The Modeling of Multi-criteria Assessment Activity in Enterprise Management

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Abstract— **A lot of functions of enterprise management are grounded on the analytical basis that include the models of activity assessment which appears to be multicriteria under the complicated conditions of globalistics. The aim of the study is to improve the mathematical instrument for modeling the multicriteria assessment of enterprise activity. Taking into account the positive practice of using the Balanced Scorecard for assessing enterprise performance, its criteria are structured according to four components and serve for content assessment model. The assessment of enterprise activity based on the Balanced Scorecard mostly accounted for cause and effect interconnections, but this is just its level that influences the assessment.**

The paper presents the improved function of transforming the assessment criteria values and the formula of value calibration. The advantages of this function are flexibility and taking account the regular tendencies of changes in the criteria values. The level of enterprise performance is determined by an integrated index obtained as partial desirability functions folding by gmean. This generalizing desirability function is sensitive to small transformed criteria values that realizes tough requirements to assessment. The developed methodological approach in the modeling of multicriteria assessment of enterprise activity provides for taking into account the main criteria and possibility of their hierarchical systematization. The results of such modeling can be used in the processes of control, controlling and monitoring of this activity.

***Keywords*—** *Balanced Scorecard criteria, function of values transformation, calibration, assessment model, methodological approach in modeling.*

1. Introduction

Under the modern complicated global socioeconomic conditions of enterprise functioning the peculiar feature of its management is taking into account multicriteriality that is realized while developing economic and mathematical models and is provided by these methods' potential. The expediency of this approach is proved by the practice of enterprise management based on the assessment of enterprise activity by means of the Balanced Scorecard system. The Balanced Scorecard (BSC) is supposed to include such components as finance, customers, internal business processes, training and growth and to reflect the main spheres of enterprise activity, namely: financial, production, marketing ones; personnel and innovative and investment activity. The scientific ground for this statement are the studies of Robert S. Kaplan, David Norton published in Harvard Business Review [1]. There are the eight articles published in HBR and six books in which they explain in details their management conception based on the Balanced Scorecard. A great number of works written by these scientists and practitioners were devoted to solving the problems of measuring corporate performance. The complex solution to the problem of measuring corporate performance is given in the works of Paul R. Niven [2] who is a management consultant and noted speaker on the subjects of performance management and the Balanced Scorecard. As both a practitioner and consultant he has developed successful performance management systems for organizations large and small around the globe. Nils-Göran Olve, Jan Roy and Magnus Wetter have also conceptually substantiated solving the problems of assessing enterprise activity with the Balanced Scorecard [3]. Hubert K. Rampersad [4] has offered his own improved version of a Balanced Scorecard system combining it with other

International Journal of Supply Chain Management
IJSCM, ISSN: 2050-7399 (Online), 2051-3771 (Print)

advanced conceptions, i.e. the universal system of performance indices allowing to achieve the results and save the integrality. Marshall W. Meyer [5] substantiated a measurement technique called activity-based profitability analysis (ABPA) suggested as a partial solution, especially to the problem of combining dissimilar measures. ABPA estimates the revenue consequences of each activity performed for the customer, allowing firms to compare revenues with costs for these activities and hence to discriminate between activities that are ultimately profitable and those that are not. In work [6] the purpose of study is to contribute to the understanding of how BSC is developed and applied in evaluating the performance of a Large Local Bank (LLB) in Iraq. The analysis assisted the cause-effect relationships between the non-financial, and the financial dimensions of the BSC. The disadvantage of the work is the conversion of metric data into non-metric data, which reduces the accuracy of the estimate. Known method [7] that will unite a method that combines the practices of the Balanced Scorecard with a method of business models representation – the Business Model Canvas.

But in these and other works on the problem of measuring corporate performance based on the Balanced Scorecard no mathematical instruments are proposed to determine the direct level of the activity.

