Проведено дослідження процесу управління інформаційною інфраструктурою цифрового підприємства в межах концепції «Індустрія 4.0». Визначено, що сучасні цифрові технології викликають експоненціальне зростання потоків даних, для ефективного функціонування яких постає питання трансформації класичного підприємства в цифрове. З'являються нові моделі ведення бізнесу, мережеві структури, що ґрунтуються на колективних методах виробництва і споживання, трансформують традиційні ринкові відносини і вимагають вироблення нових рішень в галузі управління цифровим підприємством. Зазначено, що використання всіх елементів (мобільність; соціальність; BPM; система електронного документообігу; ERP фінанси та облік; Big Data & Analytics, бізнес-аналітика) сучасних інформаційно-комунікаційних технологій дозволить підвищити продуктивність та цінність підприємств. Визначено, що інформаційно-комунікаційні технології дозволяють ефективно взаємодіяти між собою в певних галузях виробництва та забезпечують оптимізацію будь-яких бізнес-процесів за допомогою консьюмеризації. Ідентифіковано сучасні тренди розвитку цифрового підприємства та окреслено передумови до впровадження цифровізації у бізнес-простір. Структуровано складові елементи процесу управління інформаційною інфраструктурою цифрового підприємства, на базі чого запропоновано модель процесу управління інформаційною інфраструктурою. Обґрунтовано цілі цифрової інфраструктури, які зазначені: в підвищенні швидкості прийняття рішень, збільшенні варіативності процесів в залежності від потреб та особливостей клієнта, зниженні кількості залучених до процесу співробітників. Поглиблено методичні основи процесу управління інформаційною інфраструктурою цифрового підприємства в умовах концепції «Індустрія 4.0»

Ключові слова: процеси управління, інформаційна інфраструктура, цифрове підприємство, цифрова економіка, Індустрія 4.0

PROCESSES OF MANAGING INFORMATION INFRASTRUCTURE OF A DIGITAL ENTERPRISE IN THE FRAMEWORK OF THE «INDUSTRY 4.0» CONCEPT

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1. Introduction

The complication of social structures and relations, which are increasingly based on modern digital technologies, continues to cause an exponential increase in data flows, highlights the question of the effective functioning of a digital enterprise. The importance of the processes that are going through has allowed us to raise the question of the formation of a new type of information infrastructure, where relations regarding the production, processing, storage, transmission and use of a growing amount of data are becoming dominant. Data become the basis of economic

analysis, explores the patterns of functioning of modern socio-economic systems. At present, it is not the fact of owning any resource that becomes important at the enterprise, but the availability of data about this resource and the ability to use them for the purpose of planning its activities. There is significant potential for the use of modern digital technologies in the activities of enterprises. It is important to pay attention to such aspects as the use of modern computing equipment, software, and the availability of qualified specialists. It is necessary to take into account that digital enterprises have significant potential to accelerate innovation processes, therefore the indicators of investments in the development of a digital enterprise are an important factor in its competitiveness in modern conditions.

New business models emerge, network structures based on collective methods of production and consumption transform traditional market relations and require the development of new solutions in the field of digital enterprise management. Further development of the digital enterprise is important for the entire economy of the country as a whole. Many governments, predicting such changes, are increasingly seeking to develop the process of managing the information infrastructure of a digital enterprise within the framework of the concept "Industry 4.0" concept. Modern national digital strategies address issues of economic development, the creation of innovative enterprises, increasing employment, the formation of an effective public sector.

Today, the "Industry 4.0" concept is becoming more and more popular. The term *"digital enterprise"* was suggested by the *Director of MIT Media Lab* in Being Digital, which was published in 1996 [1]. Undoubtedly, the process of transition of the enterprise to the "Industry 4.0" concept is quite complex and requires the formation of an information infrastructure, which includes the use of all elements of modern information and communication technologies, in turn, will increase the productivity and value of enterprises. Given the modern course and amount of data generated in modern enterprises, it is very difficult for employees to cope with the relevant information flows, as opposed to information and communication technologies. In turn, information and communication technologies allow to effectively interact with each other in certain industries, which allows to optimize any business processes by creating an environment equipped with measuring equipment.

Information infrastructure is defined by four key trends – socialism, mobility, analytics and clouds (*social-mobile-analytics-cloud – SMAC*) – IDC calls the "*third platform*" [2], Gartner speaks of the "*Nexus of forces*") [3]. Each of these trends, taken separately, is just a technology, but together they form a powerful tool for digital transformation. At first, the corresponding four trends were used in the consumer market (B2C) and caused consumerization. It is proposed to consider consumerization as an active use of personal mobile access to a computer network by employees of the company, whose share prevails over corporate devices of information and communication technologies. Subsequently, the consummation manifested itself in a corporate (B2B), becoming the basis for the transition to a digital enterprise. At the same time, it is advisable to note that the *Internet of Things* (IoT) makes it possible to collect data for analytical systems – using embedded sensors and turning on smart devices in different control loops.

Thus, it can be noted that the fourth industrial revolution is manifested in a series of waves:

– *a digital consumer* who enjoys a more interactive and personalized experience thanks to SMAC (*social, mobile, analytical and cloud technologies*);

– *a digital enterprise* that uses SMAC technology to optimize the value of corporate functions that organize interaction in the enterprise to increase productivity;

– *digital operations* in which companies are indeed rebuilding their business using artificial intelligence, robotics, cognitive computing and the industrial Internet of things, "said *Pierre Nanterme*, CEO Accenture, at the World Economic Forum in Davos [4].

Sociality, mobility, analytics and cloud technologies are the basis on which a digital enterprise is formed, but the fact of using the corresponding tools does not render the enterprise digital. Therefore, of course, enterprises will have to rebuild their information infrastructure in accordance with the requirements of the digital world.

The formation of an information infrastructure is a process that is initiated and occurs under the influence of external factors, among which the most important is positive customer experience [5]. Partners and customers of the enterprise require a high level of availability of information about the work of the enterprise, in particular its services and products. Providing this level of user access is only possible with the use of technologies that can aggregate and process data and then pass it on to customers and partners.

It is a positive customer experience that allows enterprises not only to remain in the market, but also to increase their presence on it. Achievement of the relevant results is closely connected with the increase in operational efficiency, which is achieved in the process of building the information infrastructure. According to IDC (*an international research and consulting company that studies the global information technology and telecommunications market*), the global expenditures on building an information infrastructure – hardware, software and services – reached 1.3 billion USD in 2017. Expenditures are expected to nearly double by 2021, when the total amount spent on digitization on a global scale exceeds 2.1 billion USD [6].

The MIT Sloan research (*international business school at the Massachusetts Institute of Technology*) shows the importance of both directions of the formation of the information infrastructure – technological and management [7]. Thus, the company successfully introduced new technologies and advanced management methods, showed an average of 26 percent higher profitability compared with competitors. Those who chose exclusively the introduction of technical innovations and retained the old bureaucratic management style, as a result were in the red – the yield is 11 percent lower than the leaders.

To succeed in this new world, enterprises will have to change in all directions, being engaged in the formation of the information infrastructure of production and business processes, since only their *convergence* will ensure the transformation of the information enterprise into the modern world according to the "Industry 4.0" concept.

2. Literature review and problem statement

In the research environment, there is an active theoretical discussion about a clear interpretation of the terms: "digital economy", "digital enterprise", "virtual factory", "Industry 4.0", "deserted production", "additive technologies".

And this is not surprising, since the process of digitalization of the economy is a relatively new phenomenon. Virtually all spheres of human life (economic, social, political, cultural, social, and others) were altered to varying degrees by the discoveries and development of information computer technologies [8]. However, changes in recent years allow many researchers to assert that a new stage of informatization, the name of which is "digital economy", is starting.

In [1], the use of the term "digital economy" was due to the intensive development of information and communication technologies and the beginning of the second-generation informatization process. Leading consulting company The Boston Consulting Group (Boston, USA) notes [9] that for some countries, the digital economy is a logical continuation of the evolutionary development of the digital ecosystem and the ability to fully realize that very "creative economy", "new economy" – a system of interconnection "links where the line between online and offline becomes conditional, and the level of involvement of the state, business and citizens reaches 100 percent. This is the near future for the leading countries. But for those countries that seek rapid development digitalization is an opportunity to preserve real competitiveness as well as sustainability in the long term.

