UDC 303.732.4, 519.226
DOI: 10.20535/SRIT.2308-8893.2024.2.01

STRATEGY OF THE CYBER-PHYSICAL SYSTEM FOR THE SMALL BUSINESS ENTERPRISE GUARANTEED FUNCTIONING WITH THE DIGITAL TWIN SUPPORT

N.D. PANKRATOVA, G.S. TYMCHIK, Ye.V. PANKRATOV

Abstract. The article presents a strategy of the cyber-physical system guaranteed functioning for a small business enterprise (SBE), which is ensured by maintaining the digital twin and is due to its extremely high relevance in modern conditions. Business processes are linked to Industry 4.0 competencies. One of the innovations it implements is Digital Twin, a comprehensive facility support tool. Digital twin allows for tracking and effectively managing the entire cycle of an infrastructure project, from planning, procurement, and production to commissioning and maintenance of the facility. PEST, SWOT, SAW, TOPSIS, and VIKOR methods are used to build a strategy.

Keywords: Industry 4.0, digital twin, cyber-physical systems, strategy, internet of things, computer, physical and mathematical models.

INTRODUCTION

The development and changes in industry that ensure the automation of production and business processes in parallel with the development of computer technology are associated with the competencies of the Fourth Industrial Revolution, which has become a logical stage caused by the technological progress of the modern world [1]. Industry 4.0, characterised by sustainability, connectivity and real-time data processing, is the main driver of modern digital transformation. For manufacturing companies, it is crucial to correctly identify the most appropriate Industry 4.0 technologies that meet their operational schemes and production goals. To address this issue, various technology selection systems have been proposed, some of which are complex or require historical data from manufacturing enterprises that may not always be available. Paper [2] proposes an Industry 4.0 technology selection system that uses a fuzzy analytical hierarchy process and a fuzzy technique for ordering preferences by similarity to the ideal solution to rank different Industry 4.0 technologies based on their economic, social, and environmental impacts. The system is used to select the top three Industry 4.0 technologies out of eight technologies considered important for a manufacturing company. The results of the case study showed that cyber-physical systems, big data analytics, and autonomous/industrial robots occupy the top three places in the technology ranking with a proximity coefficient of 0.964, 0.928, and 0.601, respectively. digital twins (DTs) are used to support the guaranteed functioning of cyber-physical systems, which are used both to design new and maintain existing technical systems. The basic concept of a DT is the presence of a physical object, a virtual object and the exchange of information between them [3]. A DT can be created as a computer model of a physical object, using a set of forecasting procedures and a powerful hardware and software system. The mathematical description of DTs can be obtained by statistical and analytical modelling, machine learning [4; 5]. The development of a DTs can be based on the use of simulation modelling methods that provide the most realistic representation of a physical environment or object in the virtual world. The virtual nature of the object allows you to experiment with the model, build scenarios instead of real experiments without losing resources and risks.

The areas of application of DTs in small business include, in particular, the manufacturing sector: repair and production of bicycles, mopeds, household appliances, etc. The versatility of the technology allows it to be used at almost any enterprise. A small business enterprise's CPS is a comprehensive integration between physical production processes and their virtual representations, which allows for detailed modelling, monitoring, analysis and optimisation of SBE production. In this context, the DTs acts as a dynamic virtual representation of the physical system, which is constantly updated using data from sensors and data collection mechanisms in production. The real-time monitoring of the physical system by the DTs allows for detailed process analysis, forecasting of critical characteristics, which makes it possible to detect deviations from the normal situation in a timely manner, optimise production flows and improve overall production efficiency.

This SBE CPS includes not only automated assembly lines, but also quality management systems, logistics modules, production planning modules, and security systems. The use of DTs allows for real-time visualisation of the production process, analysis of various production scenarios, forecasting, and rapid response to changes in production conditions or orders. Such a cyber-physical system plays a key role in ensuring flexibility, efficiency and innovation at an SBE manufacturing facility, allowing not only to improve existing processes but also to implement the latest technological solutions to increase competitiveness and meet current market trends.

