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Various approaches for managing the sustainable development of enterprises and territories

Sustainable development involves the simultaneous solution of diverse and largely contradictory problems regarding economic growth while ensuring that the quality of the environment is preserved, primarily from ecological and social sphere perspectives. The search for solutions in this area is relevant for government agencies dealing with the development of regions and megacities, and for public and private companies, especially those occupying a monopoly position or owning infrastructure facilities. The formation of convenient and effective methods and tools for managing and measuring sustainable development, allowing for an unambiguous interpretation of the results obtained, is of high value both from research and management points of view. However, this task does not have a simple and obvious solution.

The articles in the third issue of the 2022 Sustainable Development and Engineering Economics Journal examine various methods and approaches for managing the sustainable development of organizations and territories, as well as measuring the results they achieved.

The first section, The Economics of Engineering and Innovation Decisions as a Part of Sustainable Development, is represented by I. Eremina's article "Information Support for Business Activities on the Basis of a Systematic Approach". In this study, the author considers the process of organizing information support, which includes a continuous analysis of basic information for business activities from both internal and external sources attuned to the market environment. As a result of the study, the author adapts the structure and content of a systematic approach in relation to the organization of information support for the regulation of entrepreneurial activity.

The Enterprises and Sustainable Development of Regions section is represented by the article "Fuzzy-Multiple Approach in Design and Technology Management Modelling Preparation Of Production at Machine-Building Enterprises" by A. Skorobogatov and V. Kobzev. Their article highlights the trends in the development of science and technology related to the digital transformation of machine-building enterprises, which are radically changing business processes, in particular reducing the time needed for carrying out design and technological preparations for production. The authors note that management mechanisms should work at the shortest possible distances within the structure in order to ensure the mobility of the entire system.

In the second section, solving the problems the Sustainable Development of Regional Infrastructure, the authors D. Rodionov, D. Dianov and S. Dianov, in the article "Agent-based Modelling of the Sustainable Development of Regional Healthcare Infrastructure", consider the issues of providing decision support for the sustainable development of regional healthcare infrastructure. The authors note that an urgent scientific task today is to optimize the spatial placement of health infrastructure facilities. The article presents the authors' concept of constructing agent-oriented models that ensure an effective decision-making process for the optimal spatial placement of such facilities.

The second article in this section is "Accurately Cognizing the Digital Economy and Facilitating Its Healthy and Sustainable Development in China", written by X. Wang, J. Shi, and Z. Wang. The authors consider the historically-formed path of the digital economy's development and conclude that it is necessary in order for the digital economy to contribute to the sustainable development of countries.

In the final section, named The Management of Knowledge and Innovation for Sustainable Development, the authors T. Kudryavtseva, A. Skhvediani, V. Brazovskaia and M. Dracheva, in the article "Engineering Economics: A Scientometric Analysis of the Subject Area", explore engineering economics and conduct a detailed analysis of the literature using VOSviewer visualization software. As a result of their research, it was revealed that the central place in the engineering economy is occupied by engineering and economic analysis, which is a combination of quantitative and qualitative methods for analysing differences in the economic efficiency of engineering alternatives.

***Irina Rudskaya**, Editor-in-Chief of SDEE Journal, Doctor of Economics, Professor*

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INFORMATION SUPPORT FOR BUSINESS ACTIVITIES ON THE BASIS OF A SYSTEMATIC APPROACH

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Abstract

The study presents a solution to the urgent research problem related to improving information support for the regulation of business activities. Theoretical aspects of its development were studied, and it was found that modern information technologies are the source and cause of the necessary transformations, both in society and in business. Scientists have argued that the process of organising information support includes a continuous analysis of basic information for business activities from both internal and external sources in the market environment. The structure and content of the systematic approach were adapted to organise the information support for the regulation of business activities. Using this approach, the information support system is captured as part of a single management system capable of ensuring the interaction of the managerial link of the business entity with external sources of information support. Further, a systematic approach is applied in conducting the functions of the regulatory process, that is, planning, organising, accounting, analysing, controlling, as well as implementing the interaction of structural elements. We conducted quality diagnostics of the parameters of information support for business entities. Based on the results of the survey, the necessary parameters were selected, and the coefficient of the quality of the information support for the regulation of business activities was determined. We offer recommendation based on the quality coefficients of information support for these business entities.

Keywords: business activities, systematic approach, information support, information, development

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ОРГАНИЗАЦИЯ ИНФОРМАЦИОННОГО ОБЕСПЕЧЕНИЯ ПРЕДПРИНИМАТЕЛЬСКОЙ ДЕЯТЕЛЬНОСТИ НА ОСНОВЕ СИСТЕМНОГО ПОДХОДА

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Аннотация

В проведенном исследовании представлено решение актуальной научной задачи, касающейся совершенствования информационного обеспечения регулирования предпринимательской деятельности. Были изучены теоретические аспекты ее развития и установлено, что применение современных информационных технологий является источником и причиной необходимых преобразований как в обществе, так и в предпринимательской деятельности. С точки зрения научного подхода было аргументировано, что процесс организации информационного обеспечения включает в себя непрерывный анализ основной информации для осуществления предпринимательской деятельности как из внутренних, так и внешних источников рыночной среды. Были адаптированы структура и содержание системного подхода, применительно к организации информационного обеспечения регулирования предпринимательской деятельности. При исследовании такого подхода оно, с одной стороны, становится частью единой системы управления, способной обеспечивать взаимодействие управляющего звена субъекта предпринимательства с внешними источниками информационного обеспечения. С другой стороны, системный подход используют для осуществления функций процесса регулирования: планирования, организации, учета, анализа, контроля, а также реализации взаимодействия структурных элементов. Проведена диагностика качества источников информационного обеспечения субъектов предпринимательства на основе параметризации ее качественных характеристик. По результатам анкетирования выделены необходимые параметры и определен коэффициент качества информационного обеспечения регулирования предпринимательской деятельности.

Ключевые слова: предпринимательская деятельность, системный подход, информационное обеспечение, информация, развитие.

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1. Introduction

The regulation of business activities cannot be achieved without proper information support, especially in the context of ongoing digital transformation. Modern realities are characterised by the dynamism and volatility of such processes. They are accompanied by the rapid advancement of information and communication technologies that form the development vector of business activities at the regional level.

The complexity and multidimensionality of regulated areas of business activities are largely related to information support. However, not enough attention has been paid to it, despite its particular importance in the context of digital transformation. Its qualitative formation is the main prerequisite for its regulation and further integrated regional development. This problem's solution should also be considered from the standpoint of improving methodological grounds of information support for the regulation of business activities and effective interaction of all its subjects in implementing the system approach. The key objective of the study is to adapt the structural elements and content of the systematic approach in relation to the organisational component of information support for business activities implemented at the regional level.

2. Literature Review

The development of information technologies is one of the main tasks in the formation of modern society as a whole and of individual spheres of management. The increasing introduction of digital technologies into various economic and social processes of the state will allow subjects of information support to be integrated into the single information space. According to D. Tapscott (1999), the information society is characterised by such features as a focus on knowledge as the basis for creating wealth and generating income; digital form of objects' representation, primarily documents, which predetermines transition to information and digital technologies; and virtual representation of the physical world through the virtualisation of various data formats.

The analysis of the specialised literature (Tyukavkin, 2012; Shekhovtsov, 2005; Khairullina, 2019) dealing with the information society suggests that it is a qualitatively new type of society that is being formed as a result of the global social revolution and the active development of information and communication technologies. In relation to our study, understanding the reasons for the decrease in the efficiency and expediency of organising information flows in the form of a traditional paper workflow and exceptionally strict administrative and command hierarchy in the formation period of the information society is extremely important for the further development of business activities.

It is obvious that modern information technologies, which appear to be a tool for restructuring the processes and directions of modern enterprise functioning, are the cause and source of the necessary transformations, both in society as a whole and in business activities in particular. However, in our opinion, this trend is typical for business activities at all stages directly or indirectly related to information technology (from the moment of accumulating information to introducing digitalised systems of document management).

The analysis of research papers on the studied problems (Burgonov and Kruglov, 2020; Gaisina, 2021; Ermakova, 2012) shows that, scientifically, the problem of regulating business activities is unresolved within a single subject area (information support in the context of digitalisation of the economy in our case), thereby predetermining the relevance of the topic. The problem reflects the need to study theoretical foundations of the business activities regulation, research of the current state of its information support, and improvement of methodological and organisational foundations of information support for the regulation of business activities.

3. Methods and Materials

The systematic approach offers a methodological basis for studying the processes of management and regulation of business entities' activities. It is used as one of the main directions of scientific knowledge, as it is the basis for the study and organisation of management processes. On the one hand, the systematic approach considers the business entity as a set of interrelated elements; on the other hand, the business entity is an element of a more complex system, such as the state economy. We assessed the quality of information support for 12 business entities in the Oryol region based on the results of a survey. We assessed the reliability of respondents' opinions regarding the quality of information support by measuring Kendall's concordance coefficient and found a sufficient level of consistency of respondents' opinions on the parameters of the quality of information support for the regulation of business activities allocated for the study.

4. Results and Discussion

Reliable and timely information data and well-established information support regulating business activities are able to establish effective interactions of all elements of the management system, both within the business entity and with the external environment. The concept of 'information' is essential in the definition of information support. There is a continuous process of information flow exchange in the process of regulating the activities of business entities.

In this case, information data moves both vertically, that is, from managers to subordinates, and horizontally, that is, between employees of the same level. First, let us consider the definition of the *information*. The word *information* comes from the Latin *informatio*, which means familiarisation, clarification, and presentation. A definition analysis of the concept of information (Epinina et al., 2020; Kurcheeva and Kurchenko, 2008; Vinogradova et al., 2020) leads to the conclusion that a single interpretation of the term is not available. The concept is associated with different belief systems in computer science, physics, mathematics, cybernetics, biology, economics, and other sciences. We propose the following definition for information related to the activities of business entities: information is data from external and internal sources related to economic, financial, personnel, production, and other business processes occurring in the activities of the business entity, whose quality affects the results of its activities.

On the one hand, information is one of the main elements of the management process (Makarova, 2021); on the other hand, it is the basis for assessing the effectiveness of business entities (Korobov et al., 2021). In relation to the process of regulating the activities of the business entity, we propose that the information support of business entities should be interpreted as a set of necessary ways and methods of searching, collecting, processing, storing, transmitting, and issuing information, as well as creating conditions for using information from external and internal sources necessary for making management decisions. Information support plays an important role in regulating the activities of business entities. The controlling body, management of the business entity, or partner business entities receive adequate, timely, reliable, objective, transparent, accurate, complete, understandable, and useful information on the business entity's activities based on internal and external information data made accessible by the information support.

Business entities come into contact with a large number of information indicators necessary to justify and make managerial decisions in the course of their activities. Leading scientists (Khmeleva et al., 2021; Kravchenko et al., 2021; Rodionov et al., 2021) engaged in the study of information support of the managerial process distinguish the following criteria for information indicators:

- by sources of occurrence: external and internal;

- by processing stage: primary and secondary;

- by managerial functions: accounting, planning, regulatory and reference, factual, control, and analytical.

Other classification criteria are rarely studied, including information stability, openness, and degrees of significance, printing methods, media types, reliability, and final results (Kayl et al., 2021; Israfilov et al., 2020). The process of regulating the activities of a business entity has a continuous and systematic impact on the functioning of its structural parts to ensure the unity of work and achieve the necessary production results. It consists of interrelated functions of planning, organising, accounting, analysing, controlling, and regulating. These functions are general and reflect the overall management processes required to manage a business entity, regardless of the type of activity. Let us take a closer look at each of them.

Planning is the process of forming the business entity, solving organisational issues, and determining goals and ways to achieve. Planning entails assessment of future directions for the development of the business entity, namely, establishing dynamics of economic phenomena, forming forecasts of possible areas of activity, and envisaging final results (Ogorodnikova et al., 2019). The organising process includes creating the structure of the business entity, providing it with everything necessary for normal functioning (equipment, personnel, funds, etc.), and distributing tasks, powers, and responsibilities between personnel to achieve the set goals (Burlakov et al., 2021). Accounting includes collecting, processing, and generalising data on all operations and processes occurring in the activities of the business entity (Kudryavtsev et al., 2021). Analysis defines and characterises key parameters that form financial performance, level of profit and loss, and any changes in accounting, statistical data, and other indicators that affect the performance of the business entity (Bulyga and Safonova, 2021). Control and regulation encompass assessing performance, providing information on them, and developing corrective actions that are aimed at ensuring that the goal is achieved, and the plans of the enterprise are implemented (Nikiforova and Tolmachev, 2020).

Specific managerial functions include processes of managerial influences aimed at individual structural divisions of the business entity (e.g. product quality management, supply department management, etc.). The systematic approach is characterised by studying information support as part of a single system for regulating the activities of the business entity, on the one hand, and as a single process consisting of its own interconnected subsystems, on the other hand.

As part of the single system of regulating activities of the business entity, information support is characterised by the interaction of the business entity control link with external sources of information support. These include data characterising the general economic situation in the state (macroeconomic and sectoral development, stock and money market conditions, etc.), regulatory information (laws, bylaws of the government and ministries and departments regulating the activities of business entities), and data characterising the activities of competitors and counterparties (e.g. publications of reporting materials on the activities of business entities in the press, open ratings of the main indicators of insurance and financial companies, publications of forecasts and studies of business activity, market conditions, foreign economic activity).

Thus, external sources of information support for the activities of business entities include all the outside information that helps to organise, control, analyse, and compare the activities of any business entity. The influence and amount of information from external sources of information support do not depend on the business entity.

Internal sources of information support include any information related to the activities of the business entity used in the internal environment of that entity. These sources include regulatory and reference information (job descriptions, workflow instructions, etc.; factual information of an accounting nature, that is, accounting, financial, and statistical (invoices, receipts, delivery notes, reports on sales and expenses, reports to tax, statistical, and other regulatory authorities); staffing information (on the number of staff, vacancies, etc.); and information on technical equipment.

The structure of information support for business regulation is shown in Figure 1.

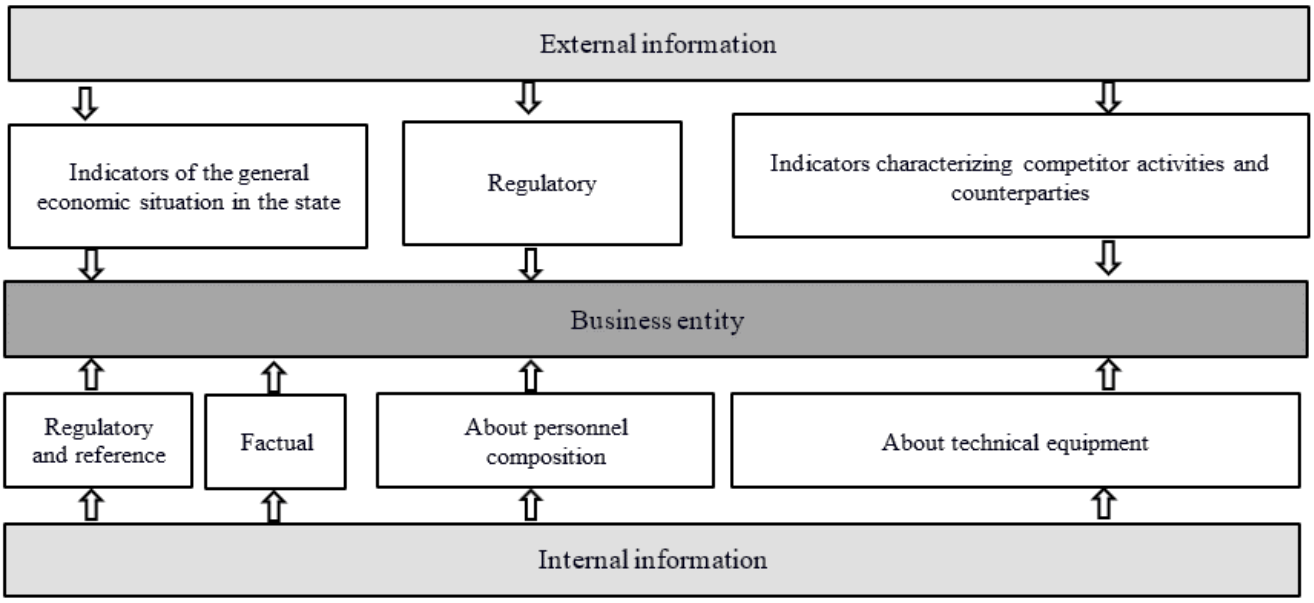

Figure 1. Structure of information support for regulating business activities

Source: compiled by the authors

Based on the discussion above, we can conclude that information support plays a significant role in the process of regulating the activities of business entities. A clearly organised process of information support determines the results of the activities of business entities, the timeliness of managerial decision-making, and the ability to promptly react to any deviations in the process of conducting financial and economic activities. The concepts and essence of the systematic approach should be considered in understanding the need to use the systematic approach in organising the information support for regulating the activities of business entities. Many scientists have used the concepts of the system and systematic approach in various studies, research areas, and activities; hence, there is a variety of definitions of the term 'system'.

The various definitions of the system concept share certain commonalities: the totality and interaction of certain elements, which can be combined, for example, common tasks, functions, or properties. According to the Business Dictionary, "the systematic approach is a direction in the methodology of research, which is based on the consideration of a complex object as an integral set of elements in the totality of relations and connections between them". Voskoboynikov (2013) identified the following principles of the systematic approach: integrity, hierarchical structure, structuring, multiplicity, and consistency (Voskoboinikov, 2013). Integrity is the consideration of a system as a single whole, on the one hand, and as a subsystem for higher levels, on the other. In the information support of the activities of business entities, here, integrity acts as a unity of two subsystems: 1) information of the external and internal environment necessary for management and 2) information from subdivisions of the business entity necessary for higher management levels.

A hierarchical structure is the presence of two or more elements arranged based on the principle of subordination of the lower-level elements to the elements of the higher level. All subdivisions transmit the necessary information to subdivisions of higher levels to which they are subordinate, and vice versa. Structuring is the analysis of system elements and their correlation within the boundaries of one organisational structure. For example, factual data obtained from accounting (accounting, financial, statistical reporting) and personnel departments, reports on the technical condition, and other information are necessary to analyse and determine the performance results of the business entity. Multiplicity is the use of a variety of different models describing individual elements of the system and the whole system, that is, economic, mathematical, etc. Consistency is the presence of all system features in the object of study. Information support is necessary to regulate the activities of both the business entity as a whole

and individual structural divisions in order to ensure continuous and full-fledged work.

Let us consider the varieties of the systematic approach in more detail.

1. The systematic element approach answers the question of what (what components) the system is formed from. The structure of the information support for the regulation of business activities includes external information, which is represented by indicators of the general economic and political situation in the state, regulatory information and indicators characterising the activities of competitors, partners, and contractors, and internal information, which includes regulatory reference and factographic reference.

2. The systematic structural approach reveals the internal organisation of the system and the ways in which its constituent components are interconnected. All the constituent elements of information support are interrelated. Thus, a direct impact on the activities of the business entity is exerted by regulatory information that controls its functioning, namely, laws, by-laws, and instructions adopted by legislative and executive authorities.

