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PARAMETRIC ASSESSMENT OF THE TECHNOLOGICAL AND INFRASTRUCTURE STATE OF FOOD ENTERPRISES ACCORDING TO INDUSTRY 4.0 TECHNOLOGY DEVELOPMENT TRENDS

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Abstract. The **purpose** of this research is to present the developed parametric model for assessing the current technological and infrastructure state of food enterprises regarding the implementation of Industry 4.0. The research is performed using a method of linear combination of parameters with weights that reflect their relative importance in the final assessment. **Methodology**: In accordance with the chosen research topic, parameters were identified as the most crucial for forming future evaluation criteria to calculate the current technological and infrastructure state of a food enterprise regarding the implementation of Industry 4.0. This was achieved using the method of linear combination of parameters (Weighted arithmetic mean, The min-max scaling method) with weights that reflect their relative importance in the final assessment. The research **finding** is the ranges of assessing the current state of enterprises. Modern technologies and tools of Industry 4.0 are rapidly evolving both in the international and national markets. The digital transformation of business models opens up new opportunities and challenges for enterprises, encompassing the rational use of resources, socio-economic relationships, technological strategy, and the incorporation of the "Industry 4.0" concept into company activities. As a practical example for assessing the current state of technological and infrastructural support for enterprises in the food industry, the Ukrainian-Spanish Urozhay LLC has been chosen. Based on the results of the conducted assessment, the current state of implementation and utilization of Industry 4.0 tools at the enterprise under consideration was determined. A set of recommendations and proposed measures aimed at improving the performance of the investigated enterprise has been provided, among which it is necessary to highlight: attracting additional investments, opening a new type of collective business involving small enterprises with different types of product portfolios. As a perspective for further research, the design of a unified production and trading hub is proposed, consisting of automated management systems, robotic stations, and physical and cloud data analytics systems.

Key words: Industry 4.0, digitization of enterprises, implementation of Industry 4.0 technologies, technologies of food enterprises, linear combination method

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INTRODUCTION

The growth of the digital economy imposes new demands on enterprises, including changes in strategic planning and development of products and services. Market competitiveness becomes more dynamic, and digital transformations require fundamental changes in all aspects of business, from infrastructure to personnel policies. The implementation of Industry 4.0 technologies and tools has become one of the key challenges and opportunities for the food industry in Ukraine. As scientific and technological progress rapidly alters the global market landscape, the strategic role of innovation and digitization for modern enterprises cannot be underestimated. Digital business has gone beyond electronic commerce, expanding not only efficiency but also the ways of creating new value and the unique experience for customers. In the digital era technologies are becoming a crucial tool for gaining competitive advantages and changing business standards (Nikitin, Kulchytskyi, 2019: 78-81).

The food industry, as one of the most important sectors of the national economy, faces the task of adapting to new realities to maintain competitiveness and improve product quality. Industry 4.0 represents a new era in manufacturing, where digital technologies, automation, Internet of Things (IoT) networks, and artificial intelligence are integral parts of business processes. They significantly optimize production processes, enhance quality control, reduce costs, and open new avenues for interacting with consumers (Schwab, 2019: 75-125). Ukrainian companies have to actively utilize digital solutions as competition intensifies, and the market becomes more accessible. One of the primary advantages of digital transformation is increased innovativeness, that helps companies enhance their market position (Andriiv, 2022: 1-3).

In the process of implementing Industry 4.0 technologies, food industry enterprises in Ukraine encounter various challenges and problems: the need for updating production facilities, ensuring cybersecurity, training personnel in new skills, and establishing appropriate legal regulations (Vorzhakova, Khlebinska, 2021: 107–111). The current situation in Ukrainian food enterprises regarding the adoption and application of Industry 4.0 technologies and tools is in the state of stagnation (Dzhaforova, Karpenko, 2021: 1-7).