Gartner estimates that by 2027, more than 40% per cent of large companies worldwide will use DTs in their projects to increase revenue [6; 7]. Furthermore, Global Market Insight estimates that the DTs market size, which was worth $8 billion in 2022, will grow at an estimated 25% per cent CAGR between 2023 and 2032 [9]. According to another recent global technology research report, by 2028, the volume of solutions supporting diabetes in smart cities will reach $5.2 billion; more than 94% of all IoT platforms will contain some form of digital twinning; DTs will become a standard feature/functionality for implementing IoT applications; leading solutions for DTs include asset twinning, component twinning, system twinning, process twinning, and workflow twinning; more than 96% of suppliers recognise the need for IIoT APIs and platform integration with digital twinning functionality for industrial verticals; more than 42% of executives across a wide range of industry verticals understand the benefits of digital twinning, and 59% of them plan to implement it in their operations by 2028 [10].

The purpose of this paper is to develop a DTs strategy to support the guaranteed functioning of the cyber-physical system in the form of a small business enterprise.

RELATED PAPERS

The use of DTs technology is growing exponentially, and it is transforming the way we do business. For a detailed history of development, classification, applications, and prospects of this technology, see [11]. Over the past few years, vital business applications have been using DTs, and it is predicted that this technology will expand to more applications, use cases, and industries in the form of CFS. Among other things, organisations are implementing DTs, the main purpose of which is scenario analysis and support of business strategies [12]. The paper [12] also describes how DTs simplify intelligent automation in various industries, defines the concept, highlights the evolution and development of, examines its key technologies, explores trends and challenges, and explores its application in various industries. Today, this technology is used in many industries to provide an accurate virtual representation of objects and simulate operational processes. The growing scale and complexity of projects, the increasing number of stakeholders, globalisation, technological advancements, changing business models and declining profitability are forcing the construction industry to undergo a digital transformation. The DTs and the Internet of Things (IoT) are among the most significant digital developments of recent years. The purpose of the article [13] is to analyse the challenges of using the technologies of digitalisation and IoT in the construction sector, which offers significant benefits, such as improved project management, reduced errors and rework, and increased productivity and efficiency. On the other hand, implementation challenges include upfront costs, integrating the DTs with existing systems, managing IoT data, and a lack of standardisation and security. The growth of Internet of Things (IoT) systems is driven by their potential to improve efficiency, enhance decision-making, and create new business opportunities in various fields. The paper [14] identifies the main selection problems in IoT systems, the criteria used in multicriteria evaluation, and the multicriteria methods used to solve IoT selection problems. Next, a Hybrid Group Multicriteria Approach is proposed to solve selection problems in IoT systems. The approach includes the Best Worst Method (BWM) weighting method, the multicriteria Simple Additive Weighting (SAW) method, the Top Order Preference by Similarity to the Ideal Solution (TOPSIS) method, the All-Criteria Optimisation and Compromise Solution (VIKOR) method, the Comprehensive Proportional Assessment (COPRAS) method, and a method that combines the solutions obtained by the four considered multicriteria methods to obtain a single solution. The SAW, TOPSIS, VIKOR and COPRAS methods were analysed in terms of their advantages, disadvantages, inputs, outputs, measurement scale, normalisation type, aggregation method, parameters, complexity of implementation and interactivity. Technological advances in cyber-physical systems, digital manufacturing and Industry 4.0 are presented in [15]. It also presents some challenges and future research topics in these areas. In [16], it is argued that DCs rely on two key elements to create business value: digital data streams, a constant flow of digital images of events generated by sensors both inside and outside the physical object, and detailed digital models. The DTs provide many new opportunities for creating value by transferring software strategies to the physical world. In [17; 18], the possibility of controlling the modes of electrocuting (MCECT) was substantiated. It is shown that the peculiarities of the multifactorial influence of the control parameters of the melt treatment process on the structure formation of castings can only be revealed by numerical experiments using adequate computer models. The basic principles of constructing an automated MCECT system are formulated and the structure of an integrated three-component information system (ITIS) is developed for its implementation using computer models of many physical processes of EOT. Computer models serve as the system basis of the algorithmic paradigm laid down in the ITIS, which includes the identification of experimental casting samples with standard prototypes and predictive algorithms for controlling the modes of electric current melt treatment. Paper [19] presents general methods of DT technology and predictive maintenance technology, analyses the gap between them, and points out the importance of using DT technology to implement predictive maintenance. The article presents the method of predictive maintenance based on DTs, provides its characteristics and its differences from traditional predictive maintenance, and introduces the application of this method in smart manufacturing and in various industries.