Data characterising the activities of contractors, partners, and competitors are no less important. This includes all kinds of information from open sources, that is, magazines, statistics, ratings, materials of conferences, exhibitions, articles in journals, etc. The general situation in the state, such as economic, political, financial, and demographic factors, also has an indirect impact. All external information received by the business entity is processed, analysed, and distributed by structural levels and used within the entity. Regulatory and reference information is an important component in the activities of business entities; they are registration papers, internal personnel instructions, contracts, internal regulations, technical instructions, summary cost rates, reference books of various features, consumption rates of materials, raw materials, labour cost standards, etc. Factual information is characterised by accounting, financial, statistical, personnel, technical reports, etc. According to current legislation, the business entity submits reports to the relevant departments within established time limits. The results of factual reporting are reflected in statistical data characterising the state of both an individual business entity and the industry as a whole.

3. The systematic functional approach defines the functions of the system and its constituent components. The functions of information support depend on the roles and activities of the structural subdivisions of the business entity. For example, the planning department provides information related to the planned performance indicators, the technical department provides information on the technical conditions of capacities and equipment, and the accounting department gives information on financial status, etc.

4. The systematic communication approach reveals the system's interaction with other systems, both horizontally and vertically. This is one of the most important aspects of information support. An important function of communication between all structural units of the business entity is carried out in the process of transmitting, processing, and distributing information data to various structural units. The result of the activity depends on how correctly the communication 'works' and how fast the barriers between its participants disappear.

5. The systematic integrative approach includes the mechanisms and factors of system preservation, modernisation, and development.

6. The system historical approach answers the questions of how and in what way a system arose, what stages it went through its evolution, and what its historical prospects are. Information support data are processed and stored in the archive. It is always possible to analyse the correctness of any collected information with the help of archival information, to find errors, and to correct them for the future. The effectiveness of information support is determined in the cohesive interaction of all structural units.

Thus, the systematic approach to the organisation of information support comes from considering

the business entity as an integral system existing in the general business system. However, the business entity as an integral system consists of its own subsystems, such as areas, departments, and employees, the workings of which are reflected on the business entity as a whole.

The definitions of these quality parameters of information support require further research to improve the effectiveness of using information support data in the process of regulating business activities. Their characteristics are presented in Table 1.

Table 1. Characteristics of the quality parameters of information support for regulating business activities

QUALITY OPTIONS			
P1: Functionality - the ability of information data to meet the needs, user-specified information			
Accuracy - the ability to provide the required results	*Ability to interact* with other information data		*Reliability* - the ability to resist unauthorised access
P2: *Reliability* - the ability of information support to keep the exact values of all information data, regardless of the time and place of their use			
Completeness - completeness of information	*Performance* regardless of failures in information flows		*Recovery* - the ability to restore information data in case of violation of integrity, reliability, etc.
P3: *Performance* - the ability of information support to achieve the required performance			
Time efficiency - the ability to provide the necessary data in the allotted time	*Efficiency of use* - the ability to solve certain problems using the necessary volumes of information		
P4: *Ease of use* - the ability of information support to provide user-friendly information, regardless of its form (written, electronic, visual, etc.), time and place of access to information data			
Clarity - the expression of information data in a format understandable to users	*Ease of use* - the ability to provide information data in user-friendly formats, regardless of the volume and form of data		
P5: *Ease of maintenance* - the ability to organise the update of information support in such a way that users of information receive all the necessary data, regardless of forms, types of information, time and location (work sites, local and corporate networks)			
Analysability - the ability to analyse the information provided	*Convenience of making changes* - the ability to organise information support at minimal cost (time, money) for making changes	*Sustainability* - the ability of information data remain complete and accurate regardless of changes	*Ease of verification* - the ability to verify information data on the job, at any time
P6*: Mobility - the ability of information support to remain operational when transferring any information from one place to another*			
Adaptability - the ability to adapt to various changes	*Ease of installation* - the ability of electronic resources to be installed in the conditions provided		

Source: compiled by the authors

A survey of 12 business entities of various forms of ownership and types of activity in the Oryol region was carried out to assess the quality of information support for regulating business activities. The entities include:

- Large business entities – GRINN Corporation JSC, Kerama Marazzi LLC, Znamensky SGC LLC, Miratorg-Orel LLC

- Medium-sized business entities – Orelregionstroy LLC, New Technologies LLC, Avto-Trans LLC,

Impulse LLC

- Small business representatives – Monolith LLC, OSK LLC, Master LLC, Palmira Grad, LLC

The respondents included heads of large, medium, and small business entities, heads of their structural divisions, lawyers, accountants, personnel officers, and individual entrepreneurs (95 people in total). They answered 30 questions and assessed internal sources of the information support of business entities on a 100-point scale. The results of the survey were summarised according to the established parameters of the quality of the information support of business management, and the coefficient of information support quality (Q) was assessed for each business entity participant (Table 2).

Table 2. Assessment of the quality parameters of information support for business activities management (on the materials of the Oryol region)

Name of business entity	**QUALITY OPTIONS**						**Information support quality factors (Q)**
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	
JSC Corporation GRINN	90	90	85	90	85	80	0.87
LLC Kerama Maratsci	90	90	90	90	80	85	0.88
LLC Znamensky SGC	85	85	85	90	85	80	0.85
LLC Miratorg-Orel	75	70	85	70	75	75	0.75
LLC Orelregionstroy	50	50	50	45	40	35	0.45
LLC New Technologies	65	65	60	50	45	45	0.55
LLC Auto-Trans	90	90	90	80	70	70	0.82
LLC Impulse	50	40	45	25	25	25	0.35
LLC Monolit	85	75	80	50	50	50	0.65
LLC OSK	90	75	75	55	45	50	0.65
LLC Master	35	25	25	25	20	25	0.26
LLC Palmira Grad	45	30	40	25	20	15	0.29

Source: assessed by the authors

Respondents assessed the quality parameters of the information support of their business entities on a 100-point scale:

- Below 50% is low quality; it is necessary to revise the document management policy and interaction with internal and external sources of information.

- 51–80% is average quality; it is advisable to make some changes in the processes of document management and the interaction of external and internal sources of information.

- 81–100% is of high quality.

Table 2 shows the quality of the information support of business entities, as characterised by the values of the quality coefficient of the information support (Q). As shown in the table,

1. Orelregionstroy LLC, Impulse LLC, Master LLC, and Palmira Grad LLC were below 0.50, indicating low-quality information support. It is necessary to revise the document management policy and interact with external and internal sources of information.

2. Miratorg-Orel LLC, New Technologies LLC, OSK LLC, and Monolith LLC ranged from 0.51 to 0.80, indicating average quality information support. It is advisable to make some changes in the interaction of external and internal sources of information and the interconnection of information flows.

3. GRINN Corporation JSC, Kerama Marazzi LLC, and Znamensky SGC LLC, and Auto-Trans LLC ranged from 0.81 to 1.00, indicating high quality information support. It is advisable to maintain an

established interaction of external and internal information sources.

The concordance coefficient (*W)* proposed by Kendall, and reflecting the correlation degree of respondents' opinions, was applied to establish the research reliability. The value of the concordance coefficient can vary from 0 (in the absence of consistency) to 1 (in full consistency). The research results would acquire practical value if $0.8 \geq W \geq 0.6$, which indicates a high degree of respondents' consistency.

The concordance coefficient was assessed by integrating the experts' ranking weights of the information support indicators of the business activities management (Table 3) and the assessment of the consistency of their opinions (Table 4).

Table 3. Results of the respondents' assessment of the ranking weight of the information support indicators of the business activities management

Quality options	**Weight of ranks**			
	1-low	*2-below average*	*3-above average*	*4-high*
P1	0	3	3	7
P2	0	2	4	8
P3	3	6	3	0
P4	0	2	5	5
P5	1	7	4	0
P6	2	8	2	0

Source: assessed by the authors

Table 4. Assessment of the consistency of expert opinions for the study of indicators of information support for business activities

Quality options	Sum of ranks	Arithmetic mean rank	Deviation	Deviation square
P1	44	33	11	121
P2	49	33	16	256
P3	23	33	-10	100
P4	37	33	4	16
P5	25	33	-8	64
P6	26	33	-7	49
Total	204	-	-	606

Source: assessed by the authors

The concordance coefficient is described by Formula 1:

$$W = \frac{12R}{m^2(k^3 - k)}, \tag{1}$$

where $R = \sum_{i=1}^{k} (R_i - \overline{R})^2$

The calculated concordance coefficient of 0.8 indicates that we obtained a sufficient level of consistency of expert opinions regarding the indicators allocated for the research in the analysis of the information support for regulating the activities of 12 business entities in the Oryol region. An assessment of the quality of the information support for each business entity was carried out based on the results of the survey representing 12 business entities in the Oryol region. A sufficient level of consistency of respondents' opinions on the parameters of the information support quality of regulating business activities under study was established as a result.

Thus, the process of regulating business entity activities implies a continuous and systematic impact on the functioning of its structural parts in order to ensure operational integrity and achieve the necessary results. The systematic approach should be applied to all interrelated functions of the managerial process, namely, planning, organising, accounting, analysing, controlling, and regulating. The role of information support in the process is to obtain complete, reliable, and timely information, both from external and internal sources, and to make it available for its intended purpose.

The system approach makes it possible to analyse the information support data not of a single subsystem of the business entity but of all its subsystems in the aggregate. Unreliable or untimely information received by the business entity can affect the operational results not only of one of its closed subsystems but of the entire entity. The systematic approach allows for focusing on separate directions and on the business entity activities as a whole, considering all its interconnected structural parts. This, in turn, makes it possible to properly organise the information support process and respond in a timely manner to any changes in this process that can lead to errors in regulating business entity activities.

Management faces a number of problems in the course of organising information support for business activities, which can significantly affect management effectiveness. These problems include a low level of regulatory and reference information, legal documentation, and internal standards of business entities; depersonalisation of information when forming primary documents, caused by a low level of organisation of regulatory support; the inability to search and obtain the necessary documents, as well as difficulty of obtaining information on information requests; inefficient workflow organisation, which leads to the appearance of duplicated or conflicting documents; and violation of deadlines when preparing documents.

Thus, information support is one of the most important elements of the system for regulating business entities' activities. Business entity management should carefully approach the implementation of the information support process when forming an organisational management structure. The implementation of the systematic approach in organising the information support of the management of business activities, on the one hand, allows us to consider it as part of a single management system, ensuring the interaction of the management link of the business entity with external sources of the information support. On the other hand, the systematic approach is used for implementing the functions of the management process (planning, organising, accounting, analysing, controlling, and regulating), as well as for implementing the interaction of structural elements of the information support of business management. Organising information support on the basis of a systematic approach makes it possible to effectively use information data in the process of regulating business entity activities.

Development directions of the information support for regulating business activities based on the systematic approach, which were taken into account when conducting the presented study, include forming legal conditions to ensure the transparency of business activities; disseminating information on business activities in the media and on the internet particularly; improving the protection of intellectual property in the course of business activities; improving requirements for business activities; ensuring the consistency of terminology in information legislation; and creating such terminology for business activities.

5. Conclusion

Given that information support is an important system element for regulating the activities of a business entity, its management should carefully approach the implementation of the information support process when forming the organisational managerial structure. Organising information support, particularly on the basis of the systematic approach, allows for the effective use of information data in the process of regulating business entity activities. This study adapted the structure and content of the systematic approach to organising the information support of the regulation of business activities. On the one hand, implementing such an approach will allow considering information support as part of the single management system; that is, it will ensure the interaction of the management link of the business

entity with external and internal sources of information. On the other hand, the systematic approach will ensure implementation and interconnection of such functions of the management process as planning, organising, accounting, analysing, controlling, and regulating, as well as implementing the interaction of structural elements of the information support for business regulation. We determined the main parameters of the quality of information support for regulating business activities, confirming a sufficient level of consistency of the respondents' opinions on the parameters.

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SECTION 2

ENTERPRISES AND THE SUSTAINABLE DEVELOPMENT OF REGIONS

РАЗДЕЛ 2

ПРЕДПРИЯТИЯ И УСТОЙЧИВОЕ РАЗВИТИЕ РЕГИОНОВ

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FUZZY-MULTIPLE APPROACH IN DESIGN AND TECHNOLOGY MANAGEMENT – MODELLING THE PREPARATION OF PRODUCTION AT MACHINE-BUILDING ENTERPRISES

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Abstract

As economic systems are characterised by influential uncertainties (or uncertainty factors), performance assessment in engineering enterprises requires a solid scientific background for managerial decision-making in business. This article offers a model of a fuzzy system for the development of design documentation at the design pre-production stage and technological documentation at the technological pre-production stage. The model aims to manage and frame the process of design and technological pre-production. Based on fuzzy logic tools, the model allows engineering enterprises to operate temporary parametrons of sequential and parallel-sequential processes involved in the development of design documentation and technological documentation. This study demonstrates that a fuzzy-set approach can serve as an effective means for design and technological pre-production management at engineering enterprises in a highly competitive market. Multiple scientific and technological improvements, together with the overall digital transformation of engineering, have driven core changes in business processes, their timing, and costs. Even with tighter deadlines for design and technological pre-production, managerial decisions are expected to fit them with sufficient flexibility to ensure mobility. This fact does not undermine the importance of general supervision and awareness of management over the existing bottlenecks in the entire production management system and in design and technological pre-production.

Keywords: economic models, fuzzy-set approach, engineering enterprises, design and technological pre-production, digital technologies, market environment, business processes, fuzzy logic

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НЕЧЕТКО-МНОЖЕСТВЕННЫЙ ПОДХОД В МОДЕЛИРОВАНИИ УПРАВЛЕНИЯ КОНСТРУКТОРСКО-ТЕХНОЛОГИЧЕСКОЙ ПОДГОТОВКОЙ ПРОИЗВОДСТВА НА ПРЕДПРИЯТИЯХ МАШИНОСТРОЕНИЯ

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Аннотация

Экономические системы характеризуются наличием влияющих на них факторов неопределенности, и анализ деятельности машиностроительных предприятий требует научной базы принятия управленческих решений в бизнес среде. В статье предлагается модель нечеткой системы разработки конструкторской документации (КД) на этапе конструкторской подготовки производства (КПП) и разработки технологической документации (ТД) на этапе технологической подготовки производства (ТПП) для управления конструкторско-технологической подготовкой производства (КТПП) на предприятиях машиностроения. Предложенная модель, основанная на математическом аппарате нечеткой логики, позволяет оперировать временными параметронами последовательного и параллельно-последовательного процессов разработки КД и ТД. Также в работе показано, что нечетко-множественный подход может являться эффективным средством управления КТПП на предприятиях машиностроения в условиях высококонкурентной среды рынка. Тенденции развития науки и техники, связанные с цифровой трансформацией предприятий машиностроения, в корне меняют бизнес-процессы, время их протекания, стоимость, сроки на проведение КТПП также сокращаются. Управленческие механизмы при этом должны работать на минимально коротких дистанциях в структуре, чтобы обеспечить подвижность. При этом должен сохраняться общий контроль и информированность руководства, особенно о наличии «узких мест», во всей системе управления производством и КТПП.

Ключевые слова: экономические модели, нечетко-множественный подход, предприятия машиностроения, конструкторско-технологическая подготовка производства, цифровые технологии, рыночная среда, бизнес-процессы, нечеткая логика.

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1. Introduction

In a highly competitive environment, engineering enterprises are pressurised by the constant need to not only reduce the pre-production and production time but also the ancillary work. Justification of the possibility of reducing the time spent on design and technological pre-production (DTPP) can be delivered from the minimax approach of fuzzy logic. This study aims to develop an economic model for the management of design and technological preproduction to reduce time at the stages of product development and production. Finding a solution to the problem of how to cut pre-production time at engineering enterprises is highly promising for business, and requires a scientific approach.

Thus, it is a matter of first priority to assess the time spent on intellectual work, which of course includes DTPP. Statistical methods are hardly applicable in terms of knowledge-intensive investment projects, since the cases are rather unique. A more effective tool is the expert forecasting of specifications, which, in turn, is characterised by the minimum, most probable, and maximum values of $\underline{a}_i = (a_{i\,min}, a_i, a_{i\,max})$, where $i = 1...n$ is the ordinal number of an expert, and n is the number of experts (Lebenkova et al., 2020).

However, we believe that management models based on fuzzy logic are more suitable for this case. Currently, such models are implemented in multiple digital systems, ranging from the simplest ones, such as household appliances, to complex dynamic systems, including aircraft, helicopters, cars, trains, etc. (Balmagambetova, 2019). Representing an important stage of a product life cycle, the DTPP process is very complex and is permanently conducted within a man-machine system. Since the operation of many digital systems often defies logic, the minimax approach to fuzzy logic seems to be the most acceptable.

Before moving deeper into the specific digital tools used in the DTPP, it is worth pointing out that the fundamentals of building the digital environment were described by one of its founders, Nicholas Negroponte, in his work "Being Digital" (1995). Today, with the economic situation far from stable, competitive national engineering enterprises gain paramount importance for a country's status. Thus, the level of natural, social, and economic development of each country is measured by the ability of its engineering enterprises to produce high-tech products. Management in DTPP at engineering enterprises is interconnected with management systems at every stage of a product life cycle, innovations, supply chain, and IT architecture (Belyakova and Fokina, 2019; Skorobogatov, 2018).

The IT architecture of a modern engineering enterprise includes a large number of information systems involved in arranging business processes and shaping a business model (DTPP) (Kobzev et al., 2013; Kobzev et al., 2014; Skorobogatov, 2020). As of 2022, the information systems used in DTPP have developed a broader range of functions with a more complex infrastructure. The programmes have exceeded their learning ability, and maintenance costs have increased, resulting in a decrease in their economic efficiency. Thus, reducing the time necessary for the DTPP at engineering enterprises is an urgent task for both the scientific community, and stakeholders of the industry.

2. Literature Review

At present, the fuzzy sets theory is widely applied by a wide range of economic entities (Zvyagin, 2019). Lotfi Zadeh, an American scientist of Azerbaijani origin, developed the fuzzy logic theory, and published his first paper on the fuzzy sets theory in 1965 (Gurbanov, 2020; Fay, 1998). Having received the "Father of Fuzzy Logic" title in 1992 at the international ISAAM Symposium, Lotfi Zadeh presented six fundamental theories. The most recognised works by Zadeh include: "Outline of a New Approach to the Analysis of Complex Systems and Decision Processes", "The Concept of a Linguistic Variable and its Application to Approximate Reasoning", and "Fuzzy Set Theory and Probability Theory: What is the Relationship?" (Gurbanov, 2020).

Similar to mathematics, where classes have clear limits, fuzzy sets make it possible to model complex humanistic systems with membership functions. Although back in the 1960s and 1970s, mathe-

maticians were very cautious about Lotfi Zadeh's works, since they were beyond traditional math frameworks, his ideas proved to be highly practical for economics and IT. Large corporations, such as Nissan, Kodak, and Sony, widely apply Zadeh's scientific findings in their production. He expanded the concept of a set by defining values in the range from 0 to 1, not just 0 and 1. Zadeh's theory has the following form: let *U* be a universal set. Then, a fuzzy set *X* on the set *U* denotes a collection of pairs *X={*μx(x*)/(x)},* where μx(x) is the membership function (Zvyagin, 2019). The concept of a fuzzy set itself can be generalized as follows: Let *U* be the reference set, universe of discourse, and *M* be the grade of membership, μ *A: U→M.* A fuzzy set A-U is denoted by μ *A*, that is, a membership function *{(u, μ A (u)):u€U}*. Therefore, fuzzy set *A* is assigned by a set of three *(U, M, μ A)* (Novotochinova, 2018).

