.

Car safety depends on braking qualities, dimensions, and the presence of additional factors that provide safe working conditions for the driver. The braking coefficient is adopted as a general indicator of active safety, and the number of stars obtained in the EuroNCAP safety rating provided by the European Passive Safety Test Program for production passenger cars, which is accepted as passive safety. Therefore, the criterion for evaluating indicators of traffic safety quality can be determined by the following equation:

$$K_s = \frac{1.8 S_T}{n_s \cdot S_{Tmin}}, \tag{10}$$

where:
n_s – the number of stars obtained in the estimated crash test rating;
S_T – stopping distance at a speed of 100 km/h, m;
S_{Tmin} – the smallest stopping distance among all tested cars, m.

The quality criterion for technical solutions is determined based on analysis concerning the indicators' values on analogues that reflect the highest global trends in their development. The indicators values for assessing the technical solutions quality of a car consist of the following: fuel consumption, car mass, acceleration time to 100 km/h, and maximum speed.

The change in the criterion for assessing the quality indicators of technical solutions (K_T) and the criterion for the safety of vehicle traffic (K_C) are shown in Figure 2.

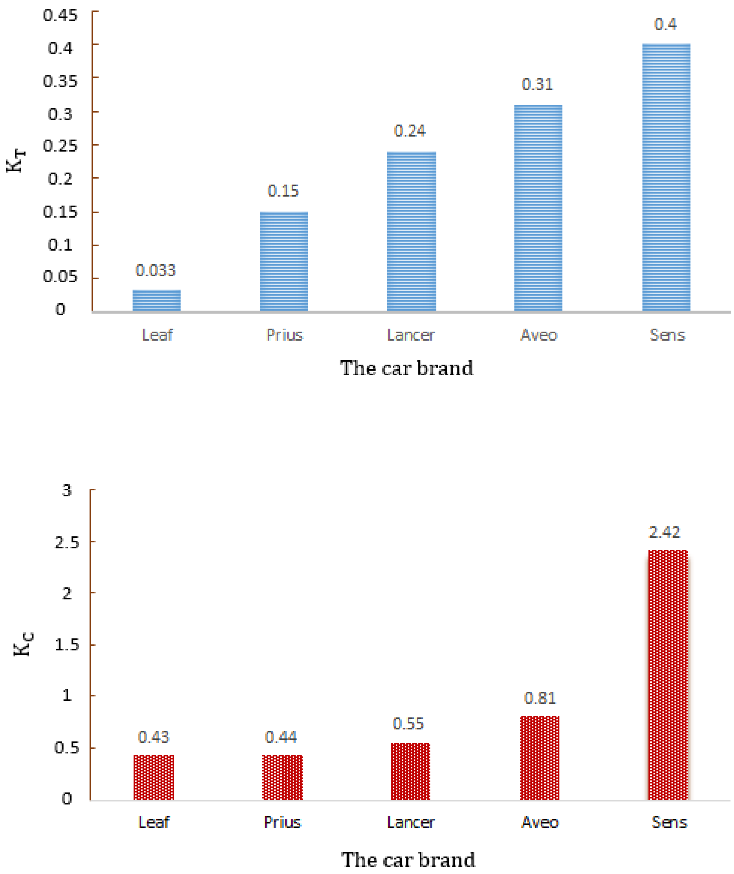


Fig. 2. Change in the criterion of car traffic safety and technical solutions quality for car brands

The criterion for assessing the quality indicators of technical solutions for base cars and hybrids is defined as:

$$K_T = \frac{0.036 H_{min} \cdot t_p \cdot \rho_T \cdot V_{max}}{G_a}, \tag{11}$$

for electric vehicles

$$K_T = \frac{0.0324 E_{ACB} \cdot t_p \cdot \rho_T \cdot V_{max}}{L_3 \cdot G_a}, \tag{12}$$

where:
G_a – car mass, kg;
t_p – acceleration time from 0 to 100 km/h.

The problem of turning a multicriteria quality assessment problem into a single criterion one can be solved by forming an integral indicator method [15, 16. 25].

It comes from the equation in which the smaller the integral criterion, the higher the car quality. Therefore, the mathematical model of the integral criterion for car quality evaluation, considering the average speed, will be as follows:

- base car

$$K_I = F + Z(40 + 0.2 \cdot V_a) + \frac{A+D}{V_a}, \quad (13)$$

where:

$$F = \left[\left(\frac{1.8S_T}{S_{Tmin} n_s}\right) + \frac{0.036H_{l.min} \cdot t_p \cdot \rho_T \cdot V_{max}}{G_a}\right], \quad (14)$$

$$Z = \frac{L_b \cdot K_K}{128L_w}, \quad (15)$$

$$A = \frac{0.079N_{max} \cdot g_{emin} \cdot C_T \cdot L_{GVM}}{C_{auth} \cdot \rho_T}, \quad (16)$$

$$D = \frac{0.0033H_{l.\,min} \cdot V_{max}}{K_{NO_x}}, \quad (17)$$

- hybrid car

$$K_I^g = F + Z(30 + 0.2 \cdot V_a) + \frac{C}{V_a} + D_r \cdot V_a, \quad (18)$$

where:

$$D_r = \frac{0.0275H_{l.\,min} \cdot N_e}{K_{NO_x} \cdot V_{max} \cdot N_{max}}, \quad (19)$$

