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Construction of an aggregated production function with implementation based on the example of the regions of the Central Federal District of the Russian Federation*

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Abstract

A three-dimensional case is considered on the basis of a method developed for estimating the parameters of the aggregated production function used to calculate dynamic standards and build integral indicators of the performances of the functioning of socio-economic systems. The aggregated production function is determined by the quadratic convolution of the production functions of the results of the functioning of the elements of the subsystem and their correlation matrix. The parameters of the aggregated production function are determined from solving the problem of maximizing the likelihood function of a random variable – the residuals of production

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functions aggregated according to a similar rule. On the example of a project subsystem within the framework of the Kleiner's spatial-temporal classification of socio-economic systems we obtained adjusted values of the parameters of a function that includes power-law multiplicative models of the relationship between the volume of gross domestic product by region for sections F (construction), G (wholesale and retail trade), K (financial activity) according to NACE 2 and the cost of fixed assets (total for section K, for sections F and G), the average annual number of employees (for sections F and G) and the average annual population (for section K), based on data for 2015–2020 (sections G, K) and 2018–2020 (section F) for the regions of the Central Federal District. The EFRA software package and Python's project were used as tools. The results obtained can be used by regional authorities in assessing the functioning of the regions and the formation of appropriate standards in the short term.

Keywords: socio-economic system, probability distribution density, aggregated production function, model, integral estimation

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Introduction

When assessing the results of the functioning of regional socio-economic systems (RSES), both private and integral indicators are used, the latter of which are reduced to aggregating the effective features of SES elements, including in the tasks of identifying significant factors, modeling and forecasting socio-economic processes [1, 2] in the context of sustainable, balanced development [3]. In most cases, aggregation is carried out in the form of averages and weighted averages of various types [4–7], or using generally recognized analysis of the functioning environment [8, 9], component analysis [10, 11]) and special algorithms for constructing integral indicators [12, 13] with an analysis of the correctness of their construction [14]. The volume of gross domestic product by region for the corresponding types of economic activity within the sectoral [15] or spatial-temporal [16] classifications of socio-economic subsystems is most often used as private indicators for assessing the functioning of the RSES, which are part of the integral indicator, to assess the balance of the functioning of the regions – subjects of the Russian Federation. According to the spatial-temporal classification of Kleiner, SES includes subsystems of four types: object (limited in space, not limited in time), environment (not limited in space or time), process (not limited in space, limited in time), project (limited in space and time). The regional project subsystem can be represented as three elements, each of which is a set of economic units – institutional units – residents of the region (in the terminology of the system of national accounts) contributing to the volume of gross domestic product by region (GDP by region) in sections F (construction), G (wholesale and retail trade), K (financial activity) in accordance with the All-Russian classifier of types of economic activity (OKVED, NACE). The second edition of OKVED 2 (NACE rev.2) has been used since 2017; previously OKVED 1 (NACE rev. 1) was used.

In order to model and predict the values of particular indicators – the results of the functioning of the elements of the RSES – we use models of the relationship of productive and factorial features in the form of economic and statistical models – production functions (PF) that establish the relationship between output volume and production factors, including linear [17, 18], quadratic [19], logarithmic [20], translogarithmic, constructed on the basis of the Cobb-Douglas function [21], transcendental [22], power multiplicative (most often found in publications), including taking into account the innovative component [23] etc. The choice of the functional form of models is most often determined by the researcher based on verification of a set of statistical hypotheses. It is also possible to introduce additional selection criteria related, for example, to the qualitative content of the model and the priorities of the RSES control centers if the models are used to set norms [24]. To estimate their parameters, conventional (OLS) and generalized least squares (GLS) and maximum likelihood (MLE) methods are traditionally used.

For an SES subsystem characterized by a set of models, its integral evaluation requires aggregation of the corresponding models of the functioning of the elements, in the simplest case determined by their simple or weighted average sum. However, due to the presence of interrelations between the elements, the procedure for searching for the parameters of the model that characterizes the result of the functioning of the subsystem as a whole, the parameters of the aggregated production function (APF) are already becoming unobvious.

The author's work [25] presents a method for estimating the parameters of the APF tested on the example of a two-component APF. In this article, we aim to apply the method for the three-dimensional case when the aggregated production function is determined by a quadratic convolution of three production functions, each of which characterizes the results of the functioning of an element of a three-element subsystem of the SES. Using the example of evaluating the results of the functioning of the project subsystems of the regions of the Central Federal District, we test the hypothesis about the possibility of using the method to refine the parameters of an aggregated production function based on the EFRA software package [26], as well as a software project specially developed in Python.

1. Methodology for evaluating the results of the subsystem functioning and constructing an aggregated production function

To evaluate the results of the functioning of the SES subsystem, we propose to use an integral indicator with the properties of monotony, identity, commensurability, dimensionlessness and transitivity, and also to take into account the relationships between the elements [27]:

$$\xi_{k,s_q}(t)=\frac{\sqrt{\sum_{i_1=1}^{I}\sum_{i_2=1}^{I} r_{i_1,i_2,s_q}\cdot y^0_{i_1,k,s_q}(t)\cdot y^0_{i_2,k,s_q}(t)}}{\sqrt{\sum_{i_1=1}^{I}\sum_{i_2=1}^{I} \hat{r}_{i_1,i_2,s_q}\cdot \hat{y}^0_{i_1,k,s_q}(t)\cdot \hat{y}^0_{i_1,k,s_q}(t)}}, \quad (1)$$

where r_{i_1,i_2,s_q}, $\hat{r}_{i_1,i_2,s_q}$ are corresponding values of the paired correlation coefficient between i_1-th $y^0_{i_1,s_q}$, $\hat{y}^0_{i_1,s_q}$ and i_2-th $y^0_{i_2,s_q}$, $\hat{y}^0_{i_2,s_q}$ variables (resultative features, respectively, actual and expected (normative), the values of the latter in the time period t, are determined using the production function (PF)) (i_1, i_2 = 1, ..., I, I is the number of resultative features of a k-subsystem of type s_q); the index "0" shows that the values of variables are reduced to a scale from 0 to 1 by converting standardized (centered and normalized) values of absolute values:

$$(\cdot)^0_{i,k,s_q}(t)= \quad (2)$$

$$=\frac{(\cdot)^*_{i,k,s_q}(t)-\min\{y^*_{i,k,s_q}(t),\hat{y}^*_{i,k,s_q}(t)\}}{\max\{y^*_{i,k,s_q}(t),\hat{y}^*_{i,k,s_q}(t)\}-\min\{y^*_{i,k,s_q}(t),\hat{y}^*_{i,k,s_q}(t)\}}.$$

Here $(\cdot)$ is y_i, $\hat{y}_i$; * means that the variables (we will consider them random variables) are centered and normalized:

$$(\cdot)^*_{k,s_q}(t) = \frac{(\cdot)_{k,s_q}(t) - M(y_{s_q})}{\sigma(y_{s_q})}, \quad (3)$$

where $M(y_{s_q})$, $\sigma(y_{s_q})$ are the mean and standard deviation of the combined k and t samples.

If the value of the indicator is greater than or equal to one, then the functioning of the subsystem can be considered satisfactory. Similarly in formula (1), particular performance indicators are constructed determined by the ratio of actual and normative values (calculated by the production function (PF)) reduced to a scale from 0 to 1 in accordance with formulas (2) and (3).

The expression standing in the denominator (1) is an aggregated production function (APF) formed by a quadratic convolution of the production functions of the productive features i_1, i_2 and the corresponding correlation matrix.

The relationship between the values of effective features and factors can be represented as [25]:

$$y_{k,i}(t) = f_i(C_{i,j}, x_{k,i,j}(t)) + \varepsilon_{k,i}(t). \quad (4)$$

where k is the number of population elements, ($k = 1, ..., K \in N$);

t is the observation time of the k-th of the population element ($t = 1, ..., T \in N$);

i is the index of a random variable ($i = 1, ..., m \in N$);

$C_{i,j}$ are parameters of the function $f_i(\cdot) = \hat{y}_i$;

$\varepsilon_{k,i}$ are the values of the stochastic random component $\varepsilon_i \sim N(0; \sigma^2_{\varepsilon_i})$:

$$f_{P,i}(\varepsilon_i) = \frac{1}{\sqrt{2\cdot\pi}\cdot\sigma_{\varepsilon,i}} \cdot \exp[-\frac{\varepsilon_i^2}{2\cdot\sigma^2_{\varepsilon,i}}] = \frac{1}{\sqrt{2\cdot\pi}\cdot\sigma_{y_i}} \cdot \exp[-\frac{(y_i - \hat{y}_i)^2}{2\cdot\sigma^2_{y_i}}]. \quad (5)$$

In order to eliminate the influence of units of measurement, we will consider standardized random variables ε_i^* with a joint probability distribution density:

$$f_P(\varepsilon_1^*, \varepsilon_2^*, ..., \varepsilon_m^*) = \frac{1}{(2\cdot\pi)^{m/2}\cdot\sqrt{\Delta_r}} \times \times \exp[-\frac{1}{2\cdot\Delta_r}\sum_{i=1}^{m}\sum_{j=1}^{m} A_{r_{ij}} \cdot \varepsilon_i^* \cdot \varepsilon_j^*], \quad (6)$$

where Δ_r, $A_{r_{ij}}$ are the determinant and algebraic complements of the correlation matrix $\|r_{ij}\|$, correspondently, the elements of which are paired correlation coefficients; $\varepsilon_i^* = (y_i^* - \hat{y}_i^*)^2 / (2\cdot\sigma^2_{y_i^*})$.

Then the probability distribution density of a random variable ε^*, which are aggregated random variables, will be defined as:

$$f_P(\varepsilon^*) = \frac{1}{(2\cdot\pi)^{m/2}\cdot\sqrt{\Delta_r}} \times \times \frac{d}{dy^*}\int\int...\int_D \exp[-\frac{1}{2\cdot\Delta_r}\sum_{i=1}^{m}\sum_{j=1}^{m} A_{r_{ij}} \cdot \varepsilon_i^* \cdot \varepsilon_j^*]dD, \quad (7)$$

where the region of integration D depends on the combination ε_i^*.

We will conside D as a quadratic convolution in two variants:

$$(y - \hat{y})^2 = \left(\sqrt{\sum_{i_1=1}^{m}\sum_{i_2=1}^{m} r_{i_1,i_2} \cdot y_{i_1}^* \cdot y_{i_2}^*} - \sqrt{\sum_{i_1=1}^{m}\sum_{i_2=1}^{m} \hat{r}_{i_1,i_2} \cdot \hat{y}_{i_1}^* \cdot \hat{y}_{i_2}^*}\right)^2 \le (\varepsilon^*)^2, \quad (8)$$

$$\sum_{i=1}^{m}\sum_{j=1}^{m} r_{ij} \cdot \varepsilon_i^* \cdot \varepsilon_j^* \le (\varepsilon^*)^2. \quad (9)$$

The formula (8) corresponds to the difference between the numerator and the denominator of the expression (1) used to calculate the integral performance indicator.

To simplify calculations, it is necessary to bring the quadratic form to a canonical form by calculating eigenvalues and eigenvectors, or use the Lagrange method.

For the two-dimensional case, an analytical expression of the probability distribution density is obtained [25]. For the three-dimensional case, the density expression can be represented in quadratures in a spherical coordinate system [28]:

$$f_P(\varepsilon^*) = \frac{1}{(2\cdot\pi)^{3/2}\cdot\Delta}\cdot\int_0^{2\cdot\pi}\int_0^{\pi}(\varepsilon^*)^2\cdot\sin\theta\times$$
$$\times\exp\left[-\frac{1}{2}\cdot(\varepsilon^*)^2\times(c_{11}\cdot\cos^2\phi\cdot\sin^2\theta+\right.$$
$$+c_{22}\cdot\sin^2\phi\cdot\sin^2\theta+c_{22}\cdot\cos^2\theta+$$
$$+c_{12}\cdot\sin2\phi\cdot\sin^2\theta+c_{13}\cdot\cos\phi\cdot\sin2\theta+$$
$$\left.c_{23}\cdot\sin\phi\cdot\sin2\theta)\right]d\theta d\phi, \qquad (10)$$

where $c_{11} = K_{11}$;

$$c_{22} = \frac{1}{K_{33}\cdot\Delta}\cdot(K_{11}\cdot r_{12}^2 + K_{22} - 2\cdot K_{12}\cdot r_{12});$$

$$c_{33} = \frac{1}{K_{33}}\cdot(r_{12}\cdot K_{23} + r_{13}\cdot K_{33})\cdot(K_{11}\cdot r_{12}\cdot K_{23} +$$
$$+K_{11}\cdot r_{13}\cdot K_{33} - 2\cdot K_{12}\cdot K_{23} - 2\cdot K_{13}\cdot K_{33}) +$$
$$+K_{33}^2 + 2\cdot K_{23}^2 + \frac{K_{22}\cdot K_{23}^2}{K_{33}};$$

$$c_{12} = \frac{1}{\sqrt{K_{33}\cdot\Delta}}\cdot(-K_{11}\cdot r_{12} + K_{12}); \qquad (11)$$

$$c_{13} = \frac{1}{\sqrt{K_{33}}}\cdot(-K_{11}\cdot r_{12}\cdot K_{23} - K_{11}\cdot r_{13}\cdot K_{33} +$$
$$+K_{12}\cdot K_{23} + K_{13}\cdot K_{33});$$

$$c_{23} = \frac{1}{K_{33}\sqrt{\Delta}}\cdot(K_{11}\cdot r_{12}\cdot(r_{12}\cdot K_{23} + r_{13}\cdot K_{33}) + K_{22}\cdot K_{23} -$$
$$-K_{12}\cdot(2\cdot r_{12}\cdot K_{23} + r_{13}\cdot K_{33}) -$$
$$-r_{12}\cdot K_{13}\cdot K_{33} + K_{23}\cdot K_{33});$$

$K_{ij}^{-1} = A_{ij}/\Delta$ are elements of the inverse covariance matrix.

In the first case, the parameters of the aggregated production function $C_{i,j\,[part]}^*$ can be determined by methods of OLS or MLE applied for each of the considered PF $f_i(\cdot) = \hat{y}_i$. In the second case, the parameters of the APF are found using MLE for a density of the form (7) with a likelihood function $\ln L(y^* \mid C_{i,j}^*, x_{i,j}^*(t), \sigma_{y^*})$:

$$\ln L(y^* \mid C_{i,j}^*, x_{i,j}^*(t), \sigma_{y^*}) =$$
$$= \sum_{k=1}^{K}\sum_{t=1}^{T} f(y^* \mid C_{i,j}^*, x_{i,j}^*(t), \sigma_{y^*}) \to \max. \qquad (12)$$

The maximum (12) is determined by $C_{i,j}^*$ ((the parameters of the standardized i-th PF) with constraints of the form:

$$\sum_{k=1}^{K}\sum_{t=1}^{T}(\varepsilon_k^*(t))^2 \le \sum_{k=1}^{K}\sum_{t=1}^{T}(\varepsilon_k^*(t))_{[part]}^2, \qquad (13)$$

where $\varepsilon_k^*(t)$ are the values of a random variable calculated for defined by (12);

[part] (partial) are the values of a random variable calculated usin $C_{i,j\,[part]}^*$.

The method presented makes it possible to refine the parameters of the APF by solving the optimization problem, with a joint search for the coefficients of the models which makes it possible to increase the reliability of estimates when constructing the normative values of the results of the functioning of the SES subsystem.

2. Conceptual scheme and algorithm of the method realization

To find the initial values of the model parameters, the EFRA software package is used. This allows you to find coefficients and conduct a number of statistical tests justifying the possibility of using models to develop standards or forecasts, including evaluating the significance of the model (according to the Fisher criterion), evaluating the significance of model parameters (Student's criterion), checking for the absence of heteroscedasticity (according to Spearman's rank correlation coefficient).

The conceptual scheme of the method for the three-dimensional case consists of five generalized blocks (*Fig. 1*) that implement the corresponding algorithm in a software project (module) in the open source programming language Python [29].

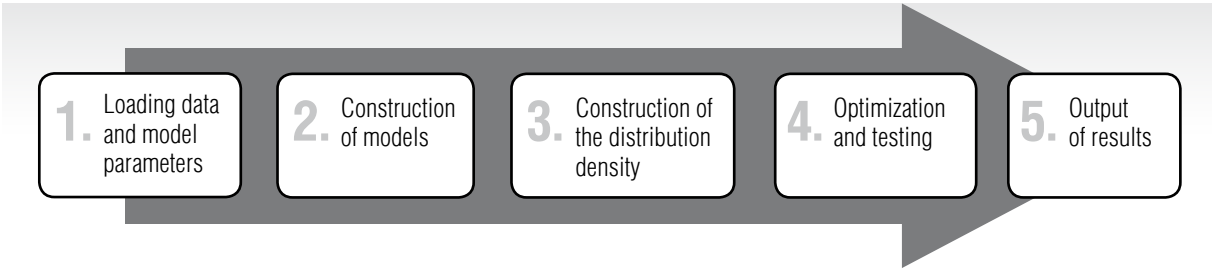


Fig. 1. Conceptual generalized scheme of the algorithm.

For the software module to work, it is necessary to connect additional Python libraries: numpy, pandas, scipy, matplotlib, opnpyxl and datetime.

Base file main.py loads additional modules and also contains the initial parameters of the models to run the corresponding blocks of the algorithm.

The first block provides loading of data and initial values of model parameters. A file has been developed for this purpose InputData.py containing the Input Data class, in which data is loaded from a specially generated statistical data file in the * format.xlsx with fields for element names, evaluation periods, and attributes. The class, like other project classes, contains the __init__() function containing data variables and the number of observations. The parameters of the initial and final evaluation period, the names of the effective and factor signs are passed to the data input function. The input parameters are sampled from the data file.

The second block provides the following functions included in the file Models.py with the Models class.

1. Formation of power multiplicative PF models according to (4) in absolute and logarithmic forms by adding the corresponding def functions to the program text with the transmitted values of the factors and coefficients of the models: def func_abs(*self, y, x1, x2, a0_3*), def func_std(*self, x1, x2, a0_3*), where *y* is the resultative feature, *x1*, *x2* are factor features, *a0_3* are coefficients of models.

2. Construction of aggregated random variables which are the residuals of the APF defined by the ratio (8) are 2 functions integr_std(s*elf, y, y_teor, m* = 3) and residuals(*self, y, y_teor*) and formula (9) is 1 function def integr_ std_y_y_teor(*self, y, y_teor, m* = 3). Here $m = 3$ is the number of transmitted variables which are resultative features; *y, y_teor* are the actual and calculated values of productive features based on PF models presented as an array for the three-dimensional case (contains three variables). The functions, in addition to the values of the aggregated random variable, return the sum of the squares of the residuals and the correlation matrix $\|r_{ij}\|$ for the case when the values of the elements $\|r_{ij}\|$ are calculated at each iteration of solving the optimization problem using a set of variable parameters of the *a0_3* model corresponding to $C_{i,j}$.

3. The function res_test(s*elf, mu, sigma, size, m* = 3) generates a set of normally distributed random variables, with mean named as *mu*, standard deviation named as sigma and volume named as size.

The third block is represented by a file DistributionDensity.py containing the DistributionDensity class, the purpose of which is to calculate the distribution density of a three–component aggregated random variable. This module contains the following functions.

1. Integrand function def UnderIntFuncti

onQuadraqticForm(s*elf, theta1, theta2, r_3, z*), which corresponds to formulas (10) and (11) with angle variables *theta1, theta2* and *z* which are values of the aggregated random variable ε^*.

2. Integrand function def UnderIntFunctionLA(*self, theta 1, theta 2, r_3, z, m* = 3), which allows converting the integrand expression in formula (7) to canonical form by calculating eigenvalues and eigenvectors of the correlation matrix $\|r_{ij}\|$. The function can be extended to the case of *m* variables by means of the built-in double sum generation cycle in (7).

3. The function Density_3var(*self, bins, r_3, t* = 1) calculates the double integral in (7) for the values of bins named as ε^*. The variable *t*, which can be equal to 0 or 1, is responsible for choosing the integrand function UnderIntFunctionQuadraqticForm or UnderIntFunctionLA.

The fourth module is represented by two files: ObjectiveFunction.py and TestFunction.py .

The first file contains the ObjectiveFunction class, designed to form the objective function objective_func_SearchParameters_3var(*a*) and a system of constraints: a) upper and lower bounds for changing parameters *a* are parameters of the aggregated production function *lb* and *ub*, the values of which are calculated using "EFRA"; b) a system of nonlinear constraints corresponding to expression (13) named as def inequality_constraint_3var(*a*). Moreover, the calculation of the right side of the inequality (13) is the separate function f01() in order to reduce the execution time of the algorithm, that is, a single calculation of f01() and transfer the result to the system of nonlinear constraints (13).

The second file contains the TestFunction class, which presents 2 testing functions: a) daf hd2(*self, res, alpha* = 0.05) checks a number of *res*(ε^*) residuals for compliance with the normal distribution law according to the criterion χ^2; b) hi2_plotn_3var(*self, res, r_3, alfa* = 0.05) checks a number of residuals (ε^*) for compliance with the law with the density of the probability distribution (7) according to the criterion χ^2. The alfa variable sets the significance level of the criterion. Splitting the sample into intervals for calculating the distribution frequencies can be done automatically or using the Sturdess formula (*n* = 1 + np.trunc(3.322 * np.log10(*n_res*))), np.trunc cuts off the fractional part, np.log10 is the decimal logarithm, *n_res* is the number of observed values ε^*.

The fifth output block is implemented through the main file main.py, in which optimization procedures, testing and plotting of frequencies ε^*, normal distribution and distribution with density as (10) are started.

The built-in minimize function from the Scipy library is used for optimization. The SLSQP (Sequential Least SQuares Programming) method is used as the basic algorithm [30]. The optimization results are output to the console and to the *.txt text file. Models with adjusted parameters are tested for compliance with the normal law and the law with the density described by formula (7), and are entered into the console.

The architecture of the project is shown in *Fig. 2.*

The necessary Python libraries are installed in the venv directory. At the same time, the project is isolated from other projects by creating its own virtual environment.

Thus, the developed Python module in combination with the EFRA software package allows is: to correct the parameters of the production functions and the aggregated production function, to test the hypothesis of the correspondence of a number of residues to the given distribution laws using the criterion χ^2 based on the method developed for estimating the parameters of the APF for the three-dimensional case.

Search Parameters	venv...
	DataImport_BD.xlsx
	DataInput.py
	DistributionDensity.py
	main.py
	Models.py
	ObjectiveFunction.py
	Results.txt
	TestFunction.py

Fig. 2. Project architecture.

3. Results of the realization of the method for estimating the parameters of a three-component APF on the example of the Central Federal District regions

3.1. Testing on model data

Initially, three normally distributed random variables $\varepsilon_i \sim N(0; 1)$ of 50, 100, 1000 and 10000 observations were generated to test the algorithm and test the hypothesis that the aggregated random variable according to (9) distribution law corresponds to the density determined by the formula (7) (*Fig. 3*).

Figure 3 shows that as the number of observations increases, the significance level for the normal law decreases, and for the law with density (7), on the contrary, it increases. At the same time, for a sample of 50 observations, the distribution of the aggregated random variable corresponds to the distribution with density (7) and is significant at the level of 0.091. That is, on samples of 50 and 100 observations, hypotheses about compliance with both the normal distribution and the distribution with density (7) cannot be rejected.

3.2. Construction of models for the SES project subsystem

In accordance with Kleiner's spatio-temporal classification, the socio-economic system includes four subsystems: object, environment, process and project type, the interaction between which forms the level of systemic balance of the economy [16]. At the same time, the project subsystem is characterized by the volume of gross regional product (GRP) according to sections F (construction), G (wholesale and retail trade), K (financial activity) according to NACE rev. 2; previously according to NACE rev. 1 sections were designated as F, G and J, respectively. In this sense, the project subsystem is three-component and can serve as an object of evaluation using the method developed.