It should be emphasized that the development of the information technology sector is accompanied by the growing role of the "digital enterprise" as a key component of the digitalization process of the economy. The term "digital enterprise" does not have an unambiguous definition in the economic literature and is debatable in nature.

In work [10] it is noted that a digital enterprise is an organization capable of quickly adapting to rapidly changing environmental conditions, including on the basis of a proactive forecast of the development of the situation in the future. In [11], the implementation of the "digital enterprise" model is based on technological innovations, among which cloud computing, big data, mobility and social networks are primarily distinguished. Thus, a traditional enterprise turns into an organization with "digital thinking", overcoming the path of digital transformation. And the product offered by such an enterprise also becomes digital.

The author [12] notes that the concept of a digital enterprise implies a complete restructuring of the business, including manufacturing, customer relations, management methods, based on the widespread use of digital technologies. The basis of digitalization is the global technological trends in information technology, the cumulative effect of which causes digital transformation. In the works [13, 14] it is noted that for the implementation of a digital enterprise, new models of business organization are needed, allowing to create enterprises whose activities will be based on processing and analyzing data based on the development strategy. This is what will contribute to the continuous operational development of the enterprise in the changing conditions of the surrounding world, as well as early preparation for future reorganization based on accurate forecasts provided by new information technologies. Modern market conditions require enterprises to make operational management decisions to determine production volumes, elect target markets for product sales [15].

The forum [16] on the strategy, technology and practice of managing a digital enterprise DigEnForum proposes the definition of a digital enterprise as an organization that uses information technology as a competitive advantage in all areas of its business: manufacturing, business process-es, marketing, and customer interaction. That is why, the primary task of implementing the process of digitization of enterprises should be a general audit of production activities, which will reveal additional competitive advantages. Such advantages may include: cost reduction, saving resources, improving quality, efficiency and reliability, developing customer feedback, switching to other products and, finally, changing the business model.

Leading consulting company Accenture (Dublin, Ireland) notes that a digital enterprise offers the opportunity for new operating models and business processes, platforms for connected products, analytics and teamwork to increase productivity [17]. It is advisable to note that the business processes of a digital enterprise are nothing more than automation based on the wide use of information technologies. However, the full implementation of automation is very expensive and often useless. After all, total automation, as a result of which all the problems and drawbacks existing at the enterprise are also automated, not only will not bring the expected positive result, but also strengthen the problematic aspects.

PwC (*consulting company*) connects the term "digital enterprise" with the "Industry 4.0" concept, focusing primarily on changing the sphere of industrial production [18]. It should be noted that PwC's research focuses more on investments that will be focused on digital technologies – sensors and communication devices, as well as programs and applications – production management systems (PMS). In addition, in this study, the conditions for the formation of the phases of the fourth industrial revolution (Industrial Internet of Things) are not given. This means that traditional enterprises are not able to plan the training of their employees and the procedure for the implementation of organizational changes in their enterprises. This problem can be solved by attracting, retaining and training the specialists of the so-called "digital generation". It is this highly qualified staff capable of working in a dynamic digital ecosystem, optimally adapting to changes in current activities and in continuous development.

McKinsey & Company (*an international consulting company specializing in solving problems related to strategic management*) considers the most difficult part of the digital transformation, namely the cultural changes necessary to transform an enterprise into digital [19]. It should be noted that digital transformation will drastically change the social landscape. In order to prevent fatal mass technological unemployment, you need to create a social ecosystem of flexible implementation of technologies for their social design, as well as radically reform the education system and the labor market.

Any digital technology is based on infrastructure. Thus, Capgemini Consulting (*a consulting company in the field of management and information technology*) and MIT Sloan School of Management conducted research and analyzed more than 400 large companies in various industries, in understanding the essence of the term "digital enterprise". According to the results of the study, a digital enterprise is considered as an organization with an expanded range of services, an organization that offers customers revolutionary digital solutions, including an integrated personalized service based on the collection of various data integrated by the information infrastructure [20].

It should be noted that the existence of a separate information infrastructure for each individual enterprise with

its own standards, methods and algorithms is an inefficient and short-sighted solution that can lead to the chaos and disorder of the digitalization process of enterprises of the same industry. That is why an important task of the digital transformation of modern enterprises is the development and implementation of a unified information-analytical infrastructure to support management decision-making in the framework of digitalization of the economy.

3. The aim and objectives of research

The aim of research is determination of the need and features of the management process of the information infrastructure of a digital enterprise in the context of the "Industry 4.0" concept, which ensures an increase in the operating efficiency of companies and the convergence of technologies.

To achieve this aim, the following objectives are solved:
– to identify the constituent elements of the management process of the information infrastructure of a digital enterprise;
– to propose a model for managing the information infrastructure of a digital enterprise;
– to explore the possibility of using the methods of general management theory for solving specific problems of managing the information infrastructure of a digital enterprise in the context of the "Industry 4.0" concept.

4. Components and methods of researching the features of the information management processes of a digital enterprise

4. 1. The investigated constituent elements (external and internal) of the information infrastructure of a digital enterprise

Among enterprises that have transformed into digital, it is worth noting: the high-tech industry, banks and retail – right now receive the greatest benefits from digital transformation. If to consider the field, from the point of view of the conservatives, they include insurance companies that care about reducing risks and prevent them from innovating.

In the last place of the digital maturity rating: pharmaceuticals, industrial production and production of consumer goods – they have yet to build a digital transformation model that will ensure the formation of an information infrastructure.

The fact of using technology does not make an enterprise digital. Enterprises still have to rebuild their information infrastructure to meet the requirements of the digital world.

Digital transformation does not mean that enterprises need to abandon all of their existing software and implement new ones. The development goes along the path of modernization of corporate systems. Analysts consulting company Gartner noted that in China, the cost of corporate application software in 2018 will amount to 5.1 billion USD. United States, which is 18.9 percent increase compared with 2017 [21]. But in the context of new challenges, known technologies require rethinking.

The constituent elements on which a digital enterprise is built include:

– *Mobility.* The number of connected devices in 2016 was 64 billion USD. And by 2020 will reach 208 billion USD (*based on research and consulting company specializing in information technology markets – Gartner*) [21]. All employees and customers, not just managers, have become mobile, so for managing a digital enterprise, we need new mobile applications with enhanced functionality. The Internet of Things, which are essentially the development of mobile technologies, will have a greater impact. Service industries and B2C markets, primarily retail, are already experiencing another wave of mobilization, which takes their interaction with consumers to a new level;

– *BPM (business process management), Workflow, Collaboration. Business processes.* An enterprise will never be able to create a qualitatively new "digital" product, adapting social and mobile technologies, while not avoiding a radical optimization of internal processes. Enterprises need to transform and efficiently organize work within the company before engaging in more customer-oriented and introducing advanced technologies. In doing so, the transformation will require BPM tools;

– *ECM (Enterprise content management)*, EDMS (*electronic document management system*). Internal and external documents can be both a factor in the growth of efficiency and a brake if the requirements of documentation are contrary to the requirements of the business. Restrictions, imposed by law, obliging enterprises to use only paper documents, are largely removed. But the syndrome of learned helplessness remained: enterprises are not morally ready to say goodbye to paper in order to switch to digital formats of interaction. In this direction, much work should be done to change the corporate culture, whereas technical solutions for all tasks already exist. In addition, the key to the formation of the information infrastructure will be not so much the automated work on structured workflow as the integration of the management capabilities of unstructured enterprise content with analytics capabilities;

– *ERP (Enterprise Resource Planning)*, finance and accounting. Capgemini Consulting analysts call the ERP a digital transformation driver. But only this will be a new generation of ERP, meeting the principles of Design for Digital (design for digital). The goal of this restructuring is responding as quickly as possible to the demands of consumers and brings the product to the market, that is, production must be flexible, adaptive and practically personal – because the requests from each client are individual. This can be achieved by using a stack of SMAC technologies (social, mobile, analytical and cloud technologies) in the development of ERP platforms;

