Journal of Theoretical and Applied Information Technology
15th January 2023. Vol.101. No 1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

DEVELOPMENT OF MATHEMATICAL MODELS TO DETERMINE THE BALANCE OF THE SYSTEM OF PLATFORM INTERACTIONS WHEN SCALING THE END-TO-END MONITORING PROCESS FOR PRIORITY SECTORS OF THE ECONOMY

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ABSTRACT

Prerequisites for the present study are the emergence and development of new forms of business cooperation in the process of digitalization of society in the form of digital platforms. In scaling digital solutions when entering new markets of relevance is the issue of preserving the balance of the platform interactions system. In view of the complexity of such systems due to the variety of objects and forms of platform interaction, the goal of the study is to develop tools for determining the degree of balance of the platform interactions system in scaling the end-to-end monitoring process for the priority sectors of the economy in the form of mathematical models. The employed research methods include analysis, the parametric method, modeling, and methods of value engineering. The study proposes to consider the presence of a synergistic effect in the assessment of the balance of the system of platform interactions in scaling the end-to-end monitoring process for the priority sectors of the economy. The effect of types of end-to-end monitoring processes on the value of the synergistic effect is considered and a mathematical model for its calculation is proposed. To make informed decisions when scaling digital platforms to other priority sectors of the economy, a mathematical model for determining the imbalance zones of platform interaction is proposed. Considering the performance of the end-to-end monitoring process when scaling digital platforms to determine the flexibility factor, a mathematical model for calculating the design efficiency indicator is offered.

Keywords: *Platform Interaction, End-to-End Process, Monitoring, Mathematical Model, Synergy*.

1. INTRODUCTION

Analysis shows that under the influence of scientific and technological progress due to market development, there arises a need to strengthen the mutual ties between participants in the relationship. This need urges us to analyze and transform the organizational structure of interaction between partners in the market of high-tech products, depending on its life cycle and considering the existing needs [1,2].

The development of digital management technologies has contributed to the formation of new forms of cooperation between participants in different markets in the form of digital business ecosystems [3-13]. In the terms of institutional economics, digital platforms (DPs) are the next generation of intermediary institutions with different formats of interaction [6].

In the meantime, the diversity of objects and subjects of the economic, entrepreneurial, and production activities of platform interaction participants creates the potential for various kinds of interference with its existence and development, specific to both the enterprise or other economic agents in the business ecosystem, on the one hand, and to the entire ecosystem, on the other hand [4]. This issue becomes especially critical with the further development of DPs as they are scaled to new markets. Bearing in mind the complexity of such systems, changes in the value chain, and the black swan theory, the questions of making accurate forecasts of the development of business ecosystems and, therefore, their management remain unresolved, which can lead to an imbalance in platform relationships and, as a result, negatively affect the development of digital systems [14-16].

Despite the existence of several publications on the development of digital systems, the problems of balancing the system of platform interactions in scaling in the b-to-b segment remain understudied.

This work contributes to the study of the balance of the platform interactions system by compensating for the gaps in the existing literature regarding the solution to this issue when scaling digital solutions when entering new markets in the b-to-b segment in relation to scaling the end-to-end monitoring process for priority economic sectors.

In line with the above, the goal of the study is to develop mathematical models for determining the degree of balance of the platform interaction system in scaling the end-to-end monitoring process for the priority sectors of the economy.

2. LITERATURE REVIEW

From the analysis of the sources, it can be stated that an end-to-end process is designed so that the synergy of the interaction of system elements allows achieving the optimal parameters of the results of activity [17-22].

The end-to-end process is a top-level process, where intermediate inputs-outputs of individual processes become steps to achieve the final product. Consequently, the value of the system exceeds the value of its elements, and the value of the end-to-end process product exceeds the value of the individual products of lower-level processes [21-24].

Considering individual processes of an end-to-end process, they either have an independent value, or their value manifests itself only in the process of interaction of the system elements. Individual processes within an end-to-end process can be complementary [25], interchangeable, or independent.

Independent system processes are characterized by the possibility of obtaining similar results both as part of an end-to-end process (system) and outside of it. For example, if an end-to-end process involves the use of an atmospheric pressure measuring device, the latter can produce the result both on its own and in the process of determining atmospheric pressure in the end-to-end monitoring process. Therefore, the value of this individual process as part of the end-to-end process does not increase, meaning that it does not affect the end-to-end process and synergy does not occur.