- electric car

$$K_I^e = F_e + Z(30 + 0.2V_a) + \frac{B}{V_a}, \quad (20)$$

where:

$$B = \frac{2.7E_{ACB} \cdot C_e \cdot L_{GVM} \cdot V_{max}}{C_{auth} \cdot L_3}, \quad (21)$$

$$F_e = \left[\frac{1.8S_T}{S_{Tmin} \cdot n_s} + \frac{0.324E_{ACB} \cdot t_p \cdot V_{max}}{G_a \cdot G_3}\right]. \quad (22)$$

Figure 3 shows the change in the integral quality indicator from the average speed and the criterion for evaluating the quality indicators of technical solutions for car models.

This article proposes and discusses new opportunities to increase the efficiency of car use based on the obtained results of this study on the method to evaluate quality indicators at the operation stage. The proposed methodology for the actual and practical implementation of this study is based on the assessment of the quality indicators of the car. Cars operating at an average speed were evaluated based on the following criteria: traffic safety, technical solutions, environmental friendliness, comfort, and functional stability. Furthermore, this paper presents the formulation of basic methodological principles for research [17-21, 29].

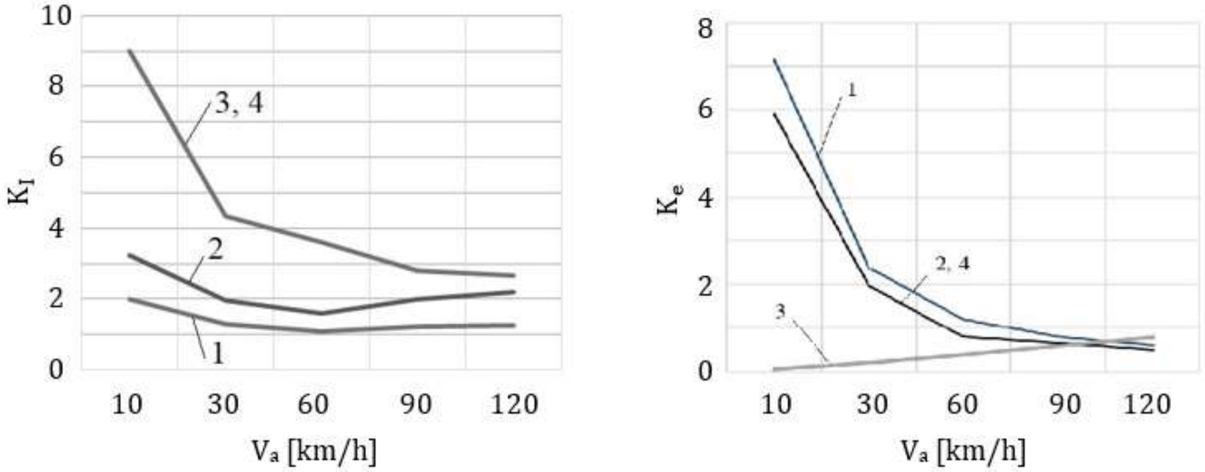


Fig. 3. Change in the criterion of car traffic safety and the criterion of quality of technical solutions for car brands, where: 1 – Chevrolet Aveo; 2 – Toyota Prius; 3 – Nissan Leaf; 4 – Mitsubishi Lancer

The integral criterion for the evaluation of vehicle quality indicators substantially depends on the conditions of operation. Table 1 shows the correction factors (coefficients) of the integral criterion for the base, hybrid, and electric vehicles with average vehicle speeds, depending on the conditions of operation.

Tab. 1

Correction factors for the integral criterion for assessing quality indicators from operating conditions

Group of operating conditions	Average vehicle speed	Integral indicator of car quality		
		base car	hybrid car	electric car
I	100	1.00	1.00	1.00
II	80	1.10	0.95	1.00
III	60	1.40	0.90	0.95
IV	30	1.50	1.00	1.05
V	20	2.25	1.40	1.60

Movement speed influences the integral criterion for evaluating automobile quality indicators the most. As the speed increases from 20 to 100 km/h, the integral criterion decreases for base cars by more than two times, and for hybrid and electric vehicles, it decreases by 1.5-1.6 times. Therefore, the problem of increasing the speed of cars should be central. Speed can be perceived as a reserve that can lead to a significant increase in the performance rating of cars.