– *Big Data & Analytics, business analytics.* Big data give impetus to the formation of information infrastructure, opening up new opportunities, new customers, new markets. Business intelligence has become a tool for decision-making, which is used not only by advanced specialists, but also by business leaders at various levels. Moving to a digital enterprise also means data growth. Information from social networks, various external sources and, mainly, various sensors gets into the control loop, since production also switches to digital format. In connection with the growth of data volume and complexity, the systems of semantic analysis and artificial intelligence will be in demand;

– *Sociality* – knowledge and people management. The sphere of marketing in the digital space is also transforming towards greater detail and personalization of the offer to customers – and this requires an in-depth study of the available information using knowledge management technologies. Despite all the advances in automating business processes, people with intuition, skills and abilities remain a key factor in the success of a digital enterprise; therefore, traditional personnel management systems are transformed into talent management, employee training and development. Sociality makes the company "*flat*" – that is, destroys the vertical hierarchy, allowing everyone to communicate directly. The corresponding trend will inevitably lead to the spread of new management concepts based on network management principles instead of command and control. For example, Facebook audience is 20.6 billion people per month (data for 1 quarter of 2018) [22]. Those who have experience of social interaction on the Web will surely bring it into their working relationships.

4. 2. Digital enterprise information infrastructure management

A general approach to solving control problems in complex systems is described in terms of the modern theory of optimal control [23, 24]. At the same time, the state space of control objects is introduced, which is defined by a set of exogenous variables

$$X = \{x_1, x_2, ... x_n\}$$

and endogenous variables

$$Y = \{y_1, y_2, ... y_m\}.$$

The trajectory of the control object in the state space is described by a system of differential equations.

$$\dot{Y}(t) = A(t) \cdot Y(t) + B(t) \cdot X(t) + W(t),$$ (1)

where $W(t)$ – the vector of disturbing influences, including errors of state estimation,

$$\dim W(t) = m \times 1.$$

Thus, the rate of change of endogenous variables at each point in time is determined by the value of endogenous variables at that point in time and the compatible control action of exogenous variables.

The control problem is to find the control law $X(t)$, which minimizes the functional

$$J(U(t)) = \int_0^{T_0} \left[Y^{\mathrm{T}}(t) Q Y(t) \right] + \left[X^{\mathrm{T}}(t) R X(t) \right] \mathrm{d}t,$$ (2)

where Q – the weight matrix, which reflects the difference in the essence of endogenous variables $\dim Q = m \times m$, R – the matrix characterizing the level of expenditures on investing exogenous variables, $\dim R = m \times m$.

The traditional approach to solving the problem (1), (2) is searching for control that is optimal on average. In this control, it is found, determined by the ratio [25–27]:

$$X(t) = -C(t) Y(t).$$ (3)

Relation (3) implements the universal control law in systems with negative feedback. In this ratio

$$C(t) = R^{-1} B^{\mathrm{T}}(t) \cdot S(t),$$ (4)

and $S(t)$ – the solution of the Riccati equation

$$\dot{S}(t) = -S(t) \cdot A(t) - A^{\mathrm{T}}(t) \cdot S(t) +$$
$$+ S(t) \cdot B(t) \cdot R^{-1} B^{\mathrm{T}}(t) \cdot S(t) - Q =$$
$$= -S(t) \cdot A(t) - A^{\mathrm{T}}(t) \cdot S(t) + S(t) \cdot B(t) C(t) - Q. .$$ (5)

Substituting (3) into (1), let's obtain

$$\dot{Y}(t) = A(t) \cdot Y(t) + B(t) \cdot C(t) \cdot W(t) + W(t) =$$
$$= (A(t) - B(t) \cdot C(t)) Y(t) + W(t).$$ (6)

The nature of further research is essentially determined by the properties of a random process of disturbances affecting the system. The assumption of Markov perturbations is natural. As is known [27], this assumption does not impose serious restrictions on the adequacy of the corresponding mathematical models, since the extension of the dimension of the state vector is almost always the non-Markov process can be transformed into a Markov process. The next step in the specification of the disturbing effect is to set the density distribution of the amplitude of this process. With reference to the central limit theorem, let's assume that this density is Gaussian with a zero mean vector and a known perturbation correlation matrix. Such a process is uniquely determined by two deterministic functions: the law of change in the average values of the components of the vector of perturbations and the law of change of the elements of the matrix of the corresponding covariances. When a Markov Gaussian process passes through a linear dynamic system, its properties are preserved [28]. This means that if $W(t)$ is a Gaussian process, then the process at the output of the system has the same property. In [27], a relation is obtained for calculating the average value of the control quality criterion:

$$\overline{J} = \frac{1}{2} Sp \int_0^T \left(QK(t) + R \cdot C(t) \cdot K(t) \cdot C^{\mathrm{T}}(t) \right) \mathrm{d}t,$$ (7)

where $K(t) = \langle Y(t) \cdot Y^T(t) \rangle$ – covariance matrix of the components of the state vector.

The complexity of directly calculating the quality control criterion is largely determined by the difficulties in solving the Riccati equation [26]. In general, this equation does not have an exact solution, which makes it expedient to find an approximate solution of the control problem. Such a solution can be obtained if it is assumed that all the functional elements in the relation (5) are constants. The corresponding situation in practice appears when, when making a decision on the change of exogenous variables, it can be compared with the duration of its implementation (or less). Moreover, as is known [25, 26], there is an established solution to the Riccati equation, in which the elements of the matrix S are also constants. Then equation (5) takes the form:

$$-SA - A^T S + SBR^{-1} B^T S - Q = 0,$$

so

$$-2 \cdot \begin{pmatrix} s_1 a_1 & 0 & ... & 0 \\ 0 & s_2 a_2 & ... & 0 \\ ... & ... & ... & ... \\ 0 & 0 & ... & s_m a_m \end{pmatrix} + \begin{pmatrix} s_1 & 0 & ... & 0 \\ 0 & s_2 & ... & 0 \\ ... & ... & ... & ... \\ 0 & 0 & ... & s_m \end{pmatrix} \cdot \begin{pmatrix} b_{11} & b_{12} & ... & b_{1n} \\ b_{21} & b_{22} & ... & b_{2n} \\ ... & ... & ... & ... \\ b_{m1} & b_{m1} & ... & b_{mn} \end{pmatrix} \begin{pmatrix} \frac{1}{\delta_1} & 0 & ... & 0 \\ 0 & \frac{1}{\delta_2} & ... & 0 \\ ... & ... & ... & ... \\ 0 & 0 & ... & \frac{1}{\delta_n} \end{pmatrix} \cdot \begin{pmatrix} b_{11} & b_{12} & ... & b_{m1} \\ b_{21} & b_{22} & ... & b_{m2} \\ ... & ... & ... & ... \\ b_{1n} & b_{2n} & ... & b_{mn} \end{pmatrix} \times$$

$$\times \begin{pmatrix} s_1 & 0 & ... & 0 \\ 0 & s_2 & ... & 0 \\ ... & ... & ... & ... \\ 0 & 0 & ... & s_m \end{pmatrix} + \begin{pmatrix} q_1 & 0 & ... & 0 \\ 0 & q_2 & ... & 0 \\ ... & ... & ... & ... \\ 0 & 0 & ... & q_m \end{pmatrix} = -2 \cdot \begin{pmatrix} s_1 a_1 & 0 & ... & 0 \\ 0 & s_2 a_2 & ... & 0 \\ ... & ... & ... & ... \\ 0 & 0 & ... & s_m a_m \end{pmatrix} + \begin{pmatrix} s_1 b_{11} & s_1 b_{12} & ... & s_1 b_{1n} \\ s_2 b_{21} & s_2 b_{22} & ... & s_2 b_{2n} \\ ... & ... & ... & ... \\ s_m b_{m1} & s_m b_{m2} & ... & s_m b_{mn} \end{pmatrix} \cdot \begin{pmatrix} \frac{1}{\delta_1} & 0 & ... & 0 \\ 0 & \frac{1}{\delta_2} & ... & 0 \\ ... & ... & ... & ... \\ 0 & 0 & ... & \frac{1}{\delta_n} \end{pmatrix} \times$$