However, if within the monitoring system the values of pressure in combination with other measured parameters determine the probability of occurrence of a risk event, then the value of the atmospheric pressure measurement process as part of the end-to-end monitoring process increases. In this case, the process of measuring atmospheric pressure becomes complementary, adding to the value of the end-to-end process itself, and therefore this interaction is marked by the appearance of a synergistic effect.

The above suggests the conclusion (statement) that if the functions that involve a separate process within the end-to-end process increase, then the process is complementary. On the other hand, if the functions performed by the individual process as part of the end-to-end process do not increase, this process is independent. Thereby the synergetic effect is determined by the emergence of new functions as a result of combining individual processes into a single end-to-end process.

Individual processes whose value manifests itself only as part of an end-to-end process are also complementary. They too affect the value of the end-to-end process and the appearance of the synergistic effect. For instance, software for predicting the occurrence of a risk event based on measured data as an independent process in predictive analytics does not have value in the absence of devices that provide information for processing. Nevertheless, when included in the end-to-end process, this process gains value, thereby affecting the synergistic effect of the combination.

Interchangeable processes have similar values (results) in isolation, but these values (results) do not add up in the system as part of an end-to-end process. Instead, the greatest value is considered when determining the synergistic end-to-end effect. For example, if the system uses two similar thermo-anemometers or a thermo-anemometer and, say, a weather station, then acting as independent units, each of the two can perform the process of air temperature measurement on its own. However, if the end-to-end process does not require spatial distance between the elements of the air temperature measurement process, the value of this process is considered only once in determining the end-to-end synergistic effect regardless of the number of units.

One exception can be the case when the presence of two or more elements in the air temperature measurement process within the end-to-end process is driven, for example, by the achievement of measurement accuracy, in which case the processes in question are complementary. However, in this scenario, the synergistic effect of the inclusion of these processes in the end-to-end process will still be determined considering only one of them (usually one with the greatest value) plus the added value of achieving measurement accuracy.

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The synergetic process effect can be determined from the combined values of processes in the end-to-end process accounting for their interaction minus the sum of the values of individual processes.

From the above we can conclude that independent processes do not affect the synergetic process effect, complementary processes reduce the value of synergy, and mutually exclusive ones, on the contrary, increase the value of synergy.

3. ASSESSMENTS OF END-TO-END PROCESS SYNERGY

For quantitative assessment of end-to-end process synergy, the value of each process can be considered as a value ranging from 0 to 1. Independent processes will thus have the value of 1. For convenience, it can be noted that mutually exclusive processes in total have an average value of 1 for all processes. As for the complementary processes, depending on their value as a separate process (0 or 1), the total value of 1 is added to them for each additional function in aggregate, being distributed among the complementary processes under consideration based on their contribution to the function in question within the end-to-end process.

However, it would be erroneous not to consider the significance of process functions for a particular end-to-end process when determining the synergistic effect.

The source and/or carrier of any process is a tangible (equipment, device, sensor, disk, etc.) or intangible (e.g., software) object. With its help, certain functions are performed in a separate process.

Using the method of ranking the processes and functions of the end-to-end process, the synergistic effect of the end-to-end process (synergistic end-to-end effect) can be determined based on the types of processes and a value engineering (VE) model (Figure 1).

Processes involved in the end-to-end process are selected from the list or entered. A new end-to-end process can be proposed/initiated both by the supplier and the buyer of equipment and/or software in the framework of scaling DPs for new priority sectors of the economy, or when changes need to be made in the existing markets under the influence of both external and internal environment factors faced by participants in the platform interaction.

The same applies to functions. A function is selected from a list, or a new function is entered for an individual end-to-end process with reference to its source and/or carrier.

Tangible (equipment, device, sensor, disk, etc.) or intangible (e.g., software) objects are entered by suppliers or requested by buyers in connection with end-to-end monitoring processes.

The importance of a process α_r is converted (determined) from the score of each process using the formula:

$$\alpha_r = \frac{b_r}{\sum_r b_r}, \tag{1}$$

where b_r – the importance of process *r*, assessed on a 10-point scale.

The importance of a function within each process *r* α_{rn} is determined similarly:

$$\alpha_{rn} = \frac{b_{rn}}{\sum_n b_{rn}} * a_r, \tag{2}$$

where b_{rn} – the importance of function *n* of process *r*, assessed on a 10-point scale.