MODELS AND METHODS

In today's conditions of rapid technological development and competitive business environment, the strategic identification of priority areas for the construction and use of a DT is becoming an integral part of the successful functioning of enterprises. The PEST, SWOT, SAW, TOPSIS, and VIKOR methods are used to build a strategy for the guaranteed functioning of the cyber-physical system of a small business enterprise with the support of a DT in the form of a computer model of a physical object. When analysing the subject area, PEST analysis [20] is used to identify the main factors, which is intended to identify political (P – political), economic (E – economic), social (S – social) and technological aspects of the external environment that affect the company's business. To find the strengths and weaknesses of this technology, opportunities and risks that accompany them, the SWOT analysis was used with further refinement by the VIKOR, TOPSIS methods.

A SWOT analysis is a critical part of the strategic management process, used to assess the strengths, weaknesses, opportunities and threats of an organisation or any activity. It is a key strategic planning tool that helps analyse internal and external factors. The purpose of a SWOT analysis is to formulate a business strategy, taking into account the existing conditions. The analysis includes four components: "Strengths", "Weaknesses", "Opportunities", "Threats", where strengths and weaknesses are internal factors of the organisation, and opportunities and threats are external. SWOT analysis helps to develop strategies that use strengths and opportunities to achieve the organisation's goals while minimising the impact of weaknesses and threats [21; 22].

The obtained results become the basis for strategic planning and implementation of the DTs, providing the enterprise with competitive advantages and sustainability in accordance with modern market requirements.

Implementation and results of the SWOT analysis procedure

In order to develop a strategy for the CPS of a small business enterprise with the support of a DT in the form of a computer model, using the results obtained by the PEST method, we formulate their characteristic critical strengths and weaknesses, opportunities and threats in the form of a SWOT matrix (Table 1).

Table 1. SWOT-matrix for building a DTs' strategy

Internal controlled factors	
Strengths	Weaknesses
S_1 — increased accuracy and efficiency of production processes: DTs allows for detailed modelling and optimisation of all aspects of the production process, increasing overall productivity and potentially reducing equipment and personnel costs.	W_1 — high cost of development and implementation: the need for significant investments in the development and implementation of software and hardware, as well as support for their correct functioning
S_2 — ability to predict and prevent failures: the use of DTs allows you to identify potential problems in equipment and processes in advance, reducing the number of breakdowns, downtime and repair costs.	W_2 — dependence on data quality and availability: accurate, up-to-date and structured data for analysis is required, and a system for collecting and organising it is needed, which can be costly and difficult to implement
S_3 — flexibility and adaptability of production: DTs allow you to quickly adapt production lines to rapidly changing market requirements, including the military situation, production conditions of small businesses, such as bicycle shops, household appliances, etc.	W_3 — the need for highly skilled professionals: the need to have a staff with highly specialised personnel with relevant programming experience and an understanding of the development approaches that will be used.
S_4— reducing the time required to repair and upgrade products: modifying, scaling and improving software, testing it quickly and safely.	W_4 — the need to integrate with existing information systems and processes: this can be a complex and time-consuming process, due to lack of proper documentation, inadequate existing systems and insufficient support.
S_5 — improving product quality: The use of DTs allows for the implementation of automated quality control systems, which will reduce the percentage of defects in the manufacture of spare parts at all stages.	W_5 — potential difficulty in managing change: resistance to change on the part of staff who may be resistant or not ready to implement new technologies due to the need to absorb new information and gain additional qualifications.
S_6 — the possibility of increasing efficiency. Automation of calculation and procurement tasks will lead to a significant increase in accuracy and sreduce the impact of the human factor, which will reduce the required resources and make more efficient use of existing ones.	W_6 — dependence on vendors: potential dependence on foreign suppliers of software, hardware and services used in the development and underlying operation of the software.