Following the ideas of Lotfi Zadeh, many scientists have contributed to the development of fuzzy sets theory, including Kofman, K. Atanassov, R. A. Aliyev, A. O. Nedosekin, O. V. Loskutov, A. E. Altunin, A. N. Borisov, M. P. Vlasov, etc. The issue of the practical implementation of fuzzy sets theory started to be widely considered by the scientific community due to its promising potential for industries (Shupletsov, 2019; Savchenko et al., 2021; Rahman et al., 2020; Ejegwa et al., 2020; Imeni, 2020). General methodology of management for enterprise architecture was observed in the works of foreign and Russian researchers such as K. Vigers (2013), J. A. Zahman (1987; 1992), I. Ilyin (2017; 2018), D. Kudryavtsev (2020), M. Lankhorst (2013), R. Sessions (2013), N. Porya (2013), A. Levina (2017; 2018), and G. Krayukhin (2019).

The fuzzy-set approach has three major traits typical for studying and modelling complex economic systems and processes: (1) linguistic variables are applied, (2) simple relations between variables are denoted by fuzzy expressions, and (3) complex relations are denoted by fuzzy algorithms (Knyazeva et al., 2018). A theoretical review of the scientific literature on the topic shows that the most preferable tools to assess pre-production deadlines at engineering enterprises lie in the plane of fuzzy mathematics, including fuzzy arithmetics, fuzzy and linguistic logic, and possibility theory. This is because the uncertainties in pre-production are dictated by market conditions, which are largely vague and unreliable (rather than random) in terms of reference data.

3. Materials and Methods

Quantifying uncertainty is an extremely problematic task due to the fact that multiple important factors should be considered, including fluctuations in demand, irregularities of supply, changes in prices for goods and services, energy costs, labour, inflation, and lack of awareness of the situation because data sources are unreliable (Knyazeva et al., 2018). Currently, many researchers emphasize the promising potential of the fuzzy-set approach, instead of probability theory, because it implies determining the possible range and the most probable value for each design parameter, ignoring its relative frequency. According to the findings of domestic and foreign scientists, quantitative methods for risk and uncertainty assessment can be divided into three fundamental groups: (1) probabilistic-statistical approaches, (2) simulation models, (3) elements of game theory, (4) expert systems, and (5) methods based on efficiency and sensitivity analysis (Bezrukova et al., 2015).

Determined by the level of digitalisation and efficiency of software, the information structure of an enterprise provides information support for business processes (Alferyev et al., 2020). In turn, the technological structure of an enterprise is shaped by technical and technological capabilities, as well as engineering facilities, depending on the type of production. Logically, production types (piece, batch flow, and mass production) determine the specific technological processes to be used at an enterprise. The IT strategy frames the development of information technologies and systems that are already implemented, or can be potentially used in the DTPP. (Baskerville et al., 2004; Sebastian, 2011). DTPP is always expected to be completed on time, performing the entire scope of work. Figure 1 shows the major areas for pre-production.

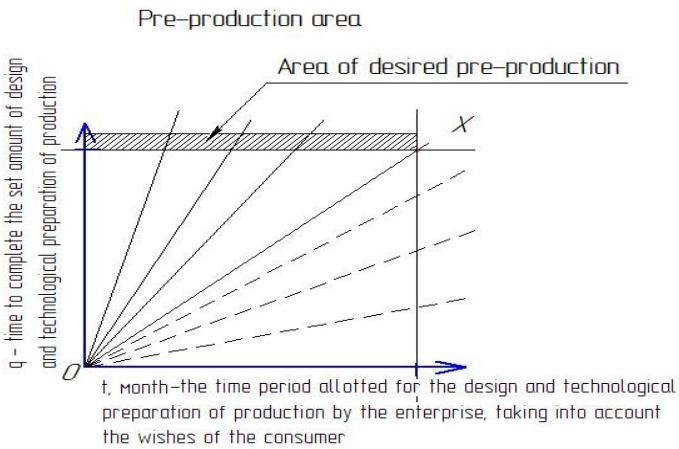

Figure 1. Areas for design and technological pre-production

The process of DTPP at an engineering enterprise implies close and permanent interaction between two separate areas: design pre-production (DPP) and technological pre-production (TPP) are interconnected with each other. To better trace this connection, we assessed the design documentation (DD) and technological documentation (TD) and incorporated the fuzzy-set approach.

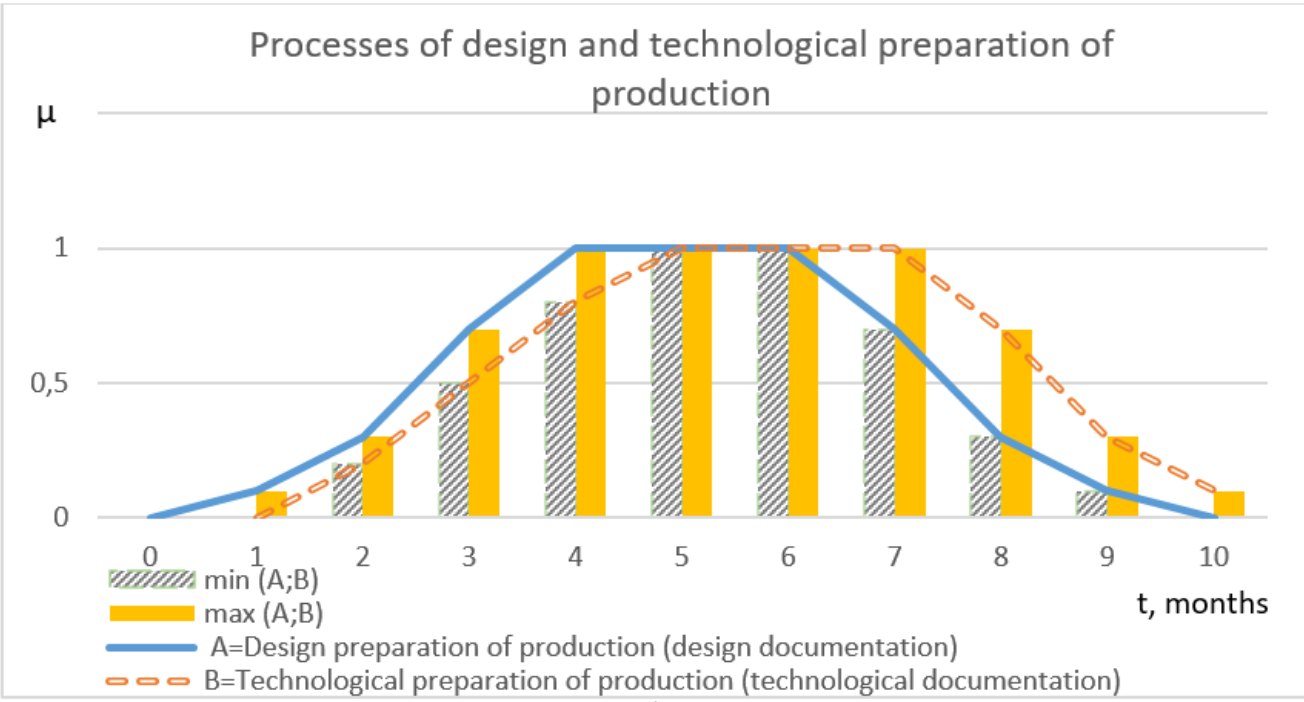

Figure 2. Design and technological pre-production via the minimax approach of fuzzy logic

The minimax approach of fuzzy logic was used to process data on DTPP according to the grade of membership of design documentation (DD) and TD.

Line A for the design pre-production indicates the duration of DD development. Line B for the technological pre-production indicates the duration of TD development.

The conjunction μ Aμ B tends to min (μ A, μ B), then the function for the simultaneous development of DD and TD is:

$$\overline{A} \cap \overline{B} = \int_U (\mu_{\overline{A}}\ (x)\ (x))/(x) \tag{1}$$

where $(\mu_{\overline{A}}(\mathrm{x})\ \mu_{\overline{B}}(\mathrm{x})) = min\ \{\mu_{\overline{A}}(x), \mu_{\overline{B}}(x)\}, x \in U$

The disjunction μ Aμ B tends to max (μ A, μ B), then the function with DD development without TD development, or TD development without DD development is:

$$\overline{A} \cap \overline{B} = \int_U (\mu_{\overline{A}}(x)\, \mu_{\overline{B}}(x))/(x) \tag{2}$$

where $(\mu_{\overline{A}}(x)\, \mu_{\overline{B}}(x)) = max\{\mu_{\overline{A}}(x), \mu_{\overline{B}}(x)\}$, $x \in U$

Thereby, parallel development of DD and TD tends to minimum and takes less time (t), whereas series development tends to maximum and, consequently, takes more time (t). This means that to optimise and reduce the time spent on DTPP at engineering enterprises, it is necessary to transfer series business processes to parallel series as much as possible. This can be made possible only with a reliable managerial mechanism when design and process engineers possess sufficient qualifications and competence. Objective functions for members of the DTPP system at an engineering enterprise are:

$$F_0(\alpha_k(N,b_k),\alpha_t(x,b_t),b_k,b_t) = G(N,x)-\alpha_k(N,b_k)-\alpha_t(x,b_t) \tag{3}$$

$$F_k(\alpha_k(N,b_k),\eta_k(b_k),N,b_k) = \alpha_k(N,b_k)-\sum_{i=1}^{n}\eta_k^i\,(x, b_k^i)-S_k(b_k) \tag{4}$$

$$F_t(\alpha_t(x,b_t),\eta_t(b_t),x,b_t) = \alpha_t(x,b_t)-\sum_{j=1}^{m}\eta_t^j(b_t^j)-S_t(b_t) \tag{5}$$

$$f_k^i(\eta_k^i(b_k^i),\eta_{kt}^i(N),N,b_k^i) = \eta_k^i(b_k^i)+\eta_{kt}^i\,(N)-S_k^i\left(N,b_k^i\right), i \in I \tag{6}$$

$$f_t^j(\eta_t^j(b_t^j),\ \eta_{tp}^j\ (x),x,\ b_t^j) = \eta_t^j(b_t^j)+\eta_{tp}^j(x)-S_t^j\left(b_t^j\right), j \in J \tag{7}$$

where:

$G(N,x)$ is the revenue function of the DTPP system;

$\alpha_k(N,b_k)$, $\alpha_t(x,b_t)$ are funds allocated by the management to the departments of design and technology;

$n_k(b_k)$, $n_t(b_t)$ is a function of motivating departments of design and technology;

$\eta_{kt}^i\,(N)$ is the function of the influence of the technology department on the performance of the *I*-th design engineer;

$\eta_{tp}^j(x)$ is the function of the influence of production on the performance of the *j*–th process engineer;

$S_k(b_k)$, $S_t(b_t)$ are functions of costs by departments of design and technology;

$S_k^i\left(b_k^i\right), S_t^j\left(b_t^j\right)$ is the function of cost per one employee from the department;

N is the quality of DD and TD while developed;

b_k, b_t are the qualifications of a design engineer or a process engineer.

The decision-making model is:

$$F_0(\alpha_k(N,b_k),\alpha_t(x,b_t),b_k,b_t) = G(N,x)-\alpha_k(N,b_k)-\alpha_t(x,b_t) \xrightarrow{k,x,b_k,b_t} max \tag{8}$$

$$A_k(N,b_k) = \gamma_k N/b_k + a_k b_k = \gamma_k(1-e^{-m_b\alpha_k})/b_k + a_k b_k \le \alpha_k^z$$

$$A_t(x,b_t) = \gamma_t x^2/2b_t + a_t b_t \le \alpha_t^z$$

$$B_k \le B_k,\ b_t \le B_t,\ \alpha_k \ge 0,\ N \ge N^z,\ x \le \overline{x}$$

The function is effective if $\frac{\Delta F_0}{\Delta N} > 0$; $\frac{\Delta F_0}{\Delta x} > 0$; $\frac{\Delta F_0}{\Delta b_k} > 0$; $\frac{\Delta F_0}{\Delta b_t} > 0$.

As shown in Figure 1, the pre-production timeframe is determined by the time gap formed between the latest and upcoming consumer demand for a product.

$$X = \frac{T_{total}}{Q_{DTPP}} \to max \tag{9}$$

where X is the value of the DTPP efficiency indicator by a specific item produced {0,1}; T_{total} is the time period for DTPP defined by the contract, and Q_{DTPP} is the volume of the DTPP. If $X \geq 1$, the efficiency of the department for design and technology in DTPP corresponds to the given time period left after meeting the previous consumer demand for a product. If $X < 1$, the efficiency of the department for design and technology in DTPP does not correspond to the given time period left after meeting the previous demand of a consumer for a product.

4. Results

Successful transition from series business processes to parallel ones and further reduction of time required for the DTPP depend on how well the goals and responsibilities of each design and technology facility are defined. According to the structure of the department for design and technology, it should be subdivided into different divisions. The functions and responsibilities of each division, or bureau, derive from production goals and annual workload. An important point here is to make sure that the goal itself is universal and common for all divisions to achieve. The functional responsibilities of the department for design and technology at an engineering enterprise are described in Table 1.

Table 1. Functional responsibilities of the department for design and technology at an engineering enterprise

№	Name of the bureau	Functions	Note
		Registration of preliminary notices	
		3D models design	
		Drawings design	
		Development of temporary design options for parts and assemblies according to production needs	
		Decision-making	
		Execution of work programs	
		Registration of test reports	
		Registration of acts	
		Registration of research certificates	
		Registration of letters	
		Conducting and processing the results details testing, defining the cause of defects. Registration of research certificates	
		Formation of an electronic archive for design documentation. Adjustments of drawings and drafts following feedback	
		Reception and issuance of design and technological documentation in the archive in accordance with the related documentation	
		Accounting and storage of design and technological documentation in the archive in accordance with the related documentation	
		Elaboration of design notices for changes in product drawings	
		Development, coordination and approval of standards for extra materials	
		Development of equipment for the workshop	
		Development of design documentation for assembly of universal equipment and devices	
		Design supervision over the manufacture of non-standard equipment, tooling and fixtures	
		Support for manufacturing of non-standard equipment, fixtures and tools	
		Elaboration of the technical specification for changing the drawings of tools; monitoring timely completion of metal tooling according to the modified drawings	
		Machining of simple parts in the production	
		Evaluation of defects in mechanical production due to the technological order; development of measures to eliminate defects	

		Adjustment of technological processes in mechanical processing	
		Registration of certificates on improvements in technological equipment	
		Development of temporary options for technological processes tailored for specific production needs	
		Introduction of automated forms and registration of acts following the reduction of labour intensity and saving materials	
		Technical guidance of overlays in the development of new technological processes and special equipment	
		Prompt solutions to current issues of technological preparation for the workshop production	
		Registration of permission cards for temporary deviation from design documentation	
		Development of machining processes for complex parts in production	
		Road maps design	
		Formation of the composition of products in the PDM system	
		Introduction of databases (regulatory documentation, tools, equipment, etc.)	
		Development and coordination of workshop layouts	
		Preparation of applications, coordination of equipment supplies and introduction of newly received equipment	
		Development of welding processes for parts when they are put into production	
		Development of welding processes for parts when they are put into production	
		Adjustment of working welding processes	
		Registration of certificates on improvements in technological equipment	
		Development of temporary options for technological processes tailored for specific production needs	
		Technical guidance of overlays in the development of new technological processes and special equipment	
		Prompt solutions to current issues of technological preparation for the workshop production	
		Registration of permission cards for temporary deviation from design documentation	
		Development of technical processes for assembly of components and the product when they are put into production	
		Evaluation of defects in assembly production following the technological order; development of measures to eliminate defects	
		Adjustment of technological processes in assembly	
		Registration of certificates on improvements in technological equipment	
		Development of temporary options for technological processes tailored for specific production needs	
		Technical guidance of overlays in the development of new technological processes and special equipment	
		Prompt solutions to current issues of technological preparation for the workshop production	
		Registration of permission cards for temporary deviation from design documentation	
		Tooling production	
		Scheduling regular inspections of special equipment (in association with the Metrological Laboratory)	
		Supervision over the provision of a monthly plan for production	
		Purchase and storage of instruments and tools	
		Purchase and delivery of measuring equipment	

To evaluate the effectiveness of DTPP carried out in AO Zavod "Universalmash" (JSC "Plant "Universalmash") in relation to the manufactured products, it is necessary to introduce Formula 9 into calculation. To define the time period T_{total} , we take the timing established by the 3-year contract for manufacturing, bearing in mind that production begins together with the DTPP. Then, to determine the scope of the DTPP, we will Q_{DTPP} sum over the time spent on production preparation in accordance with official standards. The case enterprise observed here carries out the DTPP, starting with the resumption of production of a previously manufactured product after a break, instead of designing a brand new product. Table 2 describes every area of DTPP at the Universalmash Plant.

Table 2. Areas for design and technological pre-production at the Universalmash plant

№	Types of work	Area for DTPP	Time required for a job, hour	Note
1	Reception and accounting of received design documentation from the developer	Design pre-production	130	Assessment of contract for design support
2	Verification of documents on compliance with the inventory of completeness	Design pre-production	16	Based on 17 000 items
3	Analysis of design documentation and its adjustment based on comments; discussion of changes with the developer	Design pre-production	180	Work is carried out in advance, as well as timely
4	Development of drawings with due attention to technological specifications of equipment	Design pre-production	230	
5	Introducing changes to design documentation in accordance with the technological specifications of a manufacturer	Design pre-production	170	
6	Approval of technical conditions for the installation series of the product and their series production	Design pre-production	Not required	
7	Introducing changes to design documentation in accordance with the testing results and capacity of an enterprise	Design pre-production	220	
8	Adjustment of design documentation based on the results of manufacturing and testing of first samples	Design pre-production	120	
9	Introducing changes to design documentation in accordance with the technological pre-production	Design pre-production	170	
10	Technical maintenance for production of an experimental batch	Design pre-production	Not required	
11	Adjustment of design documentation based on the results of manufacturing and testing of a pilot batch	Design pre-production	Not required	
12	Registration and approval of documentation for production of the installation series	Design pre-production	Not required	
13	Technical maintenance for production of the installation series	Design pre-production	Not required	
14	Registration and approval of documentation for series production	Design pre-production	80	

15	Release of documents on repair, export, etc.	Design pre-production	70	Production of operational documentation for the complete set of products
16	Technical maintenance for series production	Design pre-production	During the entire production period	
17	Development of a parts classifier	Technological pre-production	160	
18	Distribution of item identification	Technological pre-production	70	
19	Technological design plans	Technological pre-production	240	
20	Development of automated forms	Technological pre-production	730	
21	Design of route sheets	Technological pre-production	770	
22	Calculation and design of layouts	Technological pre-production	160	
23	Distribution of workshop sections	Technological pre-production	830	
24	Calculation of operational standards	Technological pre-production	410	
25	Calculation of standards for materials	Technological pre-production	370	
26	Determination of planning standards	Technological pre-production	180	
27	Listing of special and standard equipment	Technological pre-production	80	
28	Preparation of a technical enquiry and schedule for the development of non-standard equipment	Technological pre-production	120	
29	Implementation of special and non-standard equipment	Technological pre-production	760	
30	Arranging the order for manufacturing tools, fixtures and non-standard equipment	Technological pre-production	40	
31	Tooling production	Technological pre-production	830	
32	Equipment testing	Technological pre-production	During the entire production period	
Total:			7136	Amount of time by points 1,2,3,4,5,7,8,9,14, 15,17,18,19,20,21,22,23,24, 25,26,27,28,29,30,31

The Universalmash plant outsources design support, and that is why the major activities of the design pre-production are related to interactions with a third-party company, which results in more time spent on obtaining designs from the developer.

The overall time for all the work performed in series amounts to 7136 hours. When divided by 8-hour working day, the total number of working days is 890. An average year contains 252 working days, which means it will take 3.5 years to carry out the entire scope of work when performed in series. Total value Q_{KTPP} = 3.5 years.