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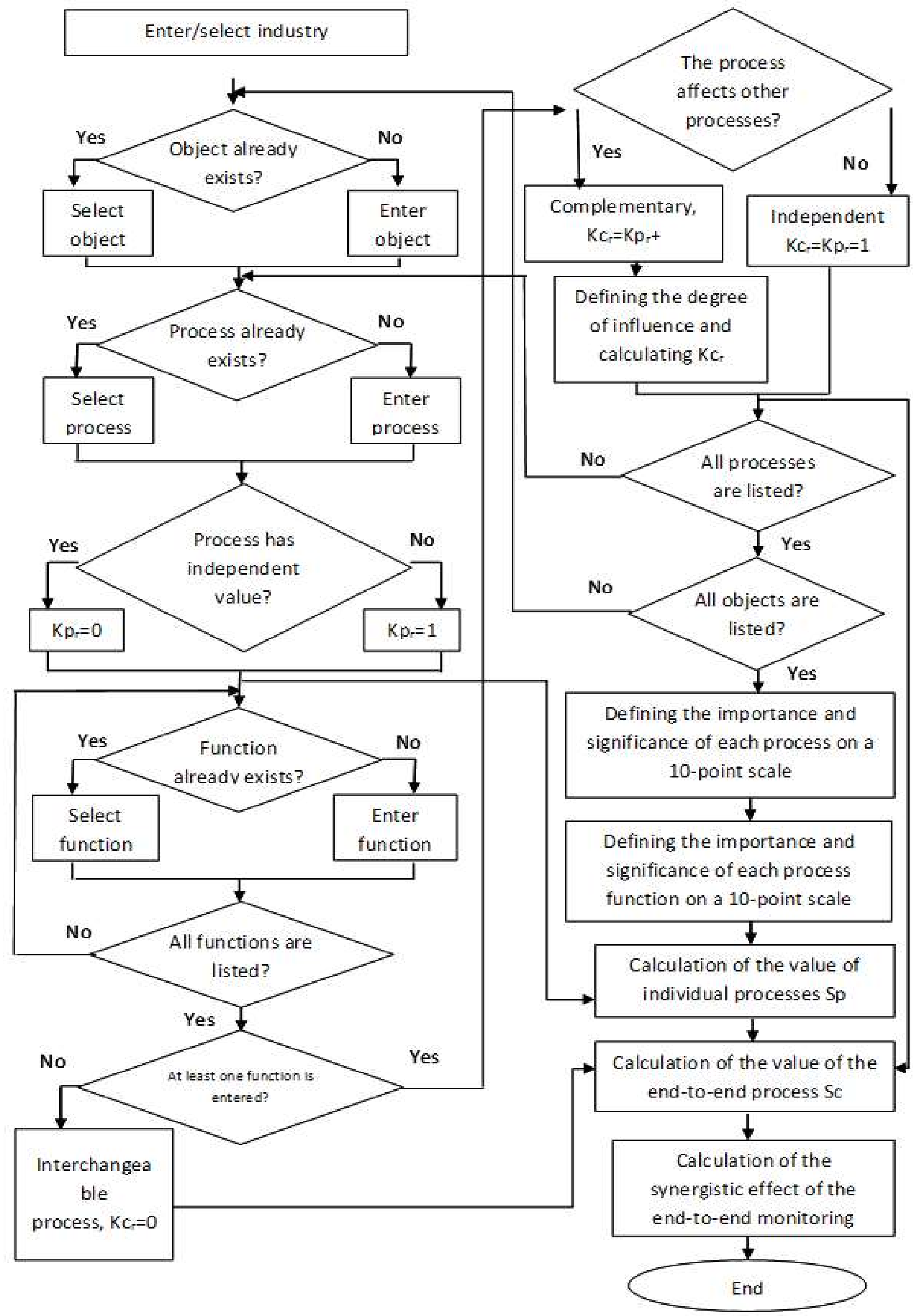

Figure 1: Algorithm for Determining the Synergistic Effect of the End-to-End Process

Calculation of the value of individual processes S_p is calculated by summing up the values of individual processes, considering their importance:

$$S_p = \sum_{rn} \frac{b_r}{\sum_r r} * \frac{b_{rn}}{\sum_n b_{rn}} * K_{p_r}, \qquad (3)$$

where K_{p_r} – the value of an individual process r.