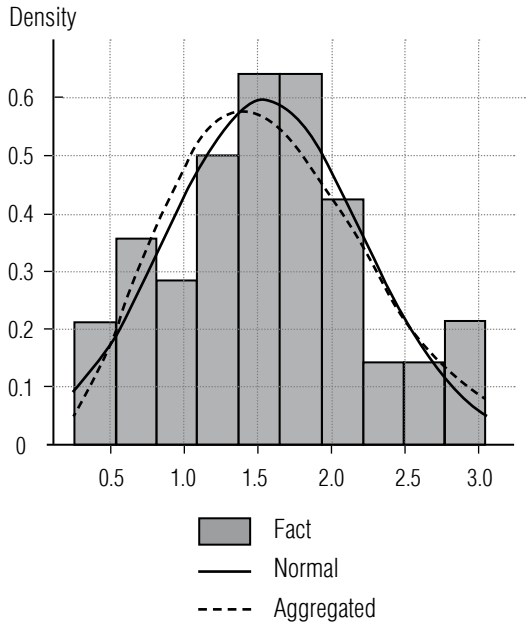
Based on previous studies [31], power-law multiplicative models were chosen as the functional form of the models, linking the volume of GDP by region in sections F(F), G(G), K(J) with the cost of fixed assets (total for section K(J), for sections F(F) and G(G)), the average annual number of employed (for sections F(F) and G(G)) and the average annual population (for section K), represented by the formula (14) and in linearized form by the formula (15):

$$\hat{y}_i = C_{i,0} \cdot x_{i,1}^{C_{i,1}} \cdot x_{i,2}^{C_{i,2}}, \quad (14)$$

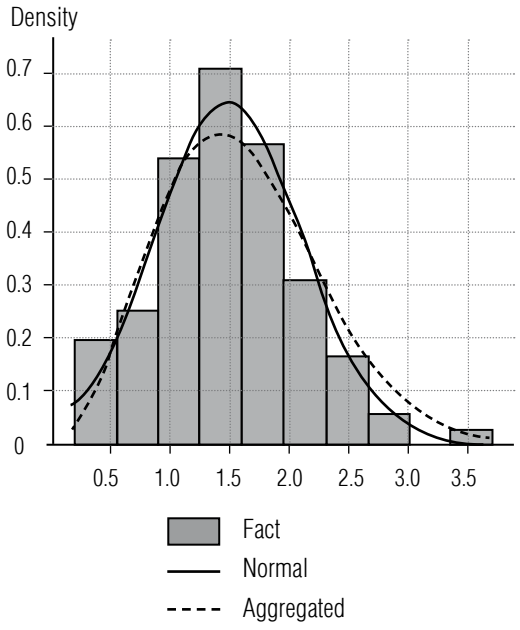
$$\ln(\hat{y}_i) = \ln(C_{i,0}) + C_{i,1} \cdot \ln(x_{i,1}) + C_{i,2} \cdot \ln(x_{i,2}). \quad (15)$$

The basis for the formation of models was Rosstat's open data for 17 regions of the Central Federal District (excluding Moscow) for the period from 2007 to 2020 [32]. All cost indicators were adjusted for the level of inflation and brought to the level of 2007 according to the formula:

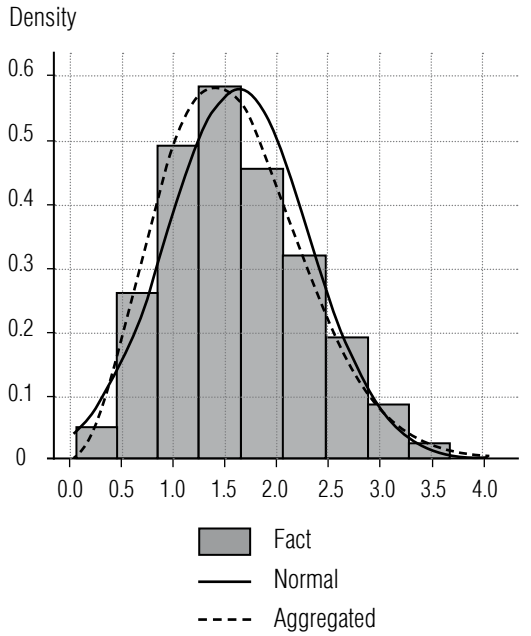
$$(\cdot)_t = (\cdot) / \prod_{i=2}^{t} (1 + \pi_i / 100). \quad (16)$$



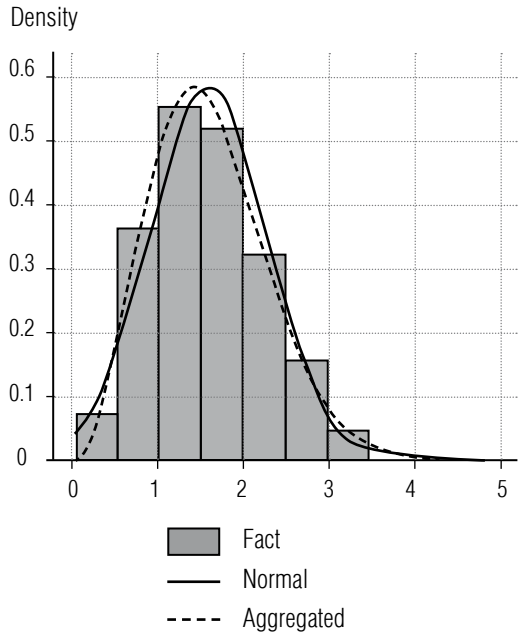
a) Residuals – 3var, p–value = 0.688 (normal law),
p–value = 0.091 (law with density (7)).



b) Residuals – 3var, p–value = 0.351 (normal law),
p–value = 0.316 (law with density (7)).



c) Residuals – 3var, p–value = 0.000 (normal law),
p–value = 0.608 (law with density (7)).



d) Residuals – 3var, p–value = 0.000 (normal law),
p–value = 0.905 (law with density (7)).

Fig. 3. Frequency diagram of the evaluation results
of a three–component random variable with $\varepsilon_i \sim N(0; 1)$ volume
a) 50 b) 100, c) 1000, d) 10000 observations;
p–value is significance level according to the criterion χ^2; number of intervals 10.

Here π_i is the inflation rate in the i-th period ($i = 2$ correspond 2008).

Preliminary results showed the significance of the coefficients of the models and the coefficient of determination R^2. However, with further testing of models and their adequacy for a number of residuals (randomness, equality of zero mathematical expectation, the presence of autocorrelation, compliance with the normal distribution law, homoscedasticity test), the sample size had to be reduced until 2018–2020 (section F(F)) and 2015–2020 (sections G(G) and K(J)). The results of the parameter evaluation are presented in *Table 1.*

Using the method presented, the parameters of APF and PF were estimated in two variants: the aggregated random variable was determined by formulas (8) and (9) with distribution density (7) and (10), likelihood function (12) and constraints (13). The volume of the combined sample for the period 2018–2020 was 51. At the same time, the algorithm by which the distribution density was calculated using eigenvalues and eigenvectors to transform the integration domain to a canonical form (the function UnderIntFunctionLA) turned out to be almost three times slower than the algorithm in which the distribution density was determined in quadratures (the function UnderIntFunctionQuadraqticForm), which led to the conclusion that it is advisable to use the Lagrange method instead of the first option when converting variables to spherical coordinates with the maximum possible analytical description of the integrand expression of the density of the distribution of an aggregated random variable.

The results of the evaluation of the models are presented in *Table 2.*

Table 1.

The main statistical characteristics of the assessed models

Model	C_0	C_1	C_2	R_2	v	rnd	M(e)	DW	W	r_{x1} / r_{x2}
F(F)	93.306	0.248	0.711	0.961	48	26/31	1.182	1.809	0.973	0.141 0.145
p–value	0.000	0.000	0.000	0.000	–	0.050	0.243	0.050	0.282	0.322 0.310
G(G)	10.365	0.415	0.838	0.961	99	47/51	1.744	1.953	0.097	0.098 0.222
p–value	0.000	0.000	0.000	0.000	–	0.050	0.084	0.050	0.027	0.326 0.025
K(J)	0.007	0.264	1.077	0.928	99	58/68	1.543	1.944	0.973	0.085 0.099
p–value	0.000	0.001	0.000	0.00	–	0.050	0.126	0.050	0.035	0.395 0.319

Note: the letter designations in the first column are the model for the NACE rev. 2; () is NACE rev. 1; p–value is the level of statistical significance; C_i are the parameters models values; R^2 is the coefficient of determination; v is degrees of freedom; rnd is critical (for the significance level of 0.05) and the estimated number of turning points (check for the randomness of a number of residuals); M(e) is t–statistics (checking the equality of 0 of the mathematical expectation of a number of residuals); DW is the Darbin–Watson criterion (checking the absence of autocorrelation of a number of residuals, significant at the specified level); W is the Shapiro–Fork criterion (checking for the normality of a number of residues); r_{xi} is t–statistics using Spearman's rank correlation coefficient of factor xi (homoscedasticity test). Residuals were constructed for linearized models.

Table 2.

The main statistical characteristics of the assessed models (aggregated estimate)

Model	C_0	C_1	C_2	R_2	v	rnd	M(e)	DW	W	r_{x1} / r_{x2}
F(F)[a]	90.101	0.253	0.708	0.960	48	26/31	1.241	1.810	0.972	0.140 0.145
p–value[a]	0.000	0.000	0.000	0.000	–	0.050	0.220	0.050	0.275	0.327 0.310
F(F)[b]	97.373	0.241	0.715	0.961	48	26/31	1.418	1.869	0.973	0.155 0.151
p–value[b]	0.000	0.000	0.000	0.000	–	0.050	0.162	0.050	0.291	0.277 0.289
G(G)[a]	11.961	0.347	0.945	0.970	99	58/57	1.847	1.979	0.969	0.125 0.317
p–value[a]	0.000	0.000	0.000	0.000	–	0.010	0.068	0.050	0.017	0.212 0.001
G(G)[b]	9.578	0.381	0.921	0.974	99	58/59	1.759	1.988	0.973	0.176 0.346
p–value[b]	0.000	0.000	0.000	0.000	–	0.050	0.082	0.050	0.037	0.077 0.000
K(J)[a]	0.008	0.283	1.035	0.927	99	58/66	1.355	1.967	0.973	0.072 0.064
p–value[a]	0.000	0.000	0.000	0.000	–	0.050	0.178	0.050	0.037	0.473 0.520
K(J)[b]	0.0245	0.181	1.085	0.900	99	58/65	0.607	1.994	0.972	0.068 0.002
p–value[b]	0.000	0.039	0.000	0.000	–	0.050	0.545	0.050	0.030	0.494 0.981

Note: a) the aggregated random variable was determined by the formula (8); b) by the formula (9).

The results of the evaluations of the models presented in *Table 2* show that the models remained adequate after adjusting their parameters, both for the first and second options.

The results of the evaluation of the aggregated random variable and the values of the likelihood function are presented in *Table 3*.

The table shows that the value of the likelihood function after optimization increased by 4.809% and 7.437%, respectively, which confirms the hypothesis of an increase in the reliability of estimates using APF with parameters adjusted after optimization. That is, the method makes it possible to establish more reasonable norms for the results of the functioning of SES subsystems, in particular for three-element subsystems. However, the reliability of estimates for the compliance of the aggregated random variable with the distribution laws under consideration decreases, although it remains significant for the case d). When using ε^*, calculated by the

Table 3.

The results of the assessment of the aggregated random variable

Characteristic / APF	ε^{*a}	ε^{*b}	ε^{*c}	ε^{*d}
$Ln(L(\varepsilon^*))$	–69.147	–66.049	–65.821	–61.136
$\Delta Ln(L(\varepsilon^*))$	–	–	3.325 (4.809%)	4.912 (7.437%)
χ^2_{norm}	10.477	16.800	10.079	39.352
$p\text{–value}_{norm}$	0.063	0.005	0.073	0.000
χ^2_{agg}	169.125	7.841	168.701	12.848
$p\text{–value}_{agg}$	0.000	0.165	0.000	0.025

Note: $Ln(L(\varepsilon^*))$ is the value of the likelihood function; $\Delta Ln(L(\varepsilon^*))$ is change of the likelihood function; χ^2_{norm} is criterion value χ^2 according to the normal law; χ^2_{agg} is criterion value χ^2 to comply with the law with the density (7); p–value (norm, agg) are statistical significant levels, respectively χ^2_{norm} and χ^2_{agg}; a) is ε^* calculated by the formula (8) before optimization; b) is ε^* calculated by the formula (9) before optimization; c) and d) are ε^* calculated by the formulae (8) and (9) after optimization, respectively.

formula (8), the aggregated random variable is closer to the normal law; when using (9) it is closer to the law with density (7). These results are consistent with the conclusions obtained earlier for a two-component aggregated random variable [25].

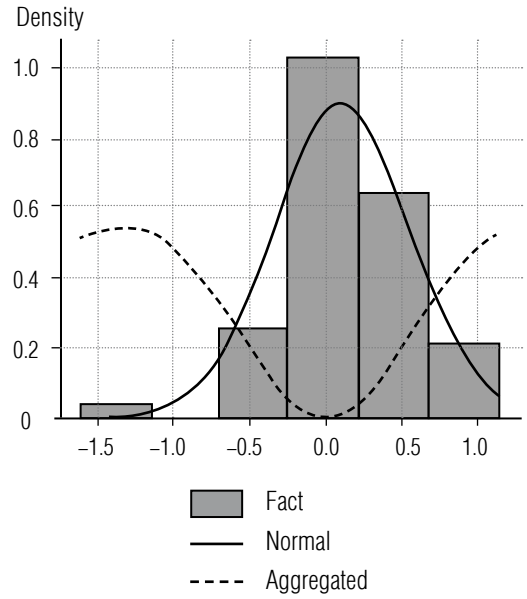
Diagrams of the aggregated random variable obtained by formulas (8) and (9) with p-value before and after optimization are shown in *Figs. 4 (a), (b), (c), (d)*, respectively.

The results of the evaluation of PF and APF parameters obtained were used to calculate the partial and integral performance indicator of the functioning of the project subsystem of the Central Federal District regions for 2018–2020 in three variants. The calculation results are presented on an external resource[1].

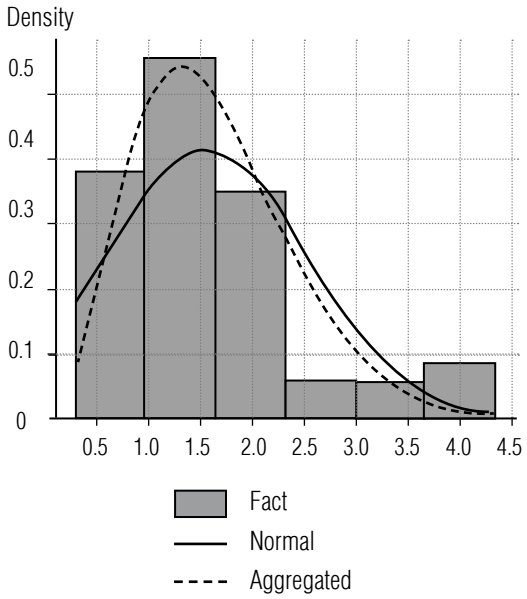
Figure 5 shows the results of the calculation of indicators for the Tula Region in 2020.

Figure 5 shows that the values of the indicators calculated for different variants are close to each other, and in the first approximation, estimates of the parameters calculated for each of the sections separately can be used to evaluate the project subsystem. If it is necessary to establish more reliable standards for the subsystem, it is advisable to adjust the parameters of the APF and PF using the distribution density of the form (9), since the likelihood function based on it is maximal among the other options.

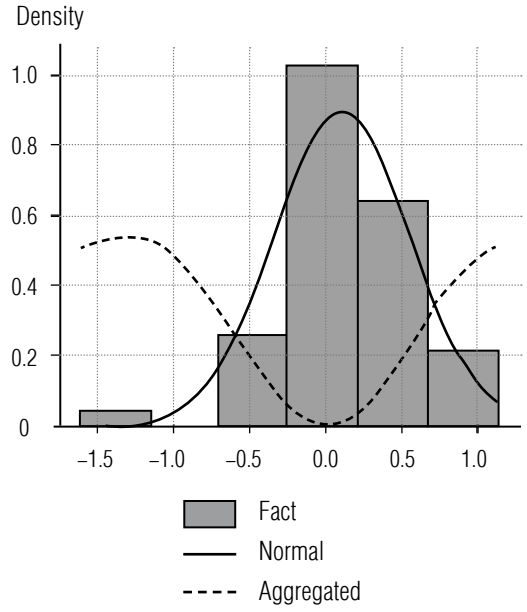
[1] The values of partial and integral performance indicators for the Central Federal District regions for 2018–2020 [Electronic resource]: https://disk.yandex.ru/i/NWOKIpcJG-sULA



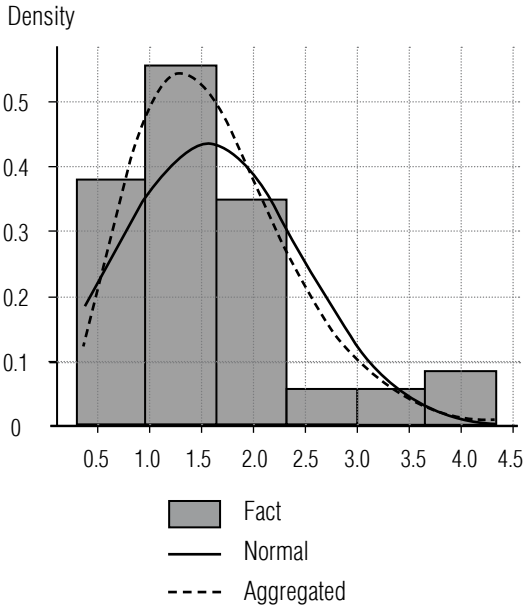
a) Residuals – 3var, p–value = 0.063 (normal law), p–value = 0.000 (law with density (7)).



b) Residuals – 3var, p–value = 0.005 (normal law), p–value = 0.165 (law with density (7)).



c) Residuals – 3var, p–value = 0.073 (normal law), p–value = 0.000 (law with density (7)).



d) Residuals – 3var, p–value = 0.000 (normal law), p–value = 0.025 (law with density (7)).

Fig. 4. Frequency diagram of the evaluation results of a three–component random variable with ε_i
a) is formula (8) before optimization, b) is formula (9) before optimization,
c) and d) are formulas (8) and (9) after optimization;
fact is histogram ε_i; Normal is normal law; Aggregated is a law with density (7);
p–value is the significance level according to the criterion χ^2;
the number of intervals is 6 (calculated by the Sturgess formula), the sample size is 51.

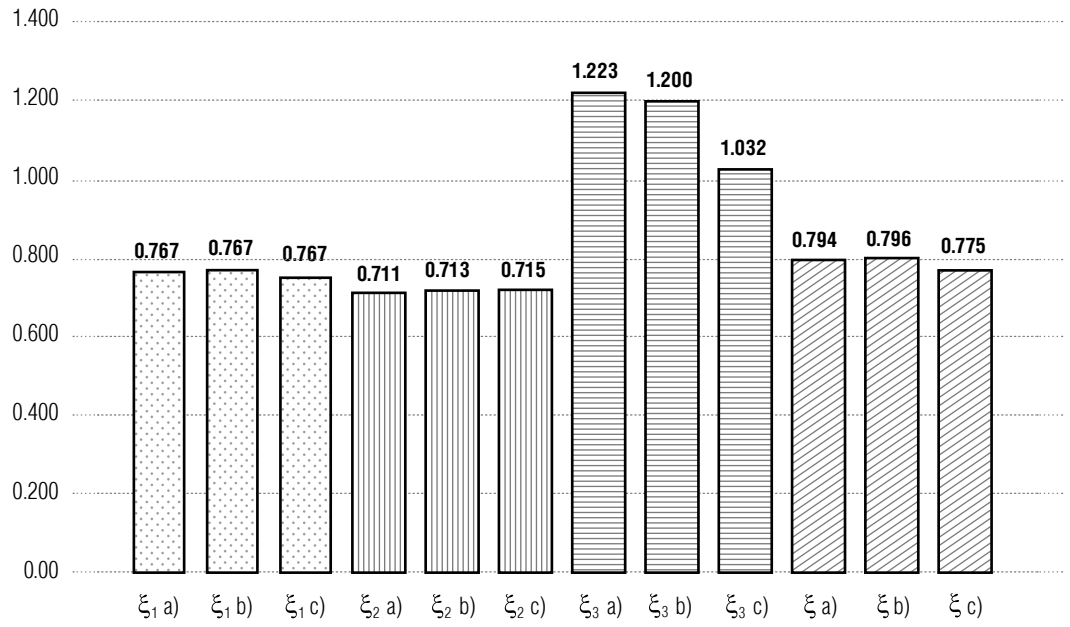


Fig. 5. The values of performance indicators for the Tula Region in 2020:
ξ_1, ξ_2, ξ_3 are partial performance indicators for sections F(F), G(G) and K(J) according to NACE rev. 2 (NACE rev. 1);
ξ is integral performance indicator of the project subsystem;
a) are PF parameters determined separately;
b) formula (8) was used to assess the parameters of APF and PF,
c) formula (9) was used.

Conclusion

This article presents a method for estimating the parameters of an aggregated production function used to calculate the standards for the results of the functioning of SES subsystems, implemented for a three-component APF. The difference of the method is the joint acquisition of the PF parameters of the SES elements, which ensures the consistency of the PF within one subsystem.

The application of the method for the regions of the Central Federal District using the developed and tested Python software project made it possible to adjust the parameters of PF and APF and obtain statistically appropriate models that can be used to build standards for elements of design subsystems and subsystems in general for the regions of the Central Federal District. This confirmed the earlier hypothesis about the possibility of using the method for three-component subsystems.

The results of the assessment of the functioning of the Central Federal District regions for 2018–2020 with the help of partial and integral indicators can be useful to regional governments for subsequent analysis and synthesis of solutions that make it possible to ensure that the actual and normative values of the resulting features correspond to a given degree of accuracy by changing and (or) intensifying the use of factors included in the models developed. ■

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Method of estimating the market cost of art objects based on the interpolation model

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Abstract

The task of assessing the market cost of an art object (AO) is relevant for artists, art dealers, collectors and museum workers, among others. Experts and appraisers who need appropriate automation tools are involved in its solution. The task is complicated by the inconsistency of the conceptual apparatus of the specialists' various fields of knowledge, the specifics of AO and the art market. Known methods for solving it, especially automated methods, are not numerous and not universal. The purpose of this study was to develop a method for automated valuation of the market value of AO, which defines it as the sum of two components: the prime cost of the AO and added cost – the cost of the asset "value of the AO." To calculate the first component, a cost–based approach and an additive model were used; the second was a comparative approach and an interpolation model. The added value of modern AO is represented by a function of the parameters of each of the four price-forming factors of AO: "the value of the artist," "the artistic value of AO," "the cultural value of AO," "the quality of the state of AO." It is proposed to implement models in the form of a software package integrated into the information systems of modern art institutions, having coordinated the data formats used.

Keywords: art object, the cost of the art object, interpolation model, spline interpolation, artistic value, cultural value

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Introduction

The development of a method for estimating market value of an art object (AO) is a complex task affecting areas of human activity, until recently, still far from each other - art (artistic, cultural values of AO) and science (mathematics, economics, qualimetry). This determined the specifics and complexity of the task.

Property valuation issues are regulated by laws and standards at the state and interstate levels. In the Russian Federation, this is the Federal Law "On Valuation Activities in the Russian Federation" and Federal Valuation Standards (FVS), for example, FVS No. 1, FVS No. 11. At the international level there are International Valuation Standards (IVS) [1–4].

FVS No. 1 offers three assessment approaches: profitable, comparative, and cost-based.

The cost approach was used by appraisers of cultural values and collectibles in a method developed by a team of authors led by Tamoikin, patented by them and proposed in 2010 as a draft of the corresponding standard [5]. This method of valuation is based on the use of the "basic value" of the collectible (the cost of materials and labor spent), which is then refined using more than two dozen coefficients determined by experts.

In addition to the cost of AO, its price is determined by "something" intangible, due to which prices for AO reach hundreds of millions of dollars [6]. An intangible "something" (an intangible asset) that largely determines the value of a joint-stock company is not only its own merits, causing, for example, an emotional response from a viewer, but also the author's name (brand) itself – an effect called "goodwill" [7, 8]. The valuation of an intangible asset is devoted to FVS No. 11 [3] and IVS 210 [4]. Obviously, when evaluating the works of artists with a name, the cost of their work can often be neglected.

In the "three asset model" [8], in addition to tangible and intangible assets, it is proposed to take into account the third asset – "value." The model itself, as the author emphasizes, "... is by no means a practical assessment tool." The paper [7] notes that the asset "value" takes into account "the level of public recognition or the significance of the collectible itself and that it is also intangible."

The market value of cultural values is determined by the corresponding price-forming factors [9]. It is necessary to form a list of price-forming factors that determine the cost of the asset "value of AO".

The art market has brought its own specifics [6, 10] to the AO pricing process: auctions and art fairs have become its main trading platforms, and collectors and branded dealers are the key figures; art objects have become symbols of status and objects of investment, and the market value of AO has become determined primarily by the artist's brand.

It was contemporary art that turned out to be at the epicenter of commercialization [10, 11]. According to a report by the French company Artprice [11], the volume of sales of contemporary art has increased by 2,100% over 20 years and reached $2 billion in 2019.

An extensive list of methods for estimating the cost of AO, considered in [12], is conditionally divided into two groups: those involving automation and others. One of the first software packages for estimating the cost of AO is Investment [7], was developed by the Fine Art Investment Group; they implemented a methodology for valuation of paintings using artists' ratings.

Artist's ratings are used by companies that form analytical reviews, including but not limited to investing in art, for example, InArt Gallery [13].

The Professional Union of Artists of the Russian Federation (PUA of RF) identified classification features and formed a rating of members of the union [14]. They determined price recommendations for AO, taking into account, among other things, the rating of the artist.

There were ideas of using new information technologies in the interests of the art market, so in [15] it is claimed that the blockchain technology will change the art market by solving the issues of transparency, copyright and authenticity of works of art using electronic AO certification [16]. A domain zone of arts ".art" has been created [17]. The creation was announced of a "Digital Twin" on its basis – "an ecosystem of various technological solutions and services in the art world" [18].

Each museum today already has its own information system (IS) [19], for example, KAMIS [20]. Standardization of data presentation formats is relevant for IS art institutions [21]. "Digital Twin" uses the standard for identification of art objects developed by the Getty Trust and accepted by UNESCO, Interpol and ICOM.

The review presented confirms the need for:

- clarification and formalization of the thesaurus of the problem area, first of all – the concepts of "market value of AO," "cultural value of AO," "artistic value of AO," "value of the artist," clarification of the composition of price-forming factors for modern AO and their parameters;
- the review presented confirms the need for an alternative to the well-known method of calculating the value of collectibles [5], using expertly assigned coefficients that refine the "base value" of AO;
- in the method of estimating the cost of AO made in various techniques, spaces and styles;
- in the implementation of the proposed method as a set of models, including an interpolation model for estimating the cost of the asset "value AO" as a function of the set of parameters of pricing factors AO;
- in the implementation of a set of models in the form of a software package and its integration with the IS of modern art institutions [16–18, 20], agreement of the data formats used [19, 21].

The purpose of this study is to develop a method that allows you to advance in the directions listed above.

1. Formation of basic concepts and definitions

We believe that market value of an AO consists of two components, "Prime Cost of AO" and value added [22]. Value added or cost asset "Value of AO" is determined by parameter values of the price-forming factors of an AO.

