

DEVELOPMENT OF A MODEL FOR ASSESSING THE TECHNICAL LEVEL OF A CAR AS PART OF AN UNMANNED AIRCRAFT SYSTEM

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Abstract. *Background.* In conditions of keen competition in the markets for goods and services, a huge emphasis is put on the stages of subject-wise planning, issuing design specification, and front-end engineering design when manufacturing new products. These stages are primarily responsible for the key technical and economic products' characteristics that directly identify the product conceptual design and marketability. Current information and analytical systems (IAS) that dictate a choice of perspective directions to develop newly created products and their most preferred specimens basically use knowledge of experts about the value of estimation indicators. The latter usually serve as a basis for opting the best specimens of the newly designed technical systems. Evaluation of quality and technical level (TL) of complex technical systems using the created IAS often involves value functions (for instance, Fishburn function), which imply that a dialogue with a decision-maker (DM) produces information about his views of "value systems" or "preference systems", used to construct value functions. Developers of new products experience considerable difficulties in choosing a value function of estimation indicators when working with IAS. *Materials and methods.* The paper proposes to determine a value function for numerical indicators using the newly designed information model, based on expert estimations consistent with estimation of truck TL. A technical device and algorithm to determine value functions of unit estimation CTS indicators were developed according to the method. An invention was registered, and a patent was issued. The method also implies taking random factors into account when evaluating CTS TL for, as an example, "reliability" as the key estimation indicator. *Results and conclusions.* Two patents of the Russian Federation were obtained for invention of a time digitizer and a device for estimating effectiveness of various systems through sampling random values. The suggested method of generating a value function enables a scientist to choose the type and nature of a value function that will allow to increase the degree of CTS TL evaluation reliability, and optimize the cost of obtaining initial information when predicting CTS reliability due to evaluation of adaptive digitalization of random processes initiated in IAS. The paper materials may be of service to designers of complex systems at the initial stages of developing thereof in evaluating possible alternatives of CTS implementation, and determining TL at all stages of CTS life cycle.

Keywords: complex technical systems, information and analytical system, value functions, unit estimation indicators, technical level, concordance coefficient, random process, digitalization, reliability

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РАЗРАБОТКА МОДЕЛИ ОЦЕНКИ ТЕХНИЧЕСКОГО УРОВНЯ АВТОМОБИЛЯ В СОСТАВЕ БЕСПИЛОТНОГО АВИАЦИОННОГО КОМПЛЕКСА

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Аннотация. *Актуальность и цели.* В условиях острой конкуренции на рынках товаров и услуг большое внимание уделяется этапам предметного планирования, выдаче проектных спецификаций, а также предварительному инженерному проектированию при производстве новой продукции. Эти этапы в первую очередь отвечают за ключевые технические и экономические характеристики продуктов, которые напрямую определяют концептуальный дизайн и конкурентоспособность продукта. Существующие информационно-аналитические системы, которые диктуют выбор перспективных направлений развития вновь созданных продуктов и их

наиболее предпочтительных образцов в основном используют знания экспертов о значении показателей оценки. Последние обычно служат основанием для выбора лучших образцов вновь создаваемых технических систем. Оценка качества и технического уровня (ТЛ) сложных технических систем с использованием созданных систем часто включает функции ценности (например, функцию Фишберна), которые подразумевают, что диалог с лицом, принимающим решения, дает информацию о его взглядах на «ценность» системы» или «системы предпочтений», используемые для построения функций ценности. Разработчики новых продуктов испытывают значительные трудности с выбором функции ценности оценочных показателей при работе с ИАС. *Материалы и методы.* В статье предлагается определить функцию ценности для числовых показателей с использованием недавно разработанной информационной модели, основанной на экспертных оценках, согласующихся с оценкой ТЛ грузовика. По методике разработаны техническое устройство и алгоритм определения стоимостных функций единичных оценочных показателей сложных технических систем. Было зарегистрировано изобретение и выдан патент. Метод также предполагает учет случайных факторов при оценке СТС ТЛ, например, для «надежности» в качестве ключевого показателя оценки. *Результаты и выводы.* Получены два патента Российской Федерации на изобретение оцифровщика времени и устройства для оценки эффективности различных систем путем выборки случайных величин. Предлагаемый метод построения функции ценности позволяет ученому выбрать тип и характер функции ценности, что позволит повысить степень надежности оценки СТС ТЛ и оптимизировать затраты на получение исходной информации при прогнозировании надежности СТС за счет оценки адаптивной цифровизации случайных процессов, инициированных в информационно-аналитических системах. Бумажные материалы могут быть полезны разработчикам сложных систем на начальных этапах их разработки при оценке возможных альтернатив реализации СТС и определении ТЛ на всех этапах жизненного цикла СТС.