Formula 9 is used to determine the value (*X*).

$$X = \frac{T_{total}}{Q_{DTPP}} = \frac{3}{3.5} = 0.85$$

If $X < 1$, the performance of the department for design and technology in the DTPP does not correspond to the time period allotted for pre-production after meeting the previous consumer demand for a certain product. In the case of the Universalmash plant *X* of *0.85<1* indicates that their performance in the DTPP is not sufficient to fulfil the contract on time. By applying Formula 9, we can conclude that a full-scale DTPP requires much more time than meeting the requirements of consumers. The amount of work presented in Table 1 is the overall time needed to perform all the work by individual business processes. Their order is described in Figure 3.

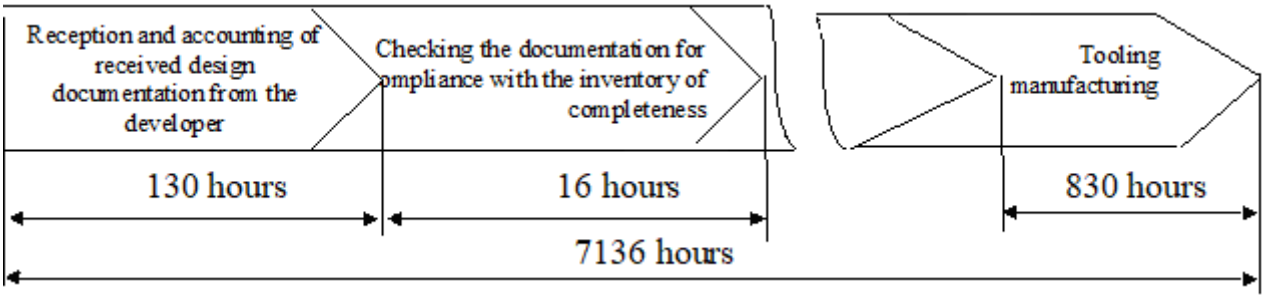

Figure 3. Overall time needed to perform the DTPP, described by business processes on the basis of data from Table 2.

To reduce the time Q_{DTPP}, it is necessary to maximise the transfer from series business processes to parallel ones. It will equalise the entire amount of work Q_{DTPP} to the longest business process or to the sum of a series of business processes that cannot be put into the parallel mode. Figure 4 gives the sum of the business processes with the longest duration.

The overall time for parallel work amounts to 3490 hours. When divided by the 8-hour working time, the total number of working days is 436. An average year contains 252 working days, which means it will take 1.73 years to carry out the entire scope of work when performed in series. Total value Q_{KTPP} = 1.7 years.

Formula 9 is used to determine the value (*X*).

$$X = \frac{T_{total}}{Q_{DTPP}} = \frac{3}{1,7} = 1.76$$

Having $1.76 > 1$ means that the performance of the department for design and technology in the DTPP corresponds to the time period allotted for pre-production after meeting the previous consumer demand for a certain product. Such efficiency is sufficient to fulfil the contract on time. When designing enterprise architecture, many practitioners from the industry note that existing framework models are very theoretical and difficult to apply (Plataniotis et al., 2013; Tucci, 2022). Nonetheless, the Zahman matrix allows for obtaining a scrupulous perspective from different stakeholders, thereby raising awareness of more specific data, functions, processes, etc.

With the architectural approach pioneered by Zahman (1987, 1992), it became realistic to systematically optimise the IT architecture and the information systems involved in the DTPP.

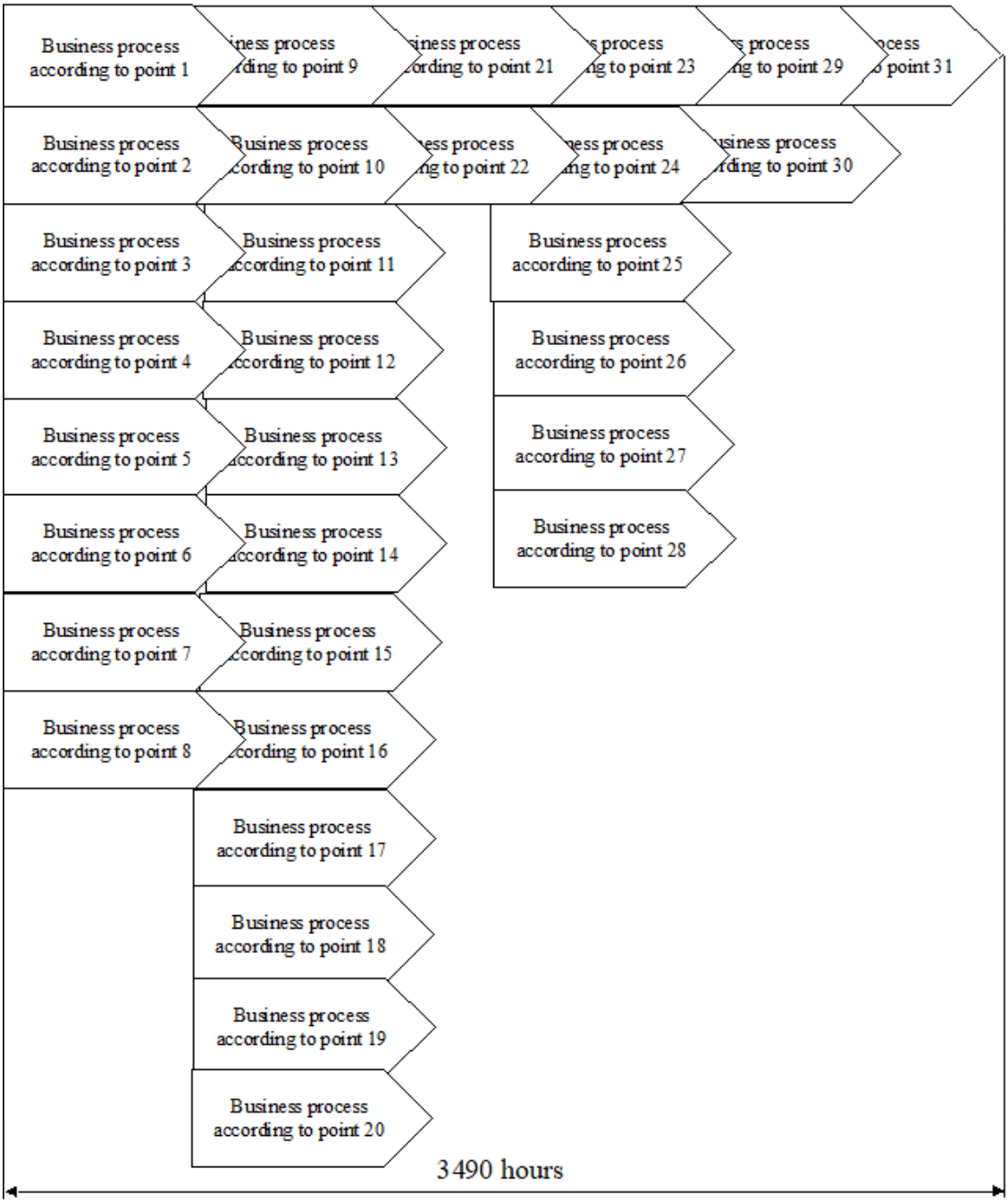

Figure 4. Overall time of all series of business processes required to complete the DTPP, based on the data from Table 2.

5. Discussion

Modelling the DTPP for an engineering enterprise not only aims to reduce time but also to minimise costs associated with this process.

Suppose x_i is the volume of the DTPP for the release of a product of the *i*-th version and k_i is the cost of the DTPP of the *i*-th product, then the amount of funds for the DTPP for the *i*-th product amount to $k_i\, x_i$ monetary units (MU). The amount of funds required for the DTPP of products manufactured by an engineering enterprise is:

$$K(x_i)=k_1x_1+k_2x_2+\ldots+k_nx_n \tag{10}$$

where $k_n\, x_n$ *are* the funds for the DTPP of a product.

$K(x_i)$ *is* the sum of funds for the total volume of the DTPP of all products manufactured by an

engineering enterprise.

Restrictions are imposed based on the resources necessary for the DTPP of an engineering enterprise to launch a product:

$$d_{j1}x_1+d_{j2}x_2+\ldots+d_{jn}x_n \le h_j,\ j=1,2,\ldots,m \tag{11}$$

$d_{jn}x_n$ *are* resources for the DTPP of each product;

h_j is the margin of resources for the DTPP.

Implicit restrictions cannot be negative for the DTPP, which means that the variables are to be non-negative, as follows:

$$x_i \ge 0 \tag{12}$$

A set of mathematical relations for the DTPP of an engineering enterprise (objective function and constraints) represents a mathematical model for the DTPP task to minimise the costs of pre-production for the product release.

$$\begin{cases} K(x_i)=k_1x_1+k_2x_2+\ldots+k_nx_n \rightarrow \min \\ d_{j1}x_1+d_{j2}x_2+\ldots+d_{jn}x_n \le h_j,\ j=1,2,\ldots,m \\ x_i \ge 0,\ i=1,2,\ldots,n \end{cases} \tag{13}$$

The matters of top priority when assessing the management prospects at an engineering enterprise are selecting the most suitable design and technological process to meet consumer needs.

6. Conclusion

Growing attention to engineering enterprises is derived from the fact that they play one of the leading roles in our country's economic systems. Among the most significant features, it is worth pinpointing that engineering enterprises:

- are major taxpayers;

- create jobs;

- manufacture products for export;

- produce domestic products;

- contribute to the transition from the commodity economy to the non-commodity export economy;

- boost competitiveness in both domestic and international markets;

- adapt to a new economic realm;

- generate new competencies and qualifications in the workforce (skill, knowledge, and experience);

- develop digital technologies;

- catalogue industrial products at all stages of production and delivery;

- maximise the profit for an enterprise;

- create high added value and consumer value;

- accelerate capitalisation of business.

Further, the availability of information flow via the market-centred DTPP at an engineering enter-

prise facilitates information exchange across industries.

However, the current situation shows that the majority of measures initiated to carry out the DTPP, DT, or TD are taken on the spot and rely on the available resources only. The reason is rather simple and boils down to the fact that modelling via quantitative indicators is complicated and time-consuming. Another important consideration is that, normally, the management of the department for design and technology does not need to obtain very specific data. In most cases, a general development track is more than enough. For instance, these tracks might weigh the importance of developing standard or group technologies—individual or group work—at a production site.

Another issue to bear in mind is that the transition from series processes to parallel-series ones makes the curve of the design pre-production and technology pre-production change, thus indicating shifts in production timeframe. Generally, the concept of DTPP modelling at an engineering enterprise can be elucidated from the perspective of IT architecture, built via a fuzzy-set approach.

By applying a fuzzy logic approach, we justified the possibility of reducing the DTPP timeframe by introducing a transition from the series processes to the parallel-series ones in the design pre-production and technology pre-production. Overall, proper integration of digital technologies promises to reduce the DTPP timeframe and introduce an IT architecture for engineering enterprises to build end-to-end designs using information systems in development and production.

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SECTION 3

SUSTAINABLE DEVELOPMENT OF REGIONAL INFRASTRUCTURE

РАЗДЕЛ 3

УСТОЙЧИВОЕ РАЗВИТИЕ РЕГИОНАЛЬНОЙ ИНФРАСТРУКТУРЫ

Research article
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AGENT-BASED MODELLING OF SUSTAINABLE DEVELOPMENT OF REGIONAL HEALTHCARE INFRASTRUCTURE

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Abstract

This study examines the problems of providing support to decision-making in the field of sustainable development of a regional healthcare infrastructure. To tackle these problems, there is a need to fund healthcare systems more efficiently, improve sanitation and hygiene, and provide access to medical services for a wide strata of the population. A network of healthcare organisations should be developed based on the structure and level of morbidity, mortality, gender and age composition of the population, climate and geography of territories, and transport accessibility of healthcare organisations. An important scientific challenge we face today is how the spatial allocation of healthcare infrastructure facilities can be enhanced. The paper presents the authors' concept of building agent-based models that safeguard decision-making on the best spatial allocation of healthcare infrastructure facilities. It includes a formal description of the objective of selecting the best location for healthcare infrastructure facilities, as well as the final description of the models, using a protocol for standardising the description of agent-based models. Relying on this concept, the paper presents a prototype of an agent-based model, built for a real-world system. The concept can potentially be used to solve a wider range of problems related to spatial allocation of social infrastructure facilities, which could ensure sustainable development of the regional social infrastructure.

Keywords: sustainable development, regional infrastructure, healthcare system, spatial allocation, agent-based modelling

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АГЕНТ-ОРИЕНТИРОВАННОЕ МОДЕЛИРОВАНИЕ УСТОЙЧИВОГО РАЗВИТИЯ РЕГИОНАЛЬНОЙ ИНФРАСТРУКТУРЫ ЗДРАВООХРАНЕНИЯ

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Аннотация

Статья посвящена вопросам обеспечения поддержки принятия решений по устойчивому развитию региональной инфраструктуры здравоохранения. Решение этих задач требует более эффективного финансирования систем здравоохранения, улучшении санитарии и гигиены и обеспечения доступности медицинских услуг для широких слоев населения. Развитие сети медицинских организаций происходит и базируется на основе структуры и уровня заболеваемости, смертности населения, его половозрастного состава, климатических, географических особенностей территорий и транспортной доступности медицинских организаций. Актуальной научной задачей на сегодняшний день является оптимизация пространственного размещение объектов инфраструктуры здравоохранения. В статье представлена авторская концепция построения агент-ориентированных моделей, обеспечивающих процесс принятия решений по оптимальному пространственному размещению объектов инфраструктуры здравоохранения. Она включает формальное описание задачи по оптимальному пространственному размещению объектов инфраструктуры здравоохранения, а также конечное описание моделей с использованием протокола, предназначенного для стандартизации описаний агент-ориентированных моделей. Представлен прототип агент-ориентированной модели для реально существующей системы, созданный на основе данной концепции. Разработанная концепция в перспективе может быть использована для решения более широкого круга задач, связанных с пространственным размещением объектов социальной инфраструктуры. Это послужит обеспечению устойчивого развития региональной социальной инфраструктуры.

Ключевые слова: устойчивое развитие, региональная инфраструктура, система здравоохранения, пространственное размещение, агент-ориентированное моделирование

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1. Introduction

In 2015, the United Nations member states officially adopted a plan of action for sustainable development called "Transforming our world: The 2030 Agenda for Sustainable Development," which includes 17 goals and 169 targets. One of the goals is to "Ensure healthy lives and promote well-being for all at all ages"[1]. Since the Agenda was adopted, considerable success has been achieved in increasing life expectancy and reducing some of the most common causes of death, especially those related to child and maternal mortality. However, the situation was aggravated by the crisis that arose due to the coronavirus pandemic, with many of the current targets being pushed into the background. The crisis also highlighted the need to make additional efforts to completely eliminate a wide range of diseases and resolve many common and new healthcare problems. To address these problems, we must fund healthcare systems more efficiently, improve sanitation and hygiene, and safeguard access to medical services for a wide strata of society.

In August 2020, the Pan-European Commission on Health and Sustainable Development was established. It aims to put forward comprehensive proposals to transform healthcare systems for future challenges. Acting on behalf of the WHO Regional Office for Europe, the commission made the following appeal[2] to its member states:

- Based on the national context, commit to ensuring timely, fair, and equal access to good quality and safe services on testing, treating, and vaccinating against COVID-19 while providing the population with unrestricted access to the main medical services;

- Develop the potential of the country in the context of readiness for emergencies, plan the recovery stage, and get ready for any potential healthcare emergencies in the future.

The 2021 survey "What Worries the World"[3], conducted by Ipsos in 28 countries, showed that every fifth respondent (21%) believed that the ineffectiveness of the healthcare system was a big problem faced by their country. The main barriers to adequate response of the healthcare system to the expectations of people are the lack of resources or non-use of many reserves for increasing the efficiency of the material, labour, and financial resources that are already being used. An interesting finding regarding the efficiency of the healthcare sector in some countries (a sample of 120 countries) with low and average incomes during 1997–2014 (Petitfour, 2017) was the decreasing efficiency of financial investment in the healthcare system as the country became more mature.

Efficient use requires planning. Planning a healthcare system refers to striking a certain balance between the population's needs for medical help, pharmacological support, sanitary-antiepidemic services, and the ability to meet these needs (Gaidarov and Gashenko, 2016). It is essential to introduce methods for evaluating health status and loss of health, and priorities for the efficient use of resources should be determined. Thus, better efficiency and stability of medical services is seen as a must for the sustainable development of a country. To eliminate drawbacks in the healthcare sector and fight new threats, we need a realistic and operative plan of action for the benefit of people, based on the needs, priorities, scientific data, and best practices.

The process of planning a network of healthcare organisations can be divided into several stages: defining a reasonable need for medical care; gauging the required network capacity by type of medical care; forming a rational network structure by type of medical care; analysing the current network of medical organisations; identifying deviations from the rational structure by type of medical care; and developing measures for eliminating deviations. An accurate picture of the current situation can be gained by sound statistical investigation, that is, scientific, accurate, and reliable information. This approach is the basis of management decision-making in healthcare and public discourse on medicine. The net-

1 UN Sustainable Development Goals. Available at: https://www.un.org/sustainabledevelopment/ru/health/

2 Statement Covid-19 a continued call for international solidarity and equity. WHO. Available at: https://www.euro.who.int/ru/health-topics/health-emergencies/coronavirus-covid-19/statements/statement-covid-19-a-continued-call-for-international-solidarity-and-equity

3 What Worries the World - November 2021. Ipsos. Available at: https://www.ipsos.com/en/what-worries-world-november-2021

work of medical organisations must be set up according to their nomenclature. The development of the network should be based on the structure and level of morbidity, mortality of the population, its gender and age composition, climate and geography of territories, and transport accessibility of healthcare organisations.

We are currently witnessing a wider use of simulation modelling for solving problems related to finding the best location for healthcare infrastructure facilities. Unlike other approaches, modelling can be used for detailed description of a system and for analysing dynamic effects, offering a powerful tool for decision-making when problems of spatial allocation of objects are being handled.

One of the advanced methods of simulation modelling is agent-based modelling. Due to their applicability to describing the individual behaviour of system elements, agent-based models can be used to solve a wider range of problems than traditional approaches. They also consider certain aspects of the operation of a complex system in a more sophisticated way (Nianogo and Arah, 2015). When solving the problems of spatial allocation of healthcare infrastructure facilities, agent-based modelling can take into account the specific needs of the population as well as the behavioural attitudes of various social groups. A significant advantage of agent-based modelling is that it considers the changing dynamics in the characteristics of the entities under study over time and the dynamics of spatial allocations of the entities, as well as the possibility of capturing the structure of relationships between these entities (El-Sayed et al., 2012).

Agent-based models can logically incorporate optimisation mechanisms with medical services capable of acting as agents, that is, having their own behaviour model, including territorial allocation. The models can search for the best options for providing services while simultaneously allowing users to cooperate or compete for services. Thus, a model built as close to reality as possible and reflecting a set of basic and principle transactions between the agents within a regional healthcare system can be helpful for making good management decisions related to resource distribution and rational spatial allocation of the infrastructure facilities of the sector.

Despite all the advantages of using agent-based models in healthcare, there are also some constraints caused by the nature of their development and parameterisation. A major problem is the tangible contradiction between the simplicity of the model and its realism. Finding a balance between the wish for a simplified representation of reality and the need to embrace quite complex elements for a new insight is a true art (Hupert et al., 2008), which is developed through trial and error. Therefore, knowing the specifics of the agent-based model, most authors focus on the development of its conceptual structure (Chekmareva, 2017). To build an agent-based model, developers need to overcome the difficulties associated with determining the types of agents, their number, and their characteristics, as well as understand the mechanism by which the agents interact with each other and the external environment (Makoveev, 2016).