$$\times \begin{pmatrix} b_{11}s_1 & b_{12}s_2 & ... & b_{m1}s_m \\ b_{12}s_1 & b_{22}s_2 & ... & b_{m2}s_m \\ ... & ... & ... & ... \\ b_{1n}s_1 & b_{2n}s_2 & ... & b_{mn}s_m \end{pmatrix} + \begin{pmatrix} q_1 & 0 & ... & 0 \\ 0 & q_2 & ... & 0 \\ ... & ... & ... & ... \\ 0 & 0 & ... & q_m \end{pmatrix} = -2 \cdot \begin{pmatrix} s_1 a_1 & 0 & ... & 0 \\ 0 & s_2 a_2 & ... & 0 \\ ... & ... & ... & ... \\ 0 & 0 & ... & s_m a_m \end{pmatrix} + \begin{pmatrix} \frac{s_1 b_{11}}{\delta_1} & \frac{s_1 b_{12}}{\delta_2} & ... & \frac{s_1 b_{1n}}{\delta_n} \\ \frac{s_2 b_{21}}{\delta_1} & \frac{s_2 b_{22}}{\delta_2} & ... & \frac{s_2 b_{2n}}{\delta_n} \\ ... & ... & ... & ... \\ \frac{s_m b_{m1}}{\delta_1} & \frac{s_m b_{m2}}{\delta_2} & ... & \frac{s_m b_{mn}}{\delta_n} \end{pmatrix} \times$$

$$\times \begin{pmatrix} b_{11}s_1 & b_{12}s_2 & ... & b_{m1}s_m \\ b_{12}s_1 & b_{22}s_2 & ... & b_{m2}s_m \\ ... & ... & ... & ... \\ b_{1n}s_1 & b_{2n}s_2 & ... & b_{mn}s_m \end{pmatrix} + \begin{pmatrix} q_1 & 0 & ... & 0 \\ 0 & q_2 & ... & 0 \\ ... & ... & ... & ... \\ 0 & 0 & ... & q_m \end{pmatrix} = -2 \cdot \begin{pmatrix} s_1 a_1 & 0 & ... & 0 \\ 0 & s_2 a_2 & ... & 0 \\ ... & ... & ... & ... \\ 0 & 0 & ... & s_m a_m \end{pmatrix} + \begin{pmatrix} s_1^2 \sum_{j=1}^{n} \frac{b_{1j}^2}{\delta_j} & s_1 s_2 \sum_{j=1}^{n} \frac{b_{1j} b_{2j}}{\delta_j} & ... & s_1 s_m \sum_{j=1}^{n} \frac{b_{1j} b_{mj}}{\delta_j} \\ s_2 s_1 \sum_{j=1}^{n} \frac{b_{2j} b_{1j}}{\delta_j} & s_2^2 \sum_{j=1}^{n} \frac{b_{2j}^2}{\delta_j} & ... & s_2 s_m \sum_{j=1}^{n} \frac{b_{2j} b_{mj}}{\delta_j} \\ ... & ... & ... & ... \\ s_m s_1 \sum_{j=1}^{n} \frac{b_{mj} b_{1j}}{\delta_j} & s_m s_2 \sum_{j=1}^{n} \frac{b_{mj} b_{2j}}{\delta_j} & ... & s_m^2 \sum_{j=1}^{n} \frac{b_{mj}^2}{\delta_j} \end{pmatrix} +$$

$$+ \begin{pmatrix} q_1 & 0 & ... & 0 \\ 0 & q_2 & ... & 0 \\ ... & ... & ... & ... \\ 0 & 0 & ... & q_m \end{pmatrix} = \begin{pmatrix} s_1^2 \sum_{j=1}^{n} \frac{b_{1j}^2}{\delta_j} - 2sa_1 - q_1 & s_1 s_2 \sum_{j=1}^{n} \frac{b_{1j} b_{2j}}{\delta_j} & ... & s_1 s_m \sum_{j=1}^{n} \frac{b_{1j} b_{mj}}{\delta_j} \\ s_2 s_1 \sum_{j=1}^{n} \frac{b_{2j} b_{1j}}{\delta_j} & s_2^2 \sum_{j=1}^{n} \frac{b_{2j}^2}{\delta_j} - 2sa_1 - q_2 & ... & s_2 s_m \sum_{j=1}^{n} \frac{b_{2j} b_{mj}}{\delta_j} \\ ... & ... & ... & ... \\ s_m s_1 \sum_{j=1}^{n} \frac{b_{mj} b_{1j}}{\delta_j} & s_m s_2 \sum_{j=1}^{n} \frac{b_{mj} b_{2j}}{\delta_j} & ... & s_m^2 \sum_{j=1}^{n} \frac{b_{mj}^2}{\delta_j} - 2s_m a_m - q_m \end{pmatrix} = 0.$$

Thus, the resulting matrix system containing m^2 algebraic equations. Of these equations, only m (they are located on the main diagonal of the matrix system) has a meaningful meaning and their solution forms the desired control. The remaining $m^2 - m$ equations have a trivial zero solution, of no interest. Each of the m informative equations contains only one unknown and therefore they can be solved independently. In this case, the i-th equation has the form:

$$s_i^2 + p_i s_i + v_i = 0, \quad i = 1, 2, ..., m, \tag{8}$$

$$p_i = -\frac{2a_i}{\sum_{j=1}^{n} \frac{b_{ij}^2}{\delta_j}}, \quad v_i = -\frac{q_i}{\sum_{j=1}^{n} \frac{b_{ij}^2}{\delta_j}}, \quad i = 1, 2, ..., m.$$

Hence, choosing a positive root, let's obtain

$$s_i = -\frac{p_i}{2} + \sqrt{\frac{p_i^2}{4} - v_i} = \frac{a_i}{\sum_{j=1}^{n} \frac{b_{ij}^2}{\delta_j}} +$$

$$+ \sqrt{\frac{a_i^2}{\left(\sum_{j=1}^{n} \frac{b_{ij}^2}{\delta_j}\right)^2} + \frac{q_i}{\sum_{j=1}^{n} \frac{b_{ij}^2}{\delta_j}}} =$$

$$= \frac{a_i}{\sum_{j=1}^{n} \frac{b_{ij}^2}{\delta_j}} \left(1 + \sqrt{1 + \frac{q_i}{a_1} \sum_{j=1}^{n} \frac{b_{ij}^2}{\delta_j}}\right),$$

$$i = 1, 2, ..., m. \tag{9}$$

Substituting (9) into (4):

$$C = R^{-1}B^T S = \begin{pmatrix} \dfrac{1}{\delta_1} & 0 & ... & 0 \\ 0 & \dfrac{1}{\delta_2} & ... & 0 \\ ... & ... & ... & ... \\ 0 & 0 & ... & \dfrac{1}{\delta_n} \end{pmatrix} \cdot \begin{pmatrix} b_{11} & b_{12} & ... & b_{m1} \\ b_{21} & b_{22} & ... & b_{m2} \\ ... & ... & ... & ... \\ b_{1n} & b_{2n} & ... & b_{mn} \end{pmatrix} \cdot \begin{pmatrix} s_1 & 0 & ... & 0 \\ 0 & s_2 & ... & 0 \\ ... & ... & ... & ... \\ 0 & 0 & ... & s_m \end{pmatrix} =$$

$$= \begin{pmatrix} \dfrac{b_{11}}{\delta_1} & \dfrac{b_{21}}{\delta_1} & ... & \dfrac{b_{m1}}{\delta_1} \\ \dfrac{b_{12}}{\delta_2} & \dfrac{b_{22}}{\delta_2} & ... & \dfrac{b_{m2}}{\delta_2} \\ ... & ... & ... & ... \\ \dfrac{b_{1n}}{\delta_n} & \dfrac{b_{2n}}{\delta_n} & ... & \dfrac{b_{mn}}{\delta_n} \end{pmatrix} \cdot \begin{pmatrix} s_1 & 0 & ... & 0 \\ 0 & s_2 & ... & 0 \\ ... & ... & ... & ... \\ 0 & 0 & ... & s_m \end{pmatrix} = \begin{pmatrix} \dfrac{b_{11}s_1}{\delta_1} & \dfrac{b_{21}s_2}{\delta_1} & ... & \dfrac{b_{m1}s_m}{\delta_1} \\ \dfrac{b_{12}s_1}{\delta_2} & \dfrac{b_{22}s_2}{\delta_2} & ... & \dfrac{b_{m2}s_m}{\delta_2} \\ ... & ... & ... & ... \\ \dfrac{b_{1n}s_1}{\delta_n} & \dfrac{b_{2n}s_2}{\delta_n} & ... & \dfrac{b_{mn}s_m}{\delta_n} \end{pmatrix}. \quad (10)$$