2. Materials and Methods

Since the assessment of enterprise activity requires unambiguous determination of the level, it is necessary to calculate the integrated index. Due to this indicator, there is a convolution of the system of criteria into one value, which adequately measures the level of activity. Multicriteriality of assessing the enterprise activity is provided by the system of partial criteria. Consequently, on the one hand, the objectivity of the assessment of enterprise activity is provided by the content of the system of criteria that reflect it, on the other hand, by the mathematical method through which the convolution of the system of criteria into one value is carried out. Many scientists have been involved in various types of the modeling of a Balanced Scorecard. Ref. [8] substantiated the proposals concerning the fact that on the basis of the Balanced Scorecard (BSC) concept the program combines imprecise data of business figures with forward and backward computation. Herewith the visualization of the simulation results is done by a Kiviat diagram. The aim of the design is a software tool based on a BSC model and MCMC methods easy to handle. In [9] you can find the results of the study when primary data are used with a large enough sample to meet the maximum likelihood estimation by assessment scale of seven semantic points. This research model is a combination of one- and two-step models. In [10] there is the analysis based on a MCDA approach, where the UTASTAR method is used in order to aggregate the marginal performance of KPIs. The main results of the proposed approach refer to the evaluation of the overall scores for each one of the main dimensions of the BSC methodology (i.e. financial, customer, internal business process, and innovation-learning). The authors of [11] pay close attention to insider driven customization and the definition of causal links. The advantage of the method described in work [12] is fuzzy modeling of the assessment of the efficiency of the central enterprise, which consists of a quantitative assessment of financial results and a qualitative assessment of management performance. Authors of work [13] used different multi-criteria decision analysis methods for ranking of the alternative ERP packages to select a suitable one. Ghosh I., Biswas S. [14] argue that in order to structure the multicriteria problem, we must define three fundamental categories of information: (1) the alternatives/scenarios/options considered, (2) the stakeholders involved, and (3) the dimensions, criteria and indicators for evaluation.

In the modeling of multicriteria assessment of the activity it is necessary to follow the appropriate principles of criteria selection, namely the criteria should: a) reflect the main properties of a modeling object; b) reflect the conceptual nature of an object; c) construct a hierarchical system containing the elementary criteria (obtained as a result of the initial measurement) and complex (formed from elementary) ones; d) be measured on metric and non-metric scales; e) be determined in conditions of certainty and uncertainty; f) be explicit and latent, generalizing and integral. These principles are formulated on the basis of generalization of the material of scientific articles [15], [16].

However, there are some common shortages in modeling the assessment of objects in the economy, namely: a) the problems in developing a scale of standardized values of indices; b) the necessity of taking into account the differences in the impact of individual factors on the overall level; c) the expediency of using both formal and informal procedures based on the preferences of a decision-maker. Many scholars believe that basing on the system of preferences, we can build a more meaningful scale of transformed values of partial indices.

One of the most effective mathematical methods for constructing integrated indices for assessing the objects in various spheres of human activity is the Harrington method [17] for constructing a quality index. When implementing this method, it is necessary to develop desirability scales. This raises the problem of establishing a correspondence between the advantages of empirical and numerical (psychological) systems. Harrington's desirability scale has the fixed reference points that divide the whole scale into intervals, namely: $[0; 0{,}2)$ corresponds to very bad, $[0{,}20; 0{,}37)$ − bad, $[0{,}37; 0{,}63)$ − satisfactory, $[0{,}63; 0{,}80)$ − good, $[0{,}80; 1)$ − very good. It is necessary to correctly correlate these intervals with real intervals of changes in the values for each partial criterion. The Harrington transformation function itself has the following form:

$$Y_{ij} = e^{-e^{-x'_{ij}}} \quad (1)$$

where x'_{ij} is a calibrated value of the i th criterion in the j th period of time. This function is recommended by many scholars and has the benefits of continuity, monotony and smoothness, and at intervals close to [0; 1], its sensitivity is much lower than in the middle zone. This method is discussed by many mathematicians.

There are also other types of transformation functions, such as the logistic function proposed by an American biologist, demographer and economist Raymond Pearl. He was one of the earliest biologists to combine biometric analyses and experimental studies to explore the dimensions of human biology. The function he proposed has the following form [18]:

$$Y(t) = \frac{Y_0}{1 + ae^{-bt}} \quad (2)$$

where $Y(t)$ is the number of population in the unit at the time t; Y_0 is the initial number of specimens in the population; a, b are the constants. The logistic curve begins at the point $\left(\frac{Y_0}{1+a}\right)$, it has a bend point with coordinates $t_k = \frac{\ln a}{b}; y_k = \frac{Y_0}{2}$. The constant a defines the position of the logistic curve in time (shift to the left, to the right), the constant b defines the slope of the curve. These constants are calculated by the formulae:

$$a = \frac{Y_0}{Y_{t=0}} - 1; \quad b = \frac{(1+a)^2}{ay_0}\left(\frac{dy}{dt}\right)_{t=0}. \quad (3)$$

