The object of research is the process of changing the technical condition of vehicles during their operation. The study solved the problem of comprehensive evaluation of change in the technical condition based on Harrington's desirability function.

The essence of the results is as follows. A scale of desirability was built and a set of criteria for assessing the technical condition of vehicles was clarified. A general desirability index is proposed as a convolution of partial Harrington desirability functions. When solving the investigated problem, the characteristics and properties of the partial and generalized Harrington's desirability function and their graphical representation were taken into account.

Using an example of the technical condition of the chassis and braking system of vehicles, a set of controlled parameters was formed. Based on the values of the controlled parameters, the regression equation of the partial Harrington desirability functions was obtained.

The value of the weighting coefficients of each of the criteria was determined and the generalized desirability function was calculated.

As a result of the study, it was established that if the generalized criterion of desirability is $D<0.37$, then individual nodes, systems, and units of the vehicle are in a pre-accident condition, if $0.37 \leq D \leq 0.63$ – in a satisfactory condition, and if $D>0.63$ – in a good condition and cannot be the cause of a traffic accident.

An applied aspect of the results is the implementation of the technique of comprehensive assessment of the technical condition of the vehicle. This causes an increase in the productivity of the expert (specialist), will shorten the period of the auto technical examination, and improve its quality. The results could be used by insurance companies and investigators, investigators and judges when considering traffic accidents

Keywords: Harrington function and desirability criteria, technical condition, vehicle, control parameter

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COMPREHENSIVE ASSESSMENT OF TECHNICAL CONDITION OF VEHICLES DURING OPERATION BASED ON HARRINGTON'S DESIRABILITY FUNCTION

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1. Introduction

Operational reliability and efficiency of vehicles significantly depends on the quality of the technical condition of their components, systems, and units. According to the current regulatory framework, the technical condition of nodes, systems, and assemblies is characterized by a set of variable properties that are determined by structural, technological, and operational parameters. When determining the technical condition of vehicles, diagnostic parameters are used, which are combined with the specified parameters. Diagnostic parameters make up a set of diagnostic information.

It was found that the process of assessing both the general technical condition and the condition of individual nodes, systems, and units of the vehicle during operation is quite complex. It requires the use of universal and effective diagnostic strategies to take into account parameters that are diverse in their physical nature.

At the same time, the issue of identification and comprehensive assessment of the technical condition of nodes, systems, assemblies, and vehicles as a whole is very important. To solve it, it is possible to use a number of approaches and criteria that are built on the basis of the methods of applied mathematics. Methods that have intellectual elements deserve attention: fuzzy methods and sets; method of neural networks; method of genetic algorithms; multi-agent method, etc. In this area, the method of comprehensive assessment of the technical condition of vehicles, based on the Harington desirability functions, is promising.

Therefore, it is a relevant task to carry out studies on devising a methodology for comprehensive and objective assessment of the technical condition of vehicles based on Harrington's desirability function.

2. Literature review and problem statement

In work [1] it is stated that the assessment of the technical condition of vehicles during operation is related to the need to take into account a number of criteria with different values and dimensions. This circumstance includes the difficulty of combining a set of indicators, values, and criteria during their computer processing. The complexity of the concept of technical condition is reflected in work [2]. This is also emphasized in paper [3]. These studies also deal with partial parameters for assessing the technical condition of nodes, systems, and units of vehicles. At the same time, a comprehensive assessment of the technical condition is more objective. Specific partial indicators of the technical condition of elements of vehicles are indicated in work [4]. These are resource-determining elements of nodes, systems, and assemblies of vehicles. Elements of the vehicle's exterior design are also taken into account. At the same time, as noted in [5], it is indicated that different parameters have different units of measurement: both qualitative and quantitative. It is not very convenient when processing them. It is desirable to operate with integrated parameters, criteria that are dimensionless.

On the other hand, in work [6], the generalization of parameters is given on the example of a binary combination. This applies to the condition of vehicle tires and the timing of wheel brakes. It follows from this that the assessment of the general condition of the vehicle is a multi-criteria task. Such a task is best solved with the help of special mathematical tools – methods of applied mathematics. This is proposed in work [7]. Since there are many methods of applied mathematics, one should choose among them those that take into account the specificity of the diagnostic database of the technical condition of vehicles. We can agree with the results reported in [8] on that the methods of fuzzy set theory are most suitable for this. But these methods require careful analysis and adaptation to a comprehensive assessment of the technical condition of vehicles. From this point of view, the methods of constructing the desirability function, which are reflected in work [9], deserve attention. At the same time, there is a need for their comparative analysis and the choice of Harrington's desirability function. Results of the comparative analysis would make it possible to devise a method of objective comprehensive assessment of the technical condition of nodes, systems, assemblies, and the vehicle as a whole.

In this context, it is important to identify the causes of traffic accidents and the propensity of these technical conditions to the possibilities of their implementation. In work [10] it is stated that the vehicle is the most potentially dangerous means of transportation, on which the majority of all traffic accidents occur. This is also confirmed by the results of studies [11, 12], which provide statistical data on traffic accidents and their severity.

The seriousness of this problem and related social, economic, and moral-psychological problems is emphasized in work [13]. Of course, the problem of identification of traffic accidents needs an objective solution. It is directly related to an objective comprehensive assessment of the technical condition of nodes, systems, assemblies, and vehicles as a whole. As stated in paper [14], in this connection, establishing the true causes of traffic accidents and ensuring a high level of objectivity in the conclusions of forensic auto technical experts is a priority goal of every investigation. There is a need to establish the real causes of traffic accidents. In work [15] it is noted that the causes of traffic accidents should be sought in the unsatisfactory technical condition of vehicles. This work reports the results of research into the technical condition of vehicles, identified malfunctions of individual units, systems, and units that could cause traffic accidents.