Finally, substituting (10) in (3), let's obtain the desired equation:

$$\begin{pmatrix} x_1 \\ x_2 \\ ... \\ x_n \end{pmatrix} = - \begin{pmatrix} \dfrac{b_{11}s_1}{\delta_1} & \dfrac{b_{21}s_2}{\delta_1} & ... & \dfrac{b_{m1}s_m}{\delta_1} \\ \dfrac{b_{12}s_1}{\delta_2} & \dfrac{b_{22}s_2}{\delta_2} & ... & \dfrac{b_{m2}s_m}{\delta_2} \\ ... & ... & ... & ... \\ \dfrac{b_{1n}s_1}{\delta_n} & \dfrac{b_{2n}s_2}{\delta_n} & ... & \dfrac{b_{mn}s_m}{\delta_n} \end{pmatrix} \cdot \begin{pmatrix} y_1 \\ y_2 \\ ... \\ y_m \end{pmatrix}. \quad (11)$$

The control problem is solved differently if the control goal is stabilization of the selected system state. In this case, the relation (1) takes the form:

$$A(t) \cdot Y(t) + B(t) \cdot X(t) + W(t) = 0. \quad (12)$$

In the particular case when the parameters of the system do not change in time, relation (12) is simplified to the form:

$$A \cdot Y + B \cdot X + W = 0. \quad (13)$$

The obtained matrix equation in expanded form is a system of linear algebraic equations, the distinguishing feature of which is that the equation of this system simultaneously contains sets of endogenous and exogenous variables, for example,

$$\begin{aligned} & a_{11}y_1 + a_{12}y_2 + ... a_{1m}y_m + b_{11}x_1 + ... + b_{1n}x_n + q_1 = 0, \\ & a_{21}y_2 + a_{22}y_2 + ... a_{2m}y_m + b_{21}x_1 + ... + b_{2n}x_n + q_2 = 0, \\ & ... \ ... \ ... \ ... \ ... \ ... \ ... \ ... \ ... \ ... \ ... \ ... \ ... \\ & a_{m1}y_2 + a_{m2}y_2 + ... a_{mm}y_m + b_{m1}x_1 + ... + b_{mn}x_n + q_m = 0. \end{aligned} \quad (14)$$

Using (14), let's express the endogenous variables through exogenous.

Moreover, if the matrix A is non-degenerate, then

$$Y = A^{-1}BX - A^{-1}W = CX + U, \ \ C = A^{-1}B, \ \ U = A^{-1}W. \quad (15)$$

If $M[U] = 0$, then the relation (15) is simplified to the form:

$$Y = CX. \quad (16)$$

The obtained ratio allows for given matrices A, B and vector W to calculate the value of the set of endogenous variables Y depending on the values of exogenous variables X.

The technology of further analysis of the original system of equations depends on whether the model is identified. A model is called identified if, using a known matrix C, using matrices 15 and 15, the matrices A and B can be uniquely calculated. Otherwise, the model is considered identified. Finally, if identification is possible in several ways, then the model is non-identifiable.

A simple feature of the identified model is formulated as follows.

Let n_j, m_j – respectively, be the number of endogenous and exogenous variables in the j-th equation of system (1). The model is identifiable if for each equation of the system the inequality is satisfied

$$m - m_j \geq n_j - 1, \ \ j = 1, 2, ..., m.$$

If a model is identified, then an indirect least squares method (ILS) can be used to analyze it. If the system of equations (1) is over-identifiable, then the two-step least squares method (TLS) is used to analyze the model. The technology of directly solving the problem in both cases is well known [28]. Therefore, we illustrate it with a simple example without detailed explanations.

As part of this study, an analysis was made of factors influencing one of the key elements on the basis of which a digital enterprise is built – sociality – knowledge and people management, using statistical data. The study of the influence of factors carried out by building a mathematical model, allows to give a quantitative assessment of the deterministic relationship between factors.

Since the object of research is a complex system, the construction of isolated regression equations is not enough to describe this system and further explain the mechanism of its functioning. A change in one variable does not occur without changing the others; therefore, the problem arises of describing the structure of relations between variables by a system of so-called simultaneous equations.

The structural form of the research model contains endogenous and exogenous variables. In particular, the classification of variables into endogenous and exogenous depends on the theoretical concept of the adopted model; in the study, the variables in some models are endogenous, and in others – exogenous variables [29].

In assessing the dynamics of development and prospects for attracting Ukrainian enterprises to the "Industry 4.0" concept, let's propose to highlight key indicators that will provide a definition:

– exogenous changes that change directly as a result of the implementation of measures of regulatory state influence due to:

– the number of employees involved in the implementation of research and development;

– the ratio of the number of doctors of science in the total number of employees involved in the implementation of research and development;

– the ratio of the number of employees involved in the implementation of research and development;

– the ratio of PhDs (candidates of science) to the total number of employees involved in the implementation of research and development;

– the proportion of scientific and technical (experimental) development in the total expenditure on the implementation of research and development;

– the proportion of enterprises performing research and development;

– *endogenous changes*, which, in response to the dynamics of external endogenous factors and with different intensity influencing each other, reflect the result of the development of science due to:

– the volume of scientific and technical works performed;

– sources of financing innovation activities of industrial enterprises;

– introduction of innovations at industrial enterprises [30].

In the course of the study, the development of digital entrepreneurship and globalization processes of world restructuring, a model of the process of managing the information infrastructure of a digital enterprise was developed. Key components in it were selected the following exogenous factors, namely:

– x_1 – the number of employees involved in the implementation of research and development by categories, which is proposed to be determined by the ratio Number of employees – total, with a 7-year lag. The presence of lag is manifested in the fact that the x_1 value calculated for 2010–2017 was used in the construction of the SVEM.

– x_2 – the ratio of the number of doctors of science in the total number of employees involved in the implementation of research and development in categories reflecting the renewal of the labor potential of the country in science;

– x_3 – the ratio of PhDs (PhD), to the total number of employees involved in the implementation of research and development by categories;

– x_4 – the proportion of scientific and technical (experimental) developments in the total amount of expenditures for research and development by type of work;

– x_5 – the proportion of enterprises performing research and development.

Also selected is a set of endogenous variables that, in response to the dynamics of exogenous factors, reflecting the result of the development of science:

– y_1 – the volume of completed scientific and scientific and technical works;

– y_2 – the volume of sources of financing innovation activities of industrial enterprises;

– y_3 – the volume of innovation in industrial enterprises.

Taking into account that endo- and exogenous variables have a simultaneous interaction, the model is constructed in the form of a system of interrelated equations:

$$\begin{cases} y_1 = b_{10} + b_{12}y_2 + a_{11}x_1 + a_{13}x_3 + a_{14}x_4 + \varepsilon_1, \\ y_2 = b_{20} + b_{21}y_1 + a_{22}x_2 + a_{23}x_3 + a_{25}x_5 + \varepsilon_2, \\ y_3 = b_{30} + b_{32}y_2 + a_{32}x_2 + a_{34}x_4 + a_{35}x_5 + \varepsilon_3. \end{cases}$$

The structural form of the model on the right side contains for endogenous variables, the coefficients b_{ik} and exogenous variables – the coefficients a_{ij}, which are called the structural coefficients of the model. All variables in the model are expressed in deviations from the average level that is, x means $x - x_{av}$, and y means $y - y_{av}$, respectively. Therefore, the free term in each equation of the system is absent:

$$\begin{cases} y_1 = b_{12}y_2 + a_{11}x_1 + a_{13}x_3 + a_{14}x_4 + \varepsilon_1, \\ y_2 = b_{21}y_1 + a_{22}x_2 + a_{23}x_3 + a_{25}x_5 + \varepsilon_2, \\ y_3 = b_{32}y_2 + a_{32}x_2 + a_{34}x_4 + a_{35}x_5 + \varepsilon_3. \end{cases}$$

Using the OLS for estimating the structural coefficients of the model gives combined and inconsistent estimates, and therefore, to determine the structural coefficients of the model, its structural form is transformed into the reduced form of the model.