The main aim of this study is to develop a concept of agent-based models, safeguarding decision-making on the best spatial allocation of healthcare infrastructure facilities. This paper contributes to the development of the theoretical and applied aspects of building agent-based models related to providing services for social systems.

2. Literature Review

Agent-based modelling is becoming an increasingly popular method for the visualisation, analysis, and evaluation of complex dynamic healthcare systems (Cassidy et al., 2019). These models can be used in virtual experiments designed to manage regional health systems. Due to the complexity of such systems, it is common to create models that embrace individual aspects of their operations. Traditionally, they have been used to predict the development of epidemic crises (Lee et al., 2010). There are agent-based models of emergency care (Brenner et al., 2010; Rohleder et al., 2011; Liu et al., 2014), distribution of the population in a certain territory by medical organisations (Jones and Evans, 2008; Bonabeau, 2002), analysis of patient flows in healthcare institutions (Hutzschenreuter et al., 2008), use of beds in

hospitals (Vasilakis and El-Darzi, 2008), and networks of medical services provided for groups of people with a specific disease (Charfeddine and Montreuil, 2010).

Patients act as prototypes of the main agents in the models. They are attributed to domain-relevant characteristics and behaviours. Paulussen et al. (2006) examined agent-based models in the field of medical research and management of medical services and concluded that the characteristics of the agents correlated with the patients' socio-demographic characteristics significant to the problem considered. Thus, Tracy et al. (2018) presented a scheme for a hypothetical healthcare agent-based model (Figure 1). People may have various characteristics at the individual level—ranging from endogenous factors to socio-economic status (blue table at the top)—as well as at the community level (green table at the top), which overlap to form individual behaviour in relation to health and the use of medical services.

As shown in the figure, the creation of a conceptual basis for an agent-based model involves various stakeholders and allows clear assumptions about the aspects of a specific system and how they work together to achieve positive public health results.

Alibrahim and Wu (2018) considered an agent-based model of patient selection by healthcare providers in accountable healthcare organisations. The structure shows the various levels of the modelling system, as well as its various agents—the payer, provider, and patient—and their key components. This model can evaluate the process of choosing a service organisation by the patient. The patient agent has seven variables: three health status variables (diabetes, hypertension, and chronic heart failure) and four demographic variables (age, race, gender, and income). The demographic variables are the predictors of the patient's preferences in relation to the service providers and their activity in searching for a service organisation. Further, the same seven patient-specific variables predict the likelihood of the patient developing chronic heart failure and the various phases of the condition and treatment. The model assumes that hospitals and clinics provide identical services and have identical carrying capacity. Thus, it calculates the number of occasions on which the patient seeks help from alternative providers. The agent behaviour models use a distance parameter, defined as the travel time between suppliers. A higher distance parameter indicates less dense, more dispersed service points, which reduces the probability that the patient will visit all the nearest service providers. A lower distance parameter means there is a more compact distribution of service points; hypothetically, the patient in this scenario is more likely to visit all local providers. The model assumes that the distance between any pair of preferred and alternative providers is the same (60 minutes) to simulate typical rural or urban conditions. In other words, if patients decide to get help from an alternative provider, they have to travel for 60 minutes. In fact, this model determines the degree of influence that distance has on the behaviour of service consumers. The service provider agents are either hospitals or primary care clinics. A key aspect of a provider agent is its ability to decide whether to participate in disease treatment programmes. The payer agent evaluates the quality of the services that have been provided and influences the distribution of investments. The decision-making process of the patient agent who chooses a service provider consists of three phases: perception, intention, and implementation. The decisions that are made affect the reimbursement of expenses for the services, as well as the patients' mortality and hospitalisation rates.

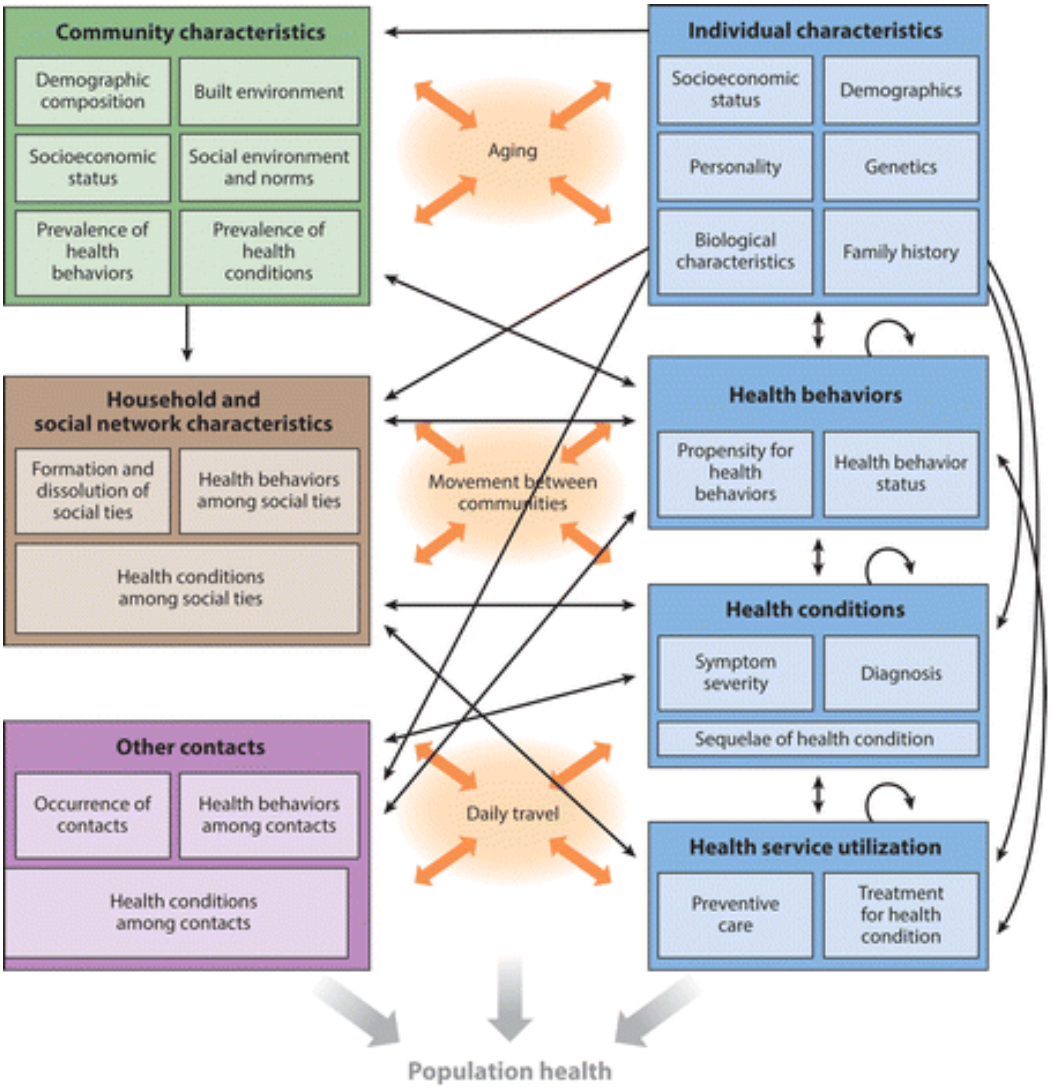

Figure 1. Scheme of a hypothetical agent-based healthcare model

Einzinger et al. (2013) presented a GAP-DRG agent model that is suitable for comparing reimbursement schemes for outpatient treatment. It simulates patients and medical staff as agents. In the simulation, patients with health problems (diseases) and medical service needs are led to healthcare providers. The behaviour of agents in the model is divided into five modules: epidemiology, need for service, use of a provider, provision of services, and reimbursement. The structure of the model allows each patient to have several health problems at a time. Each health problem creates a need for services for each quarter of the year in the form of a list of medical services and their corresponding frequencies. Patients then try to get these services in full scope from healthcare providers (the use of a provider). After they are provided with the services included in their portfolios (provision of services), the provider addresses the social insurance fund for reimbursement. Reimbursement takes place once every quarter of a year, when the reimbursement system imposes these claims and updates its statistics.

Paulussen et al. (2004) described an agent-based approach to the planning of patient placement in hospitals. In the agent-based model, patients and hospitals are seen as autonomous agents. Hospital agents consider patient agent objects to be treated. Agent patients turn to hospital agents for services. The distribution of patients in hospitals is achieved through a market mechanism. Patient agents compete with each other for services in hospitals. Their behaviour is influenced by their health status and the price of services. The modelling concept takes into account the time characteristics of the services provided and movements to the places where services are provided.

As noted earlier, there is considerable experience in agent-based modelling of the operation of

emergency departments. The model presented in Yousefi and Ferreira's (2017) study was used to investigate the possibility of redistributing the resources available in the department. Apart from patients, registry employees, nurses, and doctors act as agents here. All agents participate in the decision-making process on resource redistribution in the department based on their own observations. All available human resources are redistributed using this method during the working day. Patients can decide whether to continue treatment or leave the department at any stage of treatment. To evaluate the efficiency of this approach, six different scenarios are presented. The simulation results are the number of deaths, the number of patients who left the emergency department, the length of stay, the waiting time, and the total number of patients discharged from the emergency department.

Yousefi et al. (2018) discussed the modelling of the behaviour of patients who leave the emergency department of a public hospital without being serviced, which is mainly due to long waiting times or queues. Patient agents decide whether they should keep waiting or leave, among other things, based on the results of their communication with each other.

The agent-based model presented in Silverman et al.'s (2015) study aims to provide support in making decisions about searching for measures that would improve public health and quality of medical aid while decreasing costs. Citizen agents exist within the social structures of a higher level (organisations and society), which influence them and can also be influenced by them. These are the conditions under which their social health determinants are shaped.

Our review shows that individual elements necessary for reaching the targets of medical resource distribution are present in agent-based models. They include identification of a class of patient agents with a number of socio-demographic characteristics; determination of social, spatial, and economic factors in the behaviour of patient agents; identification of the classes of healthcare infrastructure agents (healthcare institutions, personnel, etc.), whose behaviour models consider the mechanisms of coordinated actions; formation of the spatial environment where the agents exist; formation of the processes according to which the agents interact within the framework of the medical services that are provided; and determination of the medical efficiency criteria for evaluating services. Nevertheless, there are currently no holistic universal concepts for building agent-based models that would ensure the decision-making process for the best spatial allocation of healthcare infrastructure facilities. Hence, our research aims to fill this gap by creating a variant of this concept.

3. Materials and Methods

The problem of the spatial allocation of healthcare infrastructure facilities can be described as the distribution of partially mobile services for mobile users (Dianov, 2021). The mobility of services is related to the fact that they move to users to provide services. The mobility of users is related to their ability to choose certain services and move to places where they can use them. In general, the model can be presented as follows:

$$M = (U, R, S, C) \tag{1}$$

where U is the location nodes of services and clients, R are the connections between the nodes, S is the services, C is the users.

The services and users can be in a limited number of locations. For this reason, model M can have a certain quantity of nodes where services and users are located:

$$U = \{U_1, \ldots, U_{UN}\} \tag{2}$$

Many connections can exist between the nodes–movement routes of services and clients:

$$R = \{R_1, \ldots, R_{RN}\} \tag{3}$$

The nodes and connections have a set of attributes of various natures that characterise them:

$$U : A^U = \left\{ A_1^U, \ldots, A_{AUN}^U \right\}, \; R : A^R = \left\{ A_1^R, \ldots, A_{ARN}^R \right\} \tag{4}$$

The model has many services and clients:

$$S = \left\{ S_1, \ldots, S_{SN} \right\}, \; C = \left\{ C_1, \ldots, C_{CN} \right\} \tag{5}$$

As for the problem described, they demonstrate active behaviour and belong to the category of agents. The Service Agent can be described as follows:

$$S = U_i, A^S, Bh^S \tag{6}$$

where U_i is the node of permanent dislocation of the service, A^s is the population of service attributes ($A^S = \left\{ A_1^S, \ldots, A_{ASN}^S \right\}$), and Bh^s is the model of service behaviour. The Client Agent has a similar description:

$$C = U_i, A^C, Bh^C \tag{7}$$

where U_i is the node of permanent dislocation of the service, A^c is the population of service attributes ($A^C = \left\{ A_1^C, \ldots, A_{ACN}^C \right\}$), and Bh^c is the model of service behaviour.

The behaviour models contain modules in which the behaviour scenarios of agents are defined. The modules consist of a set of rules that allow an agent to select a particular scenario, depending on the current values of the parameters of the model elements. Two modules are defined in the Service Agent's behaviour model:

$$Bh^S = \left\{ Md_s^S, Md_d^S \right\} \tag{8}$$

where Md_s^S is the service provision scenario module, Md_d^S is the movement scenario module.

There can be two types of Service Agents: stationary, firmly attached to a certain node, and mobile. No movement scenario module is defined for stationary agents:

$$Md_d^S = \varnothing \tag{9}$$

Whether a service is possible and what the procedure would be for providing the service to a particular user are defined at the level of the service provision scenario module. On that basis, the values of the user and service attributes are used in the following rules:

$$Md_s^S = \left\{ Pr_1^{MdSs}\left(A^S, A^C\right), \ldots, Pr_{PrMdSsN}^{MdSs}\left(A^S, A^C\right) \right\} \tag{10}$$

where $Pr_i^{Md\ldots}\left(X_1, \ldots, X_{XN}\right)$ is the i-th rule of the module containing parameters $X_1, \ldots, X_{XN}$.

At the level of the movement scenario module, the user's needs, possibility, parameters, and movement route are defined:

$$Md_d^S = \left\{ Pr_1^{MdSd}\left(A^S, A^C, A^U, A^R\right), \ldots, Pr_{PrMdSdN}^{MdSd}\left(A^S, A^C, A^U, A^R\right) \right\} \tag{11}$$

In the behaviour model of the User Agent, there are also two modules:

$$Bh^{\tilde{N}} = \left\{ Md_{gu}^C, Md_{pu}^C \right\} \tag{12}$$

where Md_{GU}^C is the scenario module of service generation, Md_{PU}^C is the scenario module of service use.

The scenario module of service generation provides the ability of the User Agent to initiate the need and wish to use a specific service. The module depends on the personal characteristics of the agent and the factors of the environment in which they exist:

$$Md_{gu}^{C} = \left\{ Pr_{1}^{MdCgu}\left(A^{C}, A^{U}\right), \ldots, Pr_{PrMdCguN}^{MdCgu}\left(A^{C}, A^{U}\right) \right\} \tag{13}$$

According to the rules of the service use scenario module, the User Agent is defined with the possibility and method of using the service, as well as with their actions:

$$Md_{pu}^{C} = \left\{ Pr_{1}^{MdCpu}\left(A^{S}, A^{C}, A^{U}, A^{R}\right), \ldots, Pr_{PrMdCpuN}^{MdCpu}\left(A^{S}, A^{C}, A^{U}, A^{R}\right) \right\} \tag{14}$$

The module should define the optimality criterion, connected to evaluating the dynamics of change in the properties of the Service and User Agents:

$$K = f\left(d\left(A^{S}\right), d\left(A^{C}\right)\right) \tag{15}$$

where *d (X)* is the function characterising the dynamics of change in parameter X.

The solution to the problem is connected with multiple modelling of situations with different combinations of the location of Service Agents in the nodes. Based on the results of each iteration, the value of the optimality criterion is calculated. The values of the criteria are compared. According to the results of the comparison, the model with the best, in a certain sense, criterion value is selected.

For the final description of the model, we used the ODD protocol (Overview, Design Concepts, and Details), aimed at standardising the descriptions of agent-based models (Grimm et al., 2020). The protocol consists of seven elements conceptually divided into three categories: Overview, Design Concepts, and Details. Each of these categories serves its purpose: to provide an overview, explain how design concepts that are important for the model have been used, and explain all the details of the model concept.

The Overview category is aimed at reflecting the general architecture of the model. It has three sections: Purpose and Patterns, Entities, State Variables and Scales, Process Overview, and Scheduling. The Purpose and Patterns section explains the purpose of the model. The Entities, State Variables, and Scales sections describe the structure of the model with specifications of all types of entities in the model. The Process Overview and Scheduling sections describe the processes occurring in the model and their schedules.

The Design Concepts category includes only one section with the same name, which contains a description of the concepts that build the model. The following structure of the section has been defined:

- Basic Principles. This provides a description of general concepts, theories, hypotheses, or approaches to modelling underlying the structure of the model.

- Emergence. This describes the systemic phenomena caused by the interactions between agents.

- Adaptation. This provides a description of the decision-making procedure followed by agents in response to changes in their own parameters or the parameters of elements of the surrounding environment.

- Objectives. This outlines the objectives pursued by the agents.

- Learning. This provides a description of the possibility of agents' adaptive behaviour (if any).

- Prediction. This describes the procedure according to which agents evaluate the possible consequences of their decisions.

- Sensing. This describes the mechanisms of agents' perceptions of their own parameters and the parameters of the elements of their surrounding environment, as well as the range of the parameters they perceive.

- Interaction. This provides the possible types of interactions between agents.

- Stochasticity. This describes the processes of the model, in which there are elements of a random nature.

- Collectives. This describes the possibility of forming individual elements of the model or changes in the nature of agents' behaviour related to their grouping.

- Observation. This displays a mass of data collected with a certain frequency in the course of data modelling, aimed at testing, understanding, and analysing the model.

The Details category is aimed at describing the mechanisms of implementation of the model. It includes three sections: Initialisation, Input Data, and Submodels. The Initialisation section describes the initial state of the model world—which entities are in existence and the exact values of their state variables. The Input Data section describes the sources of data that arrive in the model from external sources. The Submodels section specifies the processes described in Process Overview and Scheduling.

4. Results

We present the concept of the proposed agent-based model developed in the form of a template for describing models in the ODD protocol format, corresponding to the formal description of the problem of the spatial allocation of healthcare facilities presented earlier.

1. Purpose. The model is designed to search for the best parameters of the healthcare infrastructure in a territory: spatial allocation, number, and performance parameters of elements. The optimality criteria are the maximum possible satisfaction of the needs the population in a territory has for medical services with time characteristics to ensure their good quality, given the limited resources available.

2. Entities, State Variables and Scales. Table 1 presents the model entities, while Table 2 contains their parameters.

Table 1. Entities of the model

Name	Type	Reflection
Client	Agent	Person who needs a certain medical service
Service	Agent	Service providing medical help
Node	Environment element	Location nodes of clients and services
Route	Environment element	Route, connecting the location nodes of services with those of clients

Table 2. Parameters of model entities

Entity name		
Parameter	Scale	Range
Client		
Identifier	Names	Arbitrary identifier (letter, numeric, alphanumeric)
Time of occurrence	Date/Time	
Diagnosis	Names	Population of the names of diagnoses
State	Actual number	0..1 (0 is a mild form, 1 is an extremely severe form)
Human characteristics	Structures	Population of pairs of the form: characteristic – characteristic value

Selected service	Names	Population of service identifiers
Status	Names	{ready to move to the service, moves to the service, waiting to use the service, uses the service}
Service		
Identifier	Names	Arbitrary identifier (letter, numeric, alphanumeric)
Medical service	Names	Population of the names of medical services
Mobility type	Names	{mobile, stationary}
Provision cost	Figure (monetary)	>=0
Provision time	Integer (minutes)	>=0
Current client	Names	Population of client identifiers
Location	Names	Population of node identifiers
Schedule	Structure	Population of triples: day of the week – start of work – end of work
Node		
Name	Names	Population of the names of residential areas in a territory
Type	Names	{city, village }
Population characteristics	Structure	Population of pairs: characteristic – characteristic value
Route		
Identifier	Names	Arbitrary identifier (letter, numeric, alphanumeric)
Beginning node	Names	Population of node names
End node	Names	Population of node names
Duration	Integer (minutes)	>0
Cost	Figure (monetary)	>0
Schedule	Structure	Population of pairs: day of the week – starting time of movement

3. Process Overview and Scheduling. The model time is set in minutes. Depending on the type of medical service considered in the model, the modelling period can be chosen in different ways, which must be determined based on the frequency of the need for medical services and the duration of their provision. Table 3 presents a list of the processes.