These questions are the results of research work [16]. A number of shortcomings of the current procedure for assessing the technical parameters of vehicles during forensic examination are indicated, which, according to the authors, is outdated. This is confirmed by the research results in work [17]. Paper [18] points out the imperfection of methods for assessing the technical condition and ability of vehicles to cause traffic accidents. This especially applies to modern vehicles. At the same time, a high error is allowed when evaluating individual indicators of the technical condition of vehicles. In work [19] it is noted that existing methods do not provide for taking into account a number of operational factors that affect the effectiveness of diagnosis regarding the quality of the technical condition of vehicles. It is noted that it is impossible to influence the expert's final conclusion, as well as the driver's ability to prevent traffic accidents when driving a modern vehicle that has high energy intensity and speed.

All this gives reasons for the expediency of conducting a study on the justified use of Harrington's desirability function. The introduction of criteria for an objective comprehensive assessment of the technical condition of nodes, systems, and assemblies of vehicles and their belongings will make it possible to identify the objective conditions for the occurrence of traffic accidents.

3. The aim and objectives of the study

The purpose of this study is to identify the possibilities of using Harrington's desirability function for a comprehensive assessment of the technical condition of vehicles during operation. This will make it possible to carry out an objective auto-technical examination of the influence of the technical state of nodes, systems, and units of the vehicle on the occurrence of a traffic accident.

To achieve the goal, the following tasks were set:

– to determine the relationship between the controlled parameters of the technical condition and partial desirability functions;

– to determine the connection of the partial function of desirability with the regulatory controlled parameters of vehicles;

– to construct partial and generalized desirability functions and give their graphical interpretation.

4. The study materials and methods

The object of our research is the technical condition of vehicles. Research hypothesis: one of the possible ways to assess the technical condition of vehicles, including auto technical examination of traffic accidents, is to use the generalized Harrington desirability function [9, 10]. It is assumed that the relationship between the controlled parameter and the corresponding partial desirability function is linear. At the same time, the lowest level of desirability corresponds to the maximum permissible value of the parameter, and the best value of the parameter corresponds to the largest value of desirability *d*.

The generalized desirability function is widely used in the process of conducting various kinds of experimental studies and processing their results. The basis of the construction of the generalized function is the idea of transforming the obtained values of the property indicators into a dimensionless scale of desirability.

The Harrington desirability function has the following advantages:

– it is quantitative;

– it is expressed by one number;

– a given set of values of individual evaluation parameters corresponds to one value of the function;

– it has a universal character, and therefore can be used in various areas;

– it comprehensively characterizes the object, that is, it meets the requirements of completeness;

– it provides a simple way to convert indicators using one graph for all criteria;

– it is neutral when generalizing to the final result during construction;

– only personal preferences affect the scale of desirability;

– it is adequate, which should be understood as the equivalence of partial and generalized functions to the measured values of the optimization parameters in the sense that they can be used for all computational operations defined on the set of values of the optimization parameters.

The purpose of the scale of desirability is to establish the correspondence between the values of the criteria in the physical scales of the value of the corresponding criterion. The scale of desirability is arranged so that a better value of the criterion corresponds to a greater value of desirability. To convert the criterion values into a scale of desirability, the set of values of each criterion is divided into subsets, for which it is possible to say that the quality of the object on each of them is close to the assessment of good, satisfactory, or poor. It should be noted that there may be more gradations. Standard marks on the desirability scale are strictly mandatory. Based on the available experience, the following standard gradations can be recommended (Table 1).

Table 1

Basic desirability scale marks

A quantitative mark on the scale of desirability *d*	The desirability of the criterion value *y*
0.80...1.00	Very good
0.63...0.80	Fine
0.37...0.63	Satisfactory
0.20...0.37	Poor
0.00...0.20	Very bad

The construction of a scale of desirability, which establishes the relationship between the value of the criterion *y* and its corresponding value *d*, according to a partial function of desirability, is subjective and reflects the attitude of the researcher to individual criteria.

To construct a scale of desirability, it is convenient to use the method of quantitative assessments with an interval of values of desirability *d* from zero to one, although other variants of the scale are possible. The value of the partial function $d=0$ corresponds to the most unacceptable measured value of this parameter, and $d=1$ to the best value of the parameter, at which its further improvement is either impossible or impractical. The critical point of transition to acceptable quality is the value $d=\exp(-1)\cong 0.36788\approx 0.37$. Due to the fact that the values 0.00...0.20 and 0.20...0.37 are unacceptable according to the criterion of desirability, and the values 0.37...1.00 are acceptable.

Desirability functions can be of one of three types:

1. Two-way dependences, which are used for indicators for which the deviation of the characteristic from its optimal level in any direction leads to a decrease in quality.

2. One-sided increasing dependences, which are used for those indicators for which their quality increases in the case of an increase in the characteristic, but up to the level of 100 %.

3. One-sided decreasing dependences, which are used for those indicators for which their quality increases in the event of a decrease in the sign, but up to the level of 100 %.

The simplest type of transformation is one in which there is an upper and (or) lower limit of criteria values, and these limits are uniform and do not allow for changes.