Ключевые слова: сложные технические системы, информационно-аналитическая система, функции стоимости, показатели единичной оценки, технический уровень, коэффициент согласованности, случайный процесс, цифровизация, надежность

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Introduction

The existing information technologies for examining operations and algorithms from optimum systems theory allow to assess indicators of complex technical systems (CTS) and identify the following processes:

- compare existent CTS with optimum and assumed to be ideal (theoretical) ones;
- determine maximum possible values of CTS effectiveness criterion;
- use optimum systems theory when designing new CTS.

Definition of concepts “value function” and “unit estimation indicators”. When evaluating quality and technical level (TL) of complex technical systems (CTS), value and utility functions (for instance, Fishburn function [1]) are often used. The principle of these methods is that a dialogue with a decision-maker (DM) produces information about his “value system” or “preference system”, used to construct value functions.

Value function (utility function) is a function that establishes correspondence between TL indicator values and its estimations scaled from 0 to 1.

Unit estimation indicator shall be a parameter or characteristic that identify one of the basic CTS features and have a substantial effect on its performance and development. Value (utility) functions for unit estimation indicators are generated (chosen or determined). They are involved in identifying CTS technical level in information and analytical system (IAS).

Basically, a particular value function may be assigned to each type of estimation indicators. Value (utility) function for quality logical indicators is binary. It takes 0 or 1 value depending on whether this feature is important and preferable or not. DM shall understand that if there are no true objective preferences, only those preferences are of importance that demonstrate a subjective DM opinion about utility of values of the evaluated indicator. Fig.1 presents a utility function of “design engineering” course students’ grades as an example [2].

The presented value function slightly varies when grades are very high and very low, and sharply increases when grades are average and good. It indicates that there is good reason to increase evaluation of students’ knowledge from average and high grades.

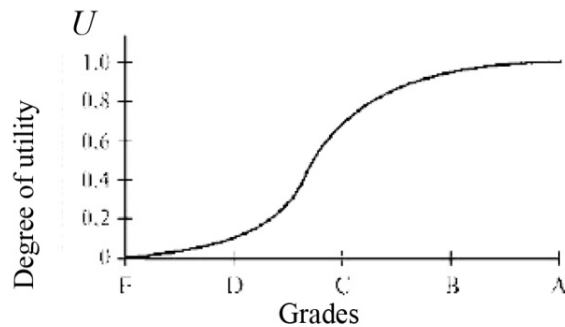


Fig. 1. Utility function of “design engineering” course students’ (F,D,C,B,A) grades

The literature may name value function as a utility function, preference function, function of estimations¹ [3–5]. Experts need to evaluate “number by number”, i.e. transform the value of indicator into its estimation. For ease in addressing this problem, a method of “principal points” is recommended, which implies that experts identify the type of relationship between values of indicators and their estimations. This relationship may be presented in the form of graphs, tables, and formulas. Graphs are constructed with the coordinate axes: values of indicators shall be on the abscissa; estimations shall be on the ordinate. A mean curve shall be constructed using curves constructed by individual experts. It can be analytically described in the form of the function formula.

1. Selecting and defining value functions of unit estimation indicators when solving multi-criteria problems in evaluating technical level of complex technical systems in information and analytical systems

1.1. Principles of generating value function of unit estimation indicators of complex technical systems

Generation of value function constitutes an integral part of a method for solving multi-criteria problems [6] and a method for evaluating technical level of CTS [7]. Information about DM preferences may be used in a variety of ways.

There is the most simple and popular method of simple weighting in order of importance. It implies that alternatives are ranked according to sums s_i of estimations r_{ij} of the alternatives, weighted by coefficients w_j of relative importance of these alternatives [3]

$$s_i = \sum_{j=1}^n w_j r_{ij}.$$

Selection of the value function type has a significant effect on the result of ranking the values of each unit estimation indicator.

The principles of constructing value functions are quite well-known [1, 2, 8]. However, as monography [9] states, construction of value functions is as much an art as a science. Hence, no unified guidelines to construct utility functions can be formulated. There are not only various methods for constructing utility functions, but also many varieties of any one of them.