The reduced form of the model is a system of linear functions of endogenous variables from exogenous:

$$\begin{cases} \hat{y}_1 = \delta_{11}x_1 + \delta_{12}x_2 + \delta_{13}x_3 + \delta_{14}x_4 + \delta_{15}x_5 + u_1, \\ \hat{y}_2 = \delta_{21}x_1 + \delta_{22}x_2 + \delta_{23}x_3 + \delta_{24}x_4 + \delta_{25}x_5 + u_2, \\ \hat{y}_3 = \delta_{31}x_1 + \delta_{32}x_2 + \delta_{33}x_3 + \delta_{34}x_4 + \delta_{35}x_5 + u_3, \end{cases}$$

where δ_{ij} – coefficients of the reduced form of the model; u_i – the residual for the reduced form.

The form shows the form of the model is no different from the system of independent equations, the parameters of which are traditionally estimated by the method of least squares. Accordingly, one can estimate δ_{ij}, and then estimate the value of endogenous variables through exogenous ones.

It should be noted that the reduced form of the model, although it allows to obtain the values of the endogenous variable through the value of exogenous variables, but is analytically inferior to the structural form of the model, since it lacks estimates of the relationship between endogenous variables.

Taking into account the calculated data in Table 1, the development trend of the information infrastructure of a digital enterprise in the "Industry 4.0" concept is visually presented (Fig. 1–3), with the construction of a polynomial trend line that grows with the coefficient of determination $R^2 = 0.9752$, which is close to 1.

Table 1

Model of development of information infrastructure of a digital enterprise in the "Industry 4.0" concept

| Years	x_1	x_2	x_3	x_4	x_5	y_1	y_2	y_3	$y_{1\,model}$	$y_{2\,model}$	$y_{3\,model}$
2010	182484	11974	46685	4343	996	9867	8046	2043	10856	-874	2044
2011	175330	11677	46321	4499	1080	10350	14334	2510	7929	1626	2376
2012	164340	11172	42050	4781	1196	11253	11481	2188	11694	5738	1913
2013	155386	11155	41196	5489	1639	11781	9563	1576	12829	8115	1470
2014	136123	9983	37082	5153	1755	10951	7696	1743	11535	12726	1733
2015	122504	9571	32849	6583	2040	12611	13814	1217	12232	17412	2077
2016	97912	7091	20208	6744	2458	13814	23230	3489	13904	24814	3521
2017	94274	6942	19219	7292	2170	23230	9118	1831	22877	27721	1462
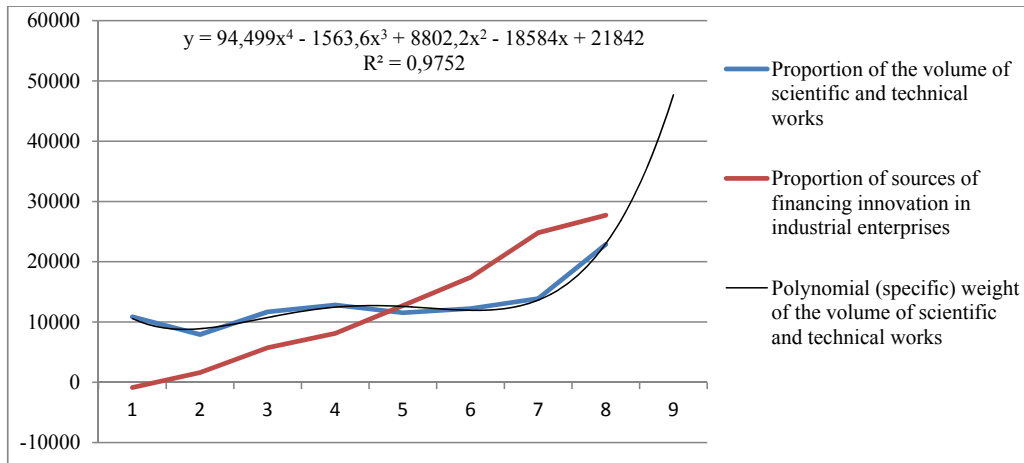
Fig. 1. Trends in the development of the information infrastructure of a digital enterprise in the "Industry 4.0" concept
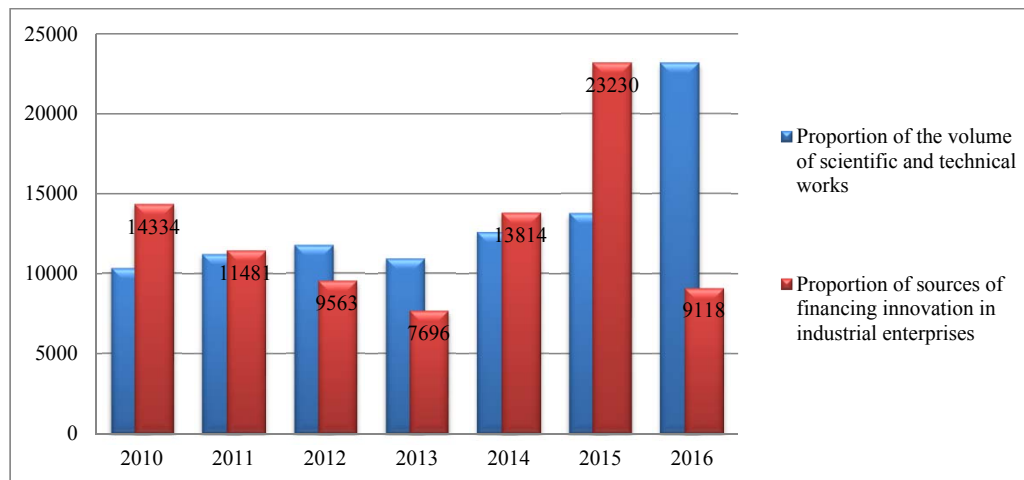

Fig. 2. Dynamics of influence of factors on the information infrastructure of a digital enterprise in the "Industry 4.0" concept
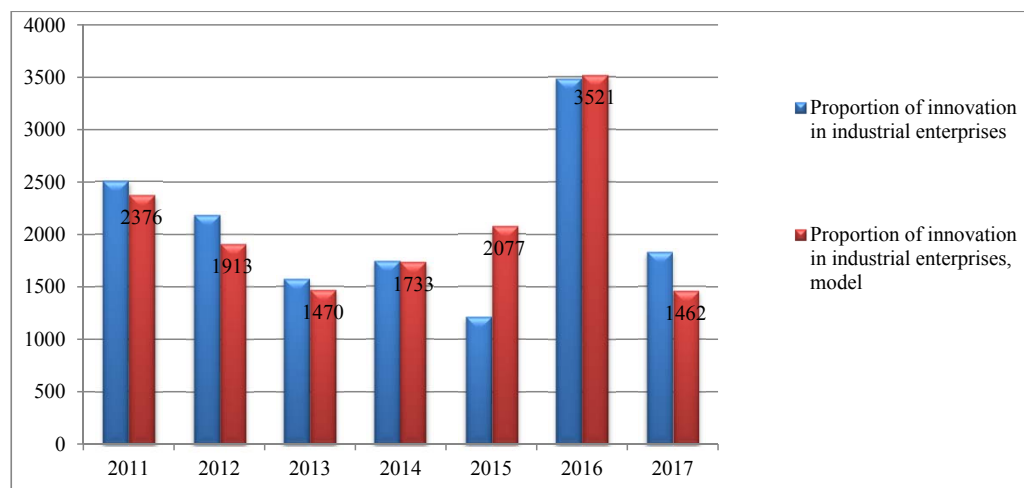

Fig. 3. The results of the simulation of factors influencing the information infrastructure of a digital enterprise in the "Industry 4.0" concept

5. The results of the application of new technologies and techniques for managing the information infrastructure of a digital enterprise

Since all equations of the system are not identified, TLS is used to estimate the structural coefficients of each equation.