Calculation of the end-to-end process value S_c is calculated as the sum of values of the processes within the end-to-end process, considering their types and importance:

$$S_c = \sum_{rn} \frac{b_r}{\sum_r b_r} * \frac{b_{rn}}{\sum_n b_{rn}} * K_{c_r}, \qquad (4)$$

where K_{c_r} – the value of process *r* within the end-to-end process considering its type, determined using the formula:

$$K_{c_r} = (K_{p_r} + \beta_{rn}), \tag{5}$$

where β_{rn} – the degree of influence, can take the following values:
$\beta_{rn} = 0$ – if the process is independent;
$0 < \beta_{rn} \leq 1$ – if the process is supplementary;
$\beta_{rn} = -K_{p_r}$ – if the process is interchangeable.

The degree of influence β_{rn} is determined through constructing a VE model [26] and distributing between the complementary processes additional units of value generated by their involvement in the end-to-end process. By default, each additional unit of value is equally distributed among the complementary processes, unless otherwise specified.

The calculation of the absolute and relative values of the synergistic effect of the end-to-end monitoring process is determined using the following mathematical models:

$$\sigma_a = S_c - S_p = \sum_{rn} \frac{b_r}{\sum_r b_r} * \frac{b_{rn}}{\sum_n b_{rn}} * (K_{p_r} + \beta_{rn}) - \sum_{rn} \frac{b_r}{\sum_r b_r} * \frac{b_{rn}}{\sum_n b_{rn}} * K_{p_r}, \tag{6}$$

$$\sigma_{rel} = \frac{S_c}{S_p} = \frac{\sum_{rn} \frac{b_r}{\sum_r b_r} * \frac{b_{rn}}{\sum_n b_{rn}} * (K_{p_r} + \beta_{rn})}{\sum_{rn} \frac{b_r}{\sum_r b_r} * \frac{b_{rn}}{\sum_n b_{rn}} * K_{p_r}}, \tag{7}$$

For assessment of the synergistic effect of the end-to-end process, the most preferable is the relative value, which characterizes the increase in the value of a combination of processes due to their interconnection.

When scaling DPs to other priority sectors of the economy, it is advisable to compare the absolute value of the synergy of end-to-end processes by industries, making decisions on the package of proposals for DP users by adjusting the balance of processes within the end-to-end monitoring process and eliminating mutually exclusive processes and adding/reinforcing complementary ones.

4. MATHEMATICAL MODEL FOR DETERMINING IMBALANCE ZONES

For the sake of informed decision-making, it is expedient to use a mathematical model for determining imbalance zones. For its construction, we shall refer to the created algorithm for determining the synergistic effect of the end-to-end process. Based on a VE model, the cost of each process within the end-to-end one can be identified by transforming the model into a VE model [26]. Knowing the significance and cost of processes and functions included in the end-to-end process, it is possible to identify imbalance zones in the platform interaction system for further improvement of the DP using the results of the algorithm determining the synergistic effect of the end-to-end process and mathematical models of the effectiveness of the DP in the real economy for suppliers of functions and solutions and buyers (Figure 2).

The cost of equipment is entered by suppliers, while the cost of intangible objects of the DP (software) is determined using the formula:

$$c_k^p = D_p * c^f, \tag{8}$$

where c_k^p – the annual distributed value of the intangible object (software) k;
D_p – the maximum possible cost of use of the DP/research output, %;
c^f – the annual price of the license per point.

D_p is calculated based on the mathematical model of DP efficiency in the real economy for providers of functions and solutions according to the following formula [27]:

$$D_p = \frac{G_p}{\sum_p G_p} - \frac{G_p}{(0.5 * c^f * \sum_{g=1}^{T} (T+1-g) * A_g) - \mathrm{T} * v^f}, \tag{9}$$

where p – the number of a function and equipment supplier, p € P;
G_p – the investment of provider p in the creation of the DP in the year t_g;
g – time period number; $1 \leq g \leq$ T;
c^f – license price per point per period (annual);
A_g – equipment production limitations in g period (year).
v^f – the cost of licensed service for one point per period (annual).