Unlike [7], we believe that the "value of the AO" is not limited to the significance of the AO itself and, unlike [8], we strive for a practically realizable model for assessing the market value of the AO; therefore, the "intangible asset" is not separated into an independent asset from the "value of the AO". Article 5 of the Law No. 4804-1 of the Russian Federation of April 15, 1993 "On the export and import of cultural values" [23] states that "cultural values are movable objects of the material world,

regardless of the time of their creation, having historical, artistic, scientific or cultural significance." Therefore, it is logical to attribute the "private" values of the AO to the price-forming factors of modern AO, namely: artistic and cultural. The concept of "cultural value" has two applications. If we are talking about AO as a collectible or exported "cultural value," then we are talking about "cultural property" with a certain value [24]. The second application of the term "cultural value" is considered as a characteristic of the AO itself, used as one of the four price-forming factors of the AO that determine the cost of the "asset value of the AO." The second factor is the "artistic value of AO. The third – is "the quality of the state of AO" at the time of sale. The fourth in a row, but perhaps the first in importance – the "value of the artist" - determines the level of recognition of his art market or otherwise – the status (brand) of the author of the AO. Each of the four price-forming factors $f = \{1, ..., 4\}$ is not directly measured, but is determined by the corresponding subset of measured parameters (P_f).

This corresponds to the essence of factor analysis "... to concentrate the initial information, expressing a large number of considered features through a smaller number of more capacious internal characteristics of the phenomenon (factors), which, however, cannot be directly measured" [25].

The union of P_f subsets forms the set P of all parameters of the price-forming factors of AO:

$$P = Pv_oa \cup Pav \cup Pcv \cup Pcq, \quad (1)$$

where subsets of parameters correspond the following price – forming factors:

Pv_oa – "the value of the artist" (v_oa);

Pav – "artistic value AO";

Pcv – "cultural value AO";

Pcq – "condition quality AO".

2. The formalization of the task

The expression for calculating the Cost of the i-th AO (Cao_i) has the following form:

$$Cao_i(P \cup Ppc) = PCao_i(Ppc) + CAVao_i(P). \quad (2)$$

At the same time, $PCao_i$ – is the Prime Cost of AO, calculated using the cost approach as an additive function on a subset of Ppc parameters that determine the prime cost of AO (quantity and cost of materials, etc.), i.e.

$$PCao_i\left(Ppc\right) = \sum\nolimits_{j \in P_{pc}} C_j \cdot Q_{ij}, \quad (3)$$

where C_j is the unit price of the j-th resource, and Q_{ij} is its quantity used to create the i-th AO;

$CAVao_i(P)$- is the Cost of the Asset "Value of AO", defined as a function using a comparative approach and a multidimensional spline interpolation model [26] on the set of parameters P.

Spline interpolation is used in various fields, from medicine [27] to geology [28]. The authors have previously successfully tested the algorithms and programs given in [26] for valuation of the software quality [29]; they are proposed also for calculating the $CAVao_i(P)$ function.

The parameters of the set P in relation to AO (paintings by contemporary artists) are given in *Table 1* ($n\left|P\right| = 21$). For the desired AO, the cost of which is being determined, analogues are selected that form the set A (the procedure for selecting analogues is considered below). If the number of analogues $m = n\left|A\right|$, and $(m+1)$ is the desired AO, then its cost is equal to

$$Cao_{m+1}(P \cup Ppc) = \\ = PCao_{m+1}(Ppc) + CAVao_{m+1}(P). \quad (4)$$

In this case, $CAVao_{m+1}(P)$ is the result of interpolation by a multidimensional spline S:

$$CAVao_{m+1}(P) = S^{B_m}_{B'_{m+1}}, \quad (5)$$

which has a T-dimensional (in our case T = 21, according to the number of parameters of the price–forming factors AO) grid (t_1, ..., t_{21}) with m + 1 nodes, where B_m is the set of coordinates (values of the parameters of the AO-analogs) for m nodes and their values $CAVao_i(P)$ (i = 1, ..., m), B'_{m+1} – the set of values of the parameters of the estimated AO, i.e. the coordinates of the corresponding node on the spline, the value of which is $CAVao_{m+1}(P)$ and is the desired one.

The parameters can be both quantitative and qualitative. Qualitative parameters in the model are represented by rank variables that take quantitative relative values. For example, the values of the parameter: "very low," "low," "medium," and "high" are translated into the values of a rank (discrete) variable with the values 0.25, 0.5, 0.75, 1 [30].

A spline with discrete variables is a special case of the spline described in [26] and used, in particular, in [30].

The decision to use the spline interpolation method was made based on several factors, specifically the algorithm's simplicity and good convergence properties of approximation processes. In addition, splines are convenient for approximate description of processes that do not have a regular smoothness property [31]. Finally, the integral and the derivative of the spline are again a spline of greater or lesser dimension, which makes it possible to perform predictive and analytical actions with it regarding trends in estimates. In the future, this will allow us to give the complex new – predictive qualities [32].

3. Conditions for the formation and use of the basic software package

In accordance with (2), the software package for estimating the cost of an AO includes two models, respectively: *PCao*(*Ppc*) and *CAVaoi*(*P*). The latter uses analogues of the estimated AO. Therefore, the concept of "class AO" is introduced. To determine the features of the "class AO," the following classification features of the "Unified Art Rating of the PUA RF" are used [14]: the level and category of the artist, which determine, respectively, the professionalism and level of the artist's works; the style of the AO created by him (A – avant-garde, B – "focused on established traditions," etc.); the dimension of the space in which the artist works; the type of artistic technique used by him.

Add the attribute – price range AO. The six AO price ranges are allocated (in US dollars):
1) more than 20 000, 2) 10 000–20 000,
3) 5000–10 000, 4) 3000–5000,
5) 1000–3000, 6) less than 1000.

To test the method and models, a "basic complex" is used, the database (DB) of which contains information about the AO of the following class: paintings by modern professional Russian artists, the rating level of which is from two to six; two-dimensional; technique – easel painting; worth up to $ 20 000.

The database of the complex is formed on the basis of the works of artists of the Russian Federation implemented by the gallery "Kult-Proekt" [33] and data on sales of paintings from open sources, for example, [11]. *Table 2* shows an example of a fragment of such a database. The second line of *Table 2* contains information about the painting being evaluated: Ch (the first letters of its name), TA (the first letters of the last name and first name of the artist). An artist of the second level in the rating of the PUA RF, style of works – avant-garde (A), a two–dimensional painting, easel painting with a relative area of 2.24 (the area of the painting S divided by 2500 (2500 cm^2 is the base area of the painting according to [14])).

Accordingly, analogues are selected – this is the AO of its class: paintings by artists of the second rating level, two-dimensional, with technique – easel painting, the area of which differs from the area of the estimated painting by ± 1 base area, and the price of sales to $20 000.

Table 1.

Parameters of price-forming factors AO

№	Parameters	Parameter valuation type
	Parameters of the artist's value, Pv_oa	
1	The level of the artist according to the rating of the PUA RF	Integer (1–10)
2	The number of art unions of which the artist is a member: 1– regional, 2 – and the Russian Federation, 3 – and international	Integer (1–3)
3	Number of titles, prizes, and awards of the artist	Integer
4	Of these, international	Integer
5	The number of the artist's works in the collections of museums, famous galleries or collectors	Integer
6	Of these, international	Integer
7	Number of solo exhibitions	Integer
8	Of them in status institutions	Integer
9	Of these, international	Integer
	Parameters of cultural value of the painting, *Pcv*	
10	Has been in the collections of: museums, status galleries or collectors (number of times)	Integer
11	Of these, international	Integer
12	Participated in status projects (exhibitions, competitions) (number of times)	Integer
13	Of these, international	Integer
14	The author is recognized as a laureate or diploma holder of status projects (number of times)	Integer
15	Of these, international	Integer
	Parameters of the artistic value of the painting, *Pav*	
16	Novelty of the artist's vision (absent 0; elements of originality – 0.25; mostly original – 0.5; original – 0.75; paradoxical – 1)	One of the values: 0.25, 0.5, 0.75, 1

№	Parameters	Parameter valuation type
17	Originality of content – ideas (absent; elements present; mostly original; original)	One of the values: 0.25, 0.5, 0.75, 1
18	The originality of the form (composition, coloristic solution, chiaroscuro solution, geometry of lines and spots, texture of the paint layer). The assessment is made for each element measured in relative units 0, 0.25, 0.5, 0.75, 1. The total score is summed up. (Minimum – 0, maximum – 5).	Numbers varying in the range from 0 to 5 in increments of 0.25
19	The originality of this work among other works of the artist (absent, there are elements; mostly original; original)	One of the values: 0.25, 0.5, 0.75, 1
20	Professionalism of painting execution (low, medium, high, very high)	One of the values: 0.25, 0.5, 0.75, 1
Picture condition quality parameters, *Pcq*		
21	Quality and condition: the basics of painting, paints, stretcher. The assessment is made for each element measured by relative values 0, 0.25, 0.5, 0.75, 1. The total score is summed up (minimum – 0, maximum – 3)	Numbers varying in the range from 0 to 3 in increments of 0.25

Table 2.

Selection of AO-analogues

Artist	PUA RF level	The name of the painting	Relative area	Price, USD
SA	2A	Bve	2.89	16284
TA	2A	Ch	2.24	*
TA	2A	M	1.40	1316
PN	2A	Lx	1.68	750
PN	2A	K	1.40	680
ZhN	2A	Le	1.92	900
ZhN	2A	ZmV	3.20	2100
RI	2B	VtP	1.40	1700
RI	2B	Lg	1.40	1400

* The price of this AO is the desired one

Table 3.

Estimates of parameters of price-forming factors AO

No	Ch, TA	Bve, SA	Lx, PN	Lg, RI
		$Pv_o a$		
1	2	2	2	2
2	1	2	2	1
3	0	7	1	1
4	0	3	0	1
5	0	24	0	0
6	0	11	0	7
7	27	24	7	0
8	8	7	3	4
9	10	6	3	0
		Pcv		
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0
14	0	0	1	0
15	0	0	1	0
		Pav		
16	0.75	1	0.75	0.25
17	0	0.75	0	0
18	2	3	3	0
19	0.75	0	0.50	0
20	1	1	1	1
		Pcq		
21	3	3	3	3

Table 3 shows the values of all parameters for the estimated AO (paintings by Ch, artist TA) and AO analogues (paintings by Bve, Lx and Lg artists SA, PN and RI, respectively) (*Table 1*).

Due to the similarity of the values of the parameters (the level of the artist, size, technique) of the evaluated painting and its analogues, it can be assumed that the prime cost of their creation is approximately the same, and the difference in price is determined by *CAVao*. Therefore, *Table 2* shows the price of their sale directly, and according to the results of spline interpolation, we get the value of the desired AO (paintings by the artist) equal to $ 2540.

Of course, when it comes to estimating AO like Hirst's "Diamond Skull," then the assumption of equality of the prime cost of analogues will be unacceptable.

The appraiser works directly with the complex, among other things, entering into the database a complex of estimates of the AO parameters provided by the corresponding experts. The undoubted advantage of the complex can be the functionality that will allow the presentation of the photo of the assessed JSC and complete information (provenance, etc.) on its analogues, which will allow us to demonstrate to the buyer the "reasonableness of the price" [6] of the AO.

4. Directions of development of the basic software package

The complex is built on the principles of modular organization and consistent expansion of functionality. Directions of development of the basic complex:

- expanding the range of classes of assessed AO, increasing the accuracy of the assessment, both by increasing the number of AO-analogues in it database, and expanding (clarifying) the list of price-forming factors and/or their parameters;
- specialization for specific art institutions: auction houses (AO estimate definition [6]), art fairs, branded dealer using additional price-forming factors and/or AO valuation parameters or their own experts;
- the use of AO in the secondary market, which requires a corresponding expansion of functionality through the development of extrapolation models, additional consideration of the price-forming factor "historical value of AO," the dynamics of art prices;
- consideration of the task of assessing the market value of AO as part of a complex task – creating an "ecosystem of various technological solutions and services in the art world" [18], i.e. integrating the proposed complex with the information systems of modern art institutions [16, 18, 20];
- coordination of data formats with the IS standards of art institutions [19, 21], including in them the information used to estimate the value of AO.

Conclusion

A method is proposed for estimating the market value of AO as the sum of two components: the prime cost of AO and the added cost – the cost of the asset "value of AO." To evaluate the first component, a cost-based approach and an additive calculation model were used; the second is a comparative approach and a spline interpolation model. The thesaurus of the problem area has been clarified. The price-forming factors that determine the value of modern AO are highlighted: "the value of the artist," "the cultural value of AO," "the artistic value of AO," "the quality of the state of AO." For each of them, subsets of the parameters defining them are formed estimated by experts for the desired AO and its analogues. The obtained estimates and the sales price of analogues are used to construct an interpolation spline – a tool for calculating the value added of the estimated AO.

The method is universal. It is applicable for valuation of the AO of different levels of artistic and/or cultural value created by artists of different professional levels working in various styles and techniques, up to digital art, which is achieved by the openness of models to corresponding changes in the composition of pricing factors and/or their parameters. An example of using the method is given.

Mathematical models are implemented programmatically. An example of initial data for the basic software package and the directions of its development are presented. The implementation options of the complex can take into account the spe-cifics of various users or art institutions and can be integrated with their information systems.

Special mathematical knowledge from the users of the complex will not be required. ■

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Quality of strategic management under ambiguity: Assessment within the framework of sustainable development*

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Abstract

Amidst a high and increasing level of ambiguity, the quality of strategic management when ensuring the achievement by an enterprise of a sustainable development trajectory becomes particularly important. The issues of formation and efficient implementation of the strategic management mechanism bring into focus the task of finding tools for assessing the quality of strategic management. Meanwhile, the agenda of developing the tools to assess the quality of strategic management of an enterprise from the standpoint of achieving a sustainable development trajectory under ambiguity remains poorly understood. In this regard, the purpose of this study is to improve the quality of strategic management of industrial enterprises operating under uncertainty by developing and testing on the example of individual enterprises of the Donetsk region a toolkit for assessing the quality of strategic management in the context of an enterprise achieving a sustainable development trajectory. To reach this goal, this study uses a synthesis of systemic, cybernetic and synergetic approaches. For this purpose, within the framework of the study, a conceptualization of the main notions was carried out and theoretical and methodological approaches to the interpretation of the notions of "strategic management," "sustainable development" and "strategic uncertainty" were proposed. Based on the author's approaches to the interpretation of the main notions, it was suggested to assess the quality of strategic management in terms of the goal of such management, which is to achieve a sustainable development trajectory. Using the author's approach, an assessment was made of the quality of strategic management of industrial enterprises in the Donetsk region in the context of their achievement of sustainable development. Approbation of the proposed tools led to the conclusion that the integral

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assessment indicator for all analyzed enterprises did not have an unambiguous and unidirectional downward trend. The foregoing indicates the absence of a stable trend towards the attractor for the analyzed period for all the enterprises in question, which makes highly topical the search for reserves to increase the efficiency of strategic management of industrial enterprises in the Donetsk region, which constitute the prospect for further research.

Keywords: strategic management, ambiguity, uncertainty, sustainable development, assessment, attractor, bifurcation point, industrial enterprise

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Introduction

The non-linear character naturally inherent in most economic processes, together with the randomness, multifactorial nature and complexity of the system of interconnections and interdependencies of ongoing processes and phenomena, along with the scarcity and a high rate of obsolescence of information about them, allow us to speak of a high degree of uncertainty in the functioning of today's socio-economic systems as a global trend.

Meanwhile, the specific conditions for the functioning and management of industrial enterprises in the Donetsk region, associated with an unstable military and political situation, economic blockade, unrecognized status, rupture of economic ties with stakeholders, significant institutional changes, predetermine the formation of trends that provoke a significant increase in uncertainty.

In such conditions, while uncertainty is "an integral part of business" [1, p. 405] all over the world, in the specific conditions of functioning of industrial enterprises of the Donetsk region, it reaches an exceptionally high level. At the same time, these trends, in addition to increasing uncertainty, provoke a reduction in the adaptability of the enterprise strategic management systems by reducing the diversity of their tools.

The foregoing allows us to conclude that there is a specifically high level of uncertainty in the functioning of industrial enterprises in the Donetsk region, all of which significantly complicates the processes of strategic management and strategic decision-making, rendering the issues of assessing the quality of such management highly topical.

Considering the issues of assessing the quality of strategic management in the context of achieving sustainable development, the issues of determining a set of key indicators for such an assessment are of interest and debatable. Moreover, the assessment of the quality of management, in our opinion, should be made from the point of view of the goal of such management, which is to achieve a sustainable development trajectory.

In this regard, the analysis of approaches to assessing the achievement of sustainable development by the system is of interest. It is appropriate to mention that a significant part of the studies devoted to assessing the degree to which a system achieves a sustainable development trajectory [2–9] consider sustainable development at the macro- or meso- level and interpret it as a balance of economic, environmental and social components, transferring the assessment of achieving sustainable development into an assessment of the balance of these components. This approach does not correlate

with the author's interpretation of the term "sustainable development" and is not suitable for assessing the achievement of a sustainable development trajectory at the level of individual enterprises.

A number of researchers [10–14] project the approach described above to the micro level, evaluating the economic, environmental and social components of an enterprise's sustainable development. In our opinion, such an assessment illustrates to a greater extent the impact of the operation of the enterprise on the development of the region, rather than reflects the quality of enterprise's management through the prism of achieving its own strategic goals.

A number of researchers offer a more extensive list of components for assessing the sustainable development of an enterprise. Thus, the authors of [15] suggest highlighting the information component, along with the social, environmental and economic components. The study [16] proposes to expand the list of components for achieving sustainable development trends to the following set: financial, technological, production, organizational, marketing, innovation, investment, social, environmental.

The author of another study [17], suggests expanding the list of components to the following four indicator groups: social, environmental, economic, risk-related. However, it seems possible to conduct a risk analysis for each of these indicator groups. In addition, it is more expedient to present risk analysis as a separate stage of the enterprise's sustainable development management mechanism, and not as an additional component, including it in the assessment stage along with the economic, social and environmental components.

The study [18] suggests a radically different method. Its author affirms that the assessment of the sustainable development of an enterprise can be made "through three main characteristics: the presence of completed innovations; the degree of participation in the organization of the development of these innovations; identifying the main reasons why innovation activities were not carried out" [18]. At the same time, the justification for assessing sustainable development solely through the prism of the innovation component is questionable. Thus, the introduction of innovations, of course, can lead to qualitative and quantitative changes in the structure and/or trajectory of the system's behavior which transfer the system from the point of strategic equilibrium to the point of bifurcation, allowing the system to move to a higher level of organization, to increase the efficiency of its functioning, to increase potential and competitive advantages and, as a result, to achieve strategic goals of a higher level. Meanwhile, the introduction of innovations is associated with high risk, which does not guarantee a transition to a stable trajectory at the bifurcation point. The implementation of these risks can initiate a transition to the goals of a lower level and a lower order of system organization. In addition, innovations are not the only factor capable of moving the system from a strategic equilibrium point to a bifurcation point.

A somewhat more extensive list of components is offered in the study of Trubitskoy and Borodulya [19]. These authors suggest that we evaluate the sustainable development of an enterprise as per four components: financial, marketing, production, and innovative sustainability. Having in mind that the authors equate the concepts of "sustainability" and "sustainable development," we point out that the above set of indicators considers sustainable development/sustainability in statics, and not in dynamics, and the suggested assessment methodology does not imply the presence of an object and/or a scale for comparative analysis.

Source [16] mentions that "speaking about the stability of an organization, one cannot

but talk about the stability of the processes taking place in it" [16]. The authors of the study also provide key characteristics of sustainable processes: rhythmicity, flexibility, parallelism, elasticity and continuity. While agreeing with the need to take into account the stability of processes, we note that the above list is not exhaustive.

In summary, we'd like to point out that the wide coverage in the scientific literature of the issues of determining a set of key indicators for assessing the degree of achievement of a sustainable development trajectory did not result in the formation of a unified approach to identifying the components of such an assessment and, moreover, to identifying a set of key indicators.

In this regard, the purpose of the study is to improve the quality of strategic management of industrial enterprises operating under ambiguity by developing and testing on the example of individual enterprises of the Donetsk region a toolkit for assessing the quality of strategic management in the context of an enterprise achieving a sustainable development trajectory.

1. Conceptualization of the notions of "sustainable development" and "strategic uncertainty" in the context of the strategic management of industrial enterprises

The goal set requires clarification of the categorical apparatus of the study.

A number of works of domestic and foreign researchers are devoted to the issues of improving the categorical apparatus by interpreting the definition of "strategic management". The systematization and identification of limitations in the application of these approaches from the point of view of strategic management under ambiguity in the context of achieving the trajectory of sustainable development given by the author in [20] made it possible to form a theoretical and methodological approach to the interpretation of the notion of "strategic management." Thus, by strategic management we mean proactive management of an enterprise based on the implementation of its strategy by creating competitive advantages through a flexible response and adaptation to environmental challenges, focusing the activities on consumer needs, as well as taking on the human capital as the basis for the formation of competitive advantages aimed at achieving a sustainable development trajectory.

Postulating the achievement of the trajectory of sustainable development as the main goal of strategic management under ambiguity, the issues of conceptualization of this notion become relevant.

Taking into account the diversity of approaches given in the scientific literature to the definition of the notion of sustainable development discussed earlier in [21], it seems appropriate to generalize them and to form a unified approach to the interpretation of the notion of sustainable development from the point of view of strategic management under ambiguity. Thus, within the framework of strategic management under ambiguity, by sustainable development of an enterprise we mean a controlled transformation process that characterizes qualitative and quantitative changes in the structure and/or trajectory of the behavior of the system and/or the external environment of functioning, arising from a violation of stability caused by high dynamism and amplitude of external disturbances, as well as the uncertainty of the external environment of functioning, transferring the system from the point of strategic equilibrium. It is characterized by the correspondence of strategic goals and results, to the point of bifurcation, which allows the system moving to a higher level of organization, increasing the efficiency of its functioning, growing potential and competitive advantages and, as a result, achieving strategic goals of a higher level.

Focusing on the high and growing level of uncertainty that is permanently inherent in the external and internal environment of enterprises in the Donetsk region, which has a significant impact on the process and efficiency of strategic management, we point out that ignoring it in the process of forming strategic management tools seems counterproductive.

At the same time, we see the presence of cardinal differences in the approaches to the definition of this notion reflected in the literature. In this regard, the issues of formation of the author's theoretical and methodological approach to the interpretation of the notion of "strategic uncertainty" are being updated. By this, we mean the strategic uncertainty as a situation in which the current state of knowledge is such that the order or nature of things is unknown, the consequences, degree or level of circumstances, conditions or events are unpredictable, and reliable probabilities of the possible outcomes of the implementation of strategic decisions cannot be determined whereby the implementation of proactive strategies can lead to potential benefits.

2. Formation of an approach to assessing the quality of strategic management within the framework of an industrial enterprise achieving a sustainable development trajectory under ambiguity

An analysis of approaches to assessing the quality of strategic management of enterprises within the framework of their achievement of a sustainable development trajectory made it possible to identify their common features, given by the author in [22], which impede their efficient application in the process of strategic management of an enterprise operating in conditions of uncertainty.

In this regard, a set of requirements was formed and a scientific and methodological approach was proposed to assess the quality of strategic management within the framework of an enterprise's achieving sustainable development under uncertainty, which is a formalized process consisting of eight consecutive stages [22].

Note that the approach proposed in [22] is focused on the goals of supporting managerial decision-making in the process of strategic management within the framework of achieving a sustainable development under uncertainty and can be used with a proactive approach to management. The task of this study is not to assess the management decisions made in response to the predicted change in the parameters of the external and/or internal environment, but to assess the retrospective. Thus, the requirements for the approach used for the retrospective assessment of the quality of strategic management are significantly lower, which allows us to simplify this approach to the following steps:

1. Statement of previously defined strategic goals in the form of a set of parameters, their ranks and weight coefficients of significance of the target parameters of sustainable development;

2. Defining the attractor as an "ideal" point corresponding to the above set of parameters;

3. Collection of actual parameter values (from analysis of the enterprise reporting data);

4. Determining the distance to the "ideal" point for each of the target parameters in relative terms;

5. Integral assessment of the degree of achievement of sustainable development;

6. Assessment of the trajectory of the system in the context of achieving sustainable development.

The approach is based on the author's methodology for assessing the degree of achievement of each of the strategic goals set for the sustainable development of an enterprise under uncertainty, presented as a definition of the "distance" to achieve such a goal. This makes

it possible to calculate the integral assessment of the degree of achievement of sustainable development of an enterprise as a percentage of the remoteness of the coordinates of the system's current position in an *m*-dimensional phase space from the "ideal" point. In terms of synergetics, a set of internal and external conditions that contribute to the "choice" by the system of one of the options for sustainable development in the process of adaptation; the ideal final state to which the system tends in its development is called the attractor [23, p. 29]. In other words, the attractors are evolutionary goals at the appropriate level which all systems strive for under the influence of time-varying factors [24, p. 22].

Considering the quality of strategic management through the prism of the concept of sustainable development, we note that the interpretation of sustainable development in accordance with the author's definition (see above) indicates the following important aspects:

- sustainable development is a dynamic transformational process which actualizes the analysis not of static indicators, but of the trajectory of movement;
- sustainable development arises as a result of a violation of stability, i.e. keeping the system's parameters unchanged indicates the absence of sustainable development;
- sustainable development is associated with a violation of the strategic balance, i.e. it arises as a result of a discrepancy between the strategic goals and the results and is a process of moving from current results to strategic goals, overcoming the specified gap. Meanwhile, the achievement of the goals set presupposes the formation of strategic goals of a higher level. Thus, a system characterized by sustainable development is permanently in a "non-ideal" state;
- transition to the strategic goals of a higher level is made at the bifurcation point. The bifurcation points may involve branching not only to stable, but also to unstable trajectories, as well as to determine the transition to goals of a lower level and a lower order of organization of systems, which does not correspond to the concept of sustainable development.