If you know the time of doubling the biological populations $t_{\frac{1}{2}}$, the constant b can be determined by an approximate formula $b \cong t_{\frac{1}{2}} ln \frac{2a}{a-1}$. The logistic function has a great feature: it can clearly distinguish three main periods in the development of a system: 1) period $(0 \div t_1)$ represents the beginning of development, 'youth' (progressive section); 2) period $(t_1 \div t_2)$ corresponds to intensive development, 'maturity' (even area); 3) period $(t_2 \div \infty)$ means extensive development, 'old age' (regression area). If one knows in which of the areas of development the system is at the time of observation, it is possible to use simplified, approximate formulae describing its development. So, for the initial, low values t the development can be described by an exponential function $y(t) \cong \frac{Y_0}{a} e^{bt}$, for high values t at the moment of 'old age' $y(t) \cong Y_0$, i.e. the system approaches to the maximum asymptotically. The experimentally obtained logistic growth function can be used to reveal the internal structure of a system and to find out the mechanism of its development.

There are regular tendencies in changing the values of the criteria that reflect the normal enterprise activity. For example, the regular changes in the values of the criteria for enterprise performance efficiency are increasing, that is, when choosing a transformation function, it is necessary to take into account $x_{ij} \geq x_{j\,min}$. If the regular tendencies in changing the values of the criteria are falling, like the criteria of costs at an enterprise, namely the cost of production, then $x_{ij} \le x_{j\,max}$ is taken into account. It should be noted that there is also a third type of economic criteria with bilateral constraint, namely $x_{j\,min} \le x_{ij} \le x_{j\,max}$.

In the work [19] devoted to the complex assessment of the quality of objects in the economy, simple and quite flexible transformation functions are proposed:

symmetrical two-sided:

$$Y_{ij} = exp\left(-k \cdot \left(\frac{x_{ij}-a_i}{b_i-a_i}\right)^2\right); \tag{4}$$

symmetrical one-sided:

$$Y_{ij} = \frac{1}{1+exp\left(-k \cdot \left(\frac{x_{ij}-c_i}{a_i-c_i}\right)\right)}. \tag{5}$$

Here a_i is the value of the characteristic x_{ij} for which a two-way transformation function is equal to 1 (100%) and a one-way function is not less than 0,95; b_i is the value of the characteristic for which the quality is low, less than 0.05 (5%); c_i is the level allowing to obtain 50% of the quality, i.e. 0,5. The parameter k controls the shape of the curve. It is necessary to admit that according to economists' estimates and experiments carried out by the authors, the best value of this parameter in almost all economic problems is equal to $k = 3$, both for one-sided and for bilateral relations.

On the basis of the generalization of the results of model experiments aimed at constructing transformation functions for solving real problems in the economy, the author obtained the most typical functions of transforming characteristics of socioeconomic systems, which have such peculiar feature as flexibility. For bilateral asymmetric tendencies of the development of a system characteristic, the following transformation functions should be used:

$$Y_{ij} = \begin{cases} exp\left(-3 \cdot \left(\frac{x_{ij}-a_i}{b_i-a_i}\right)^2\right) \; for \; x_i \le a_i, b_i < a_i, \\ exp\left(-3 \cdot \left(\frac{x_{ij}-a_i}{c_i-a_i}\right)^2\right) \; for \; x_i \ge a_i, c_i > a_i \end{cases} \tag{6}$$

where a_i, b_i, c_i are reference values: a_i is the best value of the index x_{ij}, for which the transformation function reaches the largest value of 1 (100%); b_i, c_i $(b_i < c_i)$ are unsatisfactory values of the index x_{ij} (on opposite sides of the best one), in which the transformation function attains the value no greater than 0,05 (5%).