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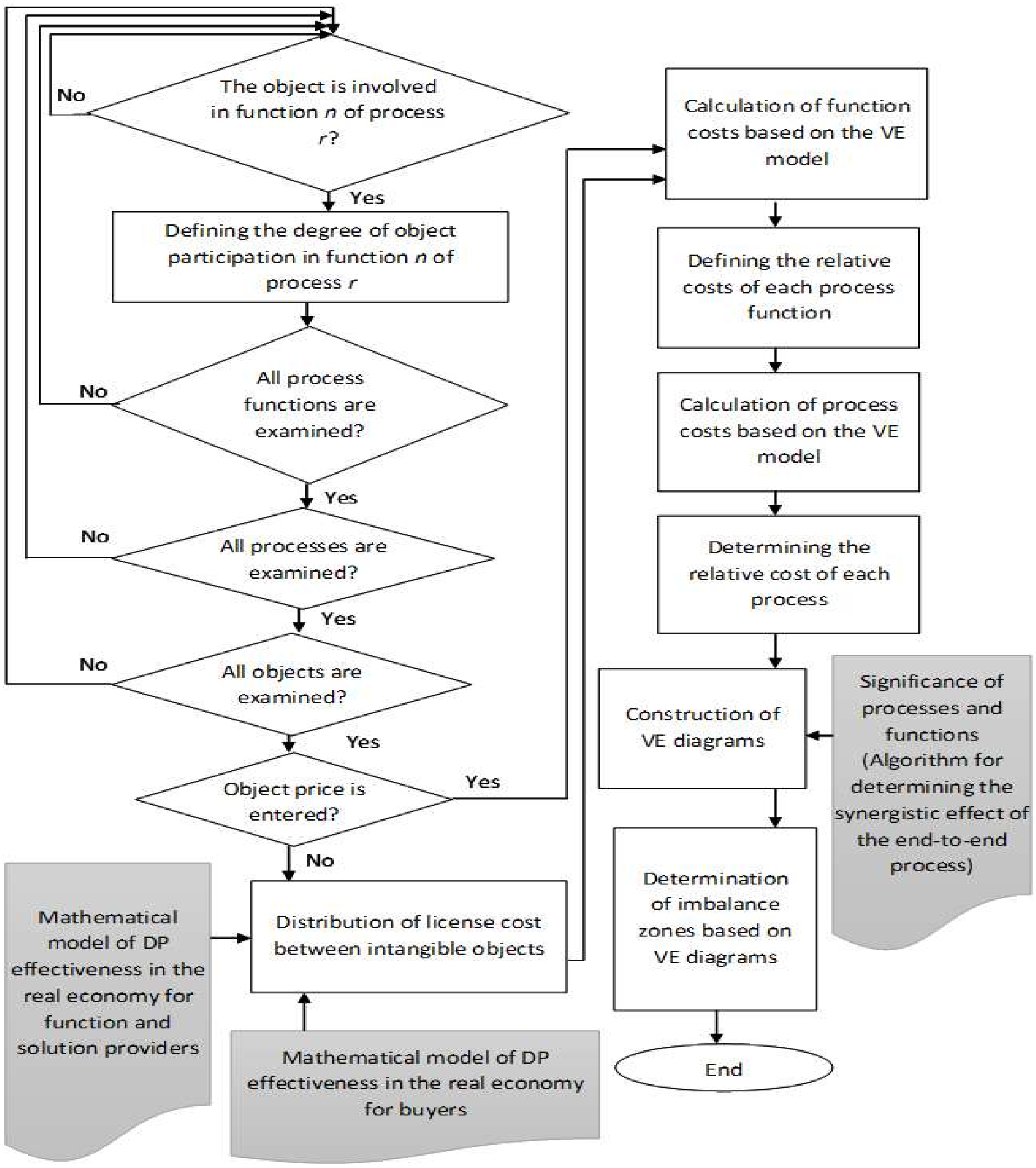

Figure 2: Algorithm for Determining DP Imbalance Zones

Based on the mathematical model of the effectiveness of DP in the real economy for buyers, c^f can be calculated using the formula [27]:

$$c^f = \frac{\sum_u \frac{b_u}{\sum_u b_u} * q_u^{\prime p} * P_a}{N_i * \sum_u \frac{b_u}{\sum_u b_u} * q_u^{\prime a}} - \sum_j c_j^m * y_{ij} \qquad (10)$$

where b_u – the importance of characteristic u assessed on a 10-point scale;
$q_u^{\prime p}$ – parameter describing how close the value of the u-th characteristic of the platform is to the ideal value;
$q_u^{\prime a}$ – parameter describing how close the value of the u-th characteristic of the alternative solution a is to the ideal value;
P_a – competitor's price;
N_i – the number of client i's points with DP equipment;
c_j^m – life cycle cost of equipment;
y_{ij} =1, if the i-th customer buys equipment resource j, 0 – otherwise.