Thus, the attractor, which is the "point of attraction" of the trajectories located in its vicinity, can be identified with the "ideal" point under the condition of a stable development of the system. Under such conditions, the system's trajectory will be in a constant motion in the direction of the target parameters, which are the attractor. It should be noted that the identification of the attractor with an "ideal" point corresponding to the target parameters of the system is expedient and becomes possible, in our opinion, only if it is considered through the prism of the concept of sustainable development.

A detailed description of the methodology for assessing the quality of strategic management within the framework of achieving sustainable development of an enterprise is given in [22].

3. An assessment of the quality of strategic management of industrial enterprises of the Donetsk region within the framework of their achievement of sustainable development

Based on the orientation of the approach to assessing the quality of strategic management of individual enterprises operating in conditions of uncertainty, its application to assess the quality of strategic management of industrial enterprises in the Donetsk region involves assessing individual enterprises in the industrial sector.

Setting the task of identifying common patterns and the general level of efficiency of the strategic management of industrial enterprises

in the context of their achievement of sustainable development, it seems appropriate to analyze the enterprises that have significant differences in such characteristics as: industry, legal form, type and range of products made, sales market, distance from suppliers of raw materials, the size of the enterprise, etc. In this regard, the following industrial enterprises of the Donetsk region were selected for analysis: Research and Production Association Yasinovataya Machine – Building Plant LLC (YMZ), "Milk River" Makeyevka Baby Food Plant Commercial Enterprise ("Milk River") and the Skochinsky Coal Mine, a standalone subdivision under the Donetsk Coal Energy Company State Enterprise (the Skochinsky Coal Mine).

YMZ is one of the largest CIS manufacturers of mining equipment for coal mines, underground mines (uranium ores, potash, diamond-bearing among others), equipment for the construction of tunnels for railway transport, subways and highways [25].

The strategic goals of YMZ are defined and lie in the plane of reducing the share of coal mining enterprises in the overall structure of clientele and the overall growth in production and sales of the company's products.

The strategic goal associated with a decrease in the share of coal mining enterprises in the overall structure of the clientele of the plant's products is due to the low level of solvent demand of coal mining enterprises in the Donetsk region and, as a result, an increase in receivables. Thus, the strategic goal of reducing the share of coal mining enterprises, postulated by the enterprise management system, is, to a greater extent, a tool for reducing the level of receivables.

The strategic goal associated with increasing the volume of production and sales of the plant's products is due not only to the desire to increase the financial result, but also to the incomplete utilization of production capacities (the average annual utilization of production capacities was less than 64%), as well as the need to ensure the rhythm of production, the absence of downtime.

Thus, the set of parameters for assessing the degree of achievement of strategic goals can be reduced to the following: the share of sales of goods and services for coal mining enterprises in the total volume of sales of goods and services; the level of receivables; volume of production and sale of goods and services in general; financial result of the activities; work level of production capacity.

Despite the certainty of strategic goals and the set of parameters for their regulation in YMZ, the ranking and selection of the highest priority goals was not made. As a result, the weighting coefficients of indicators were not determined either at the stage of setting the strategic goals. This actualizes the issues of determining weight coefficients at the stage of assessing the quality of strategic management.

Determination of weight coefficients was made using the method of expert assessments. A survey form is shown in *Table 1*, the survey was conducted using the method of direct scoring on a scale from 0 to 10. The choice of the method is due to its simplicity and saving the time of experts, who were the top managers of YMZ.

Using the method of expert assessments allows us to assess the concurrence of the managers as to the priority of strategic goals. For this purpose, the concordance coefficient [26] is used:

$$W = \frac{12\sum_{j=1}^{m} d_j^2}{n^2 \cdot \left(m^3 - m\right) - n \cdot \sum_{i=1}^{n} T_i}, \quad (1)$$

$$d_j = S_j - \overline{S}, \quad (2)$$

$$\overline{S} = \frac{1}{m}\sum_{j=1}^{m} S_j, \quad (3)$$

$$T_i = \sum_{l=1}^{k}\left(t_{li}^3 - t_{li}\right), \quad (4)$$

Table 1.

Survey Form

No.	Strategic goals set by the management of YMZ	Indicator for assessing the degree of achievement of the strategic goal	Assessment of the indicator's significance (on a 10-point scale *)
1	Reduction in the share of coal mining enterprises in the overall structure of clientele of the plant's products	The share of sales of goods and services for coal mining enterprises in the total volume of sales of goods and services	
2	Reducing the level of receivables	Level of receivables	
3	Increasing the volume of production and sales of the company's products	Volume of production of goods and services Volume of sales of goods and services	
4	Increasing the profit of the enterprise	Financial result of the activities	
5	Increasing the work level of production capacity	Work level of production capacity	

* 0 – the indicator is absolutely not significant;
10 – the significance of the indicator in terms of assessing the degree of achievement of the strategic goals of the enterprise is maximum.

where W – the concordance coefficient;

d_j – the deviation of the sum of the ranks of the estimates received by the j-th element from the arithmetic mean of the sums of the ranks of the estimates received by all elements;

m – the number of elements to evaluate;

n – the number of experts conducting the assessment;

i – the numerical order of the expert;

j – the numerical order of the element being evaluated;

T_i – related (equal) ranks of assessments assigned by the i-th expert.

l – the index of the group of equal ranks ($l = 1, ..., k$);

t_l – the number of equal ranks in the l-th group;

$\overline{S}$ – the arithmetic mean of the sums of the ranks of the estimates obtained by all elements;

S_j – the sum of the ranks of the estimates obtained by the j-th element.

Despite the high concurrence of experts' opinions assessed using the concordance coefficient, we note the non-identity of their assessments, which indicates the presence of ambiguous interpretations of the degree of significance and priority of achieving certain goals. In this situation, there may be a mismatch between the actions of the managers which will lead to a general decrease in the quality of strategic management. The above serves to confirm the author's point about the need to rank goals and to determine weighting factors at the stage of formulating strategic goals.

The final weight coefficients obtained as a result of interpreting the estimates obtained by averaging expert judgments are shown in *Table 2.*

Table 2.

Determination of the significance of the target parameters of sustainable development of YMZ through a set of weighting coefficients

No.	Strategic goal of the enterprise	Indicator for assessing the degree of achievement of the strategic goal	Designation of the target result	Weight coefficient
1	Increasing the profit of the enterprise	Financial result of the activities	a_1	0.28
2	Reducing the level of receivables	Level of receivables	a_2	0.20
3	Reduction in the share of coal mining enterprises in the overall structure of clientele of the plant's products	The share of sales of goods and services for coal mining enterprises in the total volume of sales of goods and services	a_3	0.18
4	Increasing the volume of production and sales of the company's products	Volume of production of goods and services	a_4	0.12
		Volume of sales of goods and services	a_5	0.12
5	Increasing the work level of production capacity	Work level of production capacity	a_6	0.10

Thus, from *Table 2* we can conclude that the most significant goals are to increase the profit of the enterprise and to reduce the level of receivables. The high significance of the goal aimed at reducing the level of receivables is due to its significant value, the average annual value of which for the analyzed period fluctuated within 7.1–26.4% of the annual revenue of the enterprise. The high level of significance of the goal associated with reducing the share of coal mining enterprises in the overall structure of clientele of the plant's products is due to the desire to reduce the level of uncertainty, since according to the company's management system, the level of uncertainty in relations with stakeholders in this market is significantly higher.

Having assessed the significance of strategic goals and having a set of target indicators, an attractor can be determined. Using the data of the financial and management reporting of the enterprise, the actual values of the parameters can be collected. Based on the indicated data, the distance to the "ideal" point was calculated for each of the target parameters in relative terms, a graphical representation of which by months for 4 years (48 months) is shown in *Fig. 1–6*.

Figures 1–6 reflect the degree of achievement of the key strategic goals of the enterprise over time. An increase in the distances between the target and the actual values of the resulting parameters indicates a distance from the strategic goal, and a reduction indicates an approach to its achievement.

As can be seen from *Fig. 1–6*, the trajectories of movement towards strategic goals are of a spasmodic oscillatory nature, which can be caused by the manifestation of seasonality and a violation of the rhythm of produc-

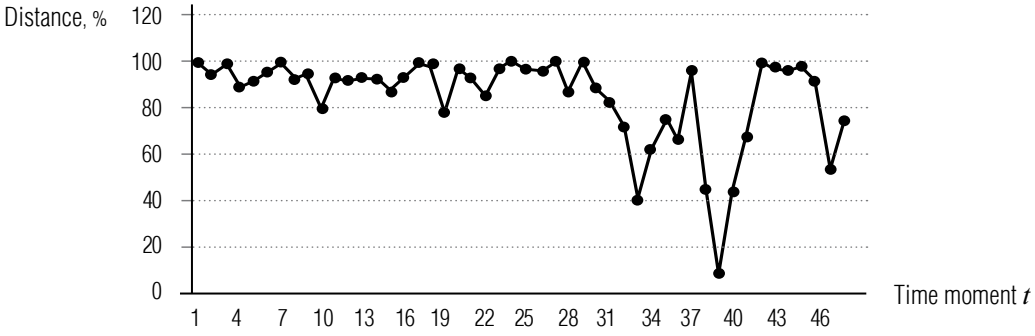

Fig. 1. Distance between the target and the actual value of the resulting parameter a_1 at the time moment *t*.

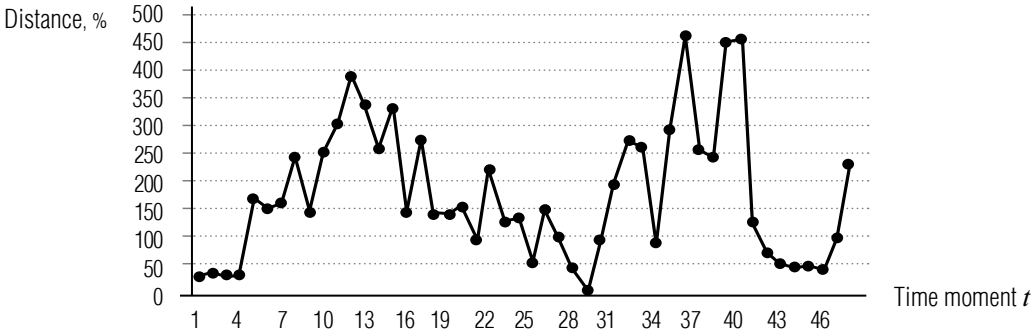

Fig. 2. Distance between the target and the actual value of the resulting parameter a_2 at the time moment *t*.

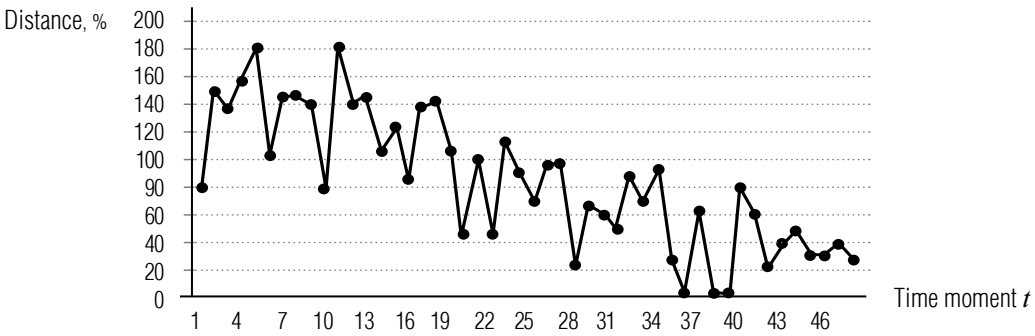

Fig. 3. Distance between the target and the actual value of the resulting parameter a_3 at the time moment *t*.

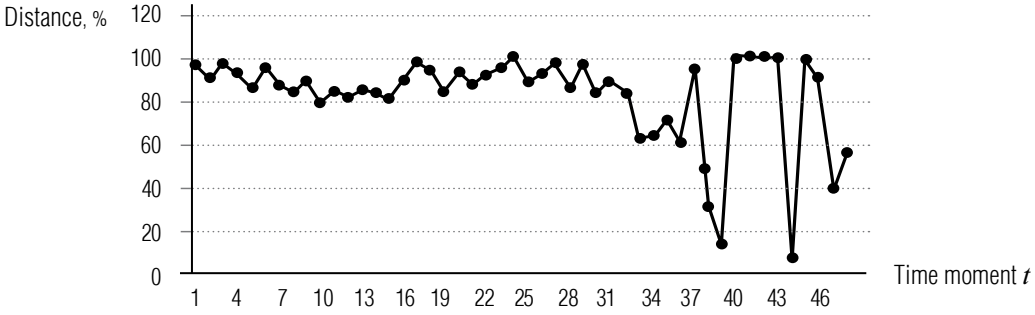

Fig. 4. Distance between the target and the actual value of the resulting parameter a_4 at the time moment *t*.

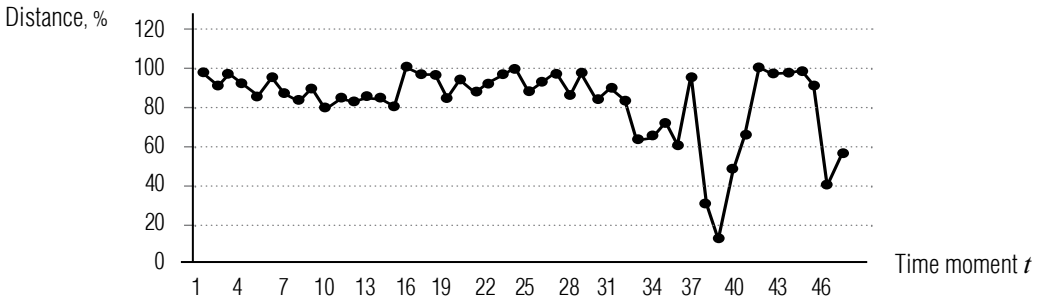

Fig. 5. Distance between the target and the actual value of the resulting parameter a_5 at the time moment t.

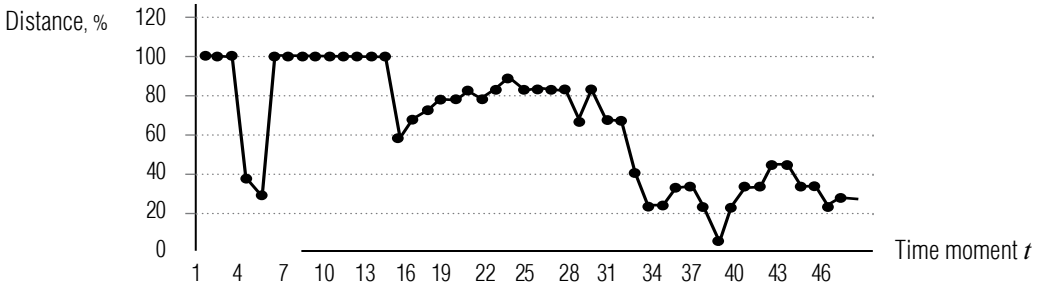

Fig. 6. Distance between the target and the actual value of the resulting parameter a_6 at the time moment t.

tion. In this regard, it is interesting to follow the analysis of the trajectory of movement to the attractor in the context of the dynamics over the years.

Based on the features of the proposed approach to assessing the quality of strategic management within the framework of an enterprise's achieving sustainable development, which involves calculating the distance to the "ideal" point for each of the target parameters, strategic goals can be represented as a reduction in such a distance, i.e. minimizing the gap between the target values of the parameters and the actual ones. In this case, we can say that the attractor of the m-dimensional phase space illustrating the smallest distance between the target values of the parameters and the actual values, is located at the origin (*Fig. 7*).

For YMZ, the assessment of the quality of strategic management of which is carried out according to six resulting parameters, the attractor of the six-dimensional phase space has coordinates (0; 0; 0; 0; 0; 0).

As can be seen in *Fig. 7*, the general trend for the five resulting parameters is to reduce the distance to the attractor, and the trend for the resulting parameter a_2 does not carry a steady movement in the direction of the attractor. Thus, without additional calculations of the integral assessment of the degree of achievement of sustainable development, an unambiguous answer regarding the direction of the trajectory at this stage cannot be given.

In this regard, calculation of the integral assessment of the degree of achievement of sustainable development of YMZ acquires interest and practical value. A graphical illustration of the dynamics of such an assessment is shown in *Fig. 8*.

Thus, as can be seen from *Fig. 8*, in 2017, compared to 2016, there was an increase in the integral estimate, which indicates an increase

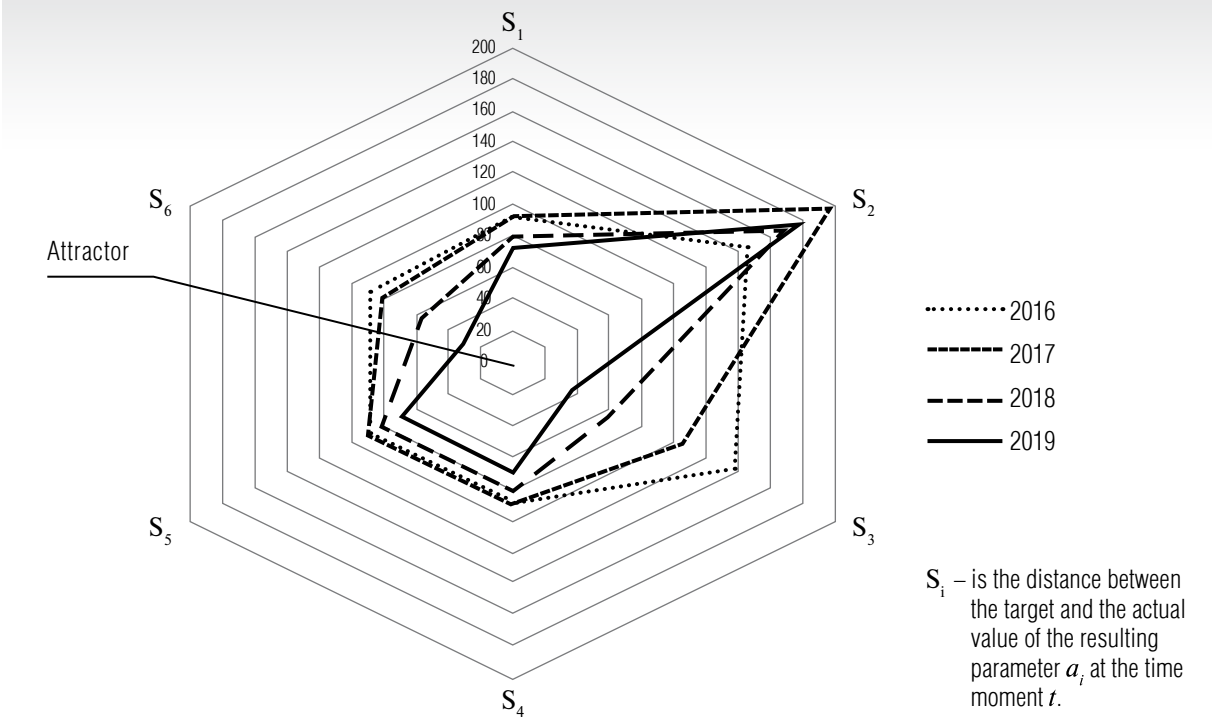

Fig. 7. The attractor and the trajectories for achieving strategic goals by YMZ in six–dimensional phase space.

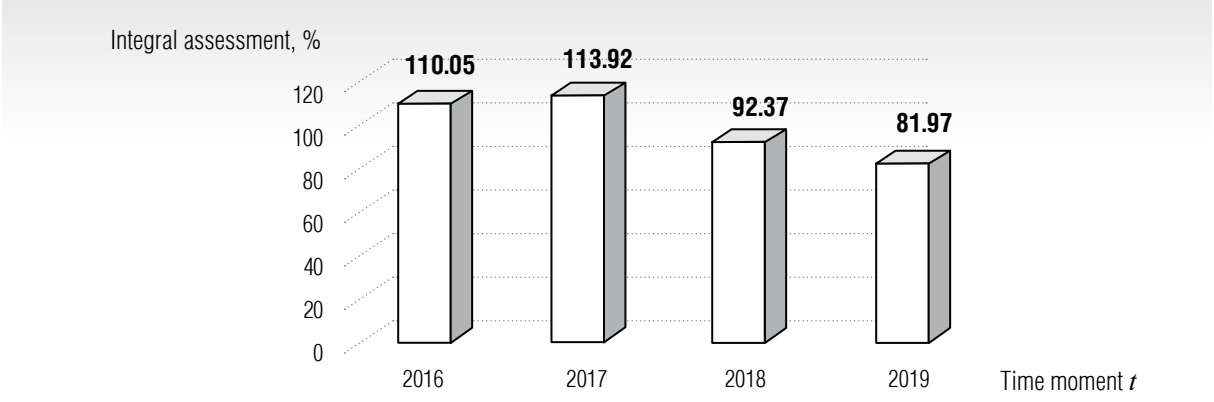

Fig. 8. Integral assessment of the degree of achievement of sustainable development by YMZ under uncertainty at the time moment t.

in the distance (i.e., remoteness) from the "ideal" point. In the next years of 2018–2019 YMZ reduced the distance to the attractor by more than 30%.

Having assessed the degree and having analyzed the trajectory of movement within the framework of achieving sustainable development by YMZ, it is of interest to conduct similar assessments and analyzes for other industrial enterprises in the region operating in conditions of uncertainty.

A graphical illustration of the results of the assessment and an analysis of the degree of achievement of sustainable development of

"Milk River" in a four-dimensional phase space, presented in the form of a petal diagram, is shown in *Fig. 9*.

As can be seen from *Fig. 9*, which illustrates the attractor and the trajectories for achieving strategic goals, over the period from 2015 to 2020 there was both a reduction in the distance to achieve the target values of the parameters by "Milk River" and an increase in this distance for all estimated resulting parameters.

A graphical illustration of the results of the assessment and an analysis of the degree of achievement of sustainable development of the Skochinsky Coal Mine in a four-dimensional phase space, presented in the form of a petal diagram, is shown in *Fig. 10*.

As can be seen from *Fig. 10*, the dynamics of actual performance results in the period from 2016 to 2018 did not undergo significant changes. In 2019–2020, the actual values of the resulting indicators have significantly moved away from the target values, increasing the distance to the attractor. In 2021, there was a qualitative change in the trajectory, as a result of which the distance to the attractor decreased.

The trends that are reflected in the dynamics of individual resulting parameters, naturally, are also reflected in the dynamics of the integral assessment of the degree of achievement of sustainable development of "Milk River" and the Skochinsky Coal Mine (*Fig. 11–12*).

Thus, within the framework of this study, an assessment was made of the quality of strategic management of industrial enterprises in the Donetsk region in the context of their achievement of sustainable development based on the author's approach to such an assessment. As a result, it was established that the integral indicator for assessing the degree of achievement of

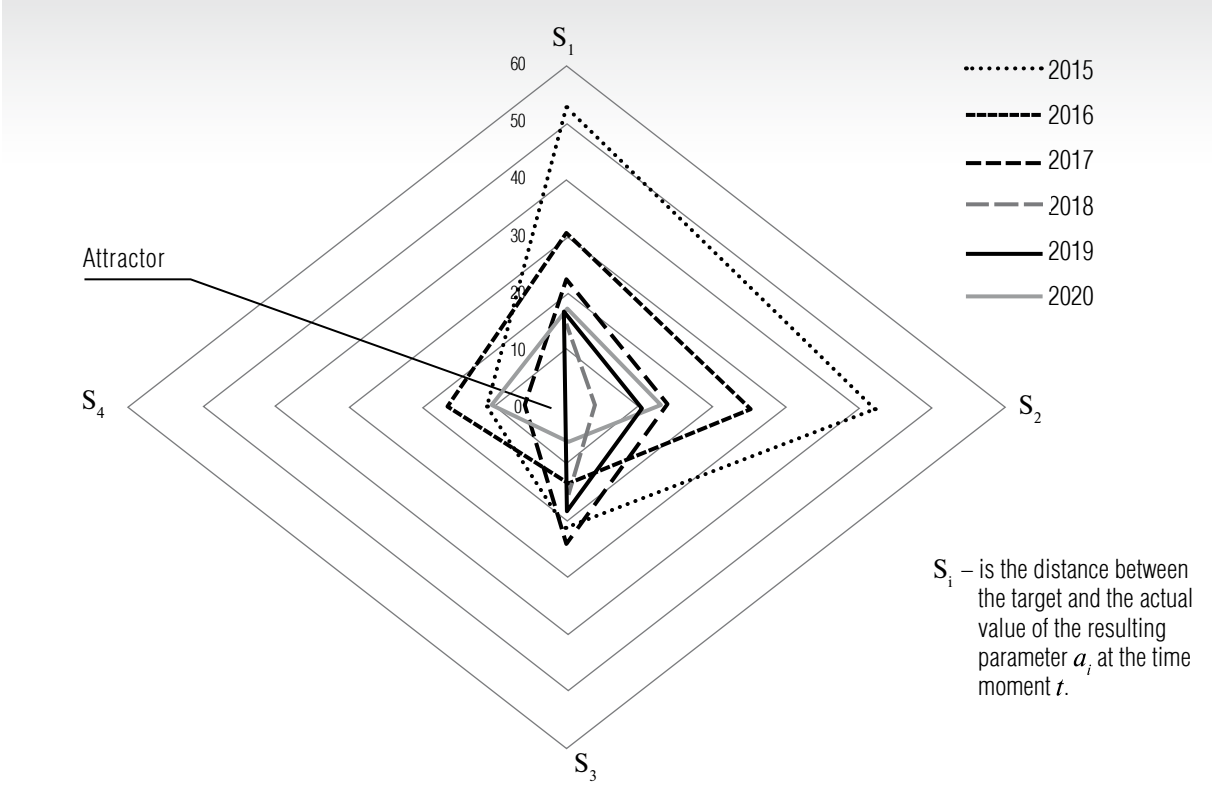

Fig. 9. The attractor and the trajectories for achieving strategic goals by "Milk River" in four–dimensional phase space.