Continued Table 1

External uncontrollable factors	
Opportunities	Threats
O_1 — the growing popularity of digital technologies in the CFS sector and consumer demand for high-quality small business products.	T_1 — risks of cyberattacks and the possibility of data loss from servers or disruption of DTs operations.
O_2 — use of artificial intelligence and analytical tools that can improve the efficiency of the DTs computer model and its analytical capabilities.	T_2 — the threat of military attacks: problems with power supply, enemy air strikes and sabotage, and the risk of physical destruction of the infrastructure that supports operations.
O_3 — increasing business resilience: rapid adaptation of the computer model of the DTs to changes and challenges of the market during the war.	T_3 — the need to constantly update and adapt the computer model of the DTs to changing market conditions during the war.
O_4 — the potential to improve the quality of products and production processes through continuous improvement and upgrade of the computer model of the DTs.	T_4 — the possibility of technical problems in the software that may cause a DTs failure and lead to data loss, business interruption and other losses.
O_5 — the ability to attract new customers and markets through the introduction of advanced technologies and increase the company's competitiveness.	T_5 — insufficient support from the state for the introduction and use of DTs.
O_6 — government support: the opportunity to receive government grants or support for project activities in areas that are a priority for the state, such as the development of cycling infrastructure.	T_6 — economic instability: macroeconomic fluctuations can affect investment and budgets for innovation.

Let's form a matrix of comparison internal and external components of SWOT analysis based on estimates of the connection strength in the range [0.1] (Table 2).

Table 2. Matrix for comparing the components of SWOT analysis

I/E components	T_1	T_2	T_3	T_4	T_5	T_6	O_1	O_2	O_3	O_4	O_5	O_6
S_1	0.2	0.0	0.5	0.2	0.2	0.3	0.5	0.8	0.7	0.2	0.0	0.3
S_2	0.7	0.3	0.4	0.3	0.3	0.3	0.6	0.7	0.5	0.3	0.0	0.3
S_3	0.3	0.0	1	0.5	0.7	0.2	0.7	0.9	1	0.5	0.6	0.6
S_4	0.6	0.0	0.9	0.4	0.6	0.5	0.8	0.8	0.9	0.6	0.5	0.5
S_5	0.7	0.0	0.6	0.6	0.5	0.6	0.7	0.6	0.5	0.2	0.7	0.4
S_6	0.2	0.0	0.1	0.2	0.3	0.5	0.2	0.2	0.3	0.3	0.0	0.7
W_1	0.8	0.7	0.7	0.5	0.7	0.9	0.3	0.9	0.8	0.8	0.6	0.8
W_2	0.9	0.0	0.6	0.7	0.0	0.5	0.1	1	0.5	0.7	0.0	0.2
W_3	0.5	0.5	0.7	0.5	0.0	0.7	0.0	0.8	0.2	1	0.0	0.5
W_4	0.6	0.4	0.3	0.7	0.0	0.6	0.2	0.6	0.4	0.6	0.0	0.6
W_5	0.6	0.0	0.8	0.6	0.4	0.3	0.0	0.3	0.7	0.3	0.0	0.5
W_6	0.7	0.3	0.7	0.6	1	0.6	0.4	0.7	0.6	0.7	0.2	0.6

Let us compare opportunities with strong and weak characteristics, as well as compare threats with strong and weak characteristics (Table 3).

Table 3. Comparison of opportunities and threats with strong and weak characteristics

Opportunities	Strengths	Weaknesses
O_1	$S_1, S_2, S_3, S_4, S_5, S_6$	W_1, W_2, W_4, W_6
O_2	$S_1, S_2, S_3, S_4, S_5, S_6$	$W_1, W_2, W_3, W_4, W_5, W_6$
O_3	$S_1, S_2, S_3, S_4, S_5, S_6$	$W_1, W_2, W_3, W_4, W_5, W_6$
O_4	$S_1, S_2, S_3, S_4, S_5, S_6$	$W_1, W_2, W_3, W_4, W_5, W_6$
O_5	S_3, S_4, S_5	W_1, W_6
O_6	$S_1, S_2., S_3, S_4, S_5, S_6$	$W_1, W_2, W_3, W_4, W_5, W_6$
Threats	**Strengths**	**Weaknesses**
T_1	$S_1, S_2, S_3, S_4, S_5, S_6$	$W_1, W_2, W_3, W_4, W_5, W_6$
T_2	S_2	W_1, W_3, W_4, W_6
T_3	$S_1, S_2, S_3, S_4, S_5, S_6$	$W_1, W_2, W_3, W_4, W_5, W_6$
T_4	$S_1, S_2, S_3, S_4, S_5, S_6$	$W_1, W_2, W_3, W_4, W_5, W_6$
T_5	$S_1, S_2, S_3, S_4, S_5, S_6$	W_1, W_5, W_6
T_6	$S_1, S_2, S_3, S_4, S_5, S_6$	$W_1, W_2, W_3, W_4, W_5, W_6$