The cost of functions c_{rn} is calculated based on the VE model using the formula:

$$c_{rn} = \sum_j \frac{c_j^m}{l_j} * x_j * \varepsilon_{rn}^j + \sum_k c_k^p * \varepsilon_{rn}^k, \qquad (11)$$

where x_j – the amount of equipment resource j per DP point;
ε_{rn}^j – degree of participation of object j in the execution of function n of process r, $\sum_j \varepsilon_{rn}^j = 1$;
ε_{rn}^k – the degree of participation of intangible object k in the execution of function n of process r, $\sum_k \varepsilon_{rn}^k = 1$;
l_j – useful life of object j.

The specific cost c_{rn}^o of function n of process r for all objects involved in its execution is calculated using the formula [26]:

$$c_{rn}^o = \frac{c_{rn}}{\sum_n c_{rn}}, \qquad (12)$$

The cost c_r of process r is calculated based on the VE model using the formula [26]:

$$c_r = \sum_n c_{rn}, \qquad (13)$$

The specific cost c_r^o of each process r is determined using the formula:

$$c_r^o = \frac{c_r}{\sum_r c_r}, \qquad (14)$$

VE diagrams are constructed based on a comparison of the significance of processes and functions from the mathematical model for determining the value of the synergistic effect of the end-to-end monitoring process with their specific cost [26]. The condition for determining the imbalance zones of the DP is an excess of the specific cost of processes and functions compared to their significance. The mathematical formula for identifying the DP imbalance zones can be presented in the following form:

$$\frac{c_{rn}}{\sum_n c_{rn}} - \frac{b_{rn}}{\sum_n b_{rn}} * a_r > 0$$
$$\frac{c_r}{\sum_r c_r} - \frac{b_r}{\sum_r b_r} > 0, \qquad (15)$$

From this we can write the condition for achieving DP balance as follows:

$$\frac{\sum_j \frac{c_j^m}{l_j} * x_j * \varepsilon_{rn}^j + \sum_k c_k^p * \varepsilon_{rn}^k}{\sum_n \left(\sum_j \frac{c_j^m}{l_j} * x_j * \varepsilon_{rn}^j + \sum_k c_k^p * \varepsilon_{rn}^k \right)} - \frac{b_{rn}}{\sum_n b_{rn}} * a_r \to 0$$
$$\frac{\sum_n (\sum_j \frac{c_j^m}{l_j} * x_j * \varepsilon_{rn}^j + \sum_k c_k^p * \varepsilon_{rn}^k)}{\sum_r \sum_n (\sum_j \frac{c_j^m}{l_j} * x_j * \varepsilon_{rn}^j + \sum_k c_k^p * \varepsilon_{rn}^k)} - \frac{b_r}{\sum_r b_r} \to 0, \qquad (16)$$

Based on the resulting model it is also possible to regulate the pricing of functions and elements of the end-to-end monitoring process.

The end-to-end process requires the input of performance indicators. For this, we shall use the notion of the internal organization of the object, which implies compliance with the principles of compatibility, actualization, concentration, and flexibility [26].

The actualization coefficient is the ratio of useful elements to their total number. In the presented case, this indicator is the most relevant in relation to the number of sensors. A useful sensor determines the occurrence of a risk event at a given rate (time interval). The coefficient of actualization is a dynamic value, which allows for controlling the efficiency of the DP.

The coefficient of concentration (functional manifestation) means the ratio of the main functions and their material carriers to their total number. This factor is relevant when scaling DPs in relation to other priority sectors of the economy and for comparative analysis.

To identify the flexibility coefficient, we can introduce the indicator of design efficiency E_y in DP scaling:

$$E_y = f(m) = 1 - \frac{m-1}{n}, \qquad (17)$$

where n is the total number of devices (e.g., sensors) to perform the functions of the end-to-end monitoring process;
m is the number of devices to get one new value (function).