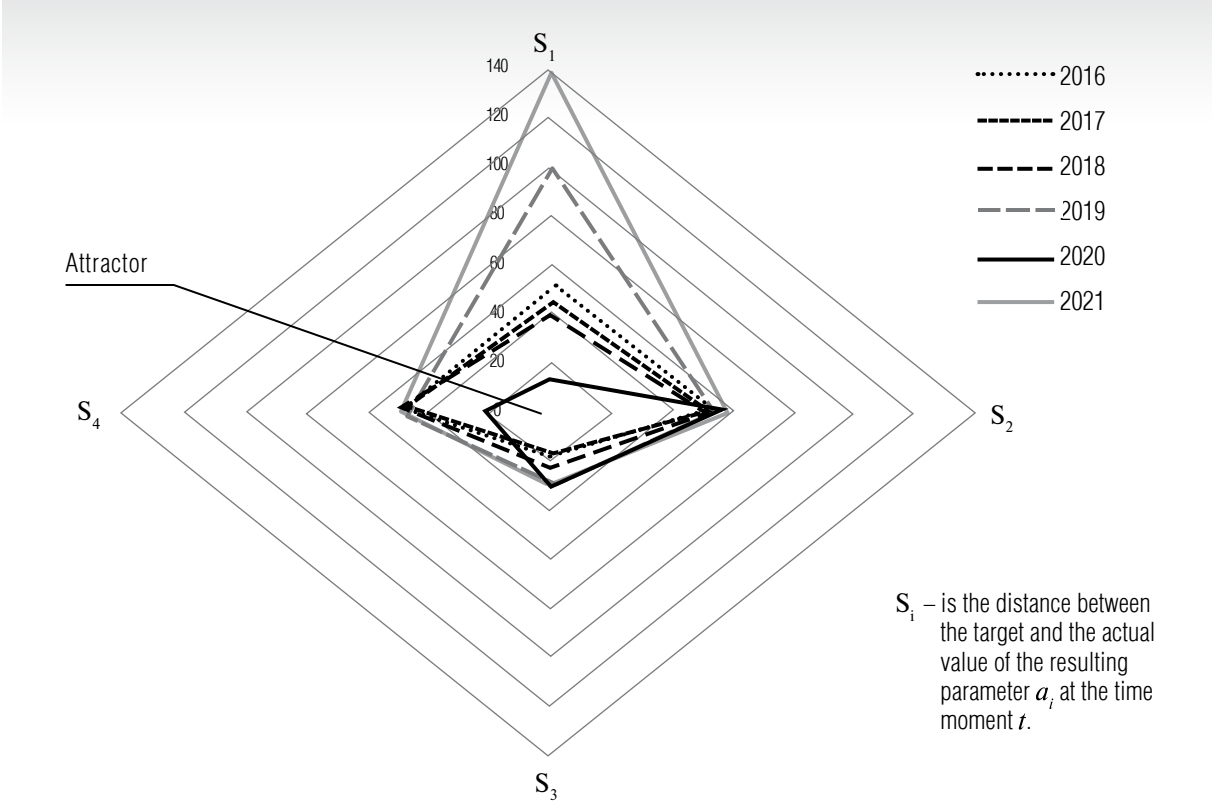

Fig. 10. The attractor and the trajectories for achieving strategic goals by Skochinsky Coal Mine in four–dimensional phase space.

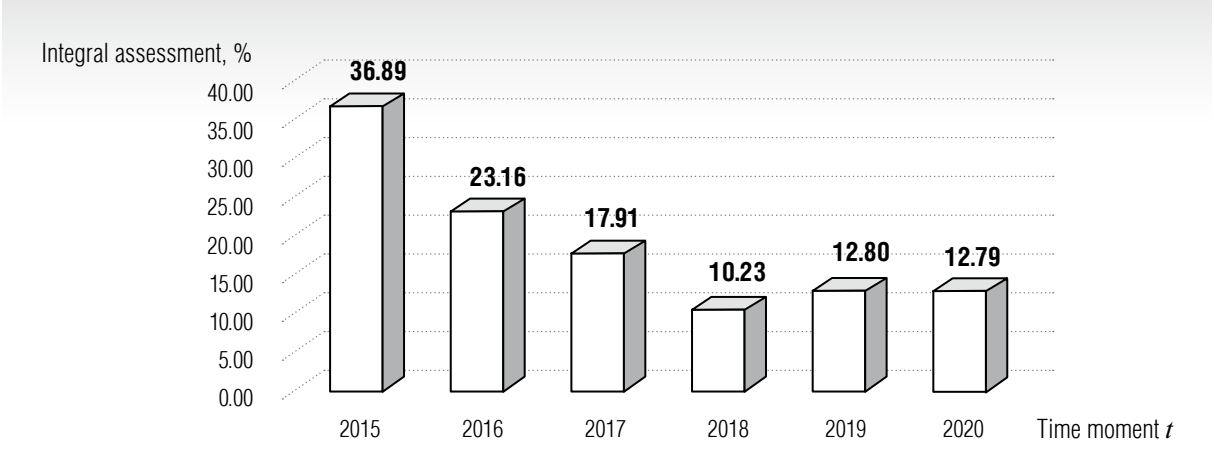

Fig. 11. Integral assessment of the degree of achievement of sustainable development by "Milk River" under uncertainty at the time moment *t*.

sustainable development of all analyzed enterprises did not have an unambiguous and unidirectional downward trend, i.e. there is no way to conclude that there is a stable trend towards the attractor for the entire analyzed period for any of the analyzed enterprises.

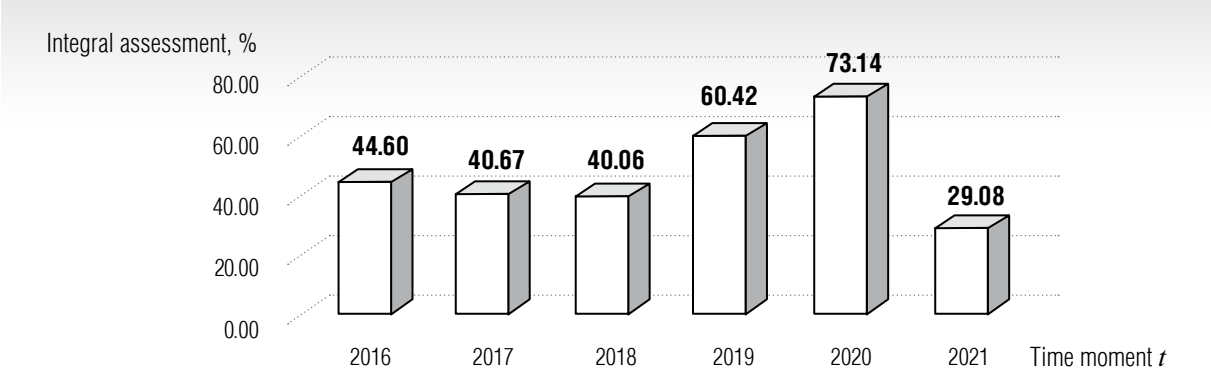

Fig. 12. Integral assessment of the degree of achievement of sustainable development by the Skochinsky Coal Mine under uncertainty at the time moment t.

Conclusion

In the course of the study, a vital task was set and solved, which is to improve the quality of strategic management of industrial enterprises operating in conditions of uncertainty through the development and testing on the example of individual enterprises of the Donetsk region of tools for assessing the quality of strategic management within the framework of an enterprise achieving a sustainable development trajectory, namely:

- a conceptualization of notions was carried out and author's approaches to the interpretation of the notions of "strategic management," "sustainable development" and "strategic uncertainty" were offered;
- a scientific and methodological approach to assessing the quality of strategic management within the framework of an enterprise's achieving sustainable development under uncertainty aimed at conducting a retrospective assessment was offered;
- an approbation of the assessment of the quality of strategic management within the framework of achieving sustainable development of an enterprise under uncertainty was carried out on the example of industrial enterprises of the Donetsk region.

As directions for further research, one can point to the formation of a system for supporting the adoption of strategic decisions and mathematical tools that make up its model basis. Noting that the issues of improving the quality of strategic management by forming an instrumental and model basis for supporting management decisions are reflected in the scientific literature (for example, [27–30]), we point out that they do not correspond to the author's approach to assessing the quality of strategic management, which actualizes their further development. ■

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High-level simulation model of tourism industry dynamics*

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Abstract

This article is devoted to the development of a high-level simulation model of tourism industry dynamics. The purpose of this study is to form recommendations for the recovery of the tourism industry from the effects of the pandemic. The resulting model considers domestic tourism from the point of view of the interdependence of the economic condition of the state, the contribution of the tourism industry to gross domestic product, the size of the tourist flow and the average income per tourist. In addition to describing the functional dependencies of the model elements, several experiments are proposed to test the logic of the elements' relationships. System dynamics tools are used to develop the model. The study also examines the class of computable general equilibrium models as a tool for analyzing supply and demand in the market of tourist products.

Keywords: system dynamics, simulation modeling, tourism, model of domestic tourism, tourism industry, economy

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Introduction

We have been living in an unfavorable epidemiological situation for the last three years. The pandemic dealt a significant blow both to the health of the population and to the economies of countries [1–3]. The largest rating agencies update monthly reports with an assessment of the losses of national economies. Countries with "emerging" economies and high debt loads were particularly affected. The UN report of January 25, 2021 indicates that in 2020 the world economy lost about 5%, which significantly exceeds the consequences of the financial crisis of 2009. The UN calls for joint financing of certain industries by states to restore the economy. The most affected industry in need of support is the tourism industry [4].

The tourism industry is a vital part of the economy of countries. On average it accounts for 5–15% of gross domestic product (GDP) for developed countries and more than 40% for some individual states. The role of tourism in the well-being of the population is revealed through millions of jobs and enterprises. Tourism is also a driving force in the protection of natural and cultural heritage, being an additional source of funding. Moreover, the researchers note that economic growth is directly related to the development of tourism infrastructure, which in some cases can serve as a tool to overcome the economic crisis [5].

Taking into account all the new waves of morbidity, the recovery of the tourism sector should begin with the development of domestic tourism. This strategy will reduce the risk of morbidity of citizens, increase the investment attractiveness of the country for foreign investment, and will also stimulate the development of entrepreneurial activity not only in the main cities but also throughout the country [6].

However, uncontrolled development of the tourism industry within one country can lead to a sharp imbalance of cash flows between regions, depletion of resources, monopolization of individual enterprises and deterioration of historical sites [7, 8]. Each region is unique in its way, and it is necessary to provide investment support by their characteristics [9]. Such important management decisions cannot be made without full information and analytical support, which can be provided by the domestic tourism model and the data model, respectively [10, 11].

Modeling of socio-economic systems is associated with several difficulties, expressed in a decrease in the level of determinism of the system. To solve this problem, it is necessary to develop an approach that ensures the integration of the following modeling tools for technical systems.

At the first stage of the model development, it is necessary to focus on the development of a system-dynamic model that describes the interrelationships of key elements and facilitates assessing the mutual impact of economic growth [12–14]. Within the framework of this work, a high-level simulation model of tourism industry dynamics has been developed. In addition, we consider the computable general equilibrium (CGE) model applicable to the tourism industry as a possible extension of the model [15–21].

1. Materials and methods

1.1. Analysis of the existing approach

Simulation models are used to replace the studied subject area with a model which describes its key indicators and connections between them. This approach ensures transparency of the processes taking place inside the system, so it allows us to predict the behavior of the system. System dynamics as a method of simulation modeling considers the interaction of the following objects: stocks (accumulated values of indicators), flows (numerical equivalents of values of indicators of a given period),

converters (auxiliary quantities for calculating flows and similar converters) [22]. Visualization of models in system dynamics is based on a static combination of elements of all three types connected in a certain way. An important feature of models in system dynamics is the ability to qualitatively predict the behavior of the system without conducting a simulation experiment based on cause-and-effect relationships, which are presented and visualized in the model [23–25].

The system dynamic modeling is used as an alternative to forecasting models for scenario planning of tourist destinations [26]. The advantage of system dynamics models is the ability to take into account the natural limitations of the system [27]. Simulation models are ideal for analyzing the risks and prospects of certain management decisions. The use of a CGE model adapted to the tourism sector makes it possible to assess the most promising areas of investment in terms of the subsequent impact on the country's economy and the durability of the results [9]. The model used allows economic agents to perfectly anticipate the demand for tourism so that they can fully adapt to future conditions.

The CGE model is a computable general equilibrium model and is used to ensure equilibrium between industries in economic modeling. The more industries, regions, types of consumers appear in the model, the more difficult it is to solve such a model analytically; therefore numerical methods processed by computer capacities are used.

CGE models are used for various sectors of the economy, in particular, to assess the impact of investments on individual economic products [28, 29]. Among the most significant models based on the concept of calculated general equilibrium models, we can single out the MONASH model of the Australian economy, as well as a similar model for the US economy – USAGE and RUSEC – the model of Russian economy [17, 18]. The RUSEC model is an example of the applicability of the CGE model to describe the impact of a particular industry on the main macroeconomic indicators of the country [19, 20], so RUSEC-GAZPROM links changes in gas tariffs with the economic situation in the Russian Federation [21].

The basic structure of the CGE model contains four economic agents:

- household;
- company;
- state;
- the outside world.

Each of the agents is connected to the others and is both a source and a supplier. Thus, households are consumers of goods and financial support, but also suppliers of labor and tax payments. Firms receive income from goods, but also are consumers of labor. The state is responsible for investments and receives taxes. In this case, the outside world is an additional source of investment that consumes goods.

Each type of agent is guided by certain rules in decision-making. These rules are described by mathematical functions.

It is worth noting that the use of all four economic agents is not mandatory. In some works, one can find a description of only three agents as the basis of the CGE model, and this allows us to conclude that such an approach is acceptable.

By analogy with the basic structure of the CGE model, the dynamics of the tourism industry can be represented by the following elements:

- tourist profile (household);
- infrastructure of tourist products (firms);
- outflow of tourist flow (the outside world).

In this case, the tourist profile should be understood as an economic agent with its characteristics and needs, the main consumer of tourist products.

Under the infrastructure of tourist products, many companies source consumer products. This indicator includes accommodation, food, transport, events and much more.

The outflow of tourist flow in this case is equivalent to the outflow of income from tourists. It is worth noting that it will be compensated to some extent by inbound tourism.

It is necessary to keep the structure of the CGE model to further enable the model to include indicators of supply and demand in the tourism products market. Thus, the task of this work is to develop a high-level model, which will be finalized in the framework of further research according to the CGE concept [30–36].

1.2. Initial data

To develop the model and test it, it was decided to independently find and select the data. When selecting data sources, emphasis was placed on their openness and reliability. In the end, all the data used in the model were taken from the website of the World Tourism Organization.

It is worth noting that as part of the development and testing of the model, no emphasis was placed on the use of data about the Russian Federation. In this case, it was necessary to focus on a developed country with stable economic indicators and with a minimum number of tourist zones. The latter requirement is due to the inability to obtain reliable results based on the average for several different points of attraction. Based on the stated requirements, the choice of the country for the study settled on Austria, for a number of the following reasons:

- relative completeness of data in comparison with other countries;
- stable contribution of the tourism industry to the country's GDP (about 6%);
- developed domestic tourism (at least 40% of the tourist flow);
- stability of economic indicators;
- the country is included in the list of developed countries;
- relative limitations of tourist points of attraction.

It was important to identify and provide at least a few necessary indicators [22–25]. Below is a list of indicators that could be found in open sources; the time range is 2008–2018:

- tourists, thousand people (inbound tourism);
- tourism expenses in the country in millions of USD (inbound tourism);
- tourists, thousand people (outbound tourism);
- tourism expenses in the country in millions of USD (outbound tourism);
- tourists, thousand people (domestic tourism);
- tourism expenses in the country in millions of USD (inbound tourism);
- GDP;
- the contribution of tourism to GDP.

2. Model description

Within the framework of the study, a simplified model of the dynamics of the tourism industry has been developed. The main purpose of the model is to analyze the connection between the tourism industry and the well-being of the country's population. Such simplification will allow us to refine the model in the future, considering the specifics of pricing policy, production, the economic situation and measures to contain the epidemic of each country separately.

The elements of the model being developed can be divided into three groups according to the purposes of the calculation:

- calculation of the contribution of the tourism industry to GDP;
- calculation of profit from consumption of tourist products within the framework of domestic tourism;
- calculation of the tourist flow within the framework of domestic tourism.

The model we developed is presented below (*Fig. 1*).

The model presents two indicators containing the accumulated values of existing flows.

Total tourist flow (*T.t.f.*) – the accumulated value of the tourist flow, reflecting the number of tourist trips of citizens of a given country for a specified period. This indicator directly depends on the growth rate of the number of tourists (*Tourist flow growth, T.f.g.*):

$$T.t.f.(t) = T.t.f.(t - dt) + (T.f.g.) \cdot dt \qquad (1)$$

Total income (*T.i.*) – the accumulated value of profit from tourist products. This indicator depends on the level of annual profit from tourist products (*Yearly income, Y.i.*):

$$T.i.(t) = T.i.(t - dt) + (Y.i.) \cdot dt \qquad (2)$$

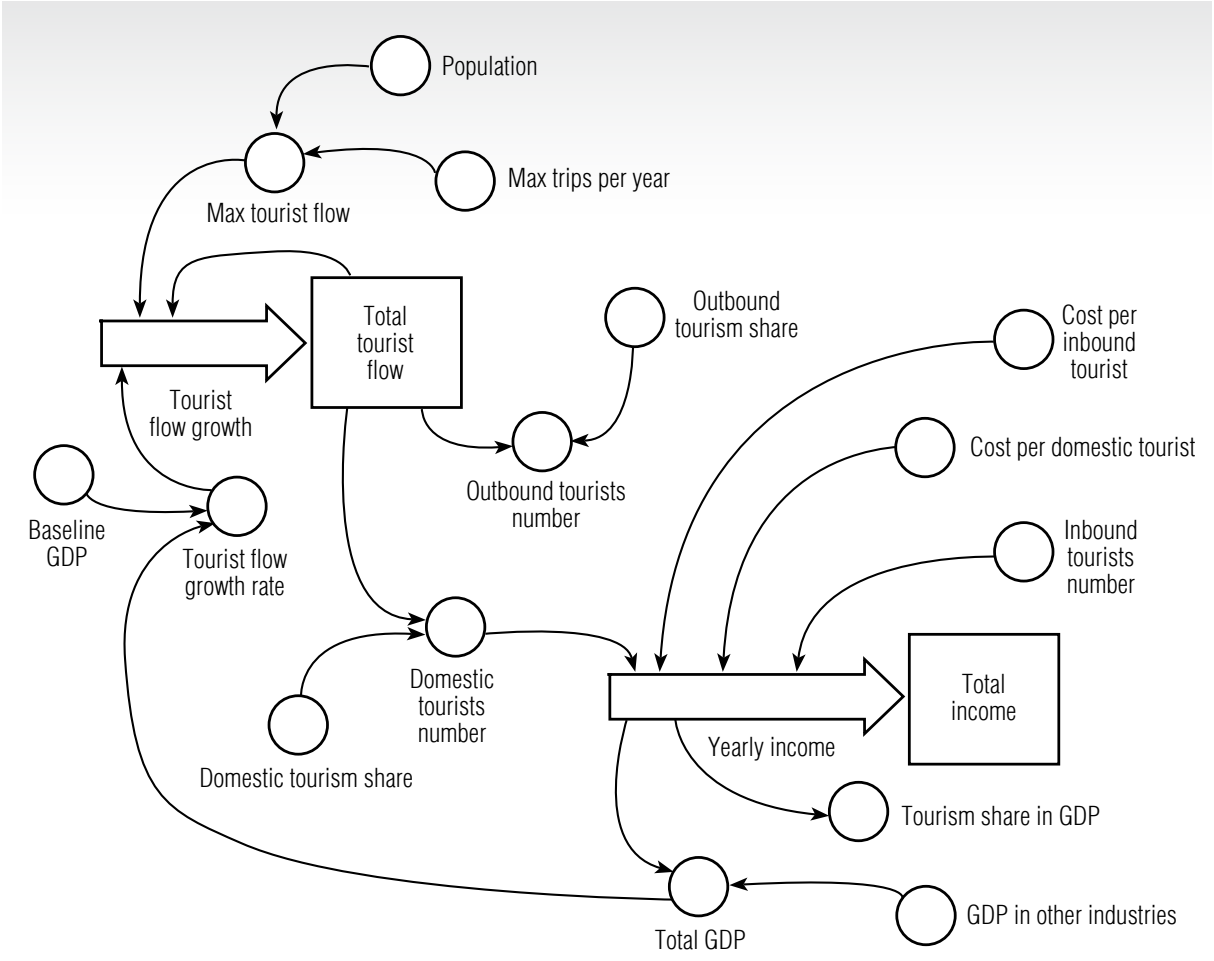

Fig. 1. Model of domestic tourism.

The model also includes two flows that precede changes in indicators containing accumulated values of existing flows:

Tourist flow growth (*T.f.g.)* – the growth rate of the tourist flow. This indicator depends on the level of growth of the tourism industry (*Tourist flow growth rate, T.f.g.r.)*, as well as on the maximum possible size of the tourist flow (*Max tourist flow, M.t.f.*), which is a limitation of the system:

$$T.f.g. = \left(M.\ t.\ f. - T.\ t.\ f.\right) \cdot 2^{\left(-\frac{1}{T.f.g.r.}\right)} \quad (3)$$

Yearly income (*Y.i.*) – the rate of annual profit growth from the tourist flow. This figure depends on the number of domestic tourists (*Domestic tourists number, D.t.n.*), the number of inbound tourists (*Inbound tourists number, I.t.n.*), the average revenue per domestic tourist (*Cost per domestic tourist, C.d.t.*), average income from inbound tourists (*Cost per inbound tourist, C.i.t.*):

$$Y.i. = C.d.t. \cdot D.t.n. + C.i.t. \cdot I.t.n. \quad (4)$$

In the model there are also fifteen converters required for the calculation of stream values:

Baseline GDP (*B. GDP*)– is the basic value of Austria's GDP. It is necessary to estimate the annual growth in GDP. A static value is set in the model:

$$B.\ GDP = 426000000000\ (USD). \quad (5)$$

Cost per domestic tourist (*C.d.t.*) – average income from domestic tourist. A static value is set in the model. However, this indicator is one of the main levers of influence on the model:

$$C.d.t. = 600\ (USD). \quad (6)$$

Cost per inbound tourist (*C.i.t.*) – the basic value of Austria's GDP. A constant value is set in the model:

$$C.i.t. = 800\ (USD). \quad (7)$$

Domestic tourism share (*D.t.s.*) – the share of tourists who prefer domestic tourism. A constant value is set in the model, but this indicator will be the lever of influence on the model:

$$D.t.s. = 0.5. \quad (8)$$

Domestic tourists number (*D.t.n.*) – the actual number of domestic tourists. It depends on the accumulated value of the tourist flow (*Total tourist flow, T.t.f.*) and the share of domestic tourism (*Domestic tourism share, D.t.s.*):

$$D.t.n. = D.t.s. \cdot T.t.f. \quad (9)$$

GDP in other industries (*GDP.o.i.*) – contribution to the GDP of other industries. A constant value is set in the model:

$$GDP.o.i. = 400000000000\ (USD). \quad (10)$$

Inbound tourists number (*I.t.n.*) – the actual number of incoming tourists. A constant value is set in the model:

$$I.t.n. = 25000000. \quad (11)$$

Max tourist flow (*M.t.f.*) – the maximum possible number of tourists. Depends on the maximum number of trips per tourist per year (*Max trips per year, M.t.y.*) and on the actual value of the population (*Population, P.*):

$$M.t.f. = P. \cdot M.t.y. \quad (12)$$

Max trips per year (*M.t.y.*) – the maximum number of trips per tourist:

$$M.t.y. = 4. \quad (13)$$

Outbound tourism share (*O.t.s.*) – the share of outbound tourists. A constant value is set in the model:

$$O.t.s. = 0.5. \quad (14)$$

Outbound tourists number (*O.t.n.*) – the actual value of outbound tourists. Depends on the accumulated value of the tourist flow (*Total*

tourism flow, T.t.f.) and the share of outbound tourism (*Outbound tourism share, O.t.s.*):

$$O.t.n. = O.t.s. \cdot T.t.f. \quad (15)$$

Population (*P.*) – the actual value of the population. A constant value is set in the model:

$$P. = 8900000. \quad (16)$$

Total GDP (*T.GDP*) – the value of GDP. It depends on the profit from other industries (*GDP in other industries, GDP.o.i.*) and on the annual revenue from tourism products (*Yearly income, Y.i.*):

$$T.GDP = GDP.o.i. + Y.i. \quad (17)$$

Tourism share in GDP (*T.s.GDP*) – the share of the tourism industry in GDP. It is assumed that the growth of this indicator will positively affect the dynamics of the model indicators. Calculated on the basis of annual income (*Yearly income, Y.i.*) from tourist products to the total value of GDP (*Total GDP, T.GDP*):

$$T.s.GDP = \frac{Y.i.}{T.GDP} \cdot 100. \quad (18)$$

Tourist flow growth rate (*T.f.g.r.*) – increase in tourist flow. Depends on the total value of GDP (*Total GDP, T.GDP*) and the base value of GDP (*Baseline GDP, B. GDP*):

$$T.f.g.r. = \frac{T.GDP}{B.GDP} - 1. \quad (19)$$

All static values are set based on the analysis of the initial data and represent the average figures for 11 years.

As part of one of the goals of modeling, the preparation of an analytical base for making informed management decisions, the goal will be to maximize the return on investment in tourism products, namely, to maximize the contribution of the tourism industry to GDP.

After the verification stage of the model on the available data, the model will be finalized considering the possible financing of individual tourist products (hotels, roads, events, and so on). The difficulty of this stage is the lack of data to test hypotheses about the impact of investments on increasing revenue from tourism products, which is why this stage is not considered in this work.