Paper [10] suggests to determine utility function using qualitative data and estimations. CTS is arranged in order based on expert evaluations applying geometrical approach. An expert can either arrange objects in order, or make pair-wise comparisons. It is proposed to divide multiple data and evaluations into equivalence classes. A relationship between evaluations and parameters’ values, which can further be used for all multiple data and evaluations, is found through analyzing the expert’s preferences.

As mentioned in monography [9], it is very difficult to predict what method will be the best in a certain situation, since it depends on a specific decision-making person, nature of a problem, and many other factors. However, the basic ideas, used in selecting and constructing value function, remain identical for all possible procedures.

¹ ГОСТ 23554.0-79. Экспертные методы оценки качества промышленной продукции. Основные положения.

Therefore, without regard to what method would be utilized to construct a value function, relevant questions or problems that need to be considered and solved are basically the same and involve five stages:

1. Preparation to construct a value (or utility) function;
2. Identification of proper quality parameters of the evaluated object;
3. Setting quantity limits;
4. Selection of necessary value (utility) function;
5. Verification of concordance between the selected value (utility) function and experts' opinions.

In actual practice, steadily increasing (decreasing) value functions are most commonly in use. Here, it is considered that DMs tend to be risk-averse or risk-neutral. And it is the case if and only if a monotonic utility function is concave, convex, or linear [9].

Work [11] suggests a method for evaluating CTS technical level for IAS, which uses value function when defining ranking of alternatives

$$R_j(i) = \sum_1^k W_{kj} \cdot U_{kj}(i),$$

where $R_j(i)$ – ranking of the i^{th} alternative by the j^{th} integral indicator; W_{kj} – weight of the k^{th} unit indicator in the j^{th} integral indicator; $U_{kj}(i)$ – value of a value function of the k^{th} unit indicator of the i^{th} alternative of the j^{th} integral indicator.

Value function for numerical indicators implies that from two to five points of the value function curve shall be applied depending on the type of this curve. Value or utility function $U_{j-i}(g_{j-i})$ may be of several types (Fig. 2) or may be decreasing or increasing [7]. Type 1 is linear when there is no preference for an indicator, types 2 and 3 are concave and convex and shall be utilized when it is desirable to have greater or lesser effect depending on the value of an indicator; type 4 is S-shaped and shall be used, when it is desirable to have the required effect for greater values of an indicator.

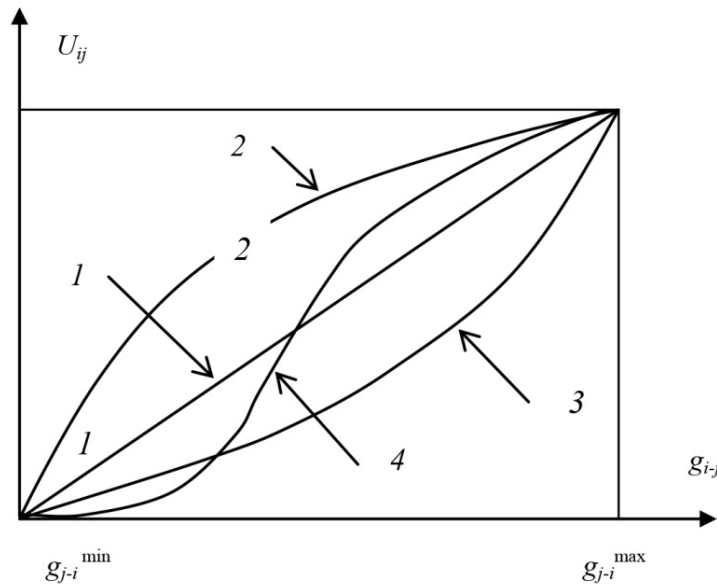


Fig. 2. Scheme of the inherent utility function types in IAS:
 1 – linear (risk-neutral); 2 – concave (risk-prone);
 3 – convex (risk-averse); 4 – S-shaped function

It is assumed that a value function is defined by five points. 0.90 value of the value function for each unit indicator corresponds to potentially attainable values of parameters or characteristics; 0.50 corresponds to those assigned in CTS design specification (DS) or common values; 0.1 corresponds to the minimum acceptable values; 0.20 and 0.70 correspond to intermediate values between the extreme and assumed as per DS values, and characterize the type of the selected value function.