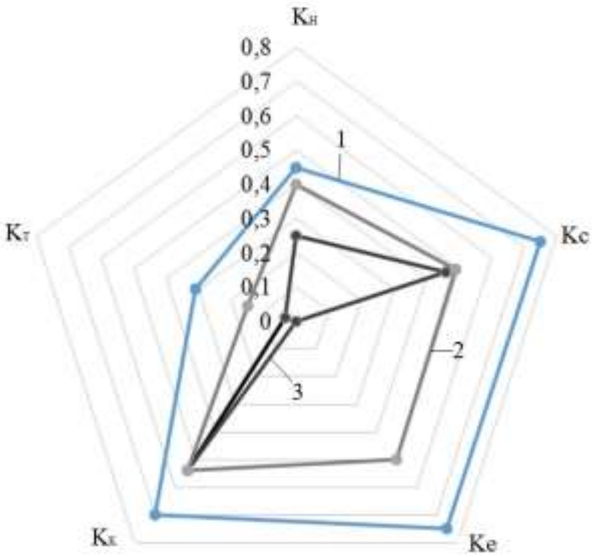
The next stage of this research included an integral assessment of quality and competitiveness indicators. This assessment was conducted based on the mathematical approach and model described in [22-24, 27-28]. The best alternative (passenger car) must meet the minimum value of the integral quality criterion. Then, the study needed the stage of modeling and calculating to get the results. From this part of the analysis, it was possible to determine the quality indicators for each criterion for the studied base, hybrid, and electric vehicles. Another achievement of this study was a general integrated evaluation of the cars' quality – the results are presented in Table 2 and Figure 4.

Figure 4 shows by what sets of indicators electric and hybrid cars surpass basic cars.

Tab. 2

Results of the integrated assessment of quality indicators

No	Name of criteria	Designation	Automobile model		
			Chevrolet Aveo	Nissan Leaf	Toyota Prius
1	Functional stability	K_Q	0.45	0.25	0.40
2	Traffic safety	K_S	0.75	0.46	0.49
3	Environmental friendliness	K_e	0.75	-	0.50
4	Comfort	K_K	0.70	0.54	0.54
5	Technical solutions	K_T	0.31	0.03	0.15
6	Integral criterion	K_I	2.96	1.28	2.08



1 – Chevrolet Aveo; 2 – Toyota Prius; 3 – Nissan Leaf

Fig. 4. Change in the integral indicator of quality from the average speed for vehicle models

3. DISCUSSION

The problem of converting a multicriteria quality assessment problem into a single-criteria one is solved by the method of forming an integral indicator.

We get: the smaller the integral criterion, the higher the quality of the passenger car. Therefore, the mathematical model of the integral criterion for evaluating the quality of cars based on the average speed is compiled for base cars, hybrid and electric vehicles.

The integral criterion for evaluating car quality indicators significantly depends on the conditions of operation. The coefficients of correction of the integral criterion for the basic, hybrid and electric vehicles are given based on the operating conditions. The speed of movement has the greatest influence on the integral criterion for assessing the quality indicators of cars. Therefore, the problem of increasing the speed of movement for cars needs deserves special attention. Speed is a reserve that can significantly increase the characteristics of the evaluation of the property of cars.

The following principles and methods have been substantiated and developed: systemic selection and quality indicators, their comparison and measurement at a differentiated level, that is, the formation of an integral criterion for assessing the quality and competitiveness of a car.

The performed studies and proposed methods for assessing the quality make it possible to obtain operational information about the features of operation in Ukraine, based on which, for manufacturers of automotive equipment, the necessary conditions and opportunities are created aimed at improving the design of cars, boosting the image of the car brand, and increasing sales.

The practical implementation of the results obtained in the process of conducting this research provides the following main opportunities and conditions for:

- automakers and their dealers: prompt receipt of the information on the features of the operation of cars and the development of measures to improve vehicle designs; promoting the image of a car brand; increasing sales;
- consumers of vehicles: the possibility of a comparative generalized assessment; the purchase of a quality car; the formation and presentation of requirements for car manufacturers to improve the design and components.

4. CONCLUSION

This article provided and developed the scientific foundations of an urgent and vital techno-scientific problem by creating and presenting the research and methodological apparatus to evaluate the quality of cars. The developed apparatus is the basis for the conception of determining the relationships and developing the mathematical models and methods for assessing and ensuring quality at the operation stage.

With an increase in the average vehicle speed, there is an increase in the comfort criterion for all types of cars by 1.6-2 times; furthermore, the criterion for assessing the environmental safety of base cars decreases by 9-11 times, and hybrid cars increase by 8-10 times. At the maximum average speed, the criteria for assessing the environmental safety of basic and hybrid cars are level. The criterion for assessing the functional stability of basic, hybrid and electric vehicles with an increase in average speed decreases by 10-11 times. However, it should be noted that the criterion for evaluating the quality of functional stability of base cars is 1.3-1.5 times more than hybrid cars and 1.8-2.0 times more than electric vehicles.

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