These values of indicators provide a static state of the model when the level of indicators remains stable except for accumulated values.

3. Simulation results and discussion

To test the operation of the model, it is necessary to conduct a series of experiments. Below is a table with a description of the experiment and the expected result. The extent to which the expected and actual results coincide determines the quality of the model (*Table 1*).

The proposed experiments are implemented in the software environment iThink.

Based on the experimental data, the logical component of the model and their interrelations are checked. Connections of the following indicators are being worked out:

- the impact of the share of domestic tourism on tourism revenues and GDP growth;
- dependence of GDP on income from tourism and income from other industries;
- the impact of income from one tourist on the annual income from tourism, the share of tourism in GDP.

We will conduct a test simulation for 10 years to check the stability of the model.

The increase in total income from tourism increases evenly since there is an equal annual increase, as can be seen from the graphs of total income from tourist products (*Fig. 2*).

The total tourist flow (*Fig. 3*) remains constant.

Table 1.

Description of experiments

No.	Description of the experiment	Description of the expected results
0	Zero starts, the values are described above.	The model is in a static state; all indicators remain at the same level in all the periods under consideration.
1	We change the indicators of the share of the distribution of domestic tourism and outbound tourism: 0.65 and 0.35 respectively.	It is assumed that the annual income from tourism will increase and a slight increase in the tourist flow.
2	We are changing the contribution of other industries, increasing it to 500 000 000 000 (USD).	It is assumed that the share of the contribution of tourism will fall, and the tourist flow and GDP will grow.
3	We return the value for other industries and double the income from domestic tourism.	It is expected to increase the contribution of tourism to DP, as well as an increase in annual income.

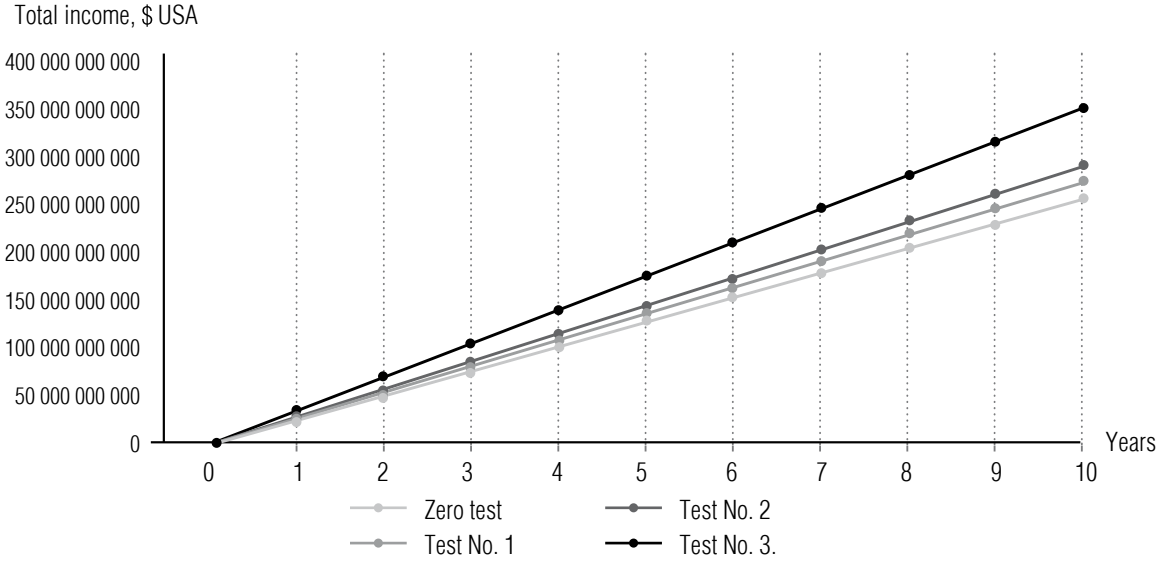

Fig. 2. Total income.

The annual income is stable, so the graph is a straight line parallel to the ordinate axis (*Fig. 4*).

Another important indicator that makes sense; displayed on the graph is the contribution of the tourism industry to GDP (*Fig. 5*).

At the zero-modeling stage, the contribution is stable and amounts to just over 6%.

We will conduct a test simulation for 10 years, taking into account the increase in the share of domestic tourism to 65%. This result can be achieved by increasing the level of attractiveness of the country in comparison

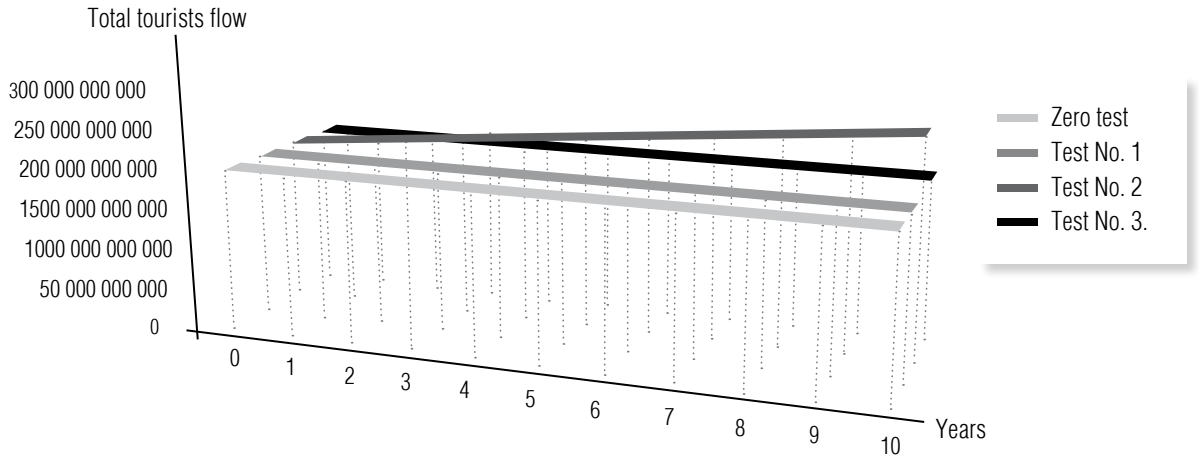

Fig. 3. Total tourists flow.

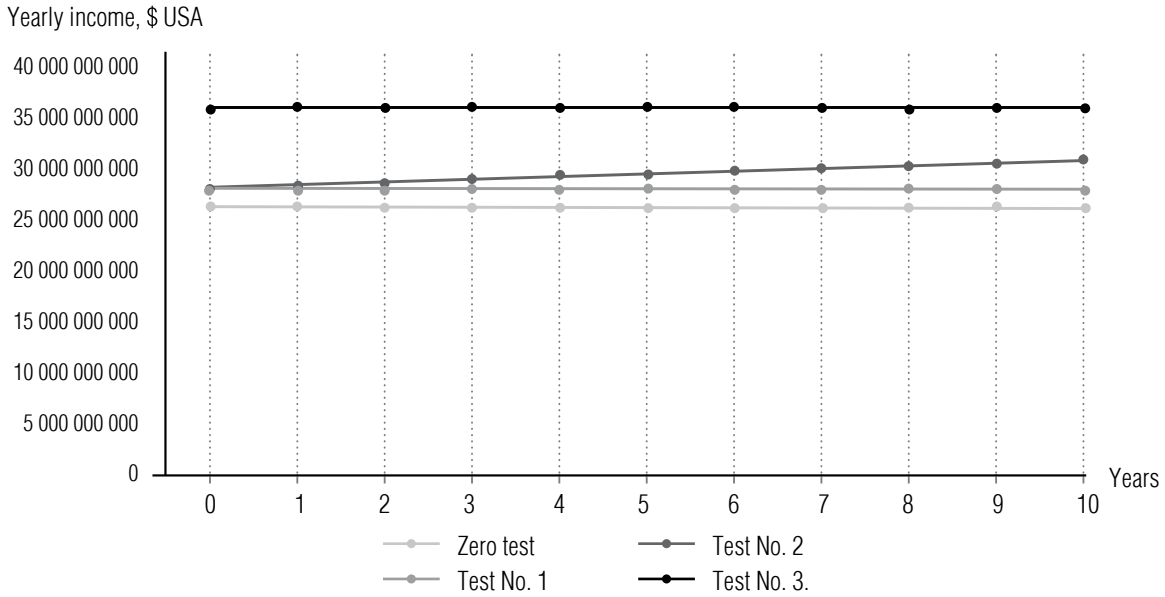

Fig. 4. Yearly income.

with other places. Let's see how the income from tourism will change after the result of the experiments.

The graph shows that the test gave similar values of the tourist flow in comparison with the zero tests. This is due to the slow growth of the tourist flow because of the relatively small contribution of the tourism industry to GDP (*Fig. 2*).

Particular attention should be paid to the values of the following indicator (*Fig. 4*). The increase in annual income from tourism products should have caused an increase in the contribution of the tourism industry to GDP (*Fig. 5*). The indicator of the contribution of the tourism industry increased by almost a percentage point, which corresponds to the expected results.

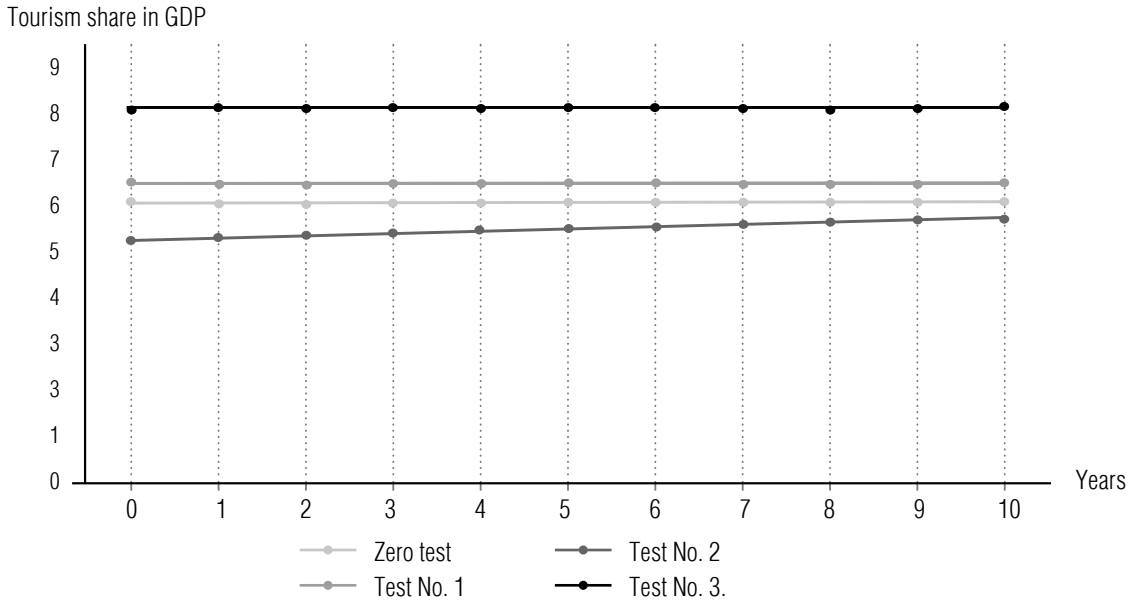

Fig. 5. Tourism share in GDP.

Since the share of tourism is about 6% of the total GDP, it is difficult to trace the change in tourist flow from GDP growth. Therefore, as part of the verification of the work of the model, we will increase the contribution of other industries to trace the dependence of the tourist flow on the level of well-being.

The graph shows a change in the trend of income growth from tourist products. In comparison with the results of the first experiments, significant nonlinear growth of the indicator is observed.

The tourist flow, taking into account recent changes, has acquired a tendency to a non-linear increase in the values of the indicator.

Annual income has acquired an upward trend. The graph shows the nonlinearity of growth (*Fig. 4*).

The graph shows the change in the share of the tourism industry, which is explained by the change in the share of other industries (*Fig. 5*). Interestingly, the share of the tourism industry has acquired a tendency to non-linear, but tangible growth, which once again proves the mutual influence of the development of economic sectors on each other.

Let's conduct a third experiment. Let's return the contribution values of other industries and return to modeling the tourism industry. Suppose that the increase in the attractiveness of the country affected the share of domestic tourism, which led some of the category of "expensive" tourists to the desire to relax in their native country. This caused a sharp increase in the average income per tourist – twice.

Consider the change in total income (*Fig. 2*). The graph shows that the total revenue from an increase in income from one tourist is growing significantly better than with an increase in total revenue from other industries.

The tourist flow is leveling off again to the previous values (*Fig. 3*).

The graph shows that the total income from an increase in income from one tourist is growing significantly better than with an increase in total revenue from other industries.

The annual income returned to a stable level but exceeded it significantly in comparison with the results of previous experiments.

Table 2.

Description of results

No.	Description of the experiment	Description of the expected results	Compliance with the results
0	Zero starts; the values are described above.	The model is in a static state; all indicators remain at the same level in all the periods under consideration.	Successfully, all indicators remain unchanged at all intervals.
1	We change the indicators of the share of the distribution of domestic tourism and outbound tourism: 0.65 and 0.35 respectively.	It is assumed that the annual income from tourism will increase and there is a slight increase in the tourist flow.	Successfully, the increase in annual income and contribution of the tourism industry to the stable values of the tourist flow.
2	We are changing the contribution of other industries, increasing it to 500 000 000 000 (USD).	It is assumed that the share of the contribution of tourism will fall; the tourist flow and GDP will grow.	Successfully, the share of the tourism industry fell but showed growth trends due to an increase in the accumulated value of income. The tourist flow schedule also showed a significant increase. The limitations of the model also work and have shown themselves in a drop in the growth rate of the tourist flow after reaching a maximum.
3	We return the value for other industries and double the income from domestic tourism.	It is expected to increase the contribution of tourism to GDP, as well as an increase in annual income.	Successfully, the contribution of the tourism industry has increased, as has the total income.

The increase in the value of one tourist caused a significant increase in the share of the tourism industry in the country's GDP; now this figure is more than 8%.

As part of this work, a series of experiments were carried out. At this stage, it is necessary to compare the expected results from the actual results of the model.

A comparative analysis is presented below (*Table 2*).

The experimental results confirmed the applicability of the model for assessing the economic dependence of the level of well-being of citizens, the size of the tourist flow and the contribution of the tourism industry to GDP. The relevance of investing in the tourism industry as a way to restore the economy and increase profits for business and the state is confirmed.

Based on the experiments, we can conclude about the stability of the model and the logically correct relationship of the indicators.

The results of the experiments do not contradict logic and fit into the general concept of the interrelation of elements in the model of domestic tourism. Accordingly, the results of the first high-level model can be considered successful.

The resulting model is a high-level simulation model of the dynamics of the tourism industry. There are plans to develop the model considering the analysis of intersectoral relations, the contribution of various tourist products and the seasonality of demand. It is also necessary to integrate into the model elements of the impact of Covid-19 restrictions and changes at the macroeconomic level on the tourist flow.

Conclusion

This article is devoted to the development of a model based on data available in open sources. The purpose of this is to model the dependence of the economic condition of the state on the development of the tourism sector. As part of the work, a high-level model of domestic tourism was developed with a description of the functional dependencies of the model elements. The resulting model was tested for compliance with the logic of functional dependencies between elements determined as a result of the analysis of international experience in modeling tourist processes. The results obtained link the indicators of the contribution of the tourism industry to the country's GDP, the tourist flow and revenue from the consumption of tourist products. This study is the first stage in a project to develop a model of domestic tourism that considers the natural limitations of the system, such as the environmental situation, available labor resources and the condition of historical heritage monuments, also taking into account functional descriptions of the propensity of tourists to save and spend for different groups of profitability, the division of tourist products by type and other economic indicators. ■

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Perceived values and purchase behavior of online game attribute products: Gender overview

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Abstract

Game-oriented business development is growing quickly and this encourages the digital economy in Indonesia. This research aims to examine the role of perceived value on the purchase behavior of online game attributes in Indonesia based on gender groups. Samples were taken from several online gaming communities in Indonesia. The variables in this study consist of perceived value variables, namely emotional, quality, social and economic value, which are antecedents for the online game attribute purchase intention and purchase behavior variables. Data were analyzed using Structural Equation Modeling. The research results show an influence on purchase intentions of perceived value which consists of emotional, quality, social and economic value and ultimately shapes the buying behavior of online game product attributes. There is a difference in each component of perceived value on purchase intention between male and female groups. Emotional and quality values do not affect the female group's pursuit intent, while social values do not significantly affect the male group.

Keywords: digital product, cyber consumer, e-business, gender effect, e-sport

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Introduction

The development of online game products has received significant attention in the digital business. Data from the Google Play store dated August 24, 2020, shows top charts with the top free category of "Among Us," "Mobile Legends: Bang Bang," and "Cube Surfer!" Game top charts with the top-grossing category consist of "Garena Free Fire: BOOYAH Day," "Mobile Legends: Bang Bang," and "Genshin Impact." During the late 1970s and early 1980s, arcade competitions became increasingly organized and sanctioned as public contests, with title sponsorship, audience, and media coverage [1]. Online games in their development are recognized as sports category games, often called e-sports. The origins of e-sports are said to hinge heavily on the launch of the world-wide web (www) in 1989 and the early 1990s, software and hardware technology with network and multiplayer functionality. In the early 1990s, the history of e-sports started, and it became increasingly popular during this decade; the number of players increased rapidly [2]. YouTube has had an essential role as a means of advertising game products. The similarity between the video and the advertised product or brand must be considered when producing ads included in YouTube e-sports videos [3]. This e-sport event is a means to promote media platforms and sports, as well as related technologies [4].

The position of competitive gaming as a mix of sport, media and technology makes it an ideal case study of a virtual spectacle of an economic experience. An e-sports event can be considered a hyper-experiential product, a "post-experience experience," in that a consumer product based on initial experience is gameplay provided by the publisher. The secondary consumption phase begins through viewing familiar games as a commodity and the viewer is considered in conjunction with the e-sports tournament audience [1]. As one of the innovative digital products, online games have contributed to the growth of the digital economy [5]. Online games are also recognized as one of the successful forms of the digital industry that has a major contribution to the growth of a country's digital economy [6]. The development of online game products is growing rapidly in several countries such as Japan, Korea, China [7], Philippines, and Indonesia. For example, e-sports has competed in Indonesia's 2018 Asian Games competition and the 2019 SEA Games in Manila, Philippines. Based on survey data from Agate Studio, a game company in Indonesia, the three most popular games in Indonesia were RPG (Role Playing Games), Strategy, and FPS (First Person Shooter) in 2012. These results also show that most people (70%) pay less than IDR 100 000 (approx. $11). 25% of respondents spend between IDR 100 000 – IDR 500 000 per month ($11 – $55). About 40% of respondents spend their money on virtual goods.

The rapid growth of the online game industry has consequences for game development companies to observe online game consumer behavior and determine the right strategy and product development. The phenomenon of the growth of online games being recognized as e-sports has become a research attraction for academics. Analysis of consumer behavior related to attributes or items of a game is essential for game companies [8]. Several existing studies have proved the importance of understanding the perceived value aspect for game companies. The consumption value theory explains that game users consider multiple values such as quality emotions such as pleasure, social and economy in purchasing decisions [9]. Park and Lee [8] state that in online games, if users can perceive items or attributes as valuable, there will be an increased tendency to make purchases. Understanding the appropriate value of consumers is a competitive advantage or source of competitive advantage for the company [10].

Perceived value influences purchase intention, especially for digital products [11]. Several previous studies confirm the role of perceived value on online game buying behavior, such as emotional [12, 13], quality or competence [13, 14], social [12, 14] and economics or monetary [12, 13]. Some of the findings also showed different results [15, 16] and the limitations of research that have not involved elements of personal characteristics in existing research. Some research is also limited to the study of behavioral intentions [11]. One of the demographic elements that impact online game use is gender. The role of gender and its phenomena related to online games still needs to be explored further [17]. Participants are only differentiated based on biological differences [18, 19]. There have not been many studies on gender differences based on social norms and expectations [14].

1. Motivation and research rationale

This research examines the role of perceived value on online game attributes' buying behavior and this behavior model based on gender overviews. Understanding users' perceived values and characteristics are expected to consider the development of user-based product innovation and determine competitive advantage strategies. The gender aspect is an essential demographic element related to information technology [20]. Islam [21] emphasize the differences in attitudes between men and women interacting online. Although online games are cross-gender digital products, their use characteristics have different attitudes [22]. Based on the motivational aspect, males and females tend to use online games with different motives. Yee [22] found that males tend to be achievement-oriented even though both have a social orientation. Regarding social orientation, females play games to maintain relationships or social interactions with others [23]. The consequences of gender roles related to information technology have also been emphasized by several researchers [24, 25]. This difference causes marketers or game development companies to adjust the value differences in-game attributes marketed based on demographic patterns. Several studies have tried to examine differences between in-game users based on demographic characteristics such as user age [22, 26], but there are indications that differences are based on cross-gender [17].

2. Literature review related to existing models

Perceived value involves customer perceptions of the reciprocal nature of things issued and received by customers [27]. The perceived value is also defined as assessing the entire use of goods or services determined from the consumer's view of the goods or services received with what is given. Customers make sacrifices to get something they want. The sacrifice can be in time, money or energy. Perceived value occurs when customers compare their perception of an item with their sacrifices and benefits. If customers get product benefits commensurate with or even exceeding the perceptions and sacrifices, the product has a positive perceived value. Conversely, if the product benefits have a lower value than the perceptions and sacrifices made by customers, the product has a negative perceived value. Perceived value can be increased by increasing the benefits or reducing the costs incurred [28].

Sweeney and Soutar [29] designed the value component to measure perceived value: emotional, social, economic, monetary and quality. This model is more comprehensive than others and is most widely used in communication studies and social media research [30, 31]. Emotional value is assessing the feelings or affective individuals in consuming the product. Social value refers to the assessment that comes from the ability of a product

to improve the social life of the individual or user. Economic or monetary value is an assessment from the built-in perception comparing the price offered and the costs incurred. The quality value measures the assessment obtained from product users' perceived quality and performance expectations. Users of the perceived value game will encourage individuals to make purchase decisions [9, 16].

There are gender differences in behavioral constructs regarding the information system responding to information [32]. Psychologically there are differences between women and men in processing messages and information, so the built-in attitudes will also be different [33]. Male and females have differences in interpreting something, including in processing information. Males tend to perceive things according to cognitive aspects, while females tend to involve affective aspects [34], so the perceived values will also differ. Social Role Theory explains that women are more focused on interactive activities than men from a social point of view [35]. Females process information based on intuition, subjectivity and emotion [36]. Salomon [37] explains that females are more sensitive in processing information, so abstract values are easier to understand than with males. The female consumers' purchase intention is more closely related to experience, affective and social identity than in the case of male groups [38]. Females and males have differences in perceiving values which will cause differences in attitudes and behavior in making decisions related to online games.

2.1. Emotional value

The emotional value is an assessment based on feelings or emotions from mobile games [39]. Emotional value in online games tends to lead to aspects of perceived playfulness. According to Hsiao and Chen [16], perceived playfulness is a feeling of joy or pleasure from users while playing games. The feeling of joy that is obtained encourages individuals to continue to get the same thing to encourage purchase intentions for the game product in question. Emotional value shows the benefits obtained based on feelings or affective aspects of online games [39]. The affective aspect that produces a sense of comfort is obtained based on joy when interacting with other people in the game world. Based on this positive attitude, the impulse or motive will stimulate a payment intention [40, 41]. Previous research also supports this emotional relationship with purchase intention on mobile products [41, 42]. The joy obtained based on the experience of playing online games impacts the purchase intention [43]. The proposed hypothesis is as follows:

H1: The higher the perceived emotional value, the higher the intention to buy online game product attributes.

2.2. Quality value

Quality or performance value refers to the player's perception of performance with the quality obtained from online games [44]. Quality value refers to the perceived access flexibility obtained by game users. Wei and Lu [41] stated that perceived access flexibility is the freedom of time and control of players in playing games. Players can freely determine the time and place to play. The form of freedom obtained is a value of control over behavior. Research conducted by Hsiao and Chen [16] state that quality value positively affects purchase intention. The game is designed with a platform that is easy to access and related to the platform's quality. Aspects of availability and flexibility of time and place of access are important factors that play a role in using the platform [44]. The value of the quality of a website will increase the intention to purchase the web [45]. The proposed hypothesis is:

H2: The higher the perceived quality value, the higher the intention to buy online game product attributes.

2.3. Social value

Social value refers to the benefits derived from mobile games through social interaction between players [39]. Connectedness is a significant component of interacting online. Zhao and Lu [46] stated that connectedness is a connection between individuals through mobile games. Positive feelings between players in a game team can be formed when the team tries to achieve a synergistic or partial victory. The interactive game process will form a communication network and encourage the social involvement of fellow players. Online game players can learn from each other's game tactics and gain experience from the games they run [47]. The research results conducted by Lu and Hsiao [44] show that perceived connectedness has a positive effect on purchase intention. Experiences gained from individuals through convenience and connectedness will form positive social relationships. Users who feel the fulfillment of social interaction needs in online games will encourage them to buy products and their attributes. The proposed hypothesis is:

H3: The higher the perceived social value, the higher the intention to buy online game product attributes.

2.4. Economic value

Economic value refers to the way individuals assess the value of a product based on the quality obtained versus the sacrifice given [39]. Economic or monetary value has parts or components in the form of perceived reasonable price and perceived reward. Perceived reasonable price is a component to measure the level of individual sacrifice in getting the desired goods or services. Lu and Hsiao [39] stated that perceived good reward refers to gifts received by players when playing games. In some games, the longer the time spent playing, the greater the player's reward. Additional prizes can motivate players to play. Economic value refers to the price representing the value that the user must sacrifice. Users in playing games consider the suitability of the monetary cost incurred with the satisfaction obtained [11]. If the user feels that what is obtained follows what is sought, this will bring up the intention or urge to consume [39]. Several studies, such as Yi & Jeon [48], Lu & Hsiao [39], and Hsiao [49], stated that perceived reward has a positive effect on purchase intention. The proposed hypothesis is:

H4: The higher the perceived economic value, the higher the intention to buy online game product attributes.