LITERATURE REVIEW

The works of the national and foreign experts were analyzed and used in this article: The digital paradigm is considered as the basis of definitions: digital business, digital enterprise, digital transformation (Nikitin, Kulchytskyi, 2019: 78-81), The fourth industrial revolution. Shaping the fourth industrial revolution (Schwab, 2019: 75-125), Digital transformation of the enterprise: theoretical basis (Andriiv, 2022: 1-3). Vorzhakova, Khlebinska, 2021: 107–111), Features and problems of implementation of Industry 4.0 in Ukraine (Dzhaforova, Karpenko, 2021: 1-7), Digital economy: trends and perspectives of avant-garde development (Kraus, Goloborodko, Kraus, 2018: 2-4), Digital transformation of the business model of the enterprise (Bortnik, 2021: 2-4).

PAPER OBJECTIVE

The relevance of the chosen research topic is driven by the rapid development of modern technologies and Industry 4.0 tools both in the international and national markets. The digital transformation of business models opens up new opportunities and challenges for enterprises. It encompasses the rational use of resources, socio-economic relations, technological strategy, and the integration of the "Industry 4.0" concept into company activities. As the implementation of these technologies and tools requires significant investment in infrastructure, it is crucial to identify and evaluate key parameters through which a company aims to automate, analyze, and assess its business operations.

METHODOLOGY

A parametric model has been developed for assessing the current technological and infrastructure state of food enterprises regarding the implementation of Industry 4.0. This model utilizes a method of linear combination of parameters with weights that reflect their relative importance in the final assessment.

RESULTS AND DISCUSSION

Since the digital era creates new requirements for conducting business, modern enterprises are faced with the issue of the digital transformation of their structure. Digital development brings revolutionary changes and emphasizes innovation and automation. This affects marketing systems, sales, customer service, communication, and many other aspects of corporate management (Kraus, Goloborodko, Kraus, 2018: 2-4). The digital transformation of business models is manifested in the formation of rational strategies, the use of digital technologies, innovative approaches, and the development of business ecosystems. Platforms and ecosystems are becoming new business drivers due to technological progress and large volumes of data generated by users. They open up new opportunities for development and an innovative approach to business (Bortnik, 2021: 2-4).

According to the purpose of the chosen research topic, we have determined the parameters that are most important for developing future evaluation criteria for calculating the current technological and infrastructural state of the food enterprise regarding the implementation of Industry 4.0, using the method of linear combination of parameters (Weighted Average, The min-max scaling method) with weights reflecting their relative importance in the final assessment. Thus, for the mentioned type of parameters and sub-parameters, considering the trends in the development of Industry 4.0 technologies, the following should be included:

1. Internet Connection Speed (Parameter A): 1.1 Download Speed (Mbps). 1.2 Upload Speed (Mbps).
2. Number of Servers (Parameter B): 2.1 Physical Servers. 2.2 Virtual Servers.
3. Authentication Level (Parameter C): 3.1 Threat Monitoring System Level. 3.2 Physical Data Security Level.
4. Number of IoT Devices (Parameter D): 4.1 Number of Temperature and Humidity Sensors. 4.2 Number of Smart Devices for Production Process Tracking.
5. Utilization of Machine Learning Algorithms (Parameter E): 5.1 Application Level of Recommender Systems. 5.2 Natural Language Processing (NLP) Level. 5.3 Level of Supervised and Unsupervised Learning.
6. Energy Efficiency Level of the Enterprise (Parameter F): 6.1 Level of Lighting Energy Efficiency. 6.2 Level of Energy-Saving Systems. 6.3 Level of Renewable Energy Source Utilization.
7. Level of Production Automation (Parameter G): 7.1 Level of Automation in Production Lines. 7.2 Level of Automated Quality Control Systems. 7.3 Level of Inventory Management System.
8. Utilization of Cloud Computing (Parameter H): 8.1 Level of Data Storage in Cloud. 8.2 Level of Virtual Machine Utilization for Data Processing in Cloud. 8.3 Level of Utilization of Cloud Services for Development and Deployment.
9. Data and Analytics Quality Level (Parameter I): 9.1 Data Accuracy Level. 9.2 Timeliness of Data Updates. 9.3 Utilization Level of Analytics Tools.
10. Utilization of Robotic Systems (Parameter J): 10.1 Level of Industrial Robot Utilization. 10.2 Level of Logistic Robots and Tools Utilization. 10.3 Level of Customer Service Robots Utilization.