At the first stage, the reduced form of the model was found by the method of least squares in the MS Excel environment:

$$\begin{cases} y_1 = 0,491x_1 - 0,091x_2 - 2,499x_3 + 4,258x_4 + 0,431x_5 + u_1, \\ y_2 = 6,769x_1 - 10,089x_2 + 7,520x_3 + 9,027x_4 + 7,32x_5 + u_2, \\ y_3 = -22,721x_1 + 0,622x_2 + 9,588x_3 - 21,941x_4 + -42,816x_5 + u_3. \end{cases}$$

The coefficient of determination R^2 for the summary equations constructed in the first stage is rather large ($R_1^2 = 0{,}998$, $R_2^2 = 0{,}973$, $R_3^2 = 0{,}87$).

At the second stage, let's switch to the structural form of the model as follows:

$$\begin{cases} y_1 = 0{,}04 y_2 + 0{,}26 x_1 - 2{,}35 x_3 + 3{,}53 x_4, \\ y_2 = 1{,}88 y_1 - 5{,}34 x_2 + 7{,}26 x_3 + 4 x_5, \\ y_3 = -2{,}2 y_2 - 20{,}41 x_2 + 29{,}22 x_4 - 19{,}54 x_5. \end{cases}$$

The free term of the equation is included in this system, thus they passed from variables in the form of deviations from the mean to the output variables y and x:

$$b_{01} = y_1 - b_{12} y_2 - a_{11} x_1 - a_{13} x_3 - a_{14} x_4 = 15{,}38,$$
$$b_{02} = y_2 - b_{21} y_1 - a_{22} x_2 - a_{23} x_3 - a_{25} x_5 = 6{,}23,$$
$$b_{03} = y_3 - b_{32} y_2 - a_{32} x_2 - a_{34} x_4 - a_{35} x_5 = 705{,}98.$$

Upon completion of all stages of modeling, the following mathematical model is obtained:

$$\begin{cases} y_1 = 15{,}38 + 0{,}04 y_2 + 0{,}26 x_1 - 2{,}35 x_3 + 3{,}53 x_4, \\ y_2 = 6{,}23 + 1{,}88 y_1 - 5{,}34 x_2 + 7{,}26 x_3 + 4 x_5, \\ y_3 = 705{,}98 - 2{,}2 y_2 - 20{,}41 x_2 + 29{,}22 x_4 - 19{,}54 x_5. \end{cases}$$

The coefficient of determination R^2 for all equations has a high value (Table 2), which is close to unity, this indicates that the equation of the resulting system adequately describes the variations of endogenous variables. Also, for all equations of this system, the p-value of the t-statistics of variables and F-criteria of equations are close to 0, and therefore no further improvement of the structural model is required due to the removal of endogenous or exogenous variables.

Table 2

Statistical characteristics of the model

y_1	R^2=0.999	t=2.9687 p=0.0972	t=−5.904 p=0.0276	t=5.037 p=0.037	t=10.32 p=0.009	t=3.441 p=0.076	F=66,38 p=0.014
y_2	R^2=0.867	t=−1.77 p=0.2186	t=−0.407 p=0.723	t=0.906 p=0.4601	t=−0.025 p=0.0982	t=0.287 p=0.800	F=1.21 p=0.51
y_3	R^2=0.979	t=4.435 p=0.0473	t=0.7 p=0.0556	t=−2.541 p=0.126	t=−4.0556 p=0.0557	t=−3.109 p=0.0897	F=9.58 p=0.097

The obtained elasticity coefficients of the structural model show that not all exogenous variables directly proportional to the results of the formation of the management model of the information infrastructure of a digital enterprise.

The number of doctors of science x_2 reflects scientific developments, the rate of scientific development has very significantly slowed down over 7 years by 5.34 %, and the introduction of innovations at industrial enterprises y_3 over the same period will decrease by 20.41 %.

The influence of the ratio of PhDs to the total number of workers involved in research and development, the total number of workers involved in research and development X_3, and the proportion of enterprises performing research and development X_5 are sufficient contradictory nature with a predominantly positive stimulating response. Based on the signs of structural coefficients, the following conclusion is made.

Each additional percentage of the increase in the share of scientific and technical (experimental) developments has a positive effect:

– in the total expenditure on the implementation of research and development x_4;
– leads to an increase in the volume of completed scientific and scientific-technical works y_1 by 3.53 %.

From the introduction of new technologies and techniques to the management of a digital enterprise, the efficiency of a number of indicators increases, namely:
– enterprise, actively use technologies and new management methods, on average, 26 % more profitable than their competitors;
– organizations invest a lot in digital technologies, but at the same time pay little attention to management, have financial indicators 11 % lower;
– more conservative companies, which improve only the management, get plus 9% to the profits, but can get three times more through the introduction of digital technologies into production;
– those who have not chosen their development strategy have negative financial indicators as compared to other market players – minus 24 % [31, 32].

Therefore, it should be noted that the constructed mathematical model is a powerful tool for assessing the consequences of making management decisions at the national level and justifying the feasibility of macroeconomic policy measures.

Let's now show that the considered technology for constructing and analyzing systems of simultaneous equations can be successfully used to solve statistical control problems. Let's suppose, in accordance with (15), a formula is obtained for calculating the values of endogenous variables through exogenous ones. Let's consider the typical static task of rational management of the distribution of investments in the development of the infrastructure of an enterprise according to areas determined by exogenous variables.

So, according to (16)

$$y_i(x) = \sum_{j=1}^{n} c_{ij} x_j, \quad i = 1, 2, \ldots, m. \tag{17}$$

Let's introduce d_j resource consumption with an increase in investment in resource consumption with an increase in investment in the j-th direction by one unit, $j = 1, 2, \ldots, n$.

Then $d_j x_j$ – the volume of investment in the j-th direction in the implementation of the investment plan $X = (x_1, x_2, \ldots, x_n)$ and

$$\sum_{j=1}^{n} d_j x_j = D, \tag{18}$$

where D – the total allowable investment.

Let the effectiveness of the plan X, determined by the values of endogenous variables, is described by the dependency:

$$\Phi(Y(x)) = \sum_{i=1}^{m} \alpha_i Y_i^2(x) = \sum_{i=1}^{m} \alpha_i \left(\sum_{j=1}^{n} c_{ij} x_j \right)^2. \tag{19}$$

Here α_i – weighting factor that takes into account the importance of the i-th endogenous factor in the overall process of developing the infrastructure of an enterprise.

Then the problem of rational resource allocation can be formulated as follows: find a plan $X = (x_1, x_2, \ldots, x_n)$, that maximizes (19) and satisfies constraint (18). Let's use the method of indefinite Lagrange multipliers.

$$F\big(Y(x)\big) = \Phi\big(Y(x)\big) - \lambda\left(\sum_{j=1}^{n} d_j x_j - D\right) =$$

$$= \sum_{i=1}^{m} \alpha_i \left(\sum_{j=1}^{n} d_j x_j\right)^2 - \lambda\left(\sum_{j=1}^{n} d_j x_j - D\right).$$

Further

$$\frac{dF\big(Y(x)\big)}{dx_j} = 2\sum_{i=1}^{m} \alpha_i \left(\sum_{j=1}^{n} c_{ij} x_j\right) c_{ij} - \lambda d_j =$$

$$= \sum_{i=1}^{m}\sum_{j=1}^{n} 2\alpha_i c_{ij}^2 x_j - \lambda d_j =$$

$$= \sum_{j=1}^{n}\left(\sum_{i=1}^{m} 2\alpha_i c_{ij}^2\right) x_j - \lambda d_j = \sum_{j=1}^{n} r_{ij} x_j - \lambda d_j = 0,$$

$$j = 1, 2, \dots, n, \quad r_{ij} = 2\alpha_i c_{ij}^2. \tag{20}$$

Moreover, the resulting system obtained from n linear algebraic equations with n unknowns.