Value function for synthesized indicators is often defined using only two points: 0.5 as a mean value of the parameter; 0.1 as the minimum acceptable values of the parameter. In what follows, the authors suggest a method for selecting value functions for CTS.

1.2. Method for selecting value functions and determining unit estimation indicators of complex technical systems

The principal result of the suggested method for selecting value function is in identifying preference of the unit numerical estimation indicator scaled from zero to one to increase authenticity of evaluating CTS technical level. It enables to assess a degree of effect, which this and other unit estimation indicators have on performance of basic CTS functions in a standardized form (i.e. irrespective of the estimation indicator dimension) when defining a standard CTS technical level.

Furthermore, a possibility emerges to determine threshold values of unit estimation indicators, i.e. the ranges of allowable variations in values using value functions. Its own type of value function shall be assigned to each type of indicator.

Within the suggested method:

- a division of all unit estimation indicators is made into quality (logical) and quantity (numerical) ones;
- each value function for numerical indicators is presented as a curve of two-five points; for each point a value of indicator shall be specified using an expert-based method, and a value of value function shall be selected from the list.

It is recommended to determine value functions of CTS unit estimation indicators as follows:

1. Compiling a list of unit estimation indicators
2. Determination of the value function type for each unit estimation indicator
3. Establishing threshold values of unit estimation indicators
4. Selection of value functions by each expert
5. Verification of a concordance degree between expert estimations.

Matrix of κ^{th} expert inquiry presented in Table 1 (1–4 stages) constitutes an initial information for these procedures.

Table 1

Matrix of κ^{th} expert inquiry by values of indicators

Unit indicators	Values of indicators for 5 points of value function				
	$U_{ik1}(g_i) = 0.10$	$U_{ik2}(g_i) = 0.20$	$U_{ik3}(g_i) = 0.50$	$U_{ik4}(g_i) = 0.70$	$U_{ik5}(g_i) = 0.90$
g_1	g_{1k1}^{\min}	g_{1k2}^{R1}	g_{1k3}^{R2}	g_{1k4}^{R3}	g_{1k5}^{\max}
\vdots	\vdots	\vdots	\vdots	\vdots	\vdots
g_i	g_{ik1}^{\min}	g_{ik2}^{R1}	g_{ik3}^{R2}	g_{ik4}^{R3}	g_{ik5}^{\max}
\vdots	\vdots	\vdots	\vdots	\vdots	\vdots
g_n	g_{nk1}^{\min}	g_{nk2}^{R1}	g_{nk3}^{R2}	g_{nk4}^{R3}	g_{nk5}^{\max}

The total number of matrices-inquiries shall be defined by the number of experts involved in the inquiry process. The following designations are assumed in Table 1: $U_{ikj}(g_i)$ is a value function that sets up a correspondence between the values of estimation indicator and scale from 0 to 1; g_i is a unit estimation indicator for evaluation of CTS TL.

Value function explicitly sets priorities on various values of a unit indicator. Basically, its own value function may be assigned to each type of indicator. Value function for logical indicators is binary. It takes 0 or 1 values, depending on whether this property is desirable or not. Numerical indicators that imply use of five points of value function (as in Table 1) will be further considered.

Numerical values in each line of Table 2 define the pattern of value function variation: it can be steadily decreasing or increasing, linear, convex, or concave, S-shaped, triangular, or trapezoidal, etc.

It would make sense to obtain mean (as per the data of all experts) indicators g_{ij} for each j^{th} point (out of 5 points) of value function using the following formula:

$$\bar{g}_{ij} = \frac{\sum_{\kappa=1}^m g_{ikj}}{m}, \tag{1}$$

where g_{ij} – value of indicator from Table 2; $j = 1, \dots, 5$ – points of value function; $\kappa = 1, \dots, m$; $i = 1, \dots, n$; m – number of experts involved in the inquiry process; n – number of unit estimation indicators.

Mean (as per the data of all experts) values of indicators may be presented in the form of Table 2.