11. Integration Level with External Partners (Parameter K): 11.1 Level of Integration with Suppliers. 11.2 Level of Integration with Customers. 11.3 Level of Integration with Logistic Partners.

12. Workforce Readiness Level (Parameter L): 12.1 Level of Employee Training in Digital Technologies. 12.2 Level of Certification and Employee Skill Enhancement. 12.3 Employee Awareness Level Regarding Digital Transformation.

We will perform the normalization process by bringing various parameters to a common range or scale, allowing them to be correctly compared and considered in an overall assessment. Normalization helps eliminate differences in measurement units and scales between parameters.

We will standardize the parameters using min-max normalization to recalculate the obtained parameter values in the range from 0 to 1. For each parameter x, the value of the normalized parameter x will be calculated as follows (Eq. 1):

$$x = \frac{x - min\,(x)}{max(x) - min\,(x)} \qquad (1),$$

where x – is the original parameter value; min (x) – is the minimum value of the parameter; max (x) – is the maximum value of the parameter.

As a practical example of applying the linear combination method to assess the current state of implemented and utilized Industry 4.0 tools, the bakery production enterprise Ukrainian-Spanish "Urozhay" LLC (website: Urozhay LLC) has been considered. We will apply this formula to normalize all the parameters mentioned above.

We will calculate the normalized parameter "A" (Internet Connection Speed) with a weight of 0.025, with sub-parameters A_n1 "Download Speed (Mbps)" and A_n2 "Upload Speed (Mbps)".

For the calculation criteria, we will use the following ranges for download and upload speeds: the minimum range is 0 Mbps, and the maximum is 300 Mbps.

$$A_{н1} = \frac{100 - 0}{300 - 0} = 0{,}33;$$

$$A_{н2} = \frac{40 - 0}{300 - 0} = 0{,}13;$$

We will calculate the normalized parameter "B" (Number of Servers) with a weight of 0.05, including sub-parameters B_n1 "Physical Servers" and B_n2 "Virtual Servers".

For the calculation criteria, we will use the following ranges for the number of physical and virtual servers: the minimum range is 0 servers, and the maximum range is 20 servers.

$$B_{н1} = \frac{1 - 0}{20 - 0} = 0{,}05;$$

$$B_{н2} = \frac{1 - 0}{20 - 0} = 0{,}05;$$

We will calculate the normalized parameter "C" (Number of IoT Devices) with a weight of 0.20, including sub-parameters "Number of Temperature and Humidity Sensors" and "Number of Smart Devices for Production Tracking."

For the calculation criteria, we will use the following ranges:

1. Number of Temperature and Humidity Sensors: the minimum range is 0, and the maximum range is 200.
2. Number of Smart Devices for Production Tracking: the minimum range is 0, and the maximum range is 20.

$$C_{н1} = \frac{2 - 0}{200 - 0} = 0{,}1;$$

$$C_{н2} = \frac{2 - 0}{20 - 0} = 0{,}1;$$

We will calculate the normalized parameter "D" (Authentication Level) with a weight of 0.05, including sub-parameters D_n1 "Threat Monitoring System Level" and D_n2 "Level of Physical Data Security."