Table 3. Typical Model Processes

Process name	Executed by	Execution period	Execution order
Generation of the Client Agent	At the model level	One-time after a certain period of model time	Based on the analysis of the parameter values of every “Node” entity, Client Agents with certain parameter values are generated.
Change in the state of the Client Agent	Client Agent	Many times from the moment the Client Agent is created till their removal after a certain period of model time	Based on the analysis of the parameter values of the Client Agent, the value of its “State” parameter is calculated and corrected. If the value of the “State” parameter of the Client Agent is equal to 0 or 1, this agent is removed.

Getting access to the service	Client Agent	The moment of creation of the Client Agent	1. According to the value of the "Diagnosis" parameter of the Client Agent, the medical service is determined, and then a set of Service Agents with respective values of the "Medical Service" parameter is found. 2. Based on the analysis of the parameters of the routes, connecting the location nodes of Client Agents with the location nodes of the Agent Services, the current workload of the Service Agents, and the values of their own parameters, the Client Agent determines the Service Agent, which will provide the respective service, and includes it in the identifier as the value of their own "Selected Service" parameter. 3. If the selected Service Agent has the value of the "Mobility Type" parameter as mobile, the value of the "Status" parameter is set as "waiting to use a service." Otherwise, the value of the "Status" parameter is set as "ready to move to the service."
	The Client Agent with the "ready to move to the service" value of the "Status" parameter	The onset of the schedule item of any route to the location node of the Service Agent	The Client Agent determines the possibility of moving along the route. If the result is positive, they move along the route, and the value of the "Status" parameter is set as "moves to the service."
	The Client Agent with the "moving to the service" value of the "Status" parameter	The Client Agent's reach of the location node of the Service	The value of the "Status" parameter is set as "waiting to use the service"
Providing the service	The Service Agent with a non-filled value of the "Current Client" parameter and the "mobile" value of the "Mobility Type" parameter within the limits of the schedule drawn up for the Service Agent	Every cycle of model time	1. The Service Agent selects a Client Agent from among those who are waiting to use the service. 2. If there is a choice: - The identifier of the selected Client Agent is put in the "Current Client" parameter. - The Service Agent moves to the location node of the Client Agent. - The value of the "Status Parameter" of the Client Agent is set as "uses a service." - The Service Agent provides the service. - The Client Agent is removed. - The value of the "Current Client" parameter is removed. If there is no choice: If they are not in the permanent location node, he moves to it. 3. Schedule analysis: In case they go out of the range, they return to the location node.
	The Service Agent with a non-filled value of the Current Client parameter and the "stationary" value of the "Mobility Type" parameter within the limits of the schedule drawn up for the Service Agent	Every cycle of model time	1. The Service Agent selects a Client Agent from among those who are waiting to use the service. 2. If there is a choice: - The identifier of the selected Client Agent is put in the "Current Client" parameter. - The value of the "Status" parameter of the Client Agent is set as "uses a service." - The Service Agent provides the service. - The Client Agent is removed. -The value of the "Current Client" parameter is removed.

4.1. Design Concepts

4.1.1. Basic Principles

- Since medical resources are limited, the most important objective is their optimal distribution in a territory. Optimal distribution is understood as the possibility of providing medical services to the largest number of people who need them. Accessibility of medical services is an important factor for everyone. Accessibility largely depends on the infrastructure that provides access to the service and the ability of the population to bear access and service costs. The initial data of the simulation should be the parameters of the distribution dynamics of those in need of the medical services in a territory, as well as their ability to use medical services. The closest to reality in this regard would be agent-based models, which see all people living in the territory as agents. However, due to the objective difficulty in collecting real data (given their dynamic nature), and the need to use large computing resources, doing this does not seem realistic. That is why the presented model relies on an approach in which qualitative and quantitative analyses of the population composition and its spatial location in a territory are used to generate agents whose quantity and characteristics would reflect the dynamics of the appearance of people in need of medical care (Client Agents). Client Agents are associated with permanent residences of people in the territory (nodes). According to the concept, when such agents are generated, the mobility factor of the population is neutralised (an urgent need for medical service may arise at work, when staying out of town, or during visits to relatives, etc.). This point can be taken into account as the model is further developed. To make the generation of Client Agents possible, information about the parameters of the population living in the territory should be associated with nodes. A set of such parameters can be different: distribution by gender, age, social status, education, etc. Based on these data, we determine the probability of the appearance of a Client Agent with certain needs for obtaining medical services in a particular node. Thus, the Client Agent created does not characterise a specific person with a set of inherent health characteristics but a person who needs a specific medical service at a given time, in a certain place. Beyond that, it is necessary to generate an agent with a specific set of characteristics (age, gender, social status, etc.) on the basis of which we determine other behaviours related to choosing a specific medical service and methods of accessing it. To obtain an objective picture of what is happening in reality, the model must consider the dynamics of the degree of need for medical services. The state of human health can change, both for the better and for the worse. As a result, the need for medical intervention in both cases may fade away. Based on this, agents whose state parameters have changed to a critical level, as well as agents who have been provided with a service in order to optimise the computational process, are removed from the model.

- Medical services in the concept presented are interpreted quite broadly. They can be the service of a specific medical worker, medical examination, hospital treatment, etc. In accordance with the aim of modelling, there is no need to display real processes related to the organisation and the quality of medical services provided. Providing the service is important. Many potential customers may be interested in the service at any given time. The agent displaying the service (Service Agent) can serve only one client at any given time. In this case, the agent is in the “Busy” state. Everyone else should wait for the end of this process. After the Service Agent becomes free, it selects a client from a queue of Client Agents. We can form various strategies for choosing the next client in the agent behaviour model. To obtain a realistic picture, it is necessary to provide the possibility of servicing within the schedule.

- Medical services are located in certain nodes. They can be stationary and mobile (emergency medical care, a district doctor visiting patients, etc.). In the case of mobile services, the service process includes the movement of Service Agents to the location of the recipient of the service. Movement occurs by route. The routes have no direct association with the transport infrastructure of the region. They relate more to the way of travel: bus route, air travel, going by taxi, private transport, on foot, etc. The route can be complex; that is, combine different ways of movement. Each route connects two nodes of the territory. There may be several different routes between the two nodes. At the model level, the time of travel along a route is a significant parameter. Movement along routes can occur according to schedule

(for example, a route is followed by public transport). Client Agents move to stationary medical services also using routes.

- Medical services and routes have their own costs. Along with the current workload of Service Agents and the travel time along the route, it is used by the Client Agent as a parameter when choosing a service.

- The modelling process involves running the model many times by placing a different number of Service Agents in different nodes. The number of services can act as a limiting criterion. The target is to find such a location structure of Service Agents that minimises the number of unserved Client Agents within the simulation period.

4.1.2. Emergence

In our concept, Client Agents, on the one hand, are generated based on the parameters of the population of a territory, that is, a real situation, associated with the emergence of the need for medical services in a certain territory, is shown. On the other hand, agents appear with a certain degree of probability. It is impossible to know in advance the exact number of Client Agents, the values of their parameters, and their locations at any time during the operation of the model. The behaviour of Client Agents aimed at choosing a Service Agent and using the service depends on the parameters of the agent itself and the current structure of the interaction between Client Agents and Service Agents. As a result, a scheme of servicing and movement of agents along routes cannot be predicted in advance, which ultimately determines the analysed characteristics of the model. Changing any parameters of the model (creating new routes, their schedules, reducing the cost, speeding up movement along them, changing the locations of Service Agents, their number, service time, schedules, as well as the characteristics of the population in the territory) significantly changes the result, which, at the same time, cannot be calculated in advance.

4.1.3. Adaptation

The adaptive ability of the model is demonstrated at the level of Client Agents' behaviour when they select the Service Agent. The assessment of the possibility of choice is related to the assessment of the agent's own capabilities (determined by the parameters of the agent) and state. If there are alternative options, the cheapest, fastest, a certain combination of these characteristics, or none at all, can be selected. In the latter case, repeated iterations of the choice are possible if conditions become different, there are new alternatives, and the state of the agent changes.

4.1.4. Objectives

The main goal of Client Agents when choosing a Service Agent is to receive services at minimal cost and avoid a decrease in the state to some critical point. At the same time, they must remember that their states may improve.

4.1.5. Learning

The model does not envisage agents' learning.

4.1.6. Prediction

The Client Agent can predict the situation by analysing the dynamic of change in the workload of Service Agents and evaluating their own state, given the experience in the development of the state among people with similar characteristics.

4.1.7. Sensing

Agents in the model can sense the parameters of any other agent and the elements of the environment.

4.1.8. Interaction

The model does not envisage the direct communication of agents with each other. There is a synchronisation between the Service Agent and the Client Agent during the process of servicing. There is an indirect interaction between Client Agents during the choice of the Service Agent for servicing.

4.1.9. Stochasticity

Stochasticity is present in the model in the following processes:

- Generation of Client Agents;

- Change in the state of the Client Agent;

- Selection of the Service Agent by the Client Agent for servicing;

- Selection of the route by the Client to move to the location node of the Service Agent;

- Determination of the time of servicing of the Client Agent by the Service Agent;

- Determination of the time of movement along the route.

4.1.10. Collectives

The model does not envisage the formation of collectives.

4.1.11. Observation

Table 4 presents the data from the model collected for testing, comprehension, and analysis.

Table 4. Collected data from the test model

Collected	Collection Parameters
Number of generated Client Agents	During generation of an agent, the value of the respective variable-counter increases by one
Number of serviced Client Agents	After the operation of servicing, the value of the respective variable-counter increases by one
Number of Client Agents removed from the model as the "State" parameter is equal to one	When the corresponding condition is checked during the operation of change in the state of the Client Agent, the value of the respective variable-counter increases by one
Busy time of the Service Agent	The time of execution of the next process "Providing the service by the Service Agent" is registered, and the corresponding value is introduced in the relevant table
Time within which Client Agents are in the state of searching for the service	The time between the moment of generation of the Client Agent and the moment of assigning the value "waiting to use the service" to their "Status" parameter is registered, and the corresponding value is introduced in the relevant table
Time within which Client Agents are in the state of expectation of the service	The time between the moments of assigning the values "waiting to use the service" and "uses the service" to the "Status" parameter of the Client Agent is registered, and the corresponding value is introduced in the relevant table

4.2. Initialisation

The initial state of the model is characterised by:

- The set values of the environment elements "Node" and "Route," which correspond to the current situation for the simulated territory.

- Based on the established criteria (they can be grounded on the results of some analysis, reflect

the current situation, or be set arbitrarily), a certain number of Service Agents is created and located in the nodes.

- Further research of the model implies the possibility of changing the number of Service Agents, their locations, and parameters.

4.3. Input data

This model does not use input data from external sources, which are intended to represent the processes that change over time.

4.4 Submodels

This section has to describe in detail the submodels representing the processes listed in the "Process Overview and Scheduling" section. In its essence, the model is a template for building specific models related to the objective of spatial allocation of healthcare facilities. Therefore, subprocesses are described in detail, based on the context.

Using this approach, we are currently creating a prototype of an agent-based model of the best locations of rural health posts (RHPs) in the Babushkinsky Municipal District of the Vologda Region. The agents in the model are RHPs, which provide medical services to the population, and the population itself, which takes the form of people who need these services. The model is implemented in the AnyLogic modelling environment. Figure 2 shows the implementation level of the model at which the formation and interaction of agents occur.

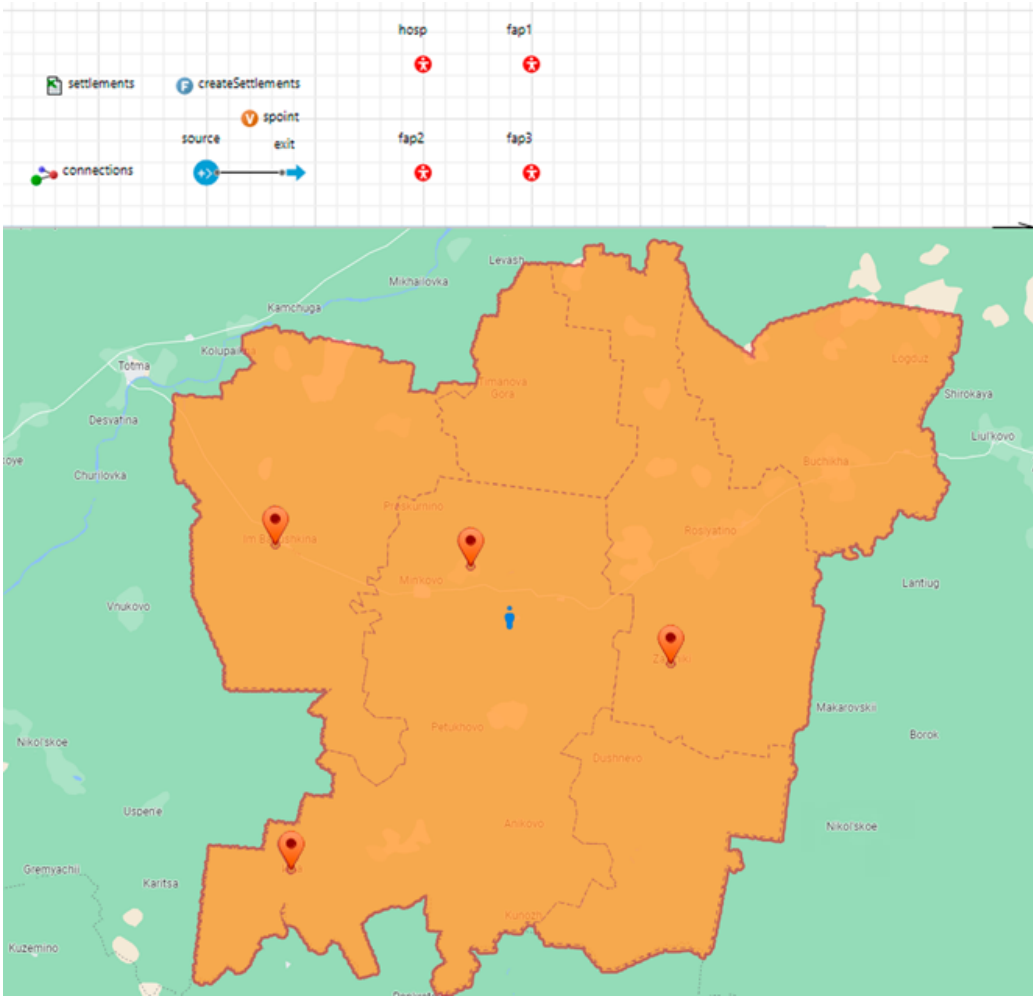

Figure 2. The level of implementation of the model at which the formation of agents and their interaction takes place

The model uses data on the location of settlements and RHPs of the Babushkinsky District, obtained from the geoinformation system incorporated into AnyLogic, as well as Rosstat data on the population of the settlements. The data on the number of appeals were obtained from Resolution N 1483 of December 14, 2020 "On the Approval of the Regional Program of the Vologda Region "Modernization of the Primary Health Care of the Vologda Region" for 2021-2025." The model implements the processes of interaction between RHPs and people concerning the possibility of using services, the choice of the location where services are provided to the public, the movement of people to the location of services, and servicing itself. Currently, the model is being filled with real data.

5. Discussion

The problem of the best spatial allocation of healthcare infrastructure facilities is important and has been considered in many studies. There is an apparatus of mathematical methods designed for solving such problems in the theory of decision-making that can also be used for tackling the problems related to finding the best location for objects. Today, the most commonly used are the methods of discrete optimisation, geoinformatics, and simulation modelling. Further, particular problems concerning the placement of specific elements of the healthcare infrastructure are resolved, which, in many ways, reduces the adequacy of the results obtained. In this regard, it is essential to choose methods that will allow us to find complex solutions. Such solutions must be adaptive to most situations related to resource allocation. Simulation modelling ensures a detailed description of the system suitable for the analysis of its dynamic characteristics. A significant advantage of agent-based modelling is the ability to consider the dynamics of change in the characteristics of the entities that are being studied over time and the dynamics of the spatial allocation of these entities, as well as the ability to take into account the structure of relationships between the entities. The analysis of agent-based models designed to support decision-making in the healthcare sector shows that some of them solve individual problems of spatial allocation of healthcare facilities. However, there is no holistic, spatial optimisation-oriented concept for building these models. In our work, we attempted to address the problem of the spatial allocation of healthcare infrastructure facilities based on the socio-demographic parameters of the territory, that is, the distribution of partially mobile services for mobile users. The problem was formally captured from the perspective of an agent-based approach, taking into account the spatial component. Using the well-known method of specifying agent-based models, we elaborated on the conceptual structure of the proposed model. This allowed us to demonstrate the approach we used in a visual form. Currently, agent-based models grounded on the developed concept are being practically implemented. The full-fledged implementation of several models of existing territorial healthcare systems will allow us to verify our approach. Creating accessible, user-friendly interfaces through which public healthcare and policy specialists can adapt the specifications of agent-based models to their specific conditions will contribute to the further introduction of these methods, increase the utility of the results of the model, and open up opportunities for independent assessments of their reliability (Badland et al., 2013). The concept can be used in the future to resolve a wider range of problems related to the spatial allocation of social infrastructure facilities. This will facilitate the sustainable development of the regional social infrastructure.

6. Conclusion

The main purpose of this study is to develop a concept of agent-based models that would ensure the decision-making process for the best spatial allocation of healthcare infrastructure facilities. To accomplish this purpose, the following problems have been resolved:

- We analysed existing approaches to building agent-based models that provide solutions to problems in the healthcare sector. The results show that agent-based models have some individual elements necessary for handling the problems of allocating healthcare resources. Currently, there are no holistic universal concepts for building agent-based models that would ensure the decision-making process for the best spatial allocation of healthcare infrastructure facilities.

- We proposed a formal description of the problem of the best spatial allocation of healthcare infra-

structure facilities. It includes the general architecture of agents and the environment within which they exist, agent behaviour models, optimality criteria, and the order of solving the problem.

- We fulfilled the final description of models using the ODD protocol (Overview, Design Concepts, and Details) aimed at standardising the descriptions of agent-based models. Our concept of an agent-based model is presented in the form of a template for describing models in the ODD protocol format, which corresponds to the formal description of the problem of the spatial allocation of healthcare facilities. The description matches all seven elements of the ODD protocol.

- We presented a prototype of an agent-based model for the best allocation of rural health posts in the Babushkinsky Municipal District of the Vologda Region. It is expected to be used as an element of verification of the approaches that have been developed. The model can be further used as a tool for planning the development of a network of RHPs in the Babushkinsky Municipal District of the Vologda Region. It can also act as a basis for the formation of similar networks in other territorial entities.