2.5. Purchase intention

The theory of planned behavior conceptually explains that intention is the best predictor of behavior. The intention is also the closest intermediary to behavior. Purchase intentions contribute positively to online buying behavior [50]. Bae [51] explained that intention is a good intermediary for various antecedents in explaining behavioral mechanisms for game products. The intention is also a good antecedent for the behavior of buying virtual products across generations [52]. The theory of planned behavior explains that intention is an intermediary for several motivational factors to behave [53, 54]. Users who have the intention to buy will have a great tendency to buy game products. The proposed hypothesis is:

H5: The higher the purchase intention, the higher the buying behavior of online game product attributes.

The relationship between variables in the study that includes a schematic relationship between emotional, quality, social and economic value variables with purchase intention and purchase behavior is shown in the research model. A research model that includes the entire hypothesis is shown in *Fig. 1.*

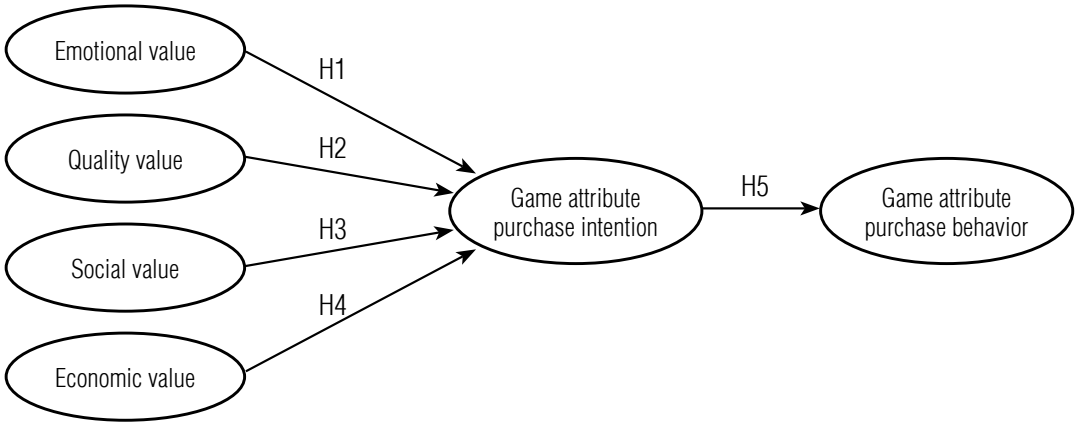

Fig. 1. Research model.

3. Methodology

This research uses a post-positivistic paradigm or hypothesis testing. We use a survey design in data collection and correlational research that relates the independent and dependent variables. The sample in this study is several online game users grouped by gender. Samples were taken from several online gaming communities in Indonesia, involving 426 respondents. The variables in this study consisted of perceived value variables, namely emotional, quality, social, and economic value as determinant factors for game attribute purchase intention and purchase behavior. Perceived value variables were measured by a questionnaire adopted by Lu and Hsiao [39]. The emotional value is an assessment based on feelings or emotions from mobile games [39]. Emotional value in online games refers to the aspect of perceived playfulness. Quality or performance value is defined as the player's perception of performance with the quality obtained from mobile games [39]. Quality value refers to the perceived access flexibility obtained by game users. The social value variable is defined as the benefits obtained from mobile games through social interaction between players [39]. Connectedness is a proxy for social value in interacting online. According to Lu and Hsiao [39], economic value refers to the way individuals assess the value of a product based on the quality obtained versus the sacrifices given. Economic value has a proxy that reflects this value in perceived reasonable price and perceived reward. The perceived good price variable is a component to measure the level of individual sacrifice in getting the desired goods or services. At the same time, the perceived reward is a reward the user obtains. Purchase intention is a person's purchase intention that can change due to the individual's perception of the product [55]. The buying behavior variable is buying a product or a form of actual purchase. Data was collected in a survey using a Likert scale adapted by several researchers. Instruments regarding the variables of purchase intention and purchase behavior were adopted from Hsu & Lin [55], Hsiao & Chen [16], and Davis [56]. Data were analyzed using Structural Equation Modeling. The analysis was carried out based on the analysis of the model in the male and female groups.

4. Results and discussion

4.1. Demographics

The total number of respondents in this study amounted to 426 respondents. The characteristics of respondents are categorized in terms of

gender, age, habit, and game experience. The following is a summary of the description of the characteristics of respondents based on gender, age, habit, and experience, which is presented in *Table 1*.

Based on the data, we found that there were 224 or 53% male, while females were as many as 202 or 47%. Based on age category, most respondents were 17–23 years, as many as 192 or 45%. Based on the habit or playing habits seen from the duration of time per day, most respondents played for 1–3 hours per day, which was 152 or 36%. Based on the experience aspect, it is known that most respondents are at the 3–5 year level, namely 143 or 34%.

4.2. Validity and reliability

The results of the validity and reliability tests using factor analysis and composite reliability are presented in *Table 2*. The value of standardized loading of each indicator (λ_i) and the value of the error variance associated with each indicator (ε_i) are used to determine the value of composite reliability and variant extraction per variable.

Based on *Table 2*, it can be seen that the factor loading coefficient of each indicator of each variable is valid. Decision-making regarding the suitability between the latent and observed variables is determined by the

Table 1.

Characteristics of respondents

Characteristics	Item	Frequency	%
Gender	Male	224	53
	Female	202	47
Age (Years)	<17	118	28
	17–23	192	45
	24–29	69	16
	30–35	37	9
	> 35	10	2
Habit (play time per day)	< 1 h	98	23
	1–3 h	152	36
	3–5 h	89	21
	> 5 h	87	20
Experience (mobile game per year)	< 1	93	22
	1–3	116	27
	3–5	143	34
	> 5	74	17

Table 2.

Composite reliability and variant extraction

Variable	λ_i	ε_i	Composite reliability	Variant extraction
Emotional value			0.93	0.81
Convenience	0.91	0.83		
Happiness	0.89	0.79		
Calm	0.87	0.76		
Playfulness	0.93	0.86		
Quality value			0.95	0.85
Performance	0.92	0.85		
Flexible	0.93	0.86		
Accessibility	0.91	0.83		
Functionality	0.92	0.85		
Social value			0.93	0.82
Interaction	0.89	0.79		
Communication	0.87	0.76		
Connectedness	0.93	0.86		
Social value	0.92	0.85		
Economic value			0.90	0.76
Suitability	0.87	0.76		
Affordability	0.86	0.74		
Appropriate rewards	0.91	0.83		
Fairness	0.84	0.71		
Online game attribute purchase intention			0.94	0.83
Desire to use	0.88	0.77		
Desire to find information	0.93	0.86		
Urge to buy	0.94	0.88		
Plan to buy	0.9	0.81		
Online game attribute purchase behavior			0.95	0.84
Decision	0.93	0.86		
Actual purchase	0.96	0.92		
Intensity of buying	0.91	0.83		

criteria for the minimum factor loading value of 0.5. Composite reliability for each variable ranges from 0.90–0.95; it is above the acceptance value of the reliability limit of 0.7. The variance extraction value is at the level of the acceptance limit, which is a minimum value of 0.5. Variations of values ranged from 0.76–0.85.

4.3. Goodness of fit results

The research model was tested based on the goodness of fit test using chi-square, CMIN/DF, GFI, AGFI, RMSEA, TLI, CFI, and ECVI. The overall model test results are summarized in *Table 3*.

Table 3 shows that the overall research model is fit. The Chi-square value with a probability > 0.05 indicates the overall goodness-of-fit model. The recommended level of significant acceptance is $p = 0.05$, which means that the actual and predicted input matrices are not statistically different or fit. In addition, the results are reasonable criteria after testing the suitability of the RMSEA, GFI, AGFI, TLI, CFI, and ECVI values compared to the cut-off value of the structural model equation.

The causality test of the model in this study was grouped into two parts, namely causality in the male and female groups.

4.4. Model causality test – Gender group

Model analysis was carried out separately based on male and female groups. The results of the model causality test in the male group are graphically reflected in *Fig. 2*. The results of the regression weights between latent variables, often referred to as estimated loading factors or lambda values, can be used to analyse variable causality tests. Based on the significance of the *t*-value or CR (Critical Ratio) with a probability value $p = 0.05$. The results of the causality test regression weights for the male group are summarized in *Table 4*.

Table 3.

Goodness of fit

Index	Cut off Value	Result (male)	Result (female)	Model Evaluation
Chi square	Close to 0	92.832	91.221	Good
Probability	≥ 0.05	0.102	0.098	Good
CMIN/DF	≤ 2.00	1.112	1.003	Good
GFI	≥ 0.90	0.932	0.921	Good
AGFI	≥ 0.90	0.952	0.935	Good
RMSEA	≤ 0.08	0.023	0.034	Good
TLI	≥ 0.90	0.977	0.963	Good
CFI	≥ 0.90	0.972	0.952	Good
ECVI	*Default model < saturated model*	0.811 < 1.216	0.716 < 1.241	Good

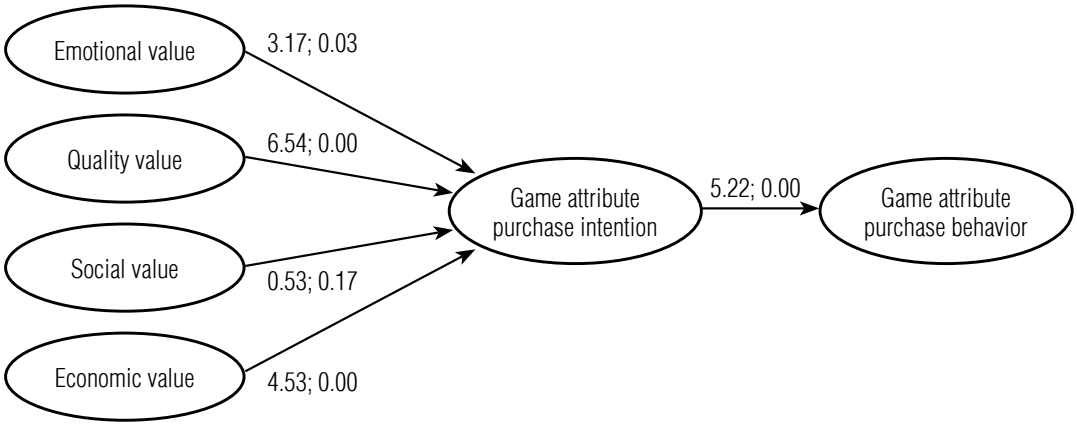

Fig. 2. Path Model – Male.

Table 4.

Evaluation of regression weights – Male group

Hypothesis	Variable	Estimation	CR	P	Conclusion
H1	Emotional value → Purchase intention	0.212	3.17	0.03	Supported
H2	Quality value → Purchase intention	0.477	6.54	0.00	Supported
H3	Social value → Purchase intention	0.018	0.53	0.17	Unsupported
H4	Economic value → Purchase intention	0.319	4.53	0.00	Supported
H5	Purchase intention → Purchase behavior	0.451	5.22	0.00	Supported

Based on the evaluation of the regression weights in *Table 4*, it can be explained that for the male group, there is an influence of emotional value variables on the purchase intention of online game attribute products with a coefficient of 0.212 and a probability of 0.03, which means H1 is supported. The quality value variable significantly affects purchase intention with a coefficient of 0.477 and a probability of 0.00, which means H2 is supported. The social value variable has no significant effect on purchase intention of online game attribute products with a coefficient of 0.018 and a probability of 0.53, which means H3 is not supported. Economic value influences purchase intention of online game attribute products with a coefficient of 0.319 and a probability of 0.00, which means H4 is supported. The purchase intention variable significantly influences purchase behavior with a coefficient of 0.451 and a probability of 0.00, which means H5 is supported.

The results of the causality test model showing the relationship of emotional, quality, social and economic value in the female group are graphically shown in *Fig. 3*. The results of the causality test regression weights which consist of estimated values, critical ratios, and probability for the male group summarized in *Table 5*.

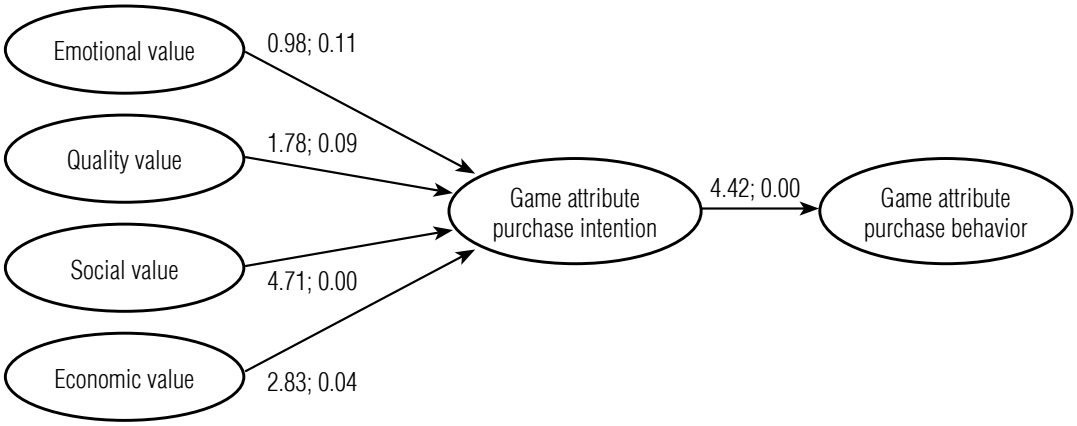

Fig. 3. Path Model – Female.

Based on the model test for the female group in *Table 5*, it can be seen that the emotional value variable has no significant effect on the purchase intention of online game attribute products with a coefficient of 0.086 and a probability of 0.98, which means H1 is not supported. The quality value variable has no significant effect on purchase intention in the female group with a coefficient of 0.091 and a probability of 0.09, which means H2 is not supported. The social value variable significantly affects the purchase intention of online game attribute products with a coefficient of 0.322 and a probability of 0.00, which means H3 is supported. Economic value significantly affects the purchase intention of online game attribute products with a coefficient of 0.127 and a probability of 0.04, which means H4 is supported. The purchase intention variable significantly influences purchase behavior with a coefficient of 0.403 and a probability of 0.00, which means H5 is supported.

Based on the study of the two models between males and females, it can be seen that in the male group there is only one hypothesis that is not supported: the role of social values is different from the female group, which prioritizes this aspect. There are two unsupported hypotheses in the female model, namely the role of emotionality and quality value on purchase intention, which differ from the male

Table 5.

Evaluation of regression weights – Female group

Hypothesis	Variable	Estimation	CR	P	Conclusion
H1	Emotional value → Purchase intention	0.086	0.98	0.11	Unsupported
H2	Quality value → Purchase intention	0.091	1.78	0.09	Unsupported
H3	Social value → Purchase intention	0.322	4.71	0.00	Supported
H4	Economic value → Purchase intention	0.127	2.83	0.04	Supported
H5	Purchase intention → Purchase behavior	0.403	4.42	0.00	Supported

group. The female users prioritized social values in buying online game attributes compared to males.

4.5. Discussion

Perceived value has a significant role in a company's competitiveness. Put another way, perceived value can be considered a source of competitive advantage [10]. Management of perceived value can be part of the consideration to influence consumer decisions. Perceived value follows its benefits as consumers perceive value regarding the benefits of the products used [16, 39]. Lovelock and Wirtz [28] state that perceived value is the value customers get by comparing perceived benefits with perceived costs. Perceived value can positively correlate with the benefits or by reducing required sacrifices [57]. If the perceived value is positive, it will encourage customers to feel the value obtained is better [58]. An increase in perceived value is when consumers want to benefit from the product. Higher perceived value can influence consumers to make purchase intentions in the future. The descriptive data also shows that respondents are dominated by respondents who have a long enough time spent, implying that consumers feel profoundly benefited by playing games online.

Emotionally, the value obtained by consumers, especially in online games, can be a sense of comfort. In online games, male consumers prioritize this aspect more than women [59]. The joy when interacting with other people in the game world is a strong impetus for men to pay for intention. The role of comfort in the intention to buy game products is reinforced by the findings of Lee [53]. Value-based on comfort is a reason that can partially explain why males are more interested in online games than females [60].

In general, Snoj [61] stated that the benefits could be measured from the quality perceived by consumers to feel more satisfied if the quality perceived by consumers is higher than expectations. Consumers who feel quality suitability will intend and are willing to pay or encourage an actual purchase. Wei and Lu [41] stated that players could freely determine the time and place to play so that it is a value that is considered in playing the game. The form of freedom obtained is a value of control over behavior. Hsiao and Chen [16] found that quality value positively affects purchase intention. The online games are designed with an easy-to-access platform related to the quality of the platform. The value of quality proxied through freedom of access is preferred by male buying game attributes. These findings are based on the consideration that men attach importance to aspects of freedom [62] from the aspect of time and access, so males tend to be more aggressive than females towards online games [63].

Schiffman and Wisenblit [64] reveal that social value encouraged being accepted in the environment and appreciated socially. Gounaris [65] explains that social motivation encourages purchasing a product to increase social values such as image, give a good impression, and provide social approval. Social motivation is formed because of the desire to be more accepted and appreciated in an unfulfilled environment. Interaction is a basic need, especially for females, so this value tends to be prioritized over men. According to gender socialization theory, females respond to something [66] and prioritize social identity more than males [38].

The customer's perceived value depends on the suitability of the price with consumer expectations. The magnitude of the economic value can affect the customer's perception of the economic value of the product obtained and the price to be paid. Price assessment is relative or depends on the customer's perception of receiving the product, so there is no definite benchmark in the level of consumer acceptance that brings consequences to pur-

chases [64]. Male and female consumers have the same perception of this economic value in purchasing online game attribute products. The primary consideration of users in playing games is the suitability of the monetary costs incurred with the satisfaction obtained [67] to encourage purchases [41].

5. Conclusion and suggestion

Determining online games' competitive advantage and product development can consider differences in values based on gender characteristics. The resistance to technological product innovation is highly dependent on the perceived value [68, 69]; therefore, understanding users' perceived value is expected to overcome the barriers to digital product innovation. Overall, this research finds that perceived value which consists of emotional, quality, social and economic value, influences purchase intention and ultimately shapes the buying behavior of online game product attributes. There is a difference in each component of perceived value on purchase intention between male and female groups. There are differences in emotional, quality, and social value on purchase intention between male and female groups. Emotional and quality values do not affect the female group's pursuit intent, while social values do not significantly affect the male group. This finding emphasizes the need for in-game treatment attributes between males and females. Socially, women are more concerned with social values in interacting online so that the specific interactive level of women's groups can be considered better. The male group enjoys a comfortable atmosphere while playing online games and likes the freedom to access online games, so online game developers can consider this aspect, such as product attributes that support comfort during playing. This research is also inseparable from several limitations, such as samples taken only in Indonesia, which has a different cultural perspective from other countries. Culture is also part of game behavior [70]. Hashimoto [71] explains that culture has a role in shaping gamers' attitudes. Future research can expand the sample and examine cultural aspects to enrich these findings. ■

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A method for identifying conflict relations between business process subjects based on paired correlations of mutual assessments

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Abstract

In this paper, a method of identifying conflict relations between the subjects of business processes is presented. The proposed solution seems quite important due to the high sensitivity of modern high-tech enterprises' business processes to negative factors, as well as the need to develop correct management decisions in conflict situations. A company's ability to identify internal conflicts and to take them into account during management decision-making is a feature of an effective business process. Modern methods of conflict detection that are available for practical use are able to identify conflict situations only at the stage of open conflict. In this case, the impact of the conflict on the business process is already material and may lead to deterioration in the company's performance. Unfortunately, existing methods have a significant disadvantage: they are not able to identify conflicts at an early stage, when the impact of the situation on the business process is not noticeable. An innovative approach based on analytical processing of survey-based data is proposed. This approach is able to identify hidden conflicts among employees of the enterprise. Identifying a conflict situation at an early stage makes it possible to manage conflict and reduce subsequent financial loss.

Keywords: conflict situation, survey-based data analysis, personnel conflict management, hidden conflict

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Introduction

A distinctive feature of high-tech companies is high concentration of human intellectual resources. Business processes of modern high-tech enterprises are determined (among other things) by the absence of contradictions among employees regarding their interests, goals, views, etc., that is, by the absence of conflict situations. The relevance of identifying conflicts among employees is only increasing [1]. This article presents a data analysis method for implementing a new approach for identification of hidden conflict situations. We will consider a conflict situation as not only the demonstrations of disagreement, contradictions in opinions, but also as a deviation from usual relationships among employees in the business process. Risk management describes such deviations as risks that lead to financial losses in the business process [2]. Of course, such financial losses reduce the company's profit.

Companies do not have many tools to identify conflict situations among employees. There are technical tools used for individual psychophysiological studies, also called a "polygraph" or "lie detectors." The advantages of the "polygraph" include the possibility of detecting conflicts among employees at a hidden stage [3, 4]. However, the significant cost of such studies does not allow them to be applied on a massive scale throughout the enterprise. Modern statistical methods of conflict detection are suitable for mass use. However, they have a significant disadvantage due to the inability to identify conflict situations at the stage of hidden conflict, i.e. when the risks of conflicts have not yet been fully realized and the losses from them are insignificant [5]. This means that the methods of conflict detection used so far do not allow us to minimize the cost of risky losses and lead to deterioration of a company's economic indicators. Modern methods applicable for identifying conflict situations are based on the survey data – assessment of an employee by his colleagues. However, this approach does not make it possible to identify conflict situations at an early stage of the conflict development.

1. The aim and objectives of the study

The aim of this study was to develop a method for identifying conflict situations among personnel at an early stage. The objective of the research was to develop a method that is able to identify conflict situations between subjects of business processes at an early stage (i.e., even during their hidden phase) in order to reduce risks to business processes associated with employees' relationships and thereby to reduce financial losses.

The method should identify conflict relations between certain pairs of participants, preventing the extension of a conflict situation, the involvement of other participants and the growth of the conflict into the open stage associated with financial losses.

2. Current state of the problem

Modern conflict researchers have identified as essential the role of conflicts both at the level of the production process and at the level of the

nation. Antsupov [6] justifies the thesis that at the country level, social and intrapersonal conflicts represent one of the main implicit factors of state defeats. Thus, he makes a conclusion regarding the importance of a comprehensive study of conflicts to ensure Russia's security.

The authors of [7] formulated the problem in this way: on the one hand, there is a need to manage conflicts among staff, and, on the other hand, personnel and social methods and technologies for their prevention are not effective enough. According to the study [8], 32% of employees of industrial enterprises reported that conflict situations periodically arise in their companies.

Moreover, interpersonal conflict is perceived as a situation of confrontation and a tangible psychological problem [9].

An important aspect is segmentation of conflicts into life cycle stages. In [10], the following stages are formulated: latent, the beginning of open conflict interaction, escalation of open conflict and conflict resolution. In our opinion, prevention of open conflict, i.e. its identification at the latent stage and its resolution, is a promising direction. Let us pay attention to the fact that during the latent period, a conflict situation arises and develops without explicit awareness by future participants, as well as without recognition of the conflict situation by at least one of the participants. It should be noted that the pace of identifying a conflict situation even in the phase of occurrence (i.e. without explicit awareness by the participants) is of paramount importance for making management decisions.

Among the founders of classical studies in the field of interpersonal relations, we can mention Jacob Moreno [11], who formed a new direction of knowledge – sociometry. This direction allows quick and technically simple quantitative assessment of the main characteristics of a group of interpersonal relationships. Sociometry is actively used to study relationships in sports teams [12], where a conflict-free psychological atmosphere is a prerequisite for successful performance at competitions. Among the methods used, the evaluation of teammates method and the method of selecting the most preferred partners are widely used.

The sociometric methodology is a base for the modular methodology of diagnosing interpersonal conflicts [13]. According to this methodology, the attitude towards employees from each of their colleagues is evaluated. Comparison of the responses forms a list of the most and least conflicting participants. Meanwhile, formation of the conflict index in a pair is based on the addition of evaluation points.

On the one hand, modern conditions of informatization form new circumstances and prerequisites for conflicts to arise and escalate. On the other hand, informatization makes it possible to use modern information technologies to study conflicts and accelerate the development of conflictology.

Among the approaches in the field of experimental data processing, it is worth mentioning the Analytical Hierarchy Process (AHP) method, proposed in the 1980s by Thomas Saaty [14]. The author developed a scientifically justified decision-making method based on hierarchical structures and making judgments. Saaty considers it reasonable to use scales of absolute values that reflect the superiority level of one element over another.

According to Saaty [14], selection of weights and criteria for formation of final rating is an important task. The development of reasonable management solution should be segmented into the following stages:

- formulating the task and determining the type of data required;
- establishing the aim construction of appropriate decision hierarchy through intermediate levels (criteria on which subsequent elements depend) to the lowest level;

- construction of a set of pairwise comparison matrices, where each element in the upper level is used to compare elements at the level directly below with respect to it;
- calculation of weights for each element, as a result of comparisons.

It is important to choose a measurement scale that demonstrates the predominance of one element over another regarding the criterion selected. For example, Saaty demonstrates a scale for comparing the relative consumption of beverages in the United States and considers it appropriate to use the inverse value of the parameter. The results of using the AHP method allowed him to discover preferences in consumption of beverages and provided reliable information for management decisions when planning procurement volumes.