For the calculation criteria, we will use the following ranges: absent – 0; low – 0.2; minimum – 0.4; satisfactory – 0.6; average – 0.8; high – 1.

$$D_{н1} = \frac{0{,}4 - 0}{1 - 0} = 0{,}4;$$

$$D_{н2} = \frac{0{,}2 - 0}{1 - 0} = 0{,}2;$$

We will calculate the normalized parameter "E" (Level of Machine Learning Algorithm Utilization) with a weight of 0.05, including sub-parameters E_n1 "Level of Recommender System Application," E_n2 "Natural Language Processing (NLP) Level," and E_n3 "Supervised and Unsupervised Learning Level."

We will use the previous calculation criteria from the example of parameter "D."

$$E_{н1} = \frac{0{,}2 - 0}{1 - 0} = 0{,}2;$$

$$E_{н2} = \frac{0 - 0}{1 - 0} = 0;$$

$$E_{н3} = \frac{0 - 0}{1 - 0} = 0;$$

We will calculate the normalized parameter "F" (Level of Energy Efficiency of the Enterprise) with a weight of 0.25, including sub-parameters F_n1 "Level of Lighting Energy Efficiency," F_n2 "Level of Energy-Saving Systems," and F_n3 "Level of Renewable Energy Source Utilization."

We will use the previous calculation criteria from the example of parameter "D".

$$F_{н1} = \frac{0,8 - 0}{1 - 0} = 0,8;$$

$$F_{н2} = \frac{0,6 - 0}{1 - 0} = 0,6;$$

$$F_{н3} = \frac{0 - 0}{1 - 0} = 0;$$

We will calculate the normalized parameter "G" (Level of Production Automation) with a weight of 0.10, including sub-parameters G_n1 "Level of Automation of Production Lines," G_n2 "Level of Automatic Quality Control Systems," and G_n3 "Level of Inventory Management System."

We will use the calculation criteria from the example of parameter "D."

$$G_{н1} = \frac{0,4 - 0}{1 - 0} = 0,4;$$

$$G_{н2} = \frac{0,4 - 0}{1 - 0} = 0,4;$$

$$G_{н3} = \frac{0,4 - 0}{1 - 0} = 0,4;$$

We will calculate the normalized parameter "H" (Level of Cloud Computing Usage) with the weight of 0.05, including sub-parameters H_n1 "Level of Usage of Cloud Data Storage," H_n2 "Level of Usage of Virtual Machines for Data Processing in the Cloud," and H_n3 "Level of Usage of Cloud Services for Application Development and Deployment."

We will use the calculation criteria from the example of parameter "D."

$$H_{н1} = \frac{0,2 - 0}{1 - 0} = 0,2;$$

$$H_{н2} = \frac{0,2 - 0}{1 - 0} = 0,2;$$

$$H_{н3} = \frac{0 - 0}{1 - 0} = 0;$$

We will calculate the normalized parameter "I" (Level of Data and Analytics Quality) with a weight of 0.10, including sub-parameters I_n1 "Level of Data Accuracy," I_n2 "Level of Timeliness of Data Updates," and I_n3 "Level of Usage of Analytics Tools."

We will use the calculation criteria from the example of parameter "D."

$$I_{н1} = \frac{0,2 - 0}{1 - 0} = 0,2;$$

$$I_{н2} = \frac{0,2 - 0}{1 - 0} = 0,2;$$

$$I_{н3} = \frac{0,4 - 0}{1 - 0} = 0,4;$$

We will calculate the normalized parameter "J" (Level of Usage of Robotic Systems) with a weight of 0.15, including sub-parameters J_n1 "Level of Usage of Production Robots," J_n2 "Level of Usage of Logistic Robots and Tools," and J_n3 "Level of Usage of Customer Service Robots."

We will use the calculation criteria from the example of parameter "D."

$$J_{н1} = \frac{0 - 0}{1 - 0} = 0;$$

$$J_{н2} = \frac{0,2 - 0}{1 - 0} = 0,2;$$

$$J_{н3} = \frac{0,2 - 0}{1 - 0} = 0,2;$$

We will calculate the normalized parameter "K" (Level of Integration with External Partners) with a weight of 0.10, including sub-parameters K_n1 "Level of Integration with Suppliers," K_n2 "Level of Integration with Customers," and K_n3 "Integration with Logistic Partners."