Under the condition of symmetric trends in the development of characteristics, the transformation function attains a new value of 1 (100%) at $a_i = \frac{b_i + c_i}{2}$. The function simplifies to:

$$Y_{ij} = exp\left(-3 \cdot \left(\frac{x_{ij}-a_i}{b_i-a_i}\right)^2\right) \tag{7}$$

or (this is the equivalent)

$$Y_{ij} = exp\left(-3 \cdot \left(\frac{x_{ij}-a_i}{c_i-a_i}\right)^2\right). \tag{8}$$

For unilateral (one-sided types of regular changes in the values of the criteria for assessing the activity, modified monotonic transformation functions of the logistic function type are recommended:

$$y_{ij} = \frac{1}{1+e^{-3\frac{x_{ij}-p_i}{q_i-p_i}}} \tag{9}$$

where q_i is the value of the index x_{ij} for which the transformation function obtains a value of at least 0,95 (95%); p_i is the value of the index x_{ij} for which the transformation function obtains a value of 0,5 (50%). It should be noted here that the level of integrated quality index depends on defining q_i and p_i. That's why assigning the values to q_i and p_i should be weighed and based on the well-known laws in the enterprise economy. The paper [20] considers the gap between theory and practice in economics.

To compare and select the form of the transformation function, the function values should be calculated with the help of formulae (1) and (9) taking as an example the profit of product sales of an enterprise (million UAH), namely PAT (Public Joint Stock Company [21]) 'Turboatom' which is one of the leading turbine plants in the world, specializing in the production of steam turbines for thermal power plants, nuclear power plants, central heating and power plants, hydroelectric power stations, gas turbines, combined cycle gas turbine units for thermal power stations and other power plants equipment (official site Join-stock corporation TURBOATON). It is believed that the higher the value of this criterion of financial activity, the more effective the whole activity of an enterprise. Fig. 1 shows the value of this criterion in 2010–2017.

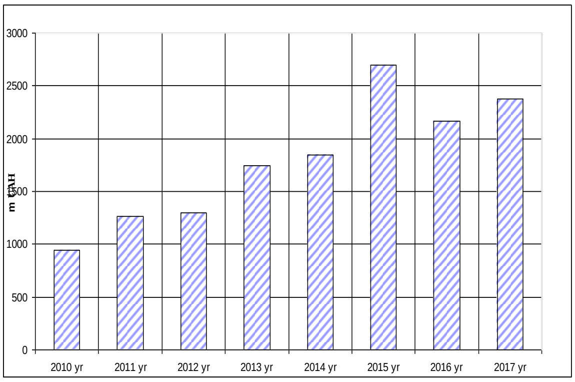

Figure 1. Dynamics of the criterion of product sales profit in Join-stock corporation TURBOATON in 2010–2017

3. Results and Discussion

To compare different functions of transformation of the net operating income index in a company, their values were calculated according to formulae (1) and (9) by quarters annually during the period of 2010–2017 (Fig. 2). Thus in formula (1) the argument was calibrated by the following formula:

$$x' = 3\frac{x_{ij} - p_i}{q_i - p_i}. \qquad (10)$$

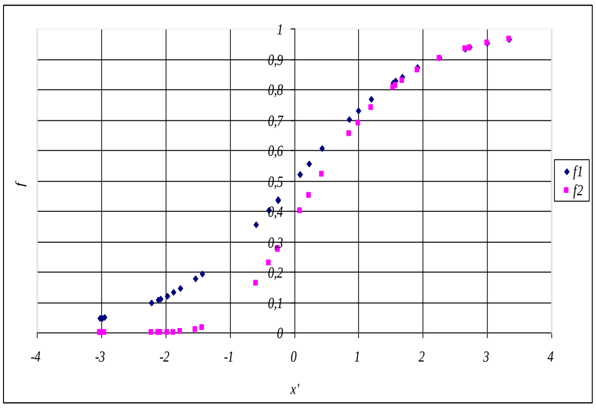

Figure 1. Two types of desirability functions of the criterion of product sales profit, namely: $f1$ – values of the index converted by formula (9); $f2$ – values of the index converted by formula (1)

When choosing the parameters a, b, q_i, p_i, numerical characteristics of the distribution of the criteria values and experts' opinions about the values of parameters were used, namely the average (1,7808), median (1,79182), standard deviation (573,678), coefficient of variation (32,2146%), minimum (932,24), maximum (2,79425) ones, q = 2,69425, p =1,81637.