To determine the most important factors, let's calculate the impact of internal characteristics on the implementation of threats and opportunities F_j, G_k, D_i, H_m using the following formulas:

$$F_j = \left(\sum_i K_{S_j T_i} + \sum_m K_{S_j O_m} \right),\ G_k = \left(\sum_i K_{W_k T_i} + \sum_m K_{W_k O_m} \right),\ j = \overline{1,11}\ , k = \overline{1,8}\ ;$$

$$D_i = \left(\sum_j K_{S_j T_i} - \sum_k K_{W_k T_i} \right),\ H_m = \left(\sum_j K_{S_j O_m} - \sum_k K_{W_k O_m} \right),\ i = \overline{1,8},\ m = \overline{1,9}\ ,$$

where $K_{S_j T_i}$ is the element of the matrix at the intersection of strength S_j and threat T_i; $K_{S_j O_m}$ is the element at the intersection of strength S_j and opportunity O_m; $K_{W_k T_i}$ is the the element at the intersection of the weakness W_k and the threat T_i; $K_{W_k O_m}$ is the element at the intersection of weakness W_k and opportunity O_m.

The calculation results are shown in Table 4.

Table 4. Calculated critical factors by degree of importance

Strengths						
Factors	S_1	S_2	S_3	S_4	S_5	S_6
F	7.1	7.0	6.1	4.7	3.9	3.0
Weaknesses						
Factors	W_1	W_6	W_3	W_2	W_4	W_5
G	8.5	7.1	5.4	5.2	5.0	4.5
Opportunities						
Factors	O_1	O_5	O_3	O_2	O_6	O_4
H	2.5	1.0	0.7	-0.3	-0.4	-2.0
Threats						
Factors	T_2	T_1	T_4	T_6	T_3	T_5
D	-1.6	-1.4	-1.4	-1.2	-0.3	0.5

Based on the results of the SWOT analysis, it is possible to propose SO, WO, ST, WT strategies for developing DTs in small business in the form of the TOWS matrix [23] (Table 5).

Table 5. TOWS matrix

	S_1	S_2	S_3	W_1	W_6	W_2
	SO-strategy			**WO-strategy**		
O_1 O_5 O_3	In order to build a strategy for small business DTs CPS taking into account all aspects of production processes, it is necessary to ensure the sustainability of business operations with rapid adaptation of the computer model of the DTs to changes and challenges of the market during the war, software modification and fast and safe testing, availability of a powerful forecasting unit involving artificial intelligence and analytical tools, and government support.			The high financial costs of developing and implementing, as well as maintaining the correct functioning of software and hardware, should be compensated by attracting highly qualified specialists, business investment, and assistance from friendly countries and foundations. Accelerate the creation of unified technical standards for DTs and legislative regulation of digitalisation. Determine the organisational and legal forms of operation of this technology, as well as quality and cybersecurity standards.		
	WT-strategy			**WT-strategy**		
T_2 T_1 T_4	In the event of the threat of military attacks, cyber-attacks and the possibility of data loss from servers or disruption of the computer model of the DTs due to technical problems in the software, compensate with the ability to predict and prevent failures, relocate critical facilities to a protected area and attract qualified personnel, which allows the company to quickly adapt production lines to rapidly changing market requirements during martial law. This will ensure fast and high-quality project implementation and prevent cyber-attacks.			To search for available financial resources and work on standardising DTs technology at the legislative level and increase the transparency of corruption-prone processes. The state and business should establish cooperation with HEIs to train qualified IT specialists and ensure comfortable legal conditions for their work. The priority is to prevent inappropriate responses from the education system and corruption, as well as to ensure a high level of cybersecurity. Ensure communication with international partners on possible threats to production and ways to overcome them.		