The partial function of desirability under one-sided restriction (Fig. 1) takes the form:

$$d=0,\ y<y_{\min};\ d=1,\ y\geq y_{\min}. \tag{1}$$

Similarly, a partial desirability function can be obtained if the constraint of the criterion from above is given. If there is a bilateral restriction for this parameter (Fig. 2), then:

$$d=0,\ y<y_{\min},\ y>y_{\max};\ d=1,\ y_{\min}\leq y\leq y_{\max}. \tag{2}$$

For a two-sided restriction, the conversion of the measured criterion *y* into the scale *d* is performed using the expression:

$$d=\exp\left(-\left|y'\right|^{n}\right). \tag{3}$$

To determine the coded parameter y', you can use the following analytical expression:

$$y'=\frac{2y-\left(y_{\max}+y_{\min}\right)}{y_{\max}-y_{\min}}. \tag{4}$$

The exponent n can be calculated by presetting some value of y with a corresponding desirability value, preferably between good and very good:

$$n=\frac{\ln\left(\ln\frac{1}{d'}\right)}{\ln|y'|}. \quad (5)$$

For one-sided constraints of the form $y \le y_{\max}$ or $y > y_{\min}$, another exponential dependence serves as a more convenient form of transformation of y into d:

$$d=\exp\left[-\exp(-y')\right], \quad (6)$$

where d is a partial function of desirability, and y' is calculated by the formula:

$$y'=b_{0i}+b_{1i}y. \quad (7)$$

The coefficients b_{0i} and b_{1i} can be determined by setting the appropriate desirability values for two values of y, preferably in the interval $0.2<d<0.8$.

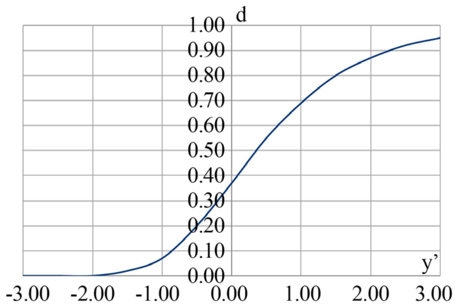

Fig. 1. Partial desirability function under unilateral constraint

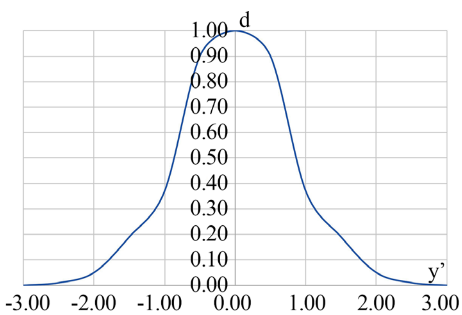

Fig. 2. Partial desirability function under bilateral constraint

Having a set of criteria transformed into a scale of desirability d, an integral generalized indicator of desirability D is determined as a convolution of partial desirability functions:

$$D=\prod_{1\le i\le q} d_i^{\alpha_i}=\exp\left[-\sum_{i=1}^{q}\alpha_i\exp(-y_i')\right], \quad (8)$$

where i is the number of analyzed parameters, α_i are weighting factors that indicate the importance of partial criteria.

If at least one partial desirability $d_i=0$, then the generalized function $D_i=0$. This means that the investigated object is in an unsatisfactory (emergency) state. If all $d_i=1$, then $D_i=1$.

With the generalized desirability index D, all operations can be performed, as with any other system response, and can also be used for research and further optimization of the process.

5. Results of investigating controlled technical condition parameters, desirability functions and their relationship

5. 1. Relation between the controlled parameters of the technical condition of vehicles and partial desirability functions

The types of controlled parameters of vehicles and the limits of their permissible values are given in Table 2.

Table 2

Controlled parameters of the chassis and braking system of vehicles

No.	Parameter	Unit of measurement	Norm
Chassis			
1	Total angular clearance, y_1	degree	<10
2	Maximum effort, y_2	N	<13
3	Tie rod condition, y_3	–	operational
4	Tire pressure, y_4	bar	2.0–2.5
5	Tread height, y_5	mm	>1.6
6	Tire condition, y_6	–	no damage
Braking system			
7	Response time, front wheels, y_7	s	<0.2
8	Axial unevenness, front wheels, y_8	%	<20
9	Response time, rear wheels, y_9	s	<0.2
10	Axial unevenness, rear wheels, y_{10}	%	<20
11	Total specific braking force, y_{11}	–	>0.59
12	Equivalent braking distance, y_{12}	m	<21.6
13	Equivalent deceleration, dry coating, y_{13}	m/s^2	>6.7
14	Equivalent deceleration, wet coating, y_{14}	m/s^2	>5.0
15	Deceleration build-up time, dry coating, y_{15}	s	<0.4
16	Deceleration build-up time, wet coating, y_{16}	s	<0.3
17	Anti-lock braking system, y_{17}	–	operational

The basic values of the partial desirability functions and the values of the controlled parameters of the vehicle state are given in Table 3.

According to expression (6):

$$0.8=\exp\left[-\exp(-y')\right],$$

hence:

$$y'=1.5;\ 0.2=\exp\left[-\exp(-y')\right],$$

hence:

$$y'=-0.4759.$$

The system of equations that determines the coefficients b_{01} and b_{11} for the total angular gap y_1 takes the following form:

$$\begin{cases} b_{01} + 1 \cdot b_{11} = 1.5, \\ b_{01} + 10 \cdot b_{11} = -0.4759. \end{cases}$$

As a result of solving this system, we get $b_{01}=1.72$, $b_{11}=-0.22$.