In general, this work contributes to the theoretical and applied aspects of creating agent-based models for the provision of services in social systems. Its further development would primarily involve the formation of behavioural models of health care infrastructure agents involved in an independent active search for the best locations for themselves.

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ACCURATELY COGNISING THE DIGITAL ECONOMY AND FACILITATING ITS HEALTHY AND SUSTAINABLE DEVELOPMENT IN CHINA

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Abstract

There is no doubt that the digital economy has brought much convenience to our work and life, improving productivity and optimising social service and government efficiency. However, there are also quite a few problems in the development of the digital economy, such as fake and even malicious information flooding the internet and new media, counterfeit e-commerce, and the shocks to the economy and society brought about by the extensively advanced development of internet technologies and fintech. People lack an understanding of the digital economy, leading to criminal offences and economic offences. This paper presents an accurate review of the development of the digital economy and its extensive effects on social economic growth. It begins with the introduction of the digital economy, with a profound influence on human productivity and people's lives, plus an essential literature review. It explains the research materials and methods, as well as the structure of the article. It then explores the development law of the digital economy and inteprets the essence of the accurate cognition of the digital economy. Further, it traces the impact of the digital economy on society and emphasises the normalisation of the development of the digital economy. This is followed by a deep assessment of the service efficiency of the digital economy and building a new area for attracting investment. It examines the importance of the information transmission mechanism in avoiding the overlapping of digital isolated islands. The paper concludes with the premise of precisely defining the development stage of the digital economy so as to stimulate the iterative innovation of social economic development.

Keywords: digital economy, digital credit, cognition, iterative innovation, sustainable development

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ЦИФРОВАЯ ЭКОНОМИКА И СОДЕЙСТВИЕ ЕЕ УСТОЙЧИВОМУ РАЗВИТИЮ В КИТАЕ

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Аннотация

Цифровая экономика принесла много удобства в нашу работу и жизнь, повысив производительность и оптимизировав социальное обслуживание и эффективность государственного управления. Однако в развитии цифровой экономики также существует немало проблем, таких как недостоверная информация, заполоняющая Интернет и новые медиа, поддельная электронная коммерция и потрясения для экономики и общества, вызванные широким развитием интернет-технологий и финтеха. Людям не хватает знаний в области цифровой экономики, что приводит к уголовным преступлениям и экономическим правонарушениям. В данной статье авторами представлен подробный обзор развития цифровой экономики и ее обширного влияния на социально-экономический рост, начиная с внедрения цифровой экономики, оказывающей глубокое влияние на производительность труда и жизнь людей, а также с обзора необходимой литературы. В нем объясняются материалы и методы исследования, а также структура статьи. Затем в статье исследуется закон развития цифровой экономики и раскрывается суть точного познания цифровой экономики. Кроме того, прослеживается влияние цифровой экономики на общество и подчеркивается нормализация развития цифровой экономики. За этим следует глубокая оценка эффективности обслуживания цифровой экономики и создание новой области для привлечения инвестиций. В статье также рассматривается важность механизма передачи информации для предотвращения дублирования цифровых изолированных островов. Статья завершается предпосылкой точного определения стадии развития цифровой экономики таким образом, чтобы стимулировать инновации для достижения социально-экономического развития.

Ключевые слова: цифровая экономика, цифровой кредит, познание, итеративные инновации, устойчивое развитие

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1. Introduction

Digital technology has been integrated into our time and has become the most visible presence in our daily lives. Nowadays, virtual reality (VR) scene technology, man-machine dialogue, artificial intelligence (AI), image and graphic processing, big data, and other technologies emerged one after another and have been applied to every aspect of our lives. Digital technology has enriched and delighted people's lives, improved the efficiency of social communication, reduced the transaction costs of business, expanded the mobility of goods, enhanced the vitality of economy, society, and science and technology, and promoted the iterative innovation of economy and society. Particularly in the current time, digital technologies have been used in epidemic prevention and containment. Clearly, people enjoy the convenience of digital technologies and services, but they are also troubled by the potential risk of personal information leakage (Chen, 2022), which calls for more attention to personal privacy information protection.

In recent years, the world has been fighting against the COVID-19 pandemic, and the application of digital economy technologies and services has played a big role. During the worst period of the COVID-19 surge in China in the first quarter of 2020, digital technology and its services supported the fundamental operation of grassroots communities and the resumption of related industries. This was an important factor for preventing social disorder and even unrest from happening in China's grassroots communities, compared to that of the United States and European countries (Wang and Wang, 2020). It is certain that the normal and healthy operation of Chinese society amid the epidemic is the achievement of the Communist Party of China (CPC) and the Chinese government in their efforts to modernise the country's governance system and capacity, and it is also the reward of all Chinese people's willingness to shoulder responsibility and their activities of dedication. Undoubtedly, digitisation has also clearly played a huge positive role in the fight against COVID-19.

The digital transformation of the world economy is an irresistible trend; the production and living systems of the human race are going digital, network, and intelligent at an accelerated pace (Zhang et al., 2019). The emergence of new forms of business has continuously had a profound impact on the global landscape of scientific and technological innovation, industrial ecological patterns, and economic trends, and Sina Finance has recommended adopting multiple measures to build a digital economic ecosystem[1]. We have seen the good side of the digital economy, but it also has downsides. For example, some people think the underlying technologies of the digital economy are not original in China, our digital economy is mainly focused on the application level, and so-called deep development has not formed the overall strength (Zhao and Yang, 2019). The competition of e-commerce platforms and other business models is overheating, taxi-hailing platforms burn money for grabbing passengers, the Eggshell lease apartment platform runs away, and the development of the platform economy is chaotic, which affects the credibility of the digital economy and disturbs the market order (Wang, Y., 2018). Today, there is less and less room for business model innovation in China; it is becoming increasingly urgent and necessary to integrate digital technologies into the real economy (Li and Huang, 2019). This requires, above all, an improvement in society's perception of the digital economy.

Further, intelligent manufacturing has not become the main carrier of the digital economy. The problem of data monopoly and data security is becoming tough day by day. A large number of people have no awareness of data security, do not seem to care about personal information leakage, and have weak legal consciousness (Feng, 2018). The violation of personal information and privacy rights occurs from time to time in China. The most serious situation is that e-commerce platforms are rife with false advertisements, frequently inducing and cheating customers. Of course, efforts have to be made offline to fight counterfeits on e-commerce platforms (Xin, 2015). Some new media and we-media are fully flooded with false and malicious information, which negatively affects people's normal lives, disturbs people's judgment, and disturbs society (Ji, 2018). Certainly, legislation is needed to purify the network environment.

1 Sina.Finance, 2022. Taking multiple measures to create a new ecosystem for the digital economy. URL: https://finance.sina.cn/2022-04-28/detail-imcwiwst4571581.d.html?share_token=6b79a6e6-2b1c-4c26-ba55-c8eb805203ad

Besides these, in some cities in China, industry digitisation and digital industrialization might have gone too far, although digital transformation remains difficult for a large number of small and medium-sized enterprises (SMEs) (Wang, and He, 2019). There are also problems with the digitisation service. AI customer service is making the customer experience worse in some service areas. E-government has brought new inconveniences to residents and businesses (Chang and Wen, 2019). In the era of the digital economy, data is a production factor, and it is extremely important for co-sharing data. However, there are many data isolated islands in the real economy and society; even within an enterprise, there are data isolated islands as well (Liu, 2018), which has been seriously weakening the productivity of the digital economy and the efficiency of the whole economy and society. At present, affected by the Ukrainian crisis and the ongoing epidemic, the security of the global supply chain has been facing challenges, and international trade and global logistics are not smooth. Today, we need more accurate service support from the digital economy to ensure the security of the supply chain and stabilise international trade and logistics.

The majority of ordinary people who use applications such as WeChat and TikTok every day can only partially feel the surface characteristics of the digital economy. People are caught in the wave of digital technology development and less actively participate in the innovative use of digital technology and digital economic activities. Therefore, they tend to think that the digital economy is overly professional and esoteric; some technical terms such as AI, blockchain, and metaverse are all overly abstract and abstruse, making people hesitate to attempt further understanding of the digital economy (Cao, Huang, 2019). Given that digital economy is used by the whole society, its inclusiveness, openness, and profound connotations need to be further understood and grasped by various social subjects.

Facing the rapid development of new technologies and continuous social development, we have to strengthen the awareness of the whole society on digital economy, so as to let people understand the changing society, and thus we could then vigorously stimulate the new kinetic energy of digital economy, furtherly people can feel and even touch the essence of the digital economy not only experience the feeling of appearance of the convenience and efficiency of digital services, thus people could make full use of its advantages and avoid its shortcomings. For example, digital education or online teaching has become more and more popular in universities, high schools, and primary schools because of the rapid spread and outbreaks of the Covid-19 epidemic across the world. In the last three years, some students have a high degree of self-control, but others have not. Online teaching has left some students behind; this has provided materials for studying the digital economy (Lv, 2019). All these efforts will contribute to the healthy and sustainable development of the digital economy itself, and create the fundamental basis for promoting economic and social iterative innovation.

2. Materials and Methods

This research adopts the methods of normative analysis, historical analysis, and horizontal comparative analysis to study the digital economy and its impacts on society and economic growth. The research materials include the existing literatures on digital economy, roughly statistics reports on digital economy, and all kinds of summaries and outlooks of digital economy. The article is organised into four sections. This section is the research materials and methods explanation; the previous section is the introduction, plus an essential literature review. The main third section is the research results and discussions, it outlines the cognition of the development process of the digital economy, with an inducive address of the healthy, scientific, and sustainable development of the digital economy; it analyses the profound impact of the digital economy on social and economic lives, with a description of the normative development of the digital economy. This is followed by tackling the issue of fully leveraging the service efficiency of digital technology to create a new highland for attracting investment; and then the rest examines the importance of information transmission mechanisms in the digital economy and discusses prevention against the repeated emergence of "digital isolated islands". The fourth section presents the conclusion with a precise definition of the development stage of the digital economy, followed by constructive comments for promoting the iterative innovation of economic and social development.

3. Results and Discussion

3.1. Digital economy has its own development law; a correct cognition is helpful to its healthy and sustained development

The Fifth Plenary Session of the 19th National Congress of the Communist Party of China specifically proposed that during the 14th Five-year Plan, China must seize new development opportunities for the digital economy and promote new drivers of economic growth, which has brought about unprecedented opportunities for the whole society to embrace the digital economy and facilitate economic transformation and upgrading. In the information era, with the popularity of the mobile internet, the digital economy has penetrated almost every corner of our earth, such as mobile payment, mobile phone navigation, WeChat, news feeding, TikTok live streaming, live shopping, online ride-hailing, and food delivery apps, and Alibaba, JD.com, and Pinduoduo and other online shopping platforms. These are certainly the contents of the digital economy but not the whole of the digital economy; these components cannot fully reflect the profound connotation of the digital economy. Obviously, ordinary people's understanding of the digital economy remains only at the level of mobile phone applications (apps)[2]; they lack a thinking of the inclusiveness and openness connotation of the digital economy, and most of them are even less sure about the development trend of the digital economy.

The digital economy actually refers to a new economy or knowledge economy. The "G20 Initiative of Digital Economy Development and Cooperation" adopted by the G20 Hangzhou Summit in 2016 defined digital economy as follows: "Digital economy refers to a series of economic activities that use digital knowledge and information as key production factors, modern information networks as an important carrier, and effective use of information and communication technologies as an important driving force for efficiency improvement and economic structure optimisation."[3] Given that the digital economy is defined as "a series of economic activities", there are factors of production in the digital economy. In the past, traditional factors of economic production mainly included capital, technology, labour, land, and institutions, but in today's new economic era, information and data in digital form are all factors of production (Li, 2019), and are even more important factors of production. Nowadays, traditional factors of production may also appear digital.

In the new economy era, the digital economy is an inevitable growth point, but at the beginning, it was mainly the competition object of venture capital funds and the popular topic of technology celebrities. It was not familiar to the public, let alone widely accepted, although people are deeply caught in all kinds of apps (Xu and Liang, 2017). The digital economy, as known to the general public, is nothing more than smartphones, the internet, e-commerce services, TIK-TOK live streaming, WeChat, and so on. It was not until after the outbreak of the COVID-19 and the game of precise organisation for national epidemic containment that the full concept of the digital economy became clear to us, and since then, the digital economy has entered the vision and life of ordinary people. During the fight against COVID-19 in the first and second quarters of 2020, the digital economy was nonofficially and officially called a "non-contact economy"[4]. This definition was quite vivid and fits the characteristics of economic development, people's livelihood, and social linkage during the fight against COVID-19 and the period of quarantine, but its essence was still the digital economy, and then the term "digital economy" was quickly accepted by society once again.

The appearance and development of the new economy has attracted the attention of economic science, which mainly studies social and economic phenomena, and has promoted the development of economic science, as the return of economic science then further serves the development of the new economy. Each step in the growth of the digital economy has attracted industry input and academic

2 XINHUANET, 2018-03-28, From narrowing the "gap" to reaping the "dividend", quoted from Zhejiang Online. URL: https://china.zjol.com.cn/201803/t20180328_6902044.shtml.

3 See "G20 Digital Economy Development and Cooperation Initiative ", September 20, 2019. URL: http://www.g20chn.org/hywj/dncgwj/201609/t20160920_3474.html, January 28, 2021.

4 See Liu Yao's "Technology Adds Fuel to the 'Contactless Economy' and Heats It Up", April 16, 2020. URL: http://www.xinhuanet.com/fortune/2020-04/16/c_1125861801.htm

attention, facilitating the local expansion of economic science with Chinese socialist characteristics. In addition, some well-known universities and research institutions have begun to actively develop and establish the disciplines of digital economy, aiming to systematically study digital economy and take the lead in developing digital economy theories so as to offer digital economy courses and teach digital economy knowledge. The School of Economics at Zhejiang University previously proposed to create three new disciplines of new economy, new trade, and new finance, and Zhejiang University has now gone a step further by proposing to create three digital economy disciplines: digital economy, digital trade, and digital finance. These moves also represent a new trend in economics teaching and research institutions. In this new era of development, the popularity of the digital economy has become apparent. Along with the input of theory and industry, this will help strengthen the whole society's understanding of the digital economy and more directly promote the iterative upgrading and innovative development of the economy and society.

The digital economy is broadly inclusive and open. It covers digital trade, digital finance, digital services, and digital industries. It also includes digital investment, digital investment attraction, digital governance, and digital government affairs, as well as digital education (or online teaching). Nowadays, technologies and services of the digital economy are manifested as the internet, e-commerce, the internet of things, and blockchain, as well as mobile payment and digital currency, which support its operation and development. The National Development and Reform Commission is also vigorously supporting the development of the digital economy. However, unlike the digital trade promoted by the Ministry of Commerce and the digital finance promoted by the People's Bank of China and the China Banking and Insurance Regulatory Commission, it is not easy for people to grasp the essence of the digital economy. Suzhou was chosen as the first city where the Central Bank of China experimented with a digital currency pilot. The National Development and Reform Commission and the Ministry of Industry and Information Technology focus on the industrial internet and the digitisation of physical manufacturing. All these show that the digital economy encompasses many points that can be particularly challenging to force forward.

Everyone can name one, two, or three figures of the new technologies and services of the digital economy, including the popular health code, travel code, non-contact economy, and quarantine economy, plus mobile payment, online shopping, etc., all of which consist of the digital economy. However, it is not easy to fully and accurately define the "digital economy". Although the digital economy was defined at the G20 Hangzhou Summit, there are still differences in understanding, which also shows that the digital economy itself is highly inclusive. By the end of 2017, Zhejiang Province and Hangzhou Municipality put forward the "No. 1 Project of Digital Economy" and the slogan "digital industrialisation, industrial digitisation"[5]. This slogan has since become the direction path for developing the new driving forces of the digital economy.

However, there is still some concern about the definition and development of the digital economy. People tend to hold back for fear that the digital economy will undermine the development of industry. Now, it seems that this fear is actually due to a lack of understanding of the digital economy. Only by paying attention to the publicity of the digital economy, enhancing the digital culture, strengthening the whole society's cognition of the digital economy, and increasing the use of digital technologies and services in all sectors can we continuously promote the iterative innovation of our economy and society.

3.2. Correctly understanding the impact of the digital economy on society and standardising its development

There is no doubt that digital technologies and services brought about by the development of the internet, computer science, and electronic communications, the field of digital technologies and services is a constant source of new knowledge, technologies, and ideas, and it is the most innovative sector of the economy. Digital technologies and services have profoundly influenced and changed our ways of

5 See anonymity's "Zhejiang Province Has Done These Things This Year to Implement the No.1 Project of Digital Economy", December 24, 2018. URL: https://www.sohu.com/a/284159572_100089098

production and lives. Nowadays, without leaving home, people can use mobile phones or computers on the internet to complete financial management, transfer and stock investment, teach and shop online, authenticate payment through facial recognition, chat online, and enjoy games and entertainment (Shi, Wang and Wang, 2019). All these have greatly reduced the transaction costs for producers and consumers, improved the efficiency of production and consumption, and finally made it possible to produce and consume multi-variety, small-batch, personalised, and customised services. The digital economy has also given new meaning to economies of scale. For example, the traditional economic law of diminishing returns of economies of scale has been rewritten in light of the new economic ecology, as the digital economy now gives a new idea of increasing returns to scale.

The advantages of the digital economy have been recognised through the test of the containment of COVID-19. For example, during the quarantine phase, people purchased food and daily necessities through various mobile phone apps, and obtained food through convenient delivery services. These platforms were also the first gateway for communities to prevent and control COVID-19 transmission, allowing people to achieve "non-contact shopping" in their daily economic lives. Another example is the health code, which matches the local level of epidemic prevention and control and is convenient for infection tracing (Du, 2020). The health code is a simple and convenient personal digital health pass that has ensured the public's attendance and communication, and guaranteed orderly production and supply of goods; thus, attention should be paid to preventing personal information leakage from the code. The use of these digital technologies is undoubtedly one of the most important and indispensable supports for China's success in the containment of COVID-19 and in restoring economic growth.

Naturally, while the digital economy has brought about great changes in the service industry, essential regulation and normalisation are needed. Nowadays, in addition to the booming of e-commerce and logistics, various kinds of food delivery apps, online ride-hailing services, road navigation, online conferences, online trade fairs, online medical care, online classes, and so on are all flourishing. As WeChat Pay and Alipay continue to facilitate our lives on these platforms, they have increasingly become leading players in the development of technologies and finance in China. However, they are also suspected of monopolisation. As a matter of fact, the Ant Financial Services Group, which originated from Alibaba, may potentially disrupt the order and balance of China's financial industry ecosystem through its natural or artificial monopoly of its super-large platform[6]. Ant Financial's services lean too heavily on informal credit consumer finance, such as Huabei (Ant Credit Pay) and Jiebei (Ant Credit Loan), and have not undertaken more of its responsibility of providing inclusive financial services for micro, small, and medium-sized enterprises. In other words, Ant Financial Services Group has not taken on enough responsibilities for supporting SMEs.

The anti-monopoly and anti-unfair competition campaign against the platform economy was officially launched in China. The Ant Financial Services Group has been under joint investigation and supervision by four official departments, including the Banking and Insurance Regulatory Commission and the China Securities Regulatory Commission. This shows that the government is aware of the seriousness of the problem and strengthens the regulation on and intervention of platform economies. If the government lacks an understanding of the digital economy, and the society does not have a fair atmosphere of digital culture, the intervention and supervision of the platform economy will frankly be a kind of destruction to its development, which would be very bad for the development of the digital economy. To adapt to the management and service of the development of the internet and digital economy, governments at all levels have set up big data bureaus to optimise effective regulation on the digital economy. However, if effective scientific management services are to be achieved, the government has to strengthen its own understanding of the digital economy and enrich its own digital literacy.