The solution of this system according to Kramer's formulas is:

$$x_1 = \frac{\lambda \det\begin{pmatrix} d_1 & \delta_{12} & \dots & \delta_{1n} \\ d_2 & \delta_{22} & \dots & \delta_{2n} \\ \dots & \dots & \dots & \dots \\ d_n & \delta_{n2} & \dots & \delta_{mn} \end{pmatrix}}{\det\begin{pmatrix} d_1 & \delta_{12} & \dots & \delta_{1n} \\ d_2 & \delta_{22} & \dots & \delta_{2n} \\ \dots & \dots & \dots & \dots \\ d_n & \delta_{n2} & \dots & \delta_{mn} \end{pmatrix}} = \lambda \frac{k_j}{k}, \dots ,$$

$$x_n = \frac{\lambda \det\begin{pmatrix} \delta_{11} & \delta_{12} & \dots & d_1 \\ \delta_{21} & \delta_{22} & \dots & d_2 \\ \dots & \dots & \dots & \dots \\ \delta_{n1} & \delta_{n2} & \dots & d_n \end{pmatrix}}{\det\begin{pmatrix} \delta_{11} & \delta_{12} & \dots & \delta_{1n} \\ \delta_{21} & \delta_{22} & \dots & \delta_{2n} \\ \dots & \dots & \dots & \dots \\ \delta_{n1} & \delta_{n2} & \dots & \delta_{mn} \end{pmatrix}} = \lambda \frac{k_n}{k}.$$

Unknown value λ is from (18). Wherein

$$\sum_{j=1}^{n} d_j x_j = \lambda \sum_{j=1}^{n} d_j \frac{k_j}{k} = D_r.$$

So

$$\lambda = \frac{D \cdot K}{\sum_{j=1}^{n} d_j k_j}.$$

Then

$$x_j = \frac{D \cdot K}{\sum_{j=1}^{n} d_j k_j}, \quad j = 1, 2, \dots, n.$$

The problem is solved.

6. Discussion of the implementation of the proposed model on the process of managing the information infrastructure of digitalization

Digital enterprise is an enterprise that uses information technology (IT) as a competitive advantage in all areas of its business: manufacturing, business processes, marketing, and customer interaction. A traditional enterprise is transforming itself into a "digital thinking" company, following the path of *digital transformation*. The product itself, offered by such an enterprise of the market, also becomes digital.

The term "digital" emphasizes a key difference from the past, when information technologies were used to automate existing industries and business processes. Thus, it was possible to achieve some growth in efficiency, while remaining within the traditional business model, while continuing to produce traditional products and provide traditional services. Now the situation is different: technologies erase the usual boundaries between the markets and define new business models. The world is entering the era of digital business, which is characterized by an unprecedented level of convergence of technology, business processes, communications, artificial intelligence and "smart" things. The transition to a digital form of business is generating a wave of disruptive innovations in many industries.

A dramatic increase in productivity, competitiveness, and enterprise value is now possible with the parallel implementation of video business process and fundamental reengineering (*BPR, Business Process Reengineering*).

In a traditional enterprise, only the optimization of its individual phases or stages is considered. Today, the end-to-end process is being analyzed as part of the creation of a digital infrastructure and the creation of a digital enterprise. It includes not only purely production steps from the idea, development, design, procurement to manufacturing products, but also related financial activities, personnel, logistics, operation, support, partner network, subcontractors.

The main goals of digital infrastructure are to increase the speed of decision making, increase the variability of processes depending on the needs and characteristics of the client, reduce the number of employees involved in the process (i.e., decision chains and create value). In general, sociality, mobility, analytics and the "cloud" is the foundation on which a digital enterprise is built [33]. And it is quite logical that this results in a potentially higher level of labor productivity, teamwork, cooperation, control, support and, accordingly, predictability of the result of work. And the timing and cost of launching new products are sometimes reduced by several times. All this is done in the name of a cardinal increase in profits, competitiveness and market value of the enterprise. And if it is not visible, in what way it is possible to seriously increase the competitiveness of an enterprise, immediately the question arises of payback or the targeted use of investments in digital transformation. Especially important this question will be for monopolies. It should be noted separately that the legal aspect of the introduction of a "digital infrastructure" or a "digital enterprise" model should be taken into account. It consists primarily in the development and adoption of a regulatory act at the state level. For example, for Ukraine this should be the level of the Cabinet of Ministers of Ukraine "On Approval of the Concept of Digital Enterprises in Ukraine" by implementing the experience of leading countries (the United Kingdom of Great Britain and Northern Ireland, the

Kingdom of the Netherlands, the Kingdom of Sweden, the Republic of Lithuania, the Republic of Austria, Poland, The Federal Republic of Germany, the French Republic, the Swiss Confederation, etc.).

The specified draft regulatory legal act should consist of three sections: Section I "General Provisions", which defines the main conceptual series, touches upon problems, defines goals, objectives, and deadlines for implementation; Section II "Ways and ways to solve problems, the timing of the implementation of the Concept of digital enterprises in Ukraine", which identifies specific measures that must be taken to achieve the goal and solve relevant problems. These measures can be divided into three groups: educational activities (the process of preparing standards of legal education), scientific events (studies), normative actions (normative acts with the regulation of the activities of entities, procedures, guarantees). In Section III "Expected results of the implementation of the Concept of a digital enterprise in Ukraine" it is necessary to disclose the main results envisaged to achieve in the above three areas (groups of activities) the implementation of the provisions of the corresponding concept.

In addition, the introduction of a digital enterprise in Ukraine is related to the Decree of the President of Ukraine of July 22, 1998 No. 810/98 "On Measures for Implementing the Concept of Administrative Reform in Ukraine", the Concept of Developing the System for Providing Administrative Services by Executive Bodies, approved by order of the Cabinet of Ministers of Ukraine February 15, 2006 No. 90-p, Concepts of e-government development in Ukraine, approved by order of the Cabinet of Ministers of Ukraine of December 13, 2010 No. 2250-p, Concepts for reforming local self-government and the rhetorical organization of power in Ukraine, approved by order of the Cabinet of Ministers of Ukraine of April 1, 2014 No. 333-p, etc.

Such consideration of the legal framework should be attributed to the practical aspects of the implementation of the proposed solutions. The direction of further research in scientific aspects is connected with the consideration of the possibilities of solving the problems formulated in the work under conditions of uncertainty of the initial data. Moreover, if these data are described in terms of inaccurate [34] or fuzzy [35] mathematics, then possible approaches to solving emerging problems are based on the technologies proposed in [36–38].

7. Conclusions

1. Elemental components of the management process of the information infrastructure of a digital enterprise are systemized, taking into account the specific features of this process. The constituent elements on which a digital enterprise is built include: mobility; sociality; BPM; electronic document management system; ERP finance and accounting; Big Data&Analytics, business analytics. That is, digital transformation does not mean that enterprises need to abandon all of their existing software and implement new ones. The development goes along the path of modernization of corporate systems and in the context of new tasks known technologies require rethinking.

2. A model is proposed for managing the information infrastructure of a digital enterprise, based on a general management theory. In the course of research, the development of digital entrepreneurship and globalization processes of world reorganization, a number of endogenous and exogenous factors were chosen as key components. At the same time, for important particular cases, the results were obtained, brought to final formulas.

3. The control problem for ensuring the movement of the investigated system along the optimal trajectory the obtained final result relies on the solution of the Riccati equation. In the task of stabilizing the state of the control object, the final result is based on solving a system of simultaneous equations. It should be noted that the constructed mathematical model is a powerful tool for assessing the consequences of making management decisions at the national level and justifying the feasibility of macroeconomic policy measures. The key objectives of digital infrastructure are increasing the speed of decision making, the variability of processes depending on the needs and characteristics of the client, and reducing the number of employees involved in the process. In general, sociality, mobility, analytics and the "cloud" is the foundation on which a digital enterprise is built. And it is quite logical that this results in a potentially higher level of labor productivity, teamwork, cooperation, control, support and, accordingly, predictability of the result of work. And the timing and cost of launching new products are sometimes reduced by several times.

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