FINDING THE OPTIMAL STRATEGY FOR DEVELOPING A SMALL BUSINESS ENTERPRISE'S DTS CPS

TOPSIS method. Results of calculations

The TOPSIS and VIKOR methods have been applied to find the optimal strategy for developing the DTs CPS of a small business enterprise. The same results obtained by both methods in most cases indicate the sustainability of the decision.

The TOPSIS method is a multi-criteria decision-making tool that can be particularly useful for small businesses when choosing the best option from various alternatives. It helps small businesses find the solution that is closest to the ideal option and at the same time furthest from the undesirable one. The method includes the steps of data normalisation, weighting of criteria, identification of the ideal and worst solution options, and analysis of the distances to them for each proposal [24]. This allows small businesses to choose the most effective solutions, increase their competitiveness and efficiency.

The TOPSIS method is used to search for compromise strategies. Using the alternatives for implementing strategies, taking into account the results of the SWOT analysis and the TOWS matrix, we form a decision matrix a_{ij}, $i=\underline{1,4}$, $j=\underline{1,12}$, where the index i corresponds to the strategy (criterion) SO, WO, ST, WT, and the index j determines the alternative $S_1, S_2, S_3, \ldots, T_2, T_1, T_4$ (Table 6).

The SAW method (Simple Additive Weighting Method) is a method of simple additive weighting that obtains the total score of each alternative by multiplying the value of the attribute for each alternative by the weight assigned to that attribute. The alternative with the highest score is the answer to the decision task. The weighting factors $w_j, j=\underline{1,12}$, which determine the importance of the factors for the decision maker and should sum to one, are shown in Table 6.

Table 6. Decision matrix and weights of alternatives

Decision matrix												
i/j	S_1	S_2	S_3	W_1	W_6	W_3	O_1	O_5	O_3	T_2	T_1	T_4
SO	4.1	4.3	3.1	4.2	3.2	1.67	3.5	0.9	3.9	0.05	2.7	2.2
WO	3.5	3.6	2.6	3.9	3.1	1.52	0.15	0.27	2.2	1.27	2.1	1.6
ST	2.5	2.25	2.5	4.3	3.9	2.42	3.5	0.9	3.4	0.01	2.4	2.2
WT	2.3	2.12	2.3	3.9	3.3	2.12	0.61	0.21	2.8	1.17	3.8	3.3
Weights of alternatives												
w/j	S_1	S_2	S_3	W_1	W_6	W_3	O_1	O_5	O_3	T_2	T_1	T_4
w	0.1	0.09	0.09	0.1	0.09	0.09	0.07	0.08	0.08	0.09	0.07	0.05

Next, the decision matrix is normalised and weighted using formulas (Table 7)

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_i^4 a_{ij}^{\ 2}}}, \quad i=\underline{1,4}, \quad j=\underline{1,12} ;$$

$$v_{ij} = w_j r_{ij}, \quad \sum_{j}^{12} w_j = 1 .$$

For each alternative $S_1, S_2, S_3, \dots, T_2, T_1, T_4$ the ideal solution will be determined by the weighted normalised decision matrix as the maximum v_j^+ and minimum v_j^- values of the SO,WO,ST,WT criterion scores using formulas (Table 7)

$$v_j^+ = \max_i r_{ij}, j = \overline{1,12}; \quad v_j^- = \min_i r_{ij}, j = \overline{1,12},$$

v_j^+ and v_j^-, $j = \underline{1,12}$ can be interpreted as, respectively, the best and worst solutions for each criterion.