It follows that the converted values obtained by formula (1) have lower values and the function is sensitive at small values of the criterion; at the same time the function $f1$ passes through the point 0,5. It should be noted that the sufficient and large values of the criterion are almost identical.

Using the improved formula (9) to construct partial desirability functions, all the criteria for the four components of the Balanced Scorecard, namely finance (S_1), customers (S_2), internal business processes (S_3), training and growth (S_4), were transformed. All the regularities of changing the values of partial indices in the Balanced Scorecard system of indices for assessing the performance of industrial enterprises are one-sided, but among them the overwhelming majority are growing, though there are also some declining indices.

Let's consider the calculation of the component of internal business processes of an enterprise, which is reflected by such criteria as: x_1 – return on assets; x_2 – productive efficiency; x_3 – ROI of employees; x_4 – the growth rate of the fixed assets cost; x_5 – the growth rate of production costs; x_6 – the growth rate of administrative expenses. The values of these criteria were the data of 2010–2017. The values of desirability functions of these criteria of the component of internal business processes are shown in Fig. 3. According to the scale of desirability, the dynamics of the criteria of the component of internal business processes of an enterprise during the investigated period varies. The values of such criteria as productive efficiency ($fSX2$), ROI of employees ($fSX3$) are subject to an increasing trend, and the values of the criteria for the growth rate of production costs ($fSX5$) and the growth rate of administrative costs ($fSX6$) have a declining trend. The rest of the criteria have a non-monotonic tendency. For unambiguous determination of the dynamics of the component of internal business processes, it is necessary to calculate the overall level of this component by the integrated index.

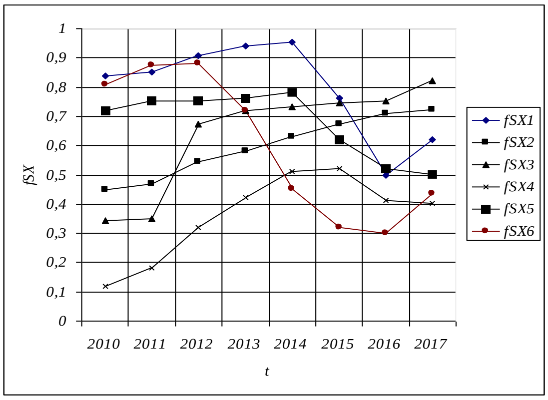

Figure 3. Dynamics of the values of partial desirability functions of the criteria of the component of internal business processes of the Balanced Scorecard

When the scale of desirability is chosen and the criteria of the desirability functions are calculated, the following problem should be solved in the calculation of the integrated index, namely the choice of the form of a function of folding the transformed values of the criteria into one value, i.e. an integrated index which by the Harrington method is called the generalizing desirability function. As for the generalized function of convolution of the transformed values of the criteria into an integrated index, there is no consensus in the views of specialists in economic and mathematical modeling.

It is necessary to point out that the most widespread analytical methods for calculating integrated indices in the economy are the average ones, namely arithmetic mean. Everyone knows the ratio of some types of averages, namely $\bar{x}_{harm} < \bar{x}_{geom} < \bar{x}_{arithm} < \bar{x}_{quadr} < \bar{x}_{cub}$ where $\bar{x}_{harm}$ is the average harmonic; $\bar{x}_{geom}$ is the geometric mean; $\bar{x}_{arithm}$ is the arithmetic mean; $\bar{x}_{quadr}$ is the medium quadratic; $\bar{x}_{cub}$ is the average cubic. As a result of the practical verification of these relationships in measuring the overall level of enterprise activity, it is recommended to use the formula of the mean geometric [22]. In the process of calculating the integrated index by the average geometric of transformed values of the criteria, there is a situation of strict taking into account zero values or values close to zero, that in a product leads to a zero value of the integrated index. In this situation, it should be taken into account that the generalizing function of desirability is sensitive to small transformed values of the criteria. The generalizing function of desirability is a quantitative, unambiguous, unique and universal index of the quality of an object or phenomenon. Its value increases when adding such properties as adequacy, efficiency and statistical sensitivity and it becomes clear that it can be used as an optimization criterion [23].