Similarly, according to the data in Table 3, the coefficients b_0 and b_1 for other controlled parameters are determined and given in Table 4.

Table 3

Basic values of partial desirability functions and corresponding values of controlled vehicle state parameters

Type of controlled parameter	Value of the controlled parameter	Value of partial desirability function	Desirability of parameter value
Total Angular Clearance, y_1, degree	1	0.8	fine
	10	0.2	poor
Maximum effort, y_2, N	1	0.8	fine
	13	0.2	poor
Tie rod condition, y_3	working	0.8	fine
	faulty	0.2	poor
Tread height, y_5, mm	3.2	0.8	fine
	1.6	0.2	poor
Tire condition, y_6	no damage	0.8	fine
	damaged	0.2	poor
Response time, front wheels, y_7, s	0.01	0.8	fine
	0.5	0.2	poor
Axial unevenness, front wheels, y_8, %	1	0.8	fine
	20	0.2	poor
Response time, rear wheels, y_9, s	0.01	0.8	fine
	0.5	0.2	poor
Axial unevenness, rear wheels, y_{10}, %	1	0.8	fine
	20	0.2	poor
Total specific braking force, y_{11}	1.0	0.8	fine
	0.59	0.2	poor
Equivalent braking distance, y_{12}, m	0.1	0.8	fine
	21.6	0.2	poor
Equivalent deceleration, dry coating, y_{13}, m/s^2	8.0	0.8	fine
	5.8	0.2	poor
Equivalent deceleration, wet coating, y_{14}, m/s^2	6.8	0.8	fine
	4.0	0.2	poor
Deceleration build-up time, dry coating, y_{15}, s	0.3	0.8	fine
	0.6	0.2	poor
Deceleration build-up time, wet coating, y_{16}, s	0.2	0.8	fine
	0.5	0.2	poor
Anti-lock braking system, y_{17}	working	0.8	fine
	faulty	0.2	poor

Table 4

The value of the coefficients b_{0i} and b_{1i} for the controlled parameters y_i of the technical condition of vehicles

y_i	y_1	y_2	y_3	y_5	y_6	y_7	y_8	y_9	y_{10}	y_{11}	y_{12}	y_{13}	y_{14}	y_{15}	y_{16}	y_{17}
b_{0i}	1.72	1.665	–0.476	–2.459	–0.476	1.54	1.604	1.54	1.604	–3.319	1.509	–5.685	–3.299	3.476	2.817	1.68
b_{1i}	–0.22	–0.165	1.97	1.235	1.976	–4.032	–0.104	–4.032	–0.104	4.819	–0.092	0.898	0.704	–6.586	–6.586	–0.087

5. 2. Relationship between partial desirability functions and normative controlled parameters of vehicles

As a result of the research, the dependences of partial desirability functions on the normative values of the controlled parameters of the vehicle were established:

$$d_1 = \exp\left[-\exp\left(-1.72 + 0.22y_1\right)\right], \quad (9)$$

$$d_2 = \exp\left[-\exp\left(-1.665 + 0.165y_2\right)\right], \quad (10)$$

$$d_3 = \exp\left[-\exp\left(0.476 - 1.976y_3\right)\right], \quad (11)$$

$$d_5 = \exp\left[-\exp\left(2.459 - 1.235y_5\right)\right], \quad (12)$$

$$d_6 = \exp\left[-\exp\left(0.476 - 1.976y_6\right)\right], \quad (13)$$

$$d_7 = \exp\left[-\exp\left(-1.54 + 4.032y_7\right)\right], \quad (14)$$

$$d_8 = \exp\left[-\exp\left(-1.604 + 0.104y_8\right)\right], \quad (15)$$

$$d_9 = \exp\left[-\exp\left(-1.54 + 4.032y_9\right)\right], \quad (16)$$

$$d_{10} = \exp\left[-\exp\left(-1.604 + 0.104y_{10}\right)\right], \quad (17)$$

$$d_{11} = \exp\left[-\exp\left(3.319 - 4.819y_{11}\right)\right], \quad (18)$$

$$d_{12} = \exp\left[-\exp\left(-1.509 + 0.092y_{12}\right)\right], \quad (19)$$

$$d_{13} = \exp\left[-\exp\left(5.685 - 0.898y_{13}\right)\right], \quad (20)$$

$$d_{14} = \exp\left[-\exp\left(3.299 - 0.706y_{14}\right)\right], \quad (21)$$

$$d_{15} = \exp\left[-\exp\left(-3.476 + 6.586y_{15}\right)\right], \quad (22)$$

$$d_{16} = \exp\left[-\exp\left(-2.817 + 6.586y_{16}\right)\right], \quad (23)$$

$$d_{17} = \exp\left[-\exp\left(-1.68 + 0.087y_{17}\right)\right]. \quad (24)$$

In the presence of bilateral restrictions for the controlled parameters of the form $y_{\min} \leq y \leq y_{\max}$, the conversion of the values of the controlled parameters y into partial desirability d was performed according to expression (3). To determine the power of n, the following ratios are established: the maximum allowable value of the controlled parameter ($y_{\max}$, $y_{\min}$) is given the value of the desirability function equal to 0.2, and the best value is 0.8 (Table 5).