Table 7. Weighted normalised decision matrix

j/i	**SO**	**WO**	**ST**	**WT**	v_j^+	v_j^-
S_1	0.06434	0.05492	0.03923	0.03609	0.06434	0.03609
S_1	0.06043	0.05059	0.03162	0.02979	0.06043	0.02979
S_3	0.05281	0.04429	0.04258	0.03918	0.05281	0.03918
W_1	0.05148	0.04780	0.05271	0.04780	0.05271	0.04780
W_6	0.04248	0.04115	0.05178	0.04381	0.05178	0.04115
W_3	0.03823	0.03480	0.05541	0.04854	0.05541	0.03480
O_1	0.04910	0.00210	0.04910	0.00855	0.04910	0.00210
O_5	0.05463	0.01638	0.05463	0.01274	0.05463	0.01274
O_3	0.04967	0.02802	0.04330	0.03566	0.04967	0.02802
T_2	0.00260	0.06616	0.00052	0.06095	0.06616	0.00052
T_1	0.03346	0.02602	0.02974	0.04709	0.04709	0.02602
T_4	0.02287	0.01663	0.02287	0.03430	0.03430	0.01663

Let us imagine an “ideal solution” that maximises all criteria simultaneously v^+ and a “worst case” v^-, that minimises all criteria

$$v^+ = (v_1^+, v_2^+, \dots, v_{12}^+) = v_{ij}; \quad v^- = (v_1^-, v_2^-, \dots, v_{12}^-) = v_{ij} .$$

For each realistic alternative, the Euclidean distance to the “ideal solution” D_i^+ and to the “worst solution” D_i^- is calculated using formulas, respectively:

$$D_i^+ = \sqrt{\sum_{j=1}^{12} (v_{ij} - v^+)^2} \; ;$$

$$D_i^- = \sqrt{\sum_{j=1}^{12} (v_{ij} - v^-)^2} \; .$$

In the TOPSIS method, a compromise alternative is selected based on the C_i indicator using formula. The results of the calculations are shown in Table 8.

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} .$$

Table 8. Finding the best compromise strategy using the TOPSIS method

	Strategies in ascending order of performance			
	SO	**WO**	**WT**	**ST**
D^+	0.06884	0.07560	0.0753c5	0.07966
D^-	0.08049	0.07166	0.06858	0.06953
C	**0.53903**	0.48662	0.47648	0.46607

According to the TOPSIS method, the best compromise strategy for the guaranteed functioning of the cyber-physical system for a small business enterprise with the support of a DT is the SO strategy. It consists in the need to ensure business sustainability with the rapid adaptation of the computer model of the DTs to changes and challenges of wartime, software modification and fast and safe testing, the availability of a powerful forecasting unit involving artificial intelligence and analytical tools, possible state suspport.

The VIKOR method. Results of calculations

The use of the VIKOR method for multi-criteria decision-making can be useful for small business development, helping to select suppliers, assess the quality of services or define business strategies. VIKOR allows to optimize operations or strategic directions based on a systematic evaluation of available options against a set of criteria [25].

Let's search for compromise strategies using the VICOR method. Let us take the decision matrix a_{ij}, $i=\overline{1,4}$, $j=\overline{1,12}$ and the weights w_j, $j=\overline{1,12}$, which were taken for the TOPSIS method (Table 6). For all alternatives, the characteristics S_i, R_i, Q_i are calculated using formulas, respectively:

$$S_i = \sum_{j=1}^{20} \frac{w_j (a_j^+ - a_{ij})}{(a_j^+ - a_j^-)}, \text{ where } a_j^+ = \max_i a_{ij}, \ a_j^- = \min_i a_{ij};$$

$$R_i = \left(\frac{w_j (a_j^+ - a_{ij})}{(a_j^+ - a_j^-)} \right), \text{where } a_j^+ = \max_i a_{ij}, \ a_j^- = \min_i a_{ij};$$

$$Q_i = \begin{cases} \dfrac{R_i - R^-}{R^+ - R^-}, \text{ if } S^+ = S^-, \\ \dfrac{S_i - S^-}{S^+ - S^-}, \text{ if } R^+ = R^-, \\ v\dfrac{S_i - S^-}{S^+ - S^-} + (1-v)\dfrac{R_i - R^-}{R^+ - R^-}, \text{ if } S^+ \neq S^- \text{ and } R^+ \neq R^-. \end{cases} \quad i=\overline{1,4}, \quad (1)$$

In formula (1), v is chosen in the range [0.1]. If there are no other conditions, $v = 0.5$, is assumed to be 0.5, which was done here. Next, Q_i are ordered in ascending order. The strategy with the minimum Q_i is assumed to be the best. The results of the calculations are shown in Table 9.