Fig. 4 shows the dynamics of the integrated index of the component of internal business processes assessment of the enterprise calculated as the average geometric values of partial desirability functions (I) by the formula:

$$Y_j = \sqrt[n]{\prod_{i=1}^{n} y_{ij}} \ . \tag{11}$$

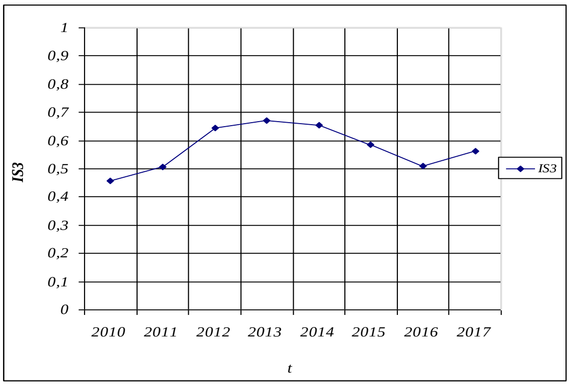

Figure 4. Dynamics of the levels of the internal business processes component of the Balanced Scorecard

In Fig. 4 it is evident that the overall level of the component of internal business processes at the enterprise has decreased in recent years that was not seen by the partial criteria of this component. Fig. 5 shows the levels of all four components of the Balanced Scorecard and the overall level of enterprise activity. In general, while assessing the activities of a company, one can state the growing tendency of its general level, although it has decreased a little bit over the past two years.

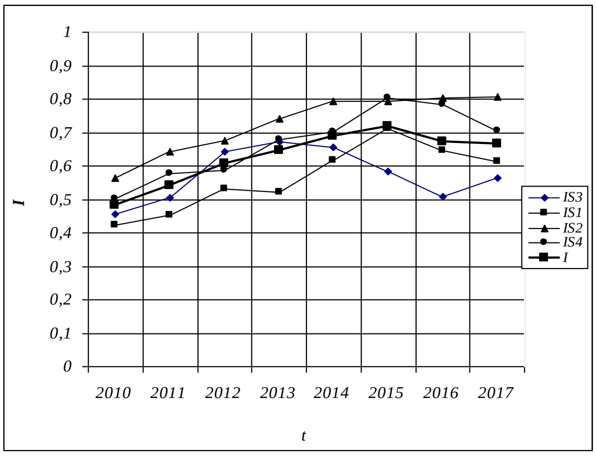

Figure 4. The levels of components of the Balanced Scorecard and the overall level of the activity of Join-stock corporation TURBOATON

One of the fact that proves the efficiency of the proposed approach to multicriteria assessment modeling is the comparison of the trends of one of the main financial criteria of product sales profit in Join-stock corporation TURBOATON (see Figure 1) with the tendency of the overall level of this enterprise activity, which was calculated taking into account many criteria of the four constituents of the Balanced Scorecard during 2010−2017.

4. Conclusion

Thus, when modeling a multicriteria assessment of enterprise activity to ensure its reliability and objectivity, it is recommended to follow the appropriate methodological approach for calculating this estimate. The content of this methodological approach is given in Table 1.

Table 1. Methodological approach to modeling the multicriteria assessment of enterprise activity

Modeling stage	**Method of implementing the stage**	**Expected results**
Systematization of enterprise activity criteria	Balanced Scorecard	System of partial criteria for assessing enterprise activity
Calibration of activity criteria	$x' = 3\dfrac{x_{ij} - p_i}{q_i - p_i}$	System of calibrated criteria
Development of partial desirability functions	$y_{ij} = \dfrac{1}{1+e^{-3\frac{x_{ij}-p_i}{q_i-p_i}}}$	Values of partial desirability functions
Measuring the overall level of enterprise activity estimate	$y_{ij} = \dfrac{1}{1+e^{-3\frac{x_{ij}-p_i}{q_i-p_i}}}$	Integrated index of enterprise activity
Identification of enterprise activity level	Harrington's desirability scale	Assessment of enterprise activity level

A substantiated methodological approach in the modeling of multicriteria assessment of enterprise activity allows: 1) taking into account the main criteria; 2) systematizing the criteria into a hierarchical system; 3) using modeling results for performing the basic functions of enterprise management, namely control, controlling, monitoring over a certain period.

Acknowledgments

The authors would like to thank the research department Simon Kuznets Kharkiv National University of Economics for support in performing the research objectives.

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