Table 5

Basic values of the desirability functions and the corresponding values of the controlled parameters of the technical condition of the vehicle

Type of controlled parameter	Value of the controlled parameter	Value of partial desirability function	Desirability of parameter value
Tire pressure, y_4, bar	2.3	0.8	good
	1.9	0.2	poor
Coefficient of adhesion, y_{18}	0.8	0.8	good
	0.2	0.2	poor

Indicators of power n for the controlled parameters y_4 and y_{18} were determined according to expression (5), having previously determined the coefficient y' based on expression (4). The power index for parameter y_4 was $n=0.922$, and for parameter y_{18} – $n=0.875$.

As a result, the dependence of the partial desirability function on the normative values of the indicator of the air pressure in the tires of the vehicle will take the following form:

$$d_4 = \exp\left[-\exp\left(y_4'\right)^{0.922}\right]. \quad (25)$$

Similarly, the dependence of the partial desirability function on the normative values of the tire adhesion coefficient with the surface was established:

$$d_{18} = \exp\left[-\exp\left(y_{18}'\right)^{0.875}\right]. \quad (26)$$

A fragment of the array of values of the controlled parameters of five M1 category vehicles, obtained as a result of undergoing technical maintenance and diagnostics, is given in Table 6.

Table 6

Value of controlled diagnostic parameters of vehicles

No.	1	2	3	4	5
y_1	9.00	10.00	5.00	6.00	4.00
y_2	10.00	4.00	6.00	11.00	10.00
y_3	operational	faulty	operational	faulty	operational
y_4	2.30	2.00	2.00	2.20	1.90
y_5	3.20	3.00	2.80	2.50	1.70
y_6	without damage	without damage	without damage	with damage	with damage
y_7	0.02	0.10	0.11	0.48	0.31
y_8	17.00	5.00	9.00	6.00	8.00
y_9	0.03	0.14	0.17	0.41	0.32
y_{10}	14.00	9.00	14.00	14.00	15.00
y_{11}	0.98	0.81	0.74	0.61	0.76
y_{12}	11.00	15.00	18.00	12.00	18.00
...	...	...	...	...	...
y_{16}	0.2	0.25	0.33	0.4	0.48
y_{17}	operational	operational	operational	faulty	operational
y_{18}	0.75	0.6	0.5	0.65	0.25

According to Table 6, it is possible to find the value of the controlled diagnostic parameters. They describe the working and malfunctioning states of vehicle components.

5. 3. Partial and generalized desirability functions and their graphic interpretations

According to expressions (9) to (26), the values of the controlled diagnostic parameters are converted in partial desirability functions d (Table 7). Weighting coefficients α were calculated for each of the criteria, taking into account which the generalized desirability function D was calculated using formula (8).

Based on the derived partial desirability functions, plots of desirability criteria were constructed (Fig. 3).

It can be seen that the graphic display of Harrington's desirability function (Fig. 3) from the set of controlled parameters gives the intervals of their change in which the serviceable and faulty states of the vehicle elements are determined. We considered options with one-sided and two-sided restrictions.

Table 7

Partial and generalized desirability functions

No.	α	1	2	3	4	5
d_1	0.06	0.273	0.199	0.584	0.512	0.649
d_2	0.05	0.373	0.693	0.601	0.313	0.373
d_3	0.06	0.718	0.338	0.718	0.338	0.718
d_4	0.07	0.800	0.464	0.464	0.711	0.200
d_5	0.07	0.799	0.750	0.692	0.587	0.239
d_6	0.06	0.718	0.718	0.718	0.338	0.338
d_7	0.07	0.793	0.726	0.716	0.227	0.473
d_8	0.05	0.308	0.713	0.599	0.687	0.630
d_9	0.06	0.785	0.686	0.653	0.326	0.459
d_{10}	0.03	0.422	0.599	0.422	0.422	0.384
d_{11}	0.06	0.782	0.573	0.458	0.432	0.492
d_{12}	0.03	0.544	0.415	0.314	0.513	0.314
...	...	...	...	...	...	...
d_{16}	0.07	0.800	0.733	0.591	0.435	0.244
d_{17}	0.06	0.718	0.718	0.718	0.338	0.338
d_{18}	0.08	0.785	0.687	0.611	0.713	0.245
D		0.744	0.592	0.631	0.365	0.358
		good	satisfactory	good	bad	satisfactory