Table 9. Finding the best compromise strategy using the VIKOR method

	Strategies in ascending order of performance			
	SO	ST	WT	WO
S	0.34353	0.44455	0.67679	0.74152
R	0.08714	0.09	0.1	0.1
Q	0	0.23801	0.91867	1

According to these results, the best strategy according to the VIKOR method is the SO strategy, since its value is minimal. In terms of all characteristics S, R, Q here is the same ordering of strategies SO, ST, WT, WO, with strategy SO being simultaneously the best in the ranking series by S and R, which emphasises the stability of the solution. Additionally, for the best alternative, the acceptable difference from the other alternatives is checked $\Delta Q = \frac{1}{4-1} = \frac{1}{3}$, which can be interpreted as a significant advantage of one alternative over the others. For VIKOR, the difference between the SO strategy and the ST strategy is $0.23801 < \frac{1}{3}$. For the other alternatives, the difference is significantly greater than $\frac{1}{3}$.

CONCLUSIONS

The carried out research allows to draw a conclusion about building a strategy for guaranteed functioning of the cyber-physical system for a small business enterprise with the support of a DT. Using PEST-analysis, the main factors in the subject area under consideration were identified, and with the help of SWOT analysis, the most significant strengths and weaknesses of the DTs technology, opportunities and threats associated with them were identified. Based on the results of the SWOT analysis, four strategies SO, ST, WO, WT were formed, on the basis of which the TOWS strategy matrix was built, and a decision matrix was formed. To find the optimal strategy, the multi-criteria decision-making methods TOPSIS and VIKOR with the involvement of the SAW method were used.

According to the results of calculations using the TOPSIS and VIKOR methods, the SO strategy was found to be the best compromise strategy for the guaranteed functioning of the cyber-physical system for a small business enterprise with the support of a DT. It consists in the need to ensure the sustainability of business operation with rapid adaptation of the computer model of the DTs to changes and challenges of the market during wartime related to possible cyber-attacks and the possibility of data loss from servers or disruption of the DTs due to technical problems of various nature, software modification and fast and safe testing, availability of a powerful forecasting unit involving artificial intelligence and analytical tools, and possible government support. This will ensure fast and high-quality execution of projects, orders, and new technical solutions.

In the future, it is planned to use the foresight and cognitive impulse modelling methodologies to build scenarios for the implementation of the strategy SO for guaranteed functioning of the SBE with the support of the DTs.

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Received 01.03.2024

INFORMATION ON THE ARTICLE

Nataliya D. Pankratova, ORCID: 0000-0002-6372-5813, Educational and Research Institute for Applied System Analysis of the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Ukraine, e-mail: natalidmp@gmail.com

Gregory S. Tymchik, ORCID: 0000-0003-1079-998X, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Ukraine, e-mail: deanpb@kpi.ua

Yevhen V. Pankratov, ORCID: 0009-0004-1508-3053, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Ukraine, e-mail: pankratov.science@gmail.com

СТРАТЕГІЯ ГАРАНТОВАНОГО ФУНКЦІОНУВАННЯ КІБЕРФІЗИЧНОЇ СИСТЕМИ ПІДПРИЄМСТВА ДРІБНОГО БІЗНЕСУ ІЗ СУПРОВОДЖЕННЯМ ЦИФРОВОГО ДВІЙНИКА / Н.Д. Панкратова, Г.С. Тимчик, Є.В. Панкратов

Анотація. Наведено стратегію гарантованого функціонування кіберфізичної системи підприємства дрібного бізнесу, що забезпечується супроводженням цифрового двійника та зумовлено його надвисокою актуальністю у сучасних умовах. Бізнес-процеси пов'язані з компетенціями Industry 4.0. Одна з інновацій, яку вона впроваджує, є Digital Twin (цифровий двійник) – всеохопний інструмент супроводу об'єкта. Цифровий двійник дозволяє відстежувати та ефективно керувати повним циклом інфраструктурного проекту: від планування, закупівель, виробництва, до введення в експлуатацію та обслуговування об'єкта. Для побудови стратегії залучаються методи PEST, SWOT, SAW, TOPSIS та VIKOR.

Ключові слова: Індустрія 4.0, цифровий двійник, кіберфізичні системи, стратегія, інтернет речей, комп'ютерні, фізичні та математичні моделі.