Table 2

Matrix of indicators values

Unit indicators	Mean values of indicators for 5 points of value function				
	$U_{i1}(g_i) = 0.10$	$U_{i2}(g_i) = 0.20$	$U_{i3}(g_i) = 0.50$	$U_{i4}(g_i) = 0.70$	$U_{i5}(g_i) = 0.90$
g_1	\bar{g}_{11}^{\min}	\bar{g}_{12}^{R1}	\bar{g}_{13}^{R2}	\bar{g}_{14}^{R3}	\bar{g}_{15}^{\max}
\vdots	\vdots	\vdots	\vdots	\vdots	\vdots
g_i	\bar{g}_{i1}^{\min}	\bar{g}_{i2}^{R1}	\bar{g}_{i3}^{R2}	\bar{g}_{i4}^{R3}	\bar{g}_{i5}^{\max}
\vdots	\vdots	\vdots	\vdots	\vdots	\vdots
g_n	\bar{g}_{n1}^{\min}	\bar{g}_{n2}^{R1}	\bar{g}_{n3}^{R2}	\bar{g}_{n4}^{R3}	\bar{g}_{n5}^{\max}

Numerical values in each line of Table 2 define the form of the required value function.

However, there is a need for verifying a degree of concordance between expert estimations for all experts (5th stage). This concordance may be determined using concordance coefficient W_j , evaluated for each of five value function points by the following formula [12]:

$$W_j = 1 - \frac{12 \sum_{i=1}^n \sum_{\kappa=1}^m d_{ijk}^2}{m^2(n^3 - n)}, \tag{2}$$

$i = 1, \dots, n$ – indicators; $\kappa = 1, \dots, m$ – experts; $j = 1, \dots, 5$ – points of value function; where d_{ijk} is a standard deviation of the current value of indicator g_{ikj} from its mean value defined by formula (1).

Value d_{ijk} shall be evaluated by the following formula:

$$d_{ijk} = \frac{\bar{g}_{ij} - g_{ijk}}{\bar{g}_{ij}} \tag{3}$$

If inequality

$$W_j \geq W_0 \tag{4}$$

holds true (where W_0 is an allowable value of concordance coefficient), the results of experts' inquiry may be considered agreed, otherwise, they need to be corrected through repeating this inquiry.

2. Example. Determination of value functions of self-driving truck TL evaluation

A specific example shall be considered to illustrate the suggested method. Value functions shall be identified for TL unit indicators of truck in IAS environment.

Six functional unit estimation indicators of truck [13] shall be specified:

- 1) velocity (U , km/h);
- 2) capacity (V , m³);
- 3) weight of load carried (m_G , t);
- 4) weight of loaded automobile (m_a , t);
- 5) angle of turn (α , degrees);
- 6) motor power (P , HP).

Fig. 3 shows value functions for unit estimation indicators of truck, suggested by each of seven experts. Numbers of value functions' curves in each figure correspond to the numbers of the appropriate ex-

perts. Numerical values of estimation indicators taken from these curves are presented in the table for each expert¹.