We will use the calculation criteria from the example of parameter "D."

$$K_{н1} = \frac{0,4 - 0}{1 - 0} = 0,4;$$

$$K_{н2} = \frac{0,4 - 0}{1 - 0} = 0,4;$$

$$K_{н3} = \frac{0,4 - 0}{1 - 0} = 0,4;$$

We will calculate the normalized parameter "L" (Level of Workforce Training) with a weight of 0.10, including sub-parameters L_n1 "Level of Employee Training in Digital Technologies," L_n2 "Level of Certification and Employee Qualification Enhancement," and L_n3 "Level of Employee Awareness of Digital Transformation."

We will use the calculation criteria from the example of parameter "D."

$$L_{н1} = \frac{0,2 - 0}{1 - 0} = 0,2;$$

$$L_{н2} = \frac{0,2 - 0}{1 - 0} = 0,2;$$

$$L_{н3} = \frac{0,2 - 0}{1 - 0} = 0,2;$$

Application of this method ensures that all parameters will fall within the range of 0 to 1, and their contributions to the overall assessment will be equally weighted.

After normalizing the parameters, weight coefficients can be applied to consider their relative importance. Weight coefficients can be determined based on expert assessments or other methods evaluating the significance of each parameter (Weighted Arithmetic Mean, 2015).

The overall assessment (Equation 2) is calculated as the weighted sum of the normalized parameters mentioned above:

$$S = w_1 \bullet x_1 + w_2 \bullet x_2 + w_3 \bullet x_3 \ldots + w_n \bullet x_n \qquad (2),$$

where S - overall assessment;

$w_1, w_2 \ldots w_n$ - weight coefficients;

$x_1, x_2, \ldots x_3$ - normalized values of parameters.

Therefore, this approach allows for considering the relative importance of parameters and provides a more objective assessment of the current state of an enterprise or system.

As the range for the assessment score (S), we will specify the following values:

1. Range S = 0.00 - 0.99 indicates a critical condition with a low level of technological infrastructure and digital automation. Serious upgrading and modernization of the enterprise are required.
2. Range S = 1.00 - 1.15 indicates a low state with underdeveloped technological infrastructure and digital automation. Improvement and implementation of modern solutions are needed.
3. Range S = 1.16 – 1.89 suggests an average state of the enterprise with basic infrastructure and automation, with potential for additional improvements and optimization.
4. Range S = 1.90 - 2.59 indicates a satisfactory state of the enterprise with developed technological infrastructure and digital automation, with opportunities for optimization and growth.
5. Range S = 2.60 – 3.00 signifies an excellent state of the enterprise with excellently developed technological infrastructure, a high degree of digital automation, and efficient infrastructure, along with the potential for further growth and innovation.

Let's calculate the weighted sum of normalized and weighted parameters.

S = 0,025*(0,33+0,13)+0,05*(0,05+0,05)+0,20*(0,1+0,1)+0,05*(0,4+0,2)+0,05*(0,2+0+0)+
+0,05*(0,8+0,6+0)+0,10*(0,4+04,+0,4)+0,05*(0,2+0,2)+0,10*(0,2+0,2+0,4)+0,15*(0+0,2+
+0,2)+0,10*(0,4+0,4+0,4) 0,10*(0,2+0,2+0,2) = 0,62

Therefore, the calculated assessment of the current state (S) leads to the conclusion that the Ukrainian-Spanish enterprise Urozhai LLC has a score of 0.62, indicating a critical condition with a low level of technological infrastructure and digital automation, requiring serious upgrading and modernization.