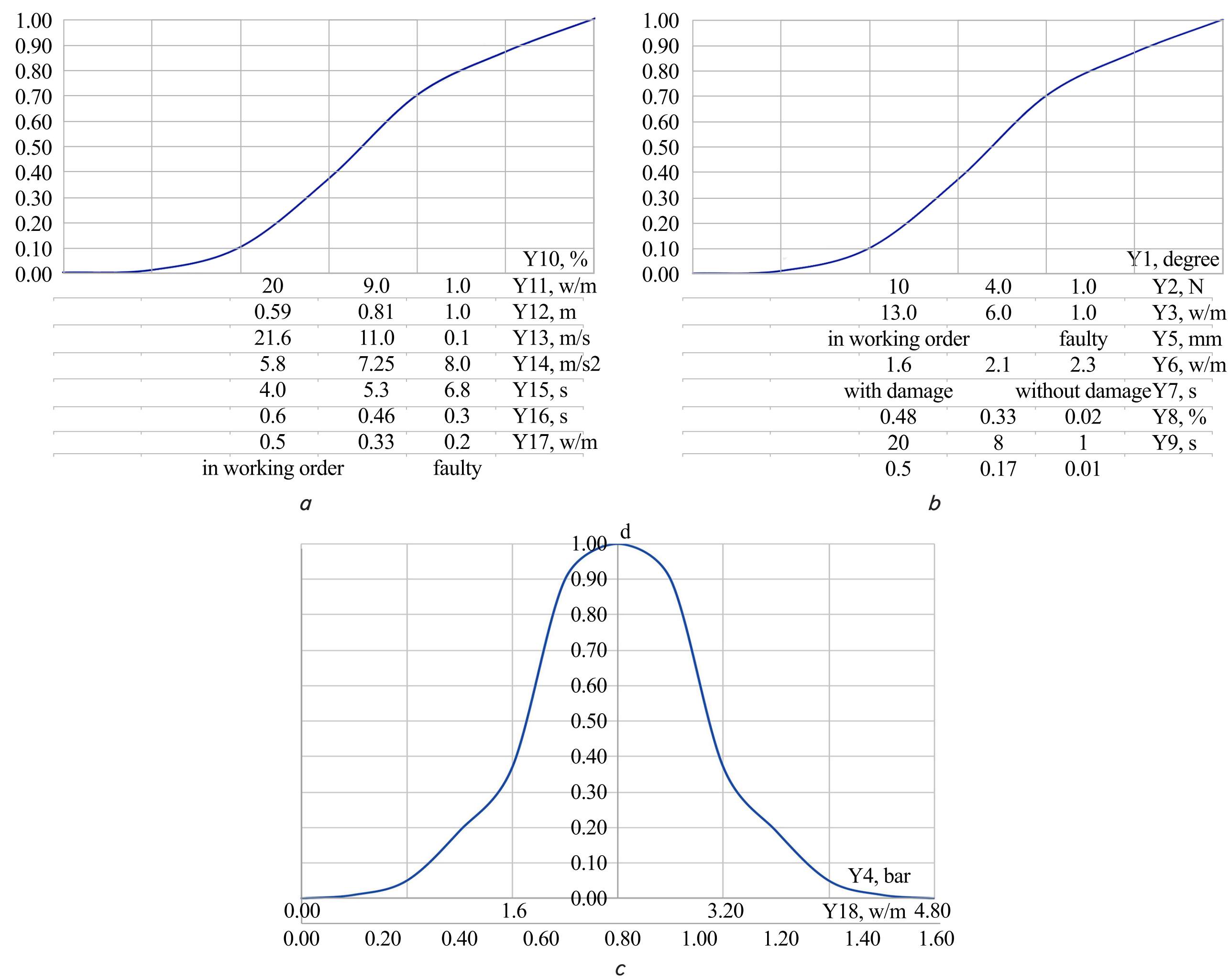

Fig. 3. Plots of desirability functions for parameters: *a* – with one-sided restriction (y_1–y_3, y_5–y_9); *b* – with one-sided restriction (y_{10}–y_{17}); *c* – bilateral restriction (y_4, y_{18})

6. Discussion of results of evaluating the technical condition of vehicles using the generalized Harrington desirability function

Controlled parameters of the chassis and braking system were used to devise a methodology for comprehensive assessment of the technical condition of vehicles during operation (Table 2). We transformed the corresponding values of the controlled parameters of the technical condition of vehicles into the values of the partial desirability functions; the generalized desirability parameter was evaluated (Tables 3, 4). It was found that the one-sided restriction is characteristic of the following controlled parameters: y_1–y_3, y_5–y_{17}. For one-sided restrictions to the controlled parameters of the form $y \leq y_{max}$, $y \geq y_{min}$, the values of the controlled parameters y into partial desirability d were converted according to expression (6). To determine the coefficients b_{0i} and b_{1i}, which are included in expression (7), taking into account the linear dependence between y and d, the following relations were established: the maximum permissible value of the controlled parameter corresponds to the level of desirability, which is bad, equal to 0.2, and the best or very good is the highest – the desirability value is 0.8 (Table 3). The statistical database made it possible to obtain the dependence of partial desirability functions on the normative values of the controlled parameters (9) to (26). The unknown coefficients b_{0i} and b_{1i} in the regression equation were determined by the method of least squares.

The values of the controlled diagnostic parameters of five vehicles are given in Tables 5–7. Analysis of our results (Table 7) for the fourth vehicle reveals that the value of the generalized Harrington desirability function D for this vehicle is 0.365. This value corresponds to the level of desirability «bad», which indicates the overall unsatisfactory technical condition of the vehicle. Partial desirability functions of the controlled parameters were analyzed to determine individual components and units of the vehicle that influenced the overall assessment of the vehicle's technical condition.

Table 7 clearly demonstrates that the values of d_2, d_3, d_6, d_7, d_9 and d_{22} correspond to the desirability level poorly. This means that the values of the controlled parameters: maximum effort; condition of steering rods; tire condition; braking time, front wheels; axial unevenness, rear wheels; anti-lock system – are outside the limits. The general technical condition of the vehicle, determined during forensic examination, indicates that malfunctions and the pre-accident condition of the above-mentioned units and assemblies could cause traffic accidents.

Thus, the use of the generalized desirability function D and its graphical interpretation for partial desirability functions (Fig. 3) allows for a comprehensive assessment of the technical condition of the vehicle. The above makes it possible to form an expert opinion on the influence of the technical condition of the components, systems, and units of the vehicle on the occurrence of traffic accidents [20–25]:

– if $D<0.37$, then individual components of the vehicle are in a pre-accident state. Malfunction of specific units of the vehicle causes traffic accidents involving a given vehicle;

– if $0.37 \leq D \leq 0.63$, then the components of the vehicle are in satisfactory condition and are unlikely to cause traffic accidents involving a given vehicle. At that time, it is necessary to pay attention to those units, systems, and assemblies of the vehicle, the partial diagnostic indicators of which are approaching an unsatisfactory state. Their detailed diagnosis can provide more information about their influence on the occurrence of traffic accidents. In addition, recommendations for unscheduled maintenance or replacement of parts may be given for these nodes, systems, and units. This minimizes the likelihood of future traffic accidents involving a given vehicle;

– if $D>0.63$, then the components, systems, and units of the vehicle are in good condition, which cannot be the cause of traffic accidents.