Saaty also applied his method in making management decisions in the field of employment. The result of his research was selecting the direction of activity after obtaining a scientific degree – working in corporate business or teaching at school or university. In Saaty's works, it is also shown that using the geometric mean rather than the frequently used arithmetic mean is more appropriate in such models. Saaty justifies this by the fact that the survey subjects (in fact, experts) are not always ready to formulate their judgments, but are only ready to present the final results obtained by their own hierarchies. For such cases, the geometric mean of the final results should be used. Since the survey subjects have different subjective priorities regarding parameters importance, the results of their judgments should take into account the subjective priority, and after that the geometric mean is formed. Consideration of the relationship between events using the AHP model was carried out by Saaty in another paper [15], where the authors examined the mutual influence of gains and losses. A pairwise comparison of events was carried out, and they proved the need of using correlation dependencies in the AHP model. Comparison of the model results and actual data showed a high coincidence (85.10%) [15].

In fact, the model [14, 15] already uses correlation dependencies. However, the model [14] does not make it possible to identify conflicting pairs of subjects of a survey.

The AHP method was developed in the study of Nishizawa [16], where the author proposes to expand the pairwise comparisons of the AHP analytical hierarchy process and points out the limitations of traditional AHP. The author explains that there are limitations in traditional AHP, such as the reciprocity property of elements in the pairwise comparison matrix. Based on the matrix of non-reciprocal evaluation by mutual evaluation, Nishizawa proposes a method for solving the evaluation matrix to obtain a perfectly consistent eigenvector. In this method, the values of the resulting eigenvector are greater even if the smaller value of the estimate is more important. In addition, for making a management decision, a final evaluation vector is presented, combining the results of a well-conditioned vector and a poorly conditioned vector. One example is mutual evaluations of students' work. The assessment was carried out according to 10 criteria, and the total maximum score was 50 points. The assessment of each student was executed by his fellow students. In this paper, the method of mutual evaluation with comparison in AHP is considered. The proposed method was built on the basis of the author's previous research [16].

The practice of using correlation and mutual assessments is considered to be a modern approach to increase the level of objectivity and accuracy of processing survey data. In the reviewed works of leading experts in this field [14–16], no solution is proposed to identify conflict pairs. So, the task formulated, as well as approaches to its solution, have a certain scientific novelty and the possibility of further development.

The method considered is based on mutual assessments of survey subjects– cross-correlations. The scoring approach in the evaluation system is a traditional approach and reflects only the subjective opinion of a particular subject by other subjects. To identify a conflict, the difference between a specific parameter value and the average among other subjects must be significant, otherwise it will not be fixed. To increase the accuracy of the model, it seems appropriate to increase the number of respondents, i.e. the subjects making the assessment. However, this measure will not lead to an increase in the model sensitivity, rather the opposite. An increase of the survey subjects sample size will affect only the accuracy of the conflict level, but not the sensitivity of the model to availability of hidden conflicts. Such an approach may be considered as traditional in the field of personnel evaluation, but it does not allow us to answer the question, which pairs of subjects are in conflict due to the fact that the evaluation of one subject among all his colleagues will not be distinguishable.

To increase the sensitivity of the model to the existence of a conflict situation, it is necessary to develop criteria that will reflect the level of conflict between two certain subjects. This parameter seems the most important one, because it characterizes the ability of the model to detect a conflict situation at its early stage. The question of choosing a criterion for evaluation is fundamental [14]. We will formulate a number of requirements for criteria to identify hidden conflicts based on data of surveys conducted among employees. The first requirement is that the criteria must be objective, i.e. formed on the basis of survey data. Secondly, the criteria should have a high sensitivity to the conflict pair, i.e. distinguish it from all possible combinations. The third requirement is that the criteria should not to be influenced by strong deviations (errors) in the survey data.

3. Description of the method proposed

The basis for the study is an array of data of mutual assessments of the business process subjects. This means that each subject evaluates all other subjects, and a two-dimensional array of data is formed according to the number of subjects. The resulting matrix $A = \{a_{ij}\}$ represents the survey result. Any rank scale can be used for the evaluation model (selection of the scale for the model is an additional task that is not examined in the current paper).

For a conflict situation to arise, the presence of at least two participants is necessary. This condition of conflict occurrence will be used for creation of a new approach. We consider it reasonable to use cross-correlation criteria, i.e. criteria that characterize distinctive features of the relationship between subjects in a particular pair. We also assume that the value of a criterion for assessing the participants in the conflict significantly differs from all other assessments of the subjects, thereby allowing us to identify even minor deviations in the relationship between two subjects. It becomes possible to identify a "hidden conflict" when the level of confrontation between the two subjects is not significant yet.

Let a_{ij} be the value of estimates of the i-th subject by the j-th subject, and $a_{ij} \in [0,1]$, $i, j = 1, ..., n$, where n is the number of subjects.

As was mentioned above, different scales may be used for mutual evaluation of the subjects, thereby simplifying or complicating the level of the evaluation stage. For example, when using the simplest binary rating system (1 or 0), subjects should form their opinions at the level of "positive or negative" ("like/dislike"). However, this approach excludes from consideration various intermediate values of opinions and, despite its simplicity, is not applicable in this case. We consider it reasonable to use at least five assessment levels. Further on, we will consider the estimates in a normalized form (using the [0, 1] range).

Following the requirement of the need to estimate the relationship between the two particular subjects, we form criteria based on a simple multiplication of the values a_{ij} and a_{ji}. Alternatively, we may use values $(1 - a_{ij})$ and $(1 - a_{ji})$ to represent the level of negativity between two subjects.

The level of conflict between two subjects based on their mutual assessments can be determined by the following formula:

$$R_{ij}^{(1)} = a_{ij} a_{ji}. \quad (1)$$

Low values of the function $R_{ij}^{(1)}$ indicate a mutually low assessment of the subjects and may be considered as an indicator of a conflict situation between them. Choosing a functional for $R_{ij}^{(1)}$ as a simple multiplication meets the above mentioned requirements to the model: the objectivity of the criterion and high sensitivity. This dependence makes a significant difference in the case of mutual negative assessments. This form allows us to avoid mistakes in the case when one subject evaluates another at a low level, while the reverse evaluation is neutral.

However, low value of a_{ij} score may reflect both the negative attitude of subject *i* to subject *j* and be considered as an indicator of the general state of the subject i regarding the criterion being evaluated. It means that the function (1) will be subject to error, which is formed relying on the general condition of one of the subjects of the pair examined.

To identify a negative attitude, let's consider the mechanism of underestimation:

$$L_i^{(j)} = \begin{cases} A_i - a_{ij}, \text{ if } a_{ij} < A_i \\ 0, \text{ if } a_{ij} \geq A_i, \end{cases} \quad (2)$$

where A_i is the average assessment of the subject by other participants of the business process:

$$A_i = \frac{1}{n-1} \cdot \sum_{l=1, l \neq i}^{n} a_{il}, \quad (3)$$

Then the conflict level can be determined on the basis of underestimation of estimates:

$$R_{ij}^{\prime(1)} = L_i^{(j)} L_j^{(i)}. \quad (4)$$

Both indexes and numerical values can be used as arguments of the model. Formation of the evaluation scale is a special task (this aspect may be studied in subsequent research).

For further considerations, it is necessary to determine threshold values of the criterion.

4. Results (by the illustrative example)

The method proposed was tested as a part of a study to identify conflicts among third year students. We assume that over the years of study in the university, a group under consideration formed certain relations, including cases of latent conflicts [17]. The initial survey data can be presented in various scales and ranges. In our survey, we used a scale from one to ten, where 1 point means the most negative attitude to the evaluated person, while 10 points – the most positive attitude.

Let's convert all numerical estimates into a range of [0, 1] (*Table 1*).

Calculation of cross-correlation coefficients for conflicting pairs (*Table 1*) in accordance with the equation (1) showed that the coefficients values lies in the range from 0.18 to 1.

Identification of conflicting pairs was performed using a simple comparison rule: $R < \gamma$, where R is the criterion used, $\gamma \in (0,1)$ is the threshold applied. In this case, latent conflict pairs were attributed to pairs for which the condition $R_{ij}^{(1)} < 0.25$ is fulfilled. Selection of the conflict boundaries is an another separate task determined by the user of the model relying on expert estimates or on previously observed precedents (it is the task of determining threshold values [18]).

The sample corresponding to the condition $R_{ij}^{(1)} < 0.25$ included 19 pairs of respondents. For

Table 1.

Example of survey data within the conflict management model after conversion

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1	0.2	1	1	0.5	0.7	0.8	0.5	0.5	0.7	0.8	0.9	0.7	1	0.7	0.6
2	0.4	0.8	0.5	0.3	0.1	0.9	1	0.6	0.5	0.6	0.7	0.8	1	0.5	0.5	0.8
3	0.9	0.5	0.9	0.8	0.7	0.7	0.9	0.8	1	1	0.8	0.8	0.7	0.7	0.6	0.6
4	0.8	0.6	0.7	0.7	0.5	0.6	0.7	0.5	0.7	0.7	0.7	0.8	0.7	0.8	0.7	0.7
5	0.5	1	0.6	0.5	0.7	0.8	0.7	1	0.6	0.8	0.5	0.6	0.6	0.4	0.7	0.2
6	0.6	0.7	0.3	0.6	0.5	1	0.8	0.8	0.7	0.8	0.6	0.8	0.7	0.8	0.7	0.6
7	0.8	0.7	0.5	0.8	0.5	0.7	1	0.7	0.5	0.6	0.7	0.8	0.8	0.8	0.8	0.7
8	0.7	0.2	0.4	0.4	0.9	0.9	0.7	0.9	0.8	0.7	0.7	0.7	0.9	0.7	0.6	0.4
9	0.6	0.6	1	0.6	0.7	1	0.8	0.8	1	1	0.8	0.6	0.8	0.7	0.7	0.7
10	0.7	0.5	1	0.9	0.7	0.7	0.7	0.6	0.9	1	0.8	0.7	0.6	0.8	0.7	0.5
11	0.6	0.5	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.7	0.5	0.5	0.4	0.5	0.4
12	1	0.5	0.7	1	0.5	0.8	0.8	0.7	0.7	0.7	0.7	1	0.7	1	0.7	0.7
13	0.5	1	0.4	0.6	0.7	0.7	0.9	0.7	0.8	0.6	0.4	0.9	0.7	0.8	0.5	1
14	1	0.7	0.8	1	0.5	0.6	0.6	0.6	0.8	0.8	0.8	1	0.9	1	0.9	0.9
15	0.8	0.5	0.5	0.8	0.3	0.8	0.9	0.2	0.7	0.6	0.8	0.7	0.7	0.8	1	0.7
16	0.3	0.8	0.4	0.5	0.4	0.4	0.6	0.6	0.7	0.6	0.7	0.6	1	0.7	0.7	0.9

four pairs $0.08 < R_{ij}^{(1)} < 0.1$, three pairs fell into the range $0.13 < R_{ij}^{(1)} < 0.18$, and the remaining 12 pairs lied within the range $0.19 < R_{ij}^{(1)} < 0.25$.

It should be highlighted that for some conflicting pairs, the criterion $R_{ij}^{(1)}$ is not unambiguous. For example, $R_{ij}^{(1)}$ for pairs 5/2 and 16/5 shows an unambiguously conflicting situation: the values of cross-correlation coefficients are 0.10 and 0.08, respectively. Let's consider the initial data for these pairs (*Table 1*). The estimates for these pairs (1 and 0.1 for 5/2, and 0.4 and 0.2 for 16/5) are not unambiguous. We mean that the relationship in a pair of 16/5 can definitely interpreted as a conflict, while in a pair of 5/2 it is too premature to make such a conclusion because mutual scores of 1 and 0.1 do not indicate the existence of a latent conflict. Hence, there is a need to take into account uniformity of the assessments between subjects.

Among simple solutions of nonlinear optimization problems, there is use of so-called penalty functions [19]. Penalty functions allow us

to transform the initial task by introduction of certain restrictions. The idea of the restriction in question is to use a penalty to the original function in such a way that violation of the imposed restriction leads to a change in the function and becomes unprofitable from the point of view of the problem of unconditional optimization.

In the case examined, it is necessary to introduce a function excluding couples from the set of conflicting ones with a significant unevenness:

$$M_{ij} = (a_{ij} - a_{ji})^2, \quad (5)$$

where $(a_{ij} - a_{ji})$ represents the unevenness of estimates.

Application of a penalty M_{ij} can increase the values of the cross-correlation functions $R_{ij}^{(1)}$ of pairs whose mutual estimates are significantly unequal. Increasing the cross-correlation functions value $R_{ij}^{(1)}$ can remove a specific pair from the group of those in conflict.

Taking into account (5), we apply a criterion that takes into account the penalty:

$$R_{ij}^{(2)} = a_{ij} a_{ji} + M_{ij}, \quad (6)$$

$$\text{or } R_{ij}^{(2)} = a_{ij} a_{ji} + (a_{ij} - a_{ji})^2. \quad (7)$$

Application of this criterion to certain data is presented *in Table 2.*

Table 2.

Cross-correlation coefficients for conflicting pairs $R_{ij}^{(2)}$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.00	0.12	0.91	0.84	0.25	0.43	0.64	0.39	0.31	0.49	0.52	0.91	0.39	1.00	0.57	0.27
2		0.64	0.26	0.27	0.91	0.59	0.79	0.28	0.31	0.31	0.39	0.49	1.00	0.39	0.50	0.64
3			0.81	0.57	0.43	0.37	0.61	0.48	1.00	1.00	0.48	0.57	0.37	0.57	0.51	0.28
4				0.49	0.25	0.36	0.57	0.21	0.43	0.67	0.37	0.84	0.43	0.84	0.81	0.39
5					0.49	0.49	0.39	0.91	0.43	0.57	0.25	0.31	0.43	0.21	0.37	0.12
6						1.00	0.57	0.73	0.79	0.57	0.31	0.64	0.49	0.52	0.57	0.28
7							1.00	0.49	0.49	0.43	0.39	0.56	0.73	0.52	1.08	0.43
8								0.82	0.64	0.43	0.39	0.49	0.67	0.43	0.28	0.28
9									1.00	0.91	0.49	0.43	0.64	0.57	0.49	0.49
10										1.00	0.49	0.49	0.36	0.64	0.43	0.31
11											0.49	0.39	0.21	0.48	0.49	0.37
12												1.00	0.67	1.00	0.49	0.43
13													0.49	0.73	0.39	1.00
14														1.00	0.73	0.67
15															1.00	0.49
16																0.90

In *Table 2*, the 0.25 boundary is used to distinguish conflict and non-conflict pairs, as in *Table 1*.

Analysis of the criterion $R_{ij}^{(2)}$ for conflicting pairs shows a significant difference in values from those obtained from other pairs of subjects. Reasonable application of the criterion $R_{ij}^{(2)}$ leads not only to a difference in the number of conflicting pairs from $R_{ij}^{(1)}$. It is important to note the qualitative difference between $R_{ij}^{(2)}$ and $R_{ij}^{(1)}$ due to the ability of $R_{ij}^{(2)}$ to exclude an "inferior conflict," where one of the subjects does not demonstrate any evident hostility to the counterparty. This means that for conflicting pairs of subjects the value of the criterion $R_{ij}^{(2)}$ is meaningful and reasonable.

Figure 1 shows a comparison of the criteria $R_{ij}^{(1)}$ and $R_{ij}^{(2)}$. The criterion $R_{ij}^{(2)}$ is the criterion taking into account the penalty, and it allows us to identify unique pairs of conflicting subjects, i.e. those points that are located below the horizontal line "boundary of non-conflict, equal to 0.25".

Pairs of subjects are lexicographically ordered according to the following principle: (1, 2), (1, 3), ..., (1, n), (2, 3), (2, 4), ..., (n – 1, n), where n is the number of subjects.

The ordinate axis is the value of the criteria, the abscissa axis is the ordinal numbers of k pairs (i, j), which are calculated as follows:

$$k = j + (i-1)n - \frac{i(i+1)}{2}, \qquad (8)$$

where j and i are the numbers of columns and rows of subjects in the array.

The criterion $R_{ij}^{(2)}$ demonstrates good identification capabilities and does not react to situations when one of the subjects evaluates the other one negatively, and the other subject, in turn, evaluates him positively. For example, the subjects of the 2/5 pair evaluate each other's

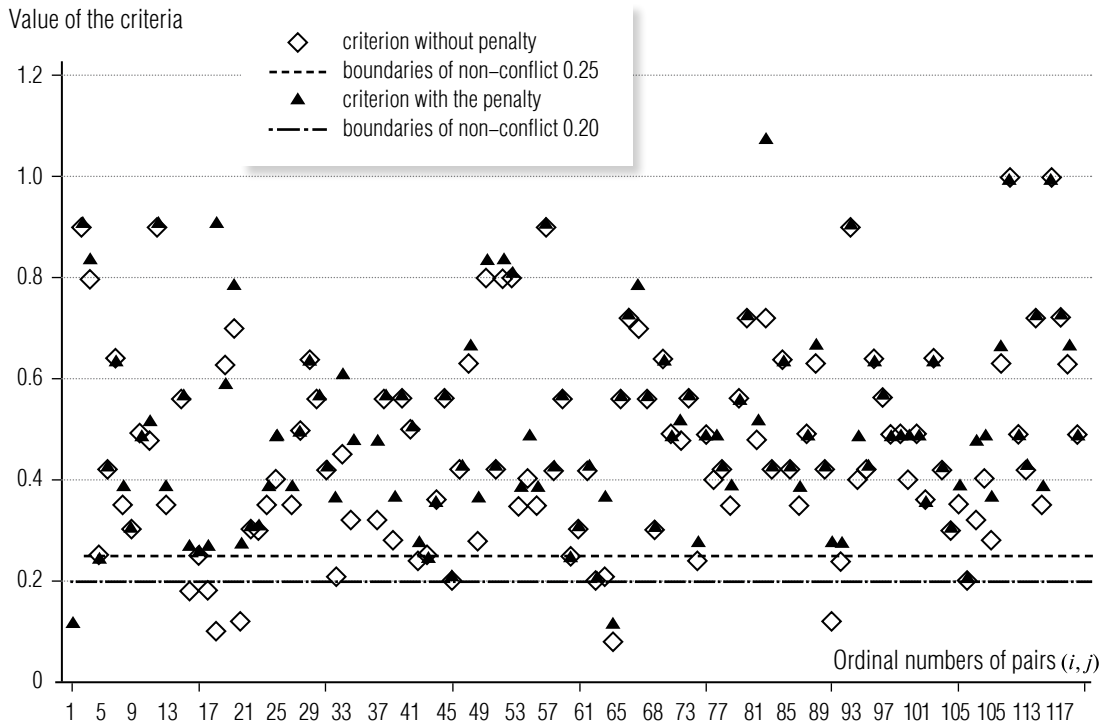

Fig. 1. Comparison of criteria (criterion without penalty) and (criterion with penalty).

conflict level as 0.1 and 1 (*Table 1*), and such a pair should be excluded from the results due to the lack of evidence of a conflict assessment from each subject.

Using the example of these conflict pairs whose level of non-conflict is below 0.25 (*Fig. 1*), there are six such conflict pairs: 1/2, 4/8, 5/11, 5/14, 5/16 and 11/13. Let's consider the mutual estimates of the identified pairs (*Table 1*): 1/2 – 0.2 and 0.4; 4/8 – 0.4 and 0.5; 5/11 – 0.5 and 0.5; 5/14 – 0.4 and 0.5; 5/16 – 0.2 and 0.4; 11/13 – 0.4 and 0.5.

In the case of applying a stronger non-conflict criterion – 0.2, there are only two such conflict pairs – 1/2 and 5/16. In *Fig. 1*, they are numbered 1 and 65 on the horizontal axis, respectively.

The method presented has one more feature – the ability to identify "conflicts of interest" between employees of the company. By conflicts of interest, we mean situations or conditions when an employee's personal interest affects the performance of their job duties. The prerequisites for such personal interest are overly positive and friendly relationships between employees. This means that by identifying extremely friendly relationships between employees, potential conflicts of interest can be identified. As an initial function, we apply the cross-correlation function already discussed above.

In the case of analysis of excessively positive attitude of the studied couples, the criterion $R_{ij}^{(1)}$ presented above can be applied. Since the criterion $R_{ij}^{(1)}$ reveals not negative, but positive mutual assessments of the subjects of the study, there is no need to apply the penalty M_{ij}.

The highest values of the cross-correlation criterion $R_{ij}^{(1)}$ demonstrate an excessively positive attitude between subjects (*Fig. 2*).

When analyzing the results of determining conflicts of interest, we pay attention to the maximum values of $R_{ij}^{(1)} = 0.5$. These values indicate that there exist excessively positive mutual relations between the subjects.

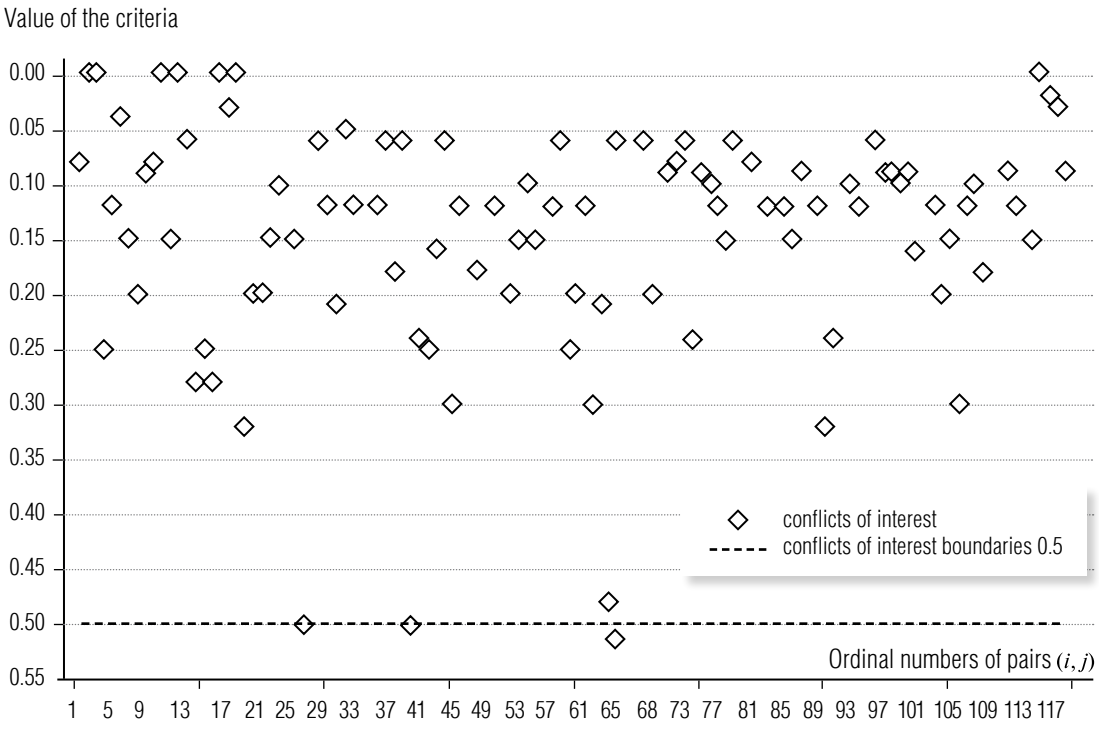

Fig. 2. Results of identifying a conflict of interest according to the criterion $R_{ij}^{(1)}$.

Thus, pairs of respondents with numbers 28 and 41 demonstrate excessively friendly relations, which also need to be taken into account when making decisions in the field of personnel management.

The method presented based on the survey data uses another, different from the traditional, level of determining the functional dependence between conflicting couples. The use of such an innovative tool significantly increases the company's ability to identify conflicts at an early stage, which makes it possible to take into account the information so obtained in the company's strategy [20–25]. By processing the survey data according to the presented model, the user company receives objective information based on up-to-date data.

Modern external conditions, such as the consequences of Covid-19, have a negative psychological impact on the level of conflict within the company. The growth of conflicts between employees of the department is not excluded [21], for which there are no effective tools for an early stage of conflicts.

5. Results and discussion

Let us analyze the results of the study according to the model presented. When determining the effectiveness of the traditional approach, consider the survey data given above (*Table 1*). The average values of each employee's ratings cannot differ noticeably, and this shows the inability of the traditional approach to identify hidden conflicts.

Let us pay attention to works in the field of data processing and analytical models. Above, we have already mentioned the work of Thomas Saaty, who introduced a new scientific method of decision-making based on hierarchical structures and making judgments – the analytical hierarchy process (AHP) [5].

The analytical hierarchy process uses the idea of developing a criterion through pairwise comparisons of data that are based on expert opinions and determining priority scales. These scales are used in relative terms for making managerial decisions.

The method presented and its approbation regarding the survey data of 3rd year students showed its effectiveness. The effectiveness of this method is understood to be the ability to unambiguously identify the most conflicting pairs in relation to which some work should be carried out. In a study of a group of 16 people, one couple was identified that is in a state of latent conflict. The functionality of the method for identifying conflicts of interest has also been confirmed. However, the study revealed certain shortcomings that should become directions for further research.

First, it is necessary to pay attention to the scale used in surveys. On the one hand, the gradation of the scale should be as clear for respondents as possible. Moreover, as a rule, this requirement leads to a reduction in the number of intervals. On the other hand, the accuracy of the study directly depends on the number of intervals, i.e. it is necessary to determine the optimal number of intervals in a survey scale.

Another problem we identified is the increased sensitivity of the method. As a result of application of the method, the most conflicting pairs should be identified. From the point of view of data analysis, the values of the cross-correlation indices for these pairs should differ significantly from the others, thereby facilitating their identification.

Research in the field under consideration shows that using correlation and mutual estimates holds certain promise for increasing the sensitivity and accuracy of models.

Conclusion

The method of conflict situations identification presented in this article uses the processing of survey data by applying cross-correlation

criteria. Such an approach is able to identify exactly conflicting pairs, even in cases when an average assessment of the conflict of a particular subject is not able to do this.

Application of the approach described in the article makes it possible to identify conflict pairs with hidden conflict at the latent stage, when the risk of damage to the business process is still insignificant. On balance, the method facilitates prompt management decisions and significantly reduces potential losses to the company. ■

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