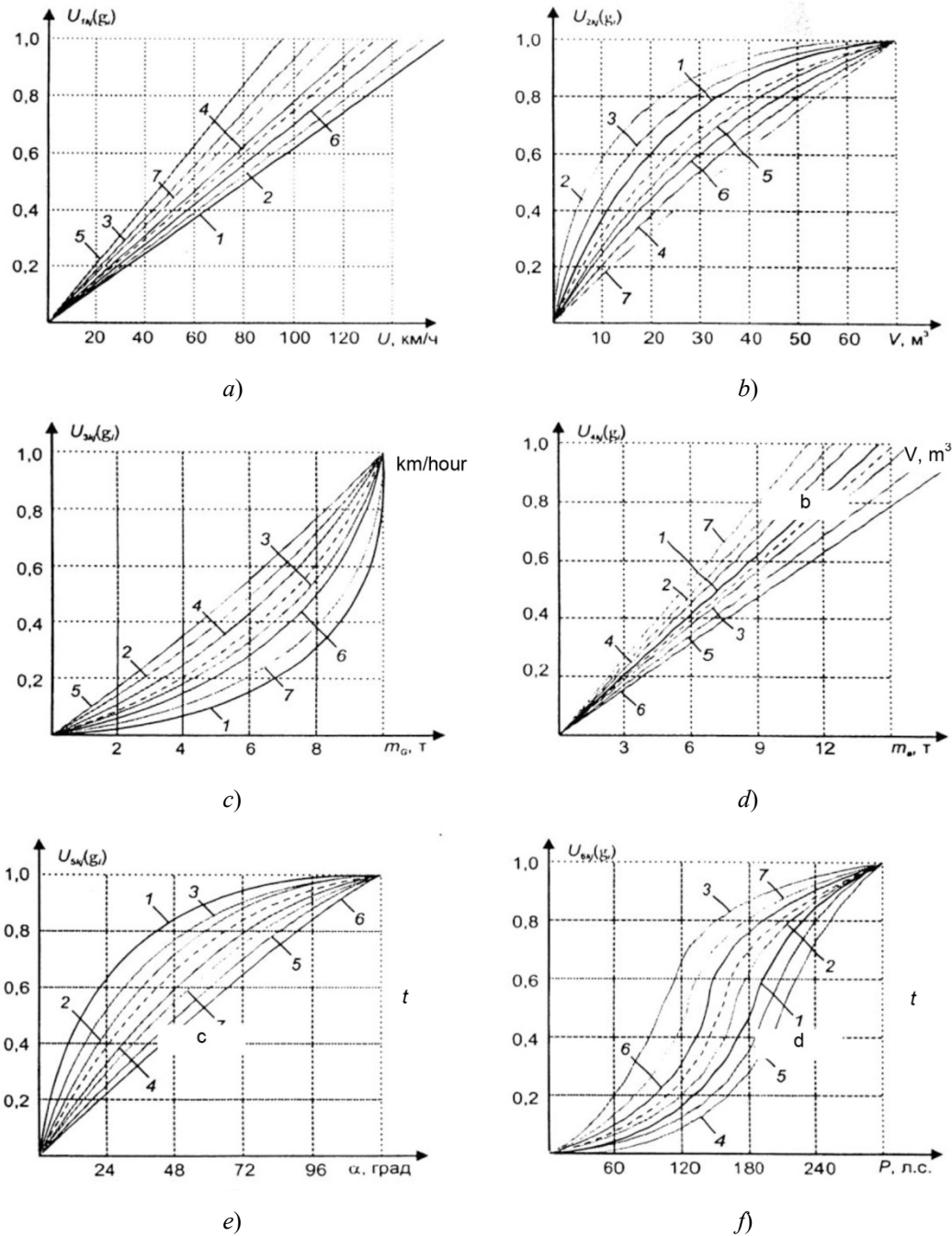


Fig. 3. Value functions for unit estimation indicators in evaluating technical level of truck in IAS:
 a – velocity U , km/h; b – capacity V , m^3 ; c – weight of load carried m_G , t;
 d – weight of loaded automobile m_a , t; e – angle of turn α , degrees; f – motor power, P – horsepower

Table 3 comprises data on numerical values of indicators for expert No.1. Table 4 contains information about mean values of indicators based on data obtained from seven experts. Table 5 includes differences between mean values of a unit indicator and values of this indicator, in expert No.1 opinion. Since squaring operation will further be made, there is no any sense in a symbol preceding these differences, hence, these tables show modules of these differences.

¹ Due to the paper scope limitations, further data are given pursuant to the algorithm of processing data only for expert No.1.

Table 3

Numerical values of indicators for expert No. 1

Indicator No.	Values of indicators				
	$U_{i11}(g_i) = 0.10$	$U_{i12}(g_i) = 0.20$	$U_{i13}(g_i) = 0.50$	$U_{i14}(g_i) = 0.70$	$U_{i15}(g_i) = 0.90$
1	17.34	32.00	80.00	111.00	142.66
2	1.96	4.65	12.80	24.30	45.00
3	5.00	7.00	9.00	9.60	9.94
4	1.20	2.90	7.25	10.20	13.15
5	2.40	3.60	14.40	28.80	67.20
6	96.00	132.00	174.00	198.00	246.00

Table 4

Mean values of indicators according to information obtained from seven experts

Indicator No.	Mean values of indicators				
	$U_{i1}(g_i) = 0.10$	$U_{i2}(g_i) = 0.20$	$U_{i3}(g_i) = 0.50$	$U_{i4}(g_i) = 0.70$	$U_{i5}(g_i) = 0.90$
1	12.72	23.72	62.69	92.26	118.29
2	2.80	6.32	17.47	30.15	49.67
3	2.71	4.36	7.41	8.68	9.38
4	1.20	2.90	7.50	10.46	13.66
5	7.20	12.59	34.69	55.21	90.17
6	91.00	115.72	156.00	182.14	238.29

Table 5

Differences between mean values of each (of 6) unit indicator and values of the indicator in expert No.1 opinion