The limitations of our study are $0.37 \leq D \leq 0.63$ and $D>0.63$. They are acceptable for solving the problem of an integrated positive assessment of the technical condition and solving the issue of low probability of the vehicle causing a traffic accident.

The devised method of comprehensive assessment of the technical condition of vehicles requires further use of specific computer application packages. It is also necessary in the future to devise a methodology and algorithm for performing successive operations in a comprehensive and objective assessment of the technical condition of vehicles.

7. Conclusions

1. The totality of the controlled parameters of the technical condition of the vehicle was determined using an example of the chassis and braking system parameters. The values of the partial Harrington desirability functions and the corresponding desirability value were found for the parameters change limits. If the equivalent braking distance changes from 0.1 m to 21.6 m, then the value of the partial desirability function decreases from 0.8 to 0.2. The desirability of the parameter at the lower limit corresponds to the «good» state, and at the upper limit – «bad». This makes it possible to establish a relationship between the values of the controlled parameters of the vehicle's technical condition and the values of the partial desirability function.

2. Based on the analysis of the database on the technical condition of the vehicle, the regression equation of the partial Harrington desirability functions from the normative controlled parameters was built. These equations are non-linear. They relate the controlled state parameters of the vehicles to the values of the partial desirability functions. Unknown regression coefficients are determined by the method of least squares. Based on these equations, it is determined that with the increase of the controlled parameters y_1, y_2, y_4, y_8–y_{10}, y_{12}, y_{15}–y_{18}, the value of the partial desirability function decreases. With the increase of controlled parameters y_3, y_5, y_6, y_{11}, y_{13}, y_{14} – increases. Regression equations make it possible to give a qualitative assessment of the technical condition of the vehicle based on normative parameters and values of partial desirability functions.

3. For the studied vehicles, the values of the controlled diagnostic parameters were converted into values of partial desirability functions. The values of partial desirability functions for all controlled parameters for each vehicle were determined by the calculated weighting coefficients. That made it possible to determine the value of the generalized desirability function D and evaluate the technical condition of the vehicle. The first and third vehicles are in good condition. The second and fifth vehicles are in satisfactory condition. The fourth vehicle is in poor condition. A graphical interpretation of the change in the desirability function

for parameters with one-sided and two-sided restrictions is given. With the help of a graphic representation of the Harrington desirability function, it is possible to determine the intervals of changes in the controlled parameters. In the interval $0.37<D$, the elements of the vehicle are in a pre-accident state. Their malfunction becomes the cause of traffic accidents involving the vehicle. In the interval $0.37\leq D\leq 0.63$, the elements of the vehicle are in satisfactory condition. There is a small possibility that they can cause traffic accidents. In the interval $D>0.63$, the elements of the vehicle are in good condition and cannot be the cause of traffic accidents.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

The data will be provided upon reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

Large Language Models were not used during the research and during the preparation of the presented manuscript.