Recommendations for the Ukrainian-Spanish enterprise Urozhai LLC include attracting investments and exploring new forms of collective business involving similar small enterprises with diverse product portfolios.

CONCLUSIONS

The method of linear combination was applied to calculate the parametric assessment of the technological-infrastructure state of food enterprises in line with Industry 4.0 technology trends. As a practical example, the Ukrainian-Spanish enterprise Urozhai LLC was selected for evaluation. The assessment was conducted based on the following key parameters: 1) internet connection speed; 2) number of servers; 3) number of IoT devices; 4) authentication level; 5) utilization of machine learning algorithms; 6) energy efficiency level; 7) level of production automation; 8) utilization of cloud computing tools; 9) data and analytics quality level; 10) use of robotic systems; 11) level of integration with external partners; 12) staff training level. The ranges of current state assessment were determined and characterized.

As a result of evaluating the current state of implemented Industry 4.0 tools at the Ukrainian-Spanish enterprise Urozhai LLC, a score of 0.62 was obtained, indicating a critical condition with a low level of technological infrastructure and digital automation. The production requires serious upgrading and modernization. The authors provided a series of recommendations and measures aimed at improving the performance of the investigated enterprise. A prospective direction for further research is the design of a unified production-trading hub comprising automated management systems, robotic stations, physical and cloud data analytics systems.

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ПАРАМЕТРИЧНА ОЦІНКА ТЕХНОЛОГІЧНО-ІНФРАСТРУКТУРНОГО СТАНУ ХАРЧОВИХ ПІДПРИЄМСТВ ВІДПОВІДНО ДО ТЕНДЕНЦІЙ РОЗВИТКУ ТЕХНОЛОГІЙ ІНДУСТРІЇ 4.0

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Метою дослідження є презентація розробленої параметричної моделі для оцінки поточного технологічного та інфраструктурного стану підприємств харчової промисловості щодо впровадження Індустрії 4.0. Це робиться за допомогою методу лінійної комбінації параметрів з вагами, що відображають їхню відносну важливість в кінцевій оцінці. Методологія: Відповідно до обраної теми дослідження були визначені параметри, які є найбільш важливими для формування майбутніх критеріїв оцінки поточного технологічного та інфраструктурного стану підприємства харчової промисловості щодо впровадження Індустрії 4.0. Це було досягнуто за допомогою методу лінійної комбінації параметрів (зважене середнє арифметичне, метод мінімакс-шкалювання) з вагами, що відображають їхню відносну важливість в кінцевій оцінці. Результатом дослідження є описані діапазони оцінки поточного стану підприємств. Сучасні технології та інструменти Індустрії 4.0 стрімко розвиваються як на зарубіжному, так і національному ринку. Цифрова трансформація бізнес-моделей відкриває перед підприємствами нові можливості й завдання та охоплює раціональне використання ресурсів, соціально-економічні відносини, технологічну стратегію і внесення концепції «Індустрія 4.0» в діяльність компаній. Як практичний приклад для оцінки поточного стану технологічно-інфраструктурного забезпечення підприємств харчової промисловості було обрано Українсько-іспанське ТОВ "Урожай". На основі результатів проведеної оцінки визначено поточний стан впровадження та використання інструментів Індустрії 4.0 на досліджуваному підприємстві. Надано низку рекомендацій та запропоновано заходи, спрямовані на підвищення показників досліджуваного підприємства, серед яких слід виокремити: залучення додаткових інвестицій, відкриття нового виду колективного бізнесу з таких же малих підприємств різного типу продуктового кошика. В якості перспективи подальшого дослідження запропоновано проектування єдиного виробничо-торгівельногу хабу, який складатиметься з автоматичних систем управління, роботизованих станцій, систем фізичної та хмарної аналітики даних.

Ключові слова: Індустрія 4.0, цифровізація підприємств, впровадження технологій Індустрії 4.0, технології харчових підприємств, метод лінійної комбінації параметрів