Indicator No.	Values of difference between values of indicators				
	$U_{i11}(g_i) = 0.10$	$U_{i12}(g_i) = 0.20$	$U_{i13}(g_i) = 0.50$	$U_{i14}(g_i) = 0.70$	$U_{i15}(g_i) = 0.90$
1	4.62	8.28	17.31	18.74	24.37
2	0.84	1.67	8.47	5.85	4.67
3	2.29	2.64	1.59	0.92	0.56
4	0.00	0.00	0.25	0.26	0.51
5	4.80	8.99	10.29	26.41	22.97
6	5.00	16.28	18.00	15.86	7.71

Table 6 contains standardized values of these differences obtained as per formula (3) for expert No. 1.

Table 6

Standardized values of difference for expert No. 1

Indicator No.	Standardized values of difference				
	$U_{i11}(g_i) = 0.10$	$U_{i12}(g_i) = 0.20$	$U_{i13}(g_i) = 0.50$	$U_{i14}(g_i) = 0.70$	$U_{i15}(g_i) = 0.90$
1	0.363	0.349	0.276	0.203	0.206
2	0.300	0.264	0.485	0.194	0.094
3	0.845	0.606	0.215	0.106	0.060
4	0.000	0.000	0.033	0.025	0.037
5	0.667	0.714	0.297	0.478	0.255
6	0.055	0.141	0.115	0.087	0.032

Table 7 contains squared standardized values for expert No. 1 for all points of value functions curves.

Table 7

Squared standardized values of difference for expert No. 1

Indicator No.	Squared standardized values of difference				
	$U_{i1}(g_i) = 0.10$	$U_{i2}(g_i) = 0.20$	$U_{i3}(g_i) = 0.50$	$U_{i4}(g_i) = 0.70$	$U_{i5}(g_i) = 0.90$
1	0.1318	0.1218	0.0762	0.0412	0.0424
2	0.0900	0.0697	0.2350	0.0376	0.0088
3	0.7141	0.3666	0.0460	0.0112	0.0036
4	0.0000	0.0000	0.0011	0.0006	0.0014
5	0.4444	0.5099	0.0880	0.2288	0.0649
6	0.0030	0.0198	0.0133	0.0076	0.0010

Table 8 shows total sums of squared standardized differences and evaluations of concordance coefficient W_j using formula (2). Table 8 shows that each value W_j is greater than 0.99.

Table 8

Total summation and evaluation of W_j

	Indicator No.	Sums of squared standardized values of difference				
		$U_{i1}(g_i) = 0.10$	$U_{i2}(g_i) = 0.20$	$U_{i3}(g_i) = 0.50$	$U_{i4}(g_i) = 0.70$	$U_{i5}(g_i) = 0.90$
Intermediate values	1	0.4361	0.3063	0.2332	0.1990	0.1757
	2	2.5264	1.9499	1.4752	0.8658	0.3247
	3	1.1679	0.9005	0.2050	0.0507	0.0079
	4	0.1882	0.2996	0.2753	0.2256	0.2459
	5	1.3826	1.5900	0.8081	0.8098	0.1755
	6	0.8787	0.6337	0.3205	0.2392	0.0591
	\sum	6.5799	5.6800	3.3173	2.3901	0.9888
	W_j	0.9923	0.9938	0.9961	0.9972	0.9988

It indicates that actions of experts are well-coordinated, and even with $W_0 = 0.80$ the obtained mean values of value function of truck unit indicators (Table 8) can be taken as a basis. The obtained mean (for 7 experts) value functions for 6 estimation indicators are presented in Fig. 3 as dotted lines.

”Evaluation and selection” IAS designed to evaluate technical level of various-purpose CTS [6, 14] may be qualified as a modern automated computer-software system that uses state-of-the-art mathematical methods of decision-making theory and information technologies. This system enables to take into account the relationship between the estimation indicator value and the value of an indicator using five nodal points of linear-broken approximation, i.e. DM’s preferences. These data shall be read out according to the results of processing data obtained from experts, using the above-mentioned procedure. A technical device and algorithm to determine value functions of unit estimation CTS indicators were developed according to the method. They were considered an invention, and the patent of the Russian Federation was issued [15].