References

1. Koteleva, N. I., Korolev, N. A., Zhukovskiy, Y. L. (2021). Identification of the Technical Condition of Induction Motor Groups by the Total Energy Flow. Energies, 14 (20), 6677. https://doi.org/10.3390/en14206677
2. Parekh, D., Poddar, N., Rajpurkar, A., Chahal, M., Kumar, N., Joshi, G. P., Cho, W. (2022). A Review on Autonomous Vehicles: Progress, Methods and Challenges. Electronics, 11 (14), 2162. https://doi.org/10.3390/electronics11142162
3. Kondratenko, O. (2020). Assessment of ecological and chemical efficiency of exploitation process of reciprocating ICE of vehicle with consideration of emission of sulphur oxides, benzo(a)pyrene and polycyclic aromatic hydrocarbons. Technogenic and Ecological Safety, 7 (1/2020), 38–50. https://doi.org/10.5281/zenodo.3780076
4. Hrynkiv, A., Rogovskii, I., Aulin, V., Lysenko, S., Titova, L., Zagurskiy, O., Kolosok, I. (2020). Development of a system for determining the informativeness of the diagnosing parameters for a cylinderpiston group in the diesel engine during operation. Eastern-European Journal of Enterprise Technologies, 3 (5 (105)), 19–29. https://doi.org/10.15587/1729-4061.2020.206073
5. Prytz, R., Nowaczyk, S., Rögnvaldsson, T., Byttner, S. (2015). Predicting the need for vehicle compressor repairs using maintenance records and logged vehicle data. Engineering Applications of Artificial Intelligence, 41, 139–150. https://doi.org/10.1016/j.engappai.2015.02.009
6. Kondratenko, O. M. (2020). Assessment of fuel and ecological efficiency of exploitation process of reciprocating ICE of power plants with considering of emission of benzo(a)pyrene and polycyclic aromatic hydrocarbons. Internal Combustion Engines, 1, 52–59. https://doi.org/10.20998/0419-8719.2020.1.07
7. Britton, M. A., Asnaashari, S., Read, G. J. M. (2016). Analysis of train derailment cause and outcome in Victoria, Australia, between 2007 and 2013: Implications for regulation. Journal of Transportation Safety & Security, 9 (1), 45–63. https://doi.org/10.1080/19439962.2015.1088906
8. Rashidi, E., Parsafard, M., Medal, H., Li, X. (2016). Optimal traffic calming: A mixed-integer bi-level programming model for locating sidewalks and crosswalks in a multimodal transportation network to maximize pedestrians' safety and network usability. Transportation Research Part E: Logistics and Transportation Review, 91, 33–50. https://doi.org/10.1016/j.tre.2016.03.016
9. Chen, X., Chen, J. (2020). Optimization of the Impeller Geometry for an Automotive Torque Converter Using Response Surface Methodology and Desirability Function. Open Journal of Applied Sciences, 10 (07), 455–475. https://doi.org/10.4236/ojapps.2020.107032
10. Padilla-Atondo, J. M., Limon-Romero, J., Perez-Sanchez, A., Tlapa, D., Baez-Lopez, Y., Puente, C., Ontiveros, S. (2021). The Impact of Hydrogen on a Stationary Gasoline-Based Engine through Multi-Response Optimization: A Desirability Function Approach. Sustainability, 13 (3), 1385. https://doi.org/10.3390/su13031385
11. Vladyslav, R. (2022). Structure of the national police of Ukraine: modern interpretation. Entrepreneurship, Economy and Law, 5, 69–74. https://doi.org/10.32849/2663-5313/2022.5.11
12. Rolison, J. J., Regev, S., Moutari, S., Feeney, A. (2018). What are the factors that contribute to road accidents? An assessment of law enforcement views, ordinary drivers' opinions, and road accident records. Accident Analysis & Prevention, 115, 11–24. https://doi.org/10.1016/j.aap.2018.02.025
13. Heydari, S., Hickford, A., McIlroy, R., Turner, J., Bachani, A. M. (2019). Road Safety in Low-Income Countries: State of Knowledge and Future Directions. Sustainability, 11 (22), 6249. https://doi.org/10.3390/su11226249
14. Dirnbach, I., Kubjatko, T., Kolla, E., Ondruš, J., Šarić, Ž. (2020). Methodology Designed to Evaluate Accidents at Intersection Crossings with Respect to Forensic Purposes and Transport Sustainability. Sustainability, 12 (5), 1972. https://doi.org/10.3390/su12051972

15. Gorea, R. K. (2016). Financial impact of road traffic accidents on the society. International Journal of Ethics, Trauma & Victimology, 2 (01), 6–9. https://doi.org/10.18099/ijetv.v2i1.11129
16. Aulin, V., Hrynkiv, A., Lysenko, S., Rohovskii, I., Chernovol, M., Lyashuk, O., Zamota, T. (2019). Studying truck transmission oils using the method of thermal-oxidative stability during vehicle operation. Eastern-European Journal of Enterprise Technologies, 1 (6 (97)), 6–12. https://doi.org/10.15587/1729-4061.2019.156150
17. Dela Cruz, O. G., Padilla, J. A., Victoria, A. N. (2021). Managing Road Traffic Accidents: A Review on Its Contributing Factors. IOP Conference Series: Earth and Environmental Science, 822 (1), 012015. https://doi.org/10.1088/1755-1315/822/1/012015
18. Ahmed, E., Gharavi, H. (2018). Cooperative Vehicular Networking: A Survey. IEEE Transactions on Intelligent Transportation Systems, 19 (3), 996–1014. https://doi.org/10.1109/tits.2018.2795381
19. Casado-Sanz, N., Guirao, B., Attard, M. (2020). Analysis of the Risk Factors Affecting the Severity of Traffic Accidents on Spanish Crosstown Roads: The Driver's Perspective. Sustainability, 12 (6), 2237. https://doi.org/10.3390/su12062237
20. Oladimeji, D., Gupta, K., Kose, N. A., Gundogan, K., Ge, L., Liang, F. (2023). Smart Transportation: An Overview of Technologies and Applications. Sensors, 23 (8), 3880. https://doi.org/10.3390/s23083880
21. Low, R., Tekler, Z. D., Cheah, L. (2020). Predicting Commercial Vehicle Parking Duration using Generative Adversarial Multiple Imputation Networks. Transportation Research Record: Journal of the Transportation Research Board, 2674 (9), 820–831. https://doi.org/10.1177/0361198120932166
22. Young, W., Sobhani, A., Lenné, M. G., Sarvi, M. (2014). Simulation of safety: A review of the state of the art in road safety simulation modelling. Accident Analysis & Prevention, 66, 89–103. https://doi.org/10.1016/j.aap.2014.01.008
23. Slobodyanyuk, M., Gorobchenko, O. (2020). Structural analysis of territorial transport systems based on classification methods. Eastern-European Journal of Enterprise Technologies, 1 (4 (103)), 23–32. https://doi.org/10.15587/1729-4061.2020.194158
24. Abu Dabous, S., Ibrahim, F., Feroz, S., Alsyouf, I. (2021). Integration of failure mode, effects, and criticality analysis with multi-criteria decision-making in engineering applications: Part I – Manufacturing industry. Engineering Failure Analysis, 122, 105264. https://doi.org/10.1016/j.engfailanal.2021.105264
25. Radu, P. V., Lewandowski, M., Szelag, A. (2020). On-Board and Wayside Energy Storage Devices Applications in Urban Transport Systems – Case Study Analysis for Power Applications. Energies, 13 (8), 2013. https://doi.org/10.3390/en13082013