The range of values of this function is $0<f(m)\leq 1$.

Accordingly, if the acquisition of one new value (the performance of an additional function) requires

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

one device, then the value (design efficiency) equals 1. In turn, with an increase in the number of devices required to obtain one new value (function), the value of design efficiency decreases. The minimum value of this parameter, when all available devices are involved in performing a new function (getting a new value), is 1/n.

5. DISCUSSION

Current approaches to determining the functioning and development of DPs are based primarily on the assessment of network effects [28-30], which is appropriate for DPs operating in the b-to-c market. Within the framework of this article, tools are proposed for determining the balance of the system of platform interactions when scaling the end-to-end monitoring process for priority sectors of the economy in the b-to-b segment.

Several authors consider the balancing of the development of IoT networks and platforms through the assessment of synergistic efficiency using the methodology of integral-expert evaluation, based on the expert scoring of private indicators before and after industrial automation [31]. The authors propose measuring the synergistic effect based on the types of processes of the end-to-end monitoring process, considering the degree of their influence on increasing the value of the totality of processes due to their combination. This allows, when scaling the CPU to other priority sectors of the economy, to manage the process of ensuring the balance of the system of platform interactions, making decisions on the formation of a package of proposals for CPU users by regulating the balance of the processes of the end-to-end monitoring process, eliminating mutually exclusive processes, and adding/strengthening complementary ones.

To make informed decisions when scaling the CPU to other priority sectors of the economy, it is proposed to apply a mathematical model for determining areas of imbalance in platform interactions.

Some authors note that in the context of digital transformation, the business model undergoes a change and, consequently, the process of value creation enters the network space of interaction between different partners and the intersection (complementation) of individual business models [32-34].

In accordance with the black swan theory, together with the need to create an effective mechanism for the redistribution of value within the DP business ecosystem, several authors note the complexity of the task due to the problem of making an accurate forecast of the development of business ecosystems and their management [14,15].

The limitations of the developed mathematical models also include the lack of historical information. However, this can be compensated by modeling various options for the development of the CPU.

The present study offers to calculate the synergistic effect to assess the balancing of the platform interaction system when scaling end-to-end monitoring processes for priority sectors of the economy. A mathematical model for calculating the synergistic effect considering the types of processes within the end-to-end monitoring process is also proposed. To ensure informed decision-making when scaling DPs for other priority sectors of the economy, it is suggested to apply a mathematical model for determining the platform interaction imbalance zones, formed based on the VE approach. In consideration of the indicators of efficiency of the end-to-end monitoring process in DP scaling, a mathematical model for calculating the design efficiency indicator is offered to determine the flexibility coefficient.

As further research, we plan to implement in software and verify the proposed mathematical models for determining the balance of the platform interaction system when scaling the end-to-end monitoring process for the priority sectors of the economy.

6. CONCLUSION

The proposed mathematical models allow for determining the presence and value of the synergistic effect of the end-to-end monitoring process in different markets, detecting imbalance zones in platform interaction, and calculating the indicators of efficiency of the end-to-end process of monitoring of the DP developed by the Leading Research Center "Trusted Sensor Systems" of the National Research University MIET. The presented models will also serve as a basis for testing the balance of the system of platform interactions. Given the above, we can conclude that the goal of this study has been achieved.

This work contributes to the study of the problems of ensuring the balance of the platform interactions system by proposing a solution to this issue when scaling digital solutions entering when new markets in the b-to-b segment in relation to scaling the end-to-end monitoring process for priority sectors of the economy.

The limitations of the application of the developed mathematical models include insufficient historical information, which can be compensated for by modeling different variants of DP development.

The presented mathematical models will serve as the basis for launching and scaling the DP developed by the Leading Research Center "Trusted Sensor Systems" of the National Research University MIET for building balanced, mutually beneficial interactions between participants in different markets in the context of the digital economy and business transformation.

In further research, it is planned to program implementation and verification of the proposed mathematical models for determining the balance of the system of platform interactions when scaling the end-to-end monitoring process for priority sectors of the economy.

ACKNOWLEDGMENTS

The article was prepared within the framework of the implementation of the Leading Research Center's program "Trusted Sensor Systems" (Contract No. 009/20 of April 10, 2020) with the financial support of the Ministry of Communications and Mass Media of Russia and RVC JSC. Subsidy agreement identifier – 000000007119P190002.

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