3. Taking into account random factors in “reliability” indicator when evaluating technical level of complex technical systems

Indicators of reliability, and no-failure operation, in particular, constitute an important component characterizing technical level of almost any CTS. To forecast reliability using information model “load-resisting strength” [16], it is required to know the value of uncorrelated maximum values of random external effects (level of loading) that may result in CTS failure. Implementation of this random process may be considered as an initial information to forecast reliability. Here, one should seek to reduce the scope of this information. It saves time and reduces the cost of its acquisition. In so doing, an adaptive digitalization may be applied when constructing implementations of random process of loading [17]. If spectrum characteristics of random factors vary [18], it makes sense to present it through adaptive digitalization. An accuracy of approximation therewith may be increased using the following Lagrange polynomial $L(t)$ [20]:

$$L(t) = \sum_{i=0}^n x_i l_i(t), \quad i = 0, \dots, n, \tag{5}$$

where x_i – i^{th} value of approximation; n – number of points of random process approximation;

$$l_i(t) = \prod_{j=0}^m \frac{t-t_j}{t_i-t_j}, \quad j=0, \dots, m, \quad (6)$$

m – maximum value of argument t degree indicator.

Taking into account formulas (5) and (6) for three approximation points and $m = 2$

$$L(t) = x_0 \frac{(t-t_1)(t-t_2)}{(t_0-t_1)(t_0-t_2)} + x_1 \frac{(t-t_0)(t-t_2)}{(t_1-t_0)(t_1-t_2)} + x_2 \frac{(t-t_0)(t-t_1)}{(t_2-t_0)(t_2-t_1)}, \quad (7)$$

where x_0 and t_0 – values of function and argument of the first point of approximation; x_1 and t_1 – values of function and argument of the second point of approximation; x_2 and t_2 – values of function and argument of the third point of approximation.

Quantitative evaluation of approximation quality shall further be done through computing difference δ between forecasted value $L(t_{np})$ and its actual value $x(t_{np})$:

$$\delta = |L(t_{np}) - x(t_{np})|. \quad (8)$$

Value δ shall further be compared with its allowable value δ_n , if $\delta \leq \delta_n$, then the result of approximation is positive, and value $L(t_{np})$ may be fixed as a working value of digitalization of the random process in question. An invention was created for solving the problem, and the Russian Federation patent was obtained [19, 20].

Key results of performed studies

Thus, the results of the studies carried out using IAS are as follows:

1. A method for selecting value function for unit estimation indicators in IAS was suggested based on construction of fuzzy logic statements in evaluating CTS TL.
2. An algorithm for evaluating TL in IAS is developed taking into account multiple-factor information model of random search and selection of alternative to elaborate preliminary DM's solutions in assessing CTS TL.
3. Information model of IAS is amended by the blocks of receiving initial information to evaluate CTS TL considering random factors.
4. Creation of IAS enabled to certify the suggested method and algorithm to evaluate TL for truck. Modelling results have evidenced an acceptable degree of evaluating unit estimation indicators of computerized IAS in preparing suggestions for DM, taking experts' opinions into account.

Discussion

Appendix A from monography [6] presents a brief analytical review of a reasonably large body of literature (156 sources) on methods for decision-making, evaluation of products' quality and CTS TL, methods of assessing quality and CTS TL, involving those based on expert estimations, and systems of decision-making support using computer technologies. However, according to analysis, no consideration in the stated works was given to the problems posed in the paper concerning construction of IAS and information model of analyzing CTS value function to practically determine TL in the context of new information technologies in the area of identifying algorithms and results of modelling the systems through combined approaches. I.e., no suggestions on generating value function of CTS unit indicators using five points of analyzing value function were put forward, and the initial information bearing factors in mind was not considered in IAS at all.

Recommendations

The suggested information technology is designed to serve a wide range of developers of the new CTS in selecting the best technical solutions using IAS and conducting comparative CTS TL analysis related to domestic and foreign specimens, as well as evaluating competitiveness of the newly created products and identifying the quality of export products.

Conclusion

1. Selection and definition of value functions of unit estimation indicators constitute an integral part of a method for solving multi-criteria problems on evaluating technical level of CTS in IAS.

2. The paper suggests a research and practical method of generating value functions of unit estimation indicators in estimating CTS technical level using evaluation of experts' concordance that enables to make rather simple and reasonable choice, generating value function for each unit estimation indicator taken.

3. A potential reduction of the cost of acquiring initial information needed for forecasting CTS reliability is shown due to acquiring evaluation of adaptive digitalization of random factors implemented in IAS.

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