The digital economy is derived from the development of computer science and information technology, and new technologies and knowledge are constantly emerging in this field. The digital economy

6 See Cheng Dan and Sun Lulu's "Four Departments Including China Securities Regulatory Commission Jointly Interviewed Yun Ma et al., and Central Bank and China Banking and Insurance Regulatory Commission Issued Blockbuster Documents on the Same Day", November 2, 2020. URL: https://baijiahao.baidu.com/s?id=1682300896276317864&wfr=spider&for=pc

is generally classified as a fictitious economy. Digital finance and digital trade are more representatives of the fictitious economy. However, we should see that the development of new technologies is not only fictitious but also real, and the carrier of the virtual economy is more real. In stark contrast to fictitious and real economy, the development of digital technologies and digital economy itself has indeed created many physical manufacturing industries, such as semiconductor industry, display screen manufacturing, touch screen manufacturing, audio and video equipment, software manufacturing, and VR scene creation. As a result of digital industrialisation, various new commercial forms, service forms, and online trade fairs created by digital economy have also been clearly classified as real economy. All of this digital economy is part of the main content of our production and lives. At the macro level, the digital economy is itself a resource of innovation elements; at the micro level, the digital economy itself includes the products, industries, and activities of technological innovation. Industrial digitisation and digital industrialisation are both new driving forces for the iterative upgrading and innovative development of the economy and society.

3.3. Highly recognising the service efficiency of the digital economy and building a new highland to attract investment

The development and application of digital technologies have significantly improved the efficiency of social governance, investment attraction, and government services. The digital economy makes investment attraction and social governance more precise and efficient, provides a good environment for economic and social iterative innovation, and greatly improves the quality of coordinated regional economic growth. With the development of technology and the investment of government and substantive departments, the efficient and accurate transformation of digital investment, digital governance, and digital government affairs has become the norm. The digital economy enables the reform of local government affairs, the simplification of administrative services and project approval, and the "no more than one visit for one item" reform, all of which have improved the efficiency of government affairs and the effectiveness of government institutions. However, digital government affairs reform and the "no more than one visit for one item" reform should also strictly prevent and eliminate possible disadvantages, such as dehumanisation and inflexible online work, due to the requirement that all affairs be limited to online registration and online processing. We should also be wary of potentially isolating the elderly and some socially vulnerable people from digital technology and the economy.

The improvement of the service efficiency of digital government affairs and digital governance undoubtedly reflects the enhancement of soft environment power for investment attraction, poverty alleviation, and fundamental public services in a region, which means the improvement of regional innovation capability (Wen, Yan and Cheng, 2019). Therefore, it is necessary to legally regulate digital resources and digital technologies, give policy support to vulnerable members who do not know how to use digital resources, and allow the inclusiveness and openness of the new economy to play roles in all social and economic sectors. The digital economy should be better at serving investment, attracting investment, alleviating poverty, and ensuring an equal supply of fundamental public services, which would create a new area for attracting investment and supporting high-quality growth and sustainable development in China.

The rapid development of digital technologies has greatly improved the level and efficiency of economic services. The more attention paid by regions, departments, and industries to digital technologies, the more they can achieve leapfrog development. Integrating the digital economy into an environment for the emergence of talents and establishing a team for accurately attracting investment are the basis and premise for using the digital economy to create the right industrial chain for investment attraction. Having a well-qualified municipal official team that pays attention to the development of the digital economy can help achieve local economic development for corner overtaking. In this respect, the investment attraction team of the Hefei municipal government in Anhui Province has a high reference value. Hefei introduced BOE in 2007, Changxin semiconductor in 2011, and NIO new energy vehicle in 2019. Nowadays, JAC, Elantra, FAW, and Changan Auto have all settled their new energy vehicle projects in

Hefei. Shanghai Volkwagen's largest new energy vehicle project has also chosen to settle in Hefei. Hefei has become the world's largest flat-panel display production base—the storage industry base of 186 integrated circuit enterprises—and the "China Sound Valley" led by iFLYTEK. New energy vehicles, flat-panel displays, or iFLYTEK products are all the content of the digital economy or are closely related to the digital economy[7]. Due to the effective investment attraction, Hefei's city status has continuously improved, and its economic growth rate has ranked top among all the provincial capital cities in China for many years since the entry of the 2000s (Wang, Z., 2018). With the guarantee of a talent team, Hefei has been very successful under the "two-wheel driven" of scientific/technological innovation and institutional innovation in recent years, and has achieved remarkable attainments in fundamental research, applied research, and industrial transformation of scientific and technological achievements.

Of course, the main players of innovation are enterprises, and the digital transformation of enterprises will bring more direct power to economic and social iterative innovation. However, we must acknowledge that many enterprises have failed in their digital transformation. A McKinsey research report showed that the failure rate of the digital transformation of enterprises around the world was as high as 80%. Even for industries with leading digital technologies, such as the high-tech industry, media industry, and telecommunications industry, the successful ratio of digital transformation did not exceed 26%. For traditional industries, such as oil, natural gas, automobile, infrastructure, and pharmacy, the successful ratio of digital transformation was only 4%–11%.[8] The main reasons for the low successful ratio of digital transformation of enterprises are the lack of managers' proficiency in digital technologies, the lack of digital ability of enterprise employees, the lack of a continuous learning environment, and the lack of an open technologies proficiency in digital technologies. This situation must be changed, and an effective change can be achieved by strengthening the awareness education of the digital economy for all members of society and allowing enterprises to form a digital cultural atmosphere. This is the key to improving the success rate of enterprises' digital transformation.

Notably, the digital economy has to rely on the principle of "economy first, digital second". The development of digital technology and the progress of digital services should serve as the overall content of economic and social development. We cannot drive digitisation for digital's sake. Digital industrialisation and industrial digitisation are reasonably and naturally mutual promotion directions, but these should be carried out around the construction of the industrial internet and the informatisation of the manufacturing and service industries, so as to improve the efficiency of the real economy of the manufacturing sector and optimise the service quality and level of the service industry. The development of the digital economy must not fall into a hollow development situation in which there might be only digital improvements without industries, or a situation of digital bubbles.

To attract investment and boom economic development, data must be refined. Figures and data are information and resources that are valuable in their own right. Data can provide important basic information liquidity for production, life, and effective social governance, thus creating multiple benefits (Du, Q., 2019). Real and reliable data can support precise and scientific decision-making, while rough and false data will bring about mistakes in economic development policy decision-making, leading to hidden dangers and potential risks sowed on the road of economic and social development, and even causing irreparable economic losses and huge social costs. Therefore, we must be careful when dealing with data processing and application in the digital economy.

3.4. Attaching importance to the information transmission mechanism, avoiding the overlapping of digital isolated islands

The greatest resource in the digital economy is data information. The application "TouTiao" conveys the concept of "information creates value" in a very eye-catching way on its home page interface. This statement can be understood as a neutral marketing and business behaviour. Only accurate and true

7 Hefei, an investment bank masquerading as a city. Originally published by Outlook Think Tank on April 27, 2021, reproduced by SOHU on April 28, 2021.URL: https://www.sohu.com/a/486196251_118927

8 See anonymity's "McKinsey: the Failure Rate of Enterprise Digital Transformation is as High as 80%", January 24, 2021. URL: https://page.om.qq.com/page/Oajhwk98mfuCCCcS4LFIkmKg0

information has intrinsic value. If the information is false, or even malicious fraud, it has no value in itself, nor can it create any value; instead, it brings only a negative impact to society (Shen, 2018). Further, the bureaucratic structures in China formed by long-term economic and social development have resulted in a resource monopoly and market segmentation among different departments and even different regions. Indeed, data and information resources in the era of the digital economy are no exceptions, as information monopoly and data segmentation are common. We often see many "digital isolated islands" in the development of the digital economy, which affect scientific and rational policy decision-making, bury potential digital risks on the road of economic development, and are not conducive to economic and social iterative innovation.

For example, some internet small loan companies and fund companies under the guise of inclusive finance have almost become synonymous with frauds in China. Some of the dodgy internet small loan companies and fund companies wear the bright coat of science and technology finance to illegally solicit deposits at high interest rates and illegally lend money. They use deceptive means similar to pyramid sales to solicit funds from people's pension money and hard-earned money, and then go on a spending spree, which eventually leads to regular money account collapse and thunder explosion, resulting in serious social stability problems. Starting in the second half of 2016, a large number of fund companies and internet micro loan companies collapsed in Hangzhou, and the local finance office and local police stations have become territories for maintaining stability. It took three years for Hangzhou to calm down the crisis of internet finance companies' cracks. In the spring and summer of 2022, the disappearance of rural bank deposits in Henan Province was another more serious event that reminded the Chinese government and society to strengthen the regulation of the digital economy and digital finance.

In addition, some small- and medium-sized, long-term rental apartment platforms have stopped serving one after another due to capital chain cracks. Sixteen medium- and small-sized long-term rental apartment app platforms, including Wole APT, Hi-Ki APT, Sancaijia, and Detaining International, have stopped their services due to capital problems that extend shocks to society[9]. Some unscrupulous long-term rental apartment platforms even have run away with money, making people become greatly disappointed with the so-called digital economy companies that operate platforms attracting liquidities. Relevant government departments have raised their vigilance and strengthened supervision and regulation on rental apartment platforms. Such incidents have had a great negative impact on people's lives, brought great losses to the economy and society, and taught us a profound lesson. We should keep the alarm bell ringing.

Fund companies and internet small loans crashed, long-term rental apartment platforms ran away with money, and the Eggshell apartment platform went bankrupt; these warn us that there are great credit risks in the actual operation of the digital economy. Therefore, it is extremely important and urgent to strengthen the construction of digital credit (Han et al., 2019). In the era of the digital economy, digital credit is an important part of the construction of a social credit system. The construction of digital credit requires the intervention of legislation and accurate cognition, scientific standardisation and reasonable supervision of the government. Of course, the government must first be honest and do a good job in administrative integrity, so as to create a good atmosphere for the construction of digital credit and make the construction of social credit systems more confident. Only with good government integrity could we bring about a good atmosphere for digital credit construction that would increase our confidence enough for social integrity construction.

The long-term development of the manufacturing sector has prompted it to produce and accumulate more data than other industries, but we seldom make use of the data, mainly because most of us have no access to those data. For example, the automobile industry has been developing for more than 100 years, and companies such as Ford have accumulated a large amount of industrial data, but most of the data are owned by the companies themselves and cannot be accessed by the outside world, let

9 There have been several explosion incidents of the long rental apartment platforms in China's domestic market, how about the new situation in Nanning? Here comes the series of reports. Published by Tencent, April 25, 2020. URL: https://new.qq.com/rain/a/20200825A0AJYR00

alone shared with peers. Accordingly, there are many such phenomena of artificially splitting of the data by departments, units, and industries, which are still popular in the era of digital economy, resulting on the one hand in the rapid and vigorous development of digital economy, and on the other hand, many artificially "digital isolated islands"[10], great waste, and even monopoly of information and data, which weaken our productivity.

Further, much of the developed and accumulated data has not been fully used for economic and social development decision-making. Alibaba's e-commerce has a large amount of first-hand data on consumers, borrowers, manufacturers, and suppliers, but it also does not share it with the outside world. In the era of the digital economy, this "digital isolated island" phenomenon is far from being a single isolated case. In fact, many organisations specialising in databases are reluctant to share their data with outsiders. For example, the databases that are widely used in economic research include the China Industrial database, China Rural Household Survey database, China Economic database, and China Population database, which are primarily accessed through purchase. These data platforms themselves are independent, charge for access, and do not share their information with others.

Of course, the resources of humanity, material, and capital have been invested in developing the database. Data is knowledge and should enjoy intellectual property rights protection; this is of benefit to digital innovation (He, 2018). However, if the databases cannot be shared after being established, the data will not play a more comprehensive role in economic policy decision-making. This situation needs the attention of policy decision-making departments, economic researchers, officials of the law, and public management. We need an anti-monopoly and counter-unfair competition role played through scientific and reasonable system design that can prevent further formation and the continuous emergence of "digital isolated islands", thus improving the liquidity of data resources and reducing the use and transaction cost of data resources.

4. Conclusions: Precisely defining the development stage of the digital economy and stimulating iterative innovation of social economic growth

Since the 1990s, scientific, and technological progress and financial innovation have tremendously accelerated the progress of the world economy, and global emerging economies have grown much more rapidly. However, the frequency of global economic crises and economic fluctuations has increased significantly, and the crisis has become increasingly serious.

Reviewing the crises and fluctuations of the global economy in the past 40 years, some patterns are obvious. In 1997, Asian countries were hit hardly by the Asian financial crisis. At that time, American economist Paul Krugman claimed that the "Four Asian Tigers" were "paper tigers". In 2004, the economy of Argentina, once a developed economy in South America, was completely defeated by the South American financial crisis and has not fully recovered from the recession until today. In 2008, the global economic crisis cast a shadow over the sustainable growth of the global economy, and European sovereign debt crisis countries failed to really lift themselves out of the shadow of economic recession for more than 10 years. Another round of sluggish global economic growth starting in 2016, combined with the global pandemic of COVID-19 since the end of 2019, has caused the world economy to suffer a serious recession.

An analysis of the triggers of each global economic crisis clearly reveals that there are technological and financial factors driving each of these events. In fact, excessive innovation in science, technology, and finance, which is far from the requirements of the current level of development, will lead to economic and social shocks. It is clear that the digital economy has such potential security problems (Wang, L., 2019). Behind every economic crisis is the shadow of overusing scientific, technological, and financial means to affect the economy, which is the reason for the frequent outbreak of economic crises today. Many scholars around the world have paid attention to and studied the phenomenon of excessive innovation in science, technology, and finance impacting the social economy and bringing about eco-

10 See anonymity's "How to Break the "Data Isolated Islands" in the 5G Era, Suggests by Zhang Jindong", March 4, 2019. http://finance.sina.com.cn/roll/2019-03-04/doc-ihsxncvf9726216.shtml

nomic crises and shocks(Ireland, 1995; Duca, 2000), which is also an issue that China has to deal with in the new development stage so as to promote the healthy and sustainable development of the digital economy.

We should strengthen the cognition of the digital economy in the whole society through education, make full use of multimedia network teaching (Wang, Shi and Wang, 2021), create a strong digital cultural atmosphere, and form a consensus of the whole society on the reasonable development of the digital economy. Laws and regulations for the development of the digital economy should be formulated scientifically and strictly in line with the national requirements for further building a market-oriented, legalised, and international business environment. By means of marketisation, legalisation, and openness, efforts should be made to prevent and resolve the "digital isolated island" and potential economic risks in the development of the digital economy, so as to escort the optimistic development of the digital economy. We should strengthen the construction of iterative credit, encourage information and data sharing among different data centres and platforms, and promote iterative innovation to attain healthy and sustainable development of China's economy and society.

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SECTION 4

MANAGEMENT OF KNOWLEDGE AND INNOVATION FOR SUSTAINABLE DEVELOPMENT

РАЗДЕЛ 4

УПРАВЛЕНИЕ ЗНАНИЯМИ И ИННОВАЦИЯМИ В ИНТЕРЕСАХ УСТОЙЧИВОГО РАЗВИТИЯ

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ENGINEERING ECONOMICS: SCIENTOMETRIC ANALYSIS OF THE SUBJECT AREA

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Abstract

Engineering economics is located at the intersection of the science of economics and engineering practice, which means it attracts the attention of both fields. Engineering economics focuses on solving engineering problems and making decisions based on systematic cost-benefit analysis. Modern technologies push for the development and implementation of new methods of efficiency evaluation, decision-making, risk analysis, etc. It is obvious that the number of studies related to engineering economics is constantly growing, but there is still a shortfall of systematic quantitative and visual studies in this area, which explains the relevance of this article. A keyword analysis and an analysis of co-authors were carried out using VOSviewer to carry out a scientometric study of engineering economics. The findings reveal that the central position in engineering economics is occupied by engineering and economic analysis, which is a combination of quantitative and qualitative methods for analysing differences in the economic efficiency of engineering alternatives. The most popular tools of engineering and economic analysis presented in scientific papers are risk analysis, cost-benefit analysis, replacement analysis, break-even analysis, method of option valuation, analysis of equivalent annual costs, and annual cash flows.

Keywords: engineering economics, engineering economics analysis, literature review, scientometric analysis, visualisation

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ИНЖЕНЕРНАЯ ЭКОНОМИКА: НАУКОМЕТРИЧЕСКИЙ АНАЛИЗ ПРЕДМЕТНОЙ ОБЛАСТИ

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Аннотация

Инженерная экономика находится на стыке экономической науки и инженерной практики, а значит привлекает внимание с обеих сторон. Инженерная экономика фокусируется на решении инженерных проблем и принятии решений, основываясь на систематической оценке экономического эффекта от них. Современные технологии подталкивают к разработке и внедрению новых методов оценки эффективности, принятия решений, анализа рисков и т. д. Очевидно, что количество исследований, связанных с инженерной экономикой, постоянно растет, однако все еще ощущается нехватка систематических количественных и визуальных исследований в этой области, что объясняет актуальность данной статьи. С помощью выбранного ПО для визуализации наукометрического исследования VOSviewer был проведен анализ по ключевым словам и анализ соавторов. В результате проведенного исследования было выявлено, что центральное место в инженерной экономике занимает инженерно-экономический анализ, который представляет собой комбинацию количественных и качественных методов для анализа различий в экономической эффективности инженерных альтернатив. Были выделены наиболее популярные инструменты инженерно-экономического анализа, представленные в научных работах: анализ рисков, анализ «затраты-выгоды», анализ замены, анализ безубыточности, метод опционов, анализ эквивалентной годовой стоимости и годовых денежных потоков.

Ключевые слова: инженерная экономика, инженерно-экономический анализ, литературный обзор, наукометрический анализ, визуализация

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1. Introduction

Given that natural resources and other materials needed for production have become increasingly scarce and expensive, it is no longer possible to simply develop and produce products and make no thorough cost analysis. In practice, engineers today have to evaluate and decide whether the benefits of implementing a project or process are more significant than the costs associated with them, and this task is solved with the help of engineering economics. Engineering involves the correct application of mathematical and natural science knowledge obtained as a result of research, experience, and practice to develop cost-efficient methods of using raw materials and energy for the benefit of mankind. The benefits and costs associated with any project that requires significant investment are usually carefully analysed by management to ensure that decisions are made to minimise costs as much as possible, since these decisions affect the overall efficiency of the firm.

Engineering economics involves the formulation, analysis, and evaluation of the expected economic outcomes of alternatives designed to achieve certain goals. In simple terms, it involves making economic decisions for engineering systems. This is a research area that encompasses applying various economic principles and computational methods to engineering processes and systems. Engineering economics uses economic concepts and methods to solve engineering issues to determine the best course of action. Engineering economics helps to systematically evaluate the economic benefits of proposed solutions for engineering problems, measure costs and benefits, provide estimates of future investments, and propose alternative uses of limited resources.

Scientometric research is an analysis of the chosen subject area to identify relevant topics for research and to search for gaps in scientific research (Eliseeva and Oleinik, 2022). This method of analysis can be used in various sciences, making it a universal method of information processing and conducting literary reviews (Blaginin et al., 2019). Scientometric analysis can also be used to increase the activity of scientists and increase their citations by highlighting the most popular keywords. For example, Kozyr (2022) compared the keywords of the topic "regional economy" in the elibrary.ru database to data in the JournalFinder system of Elsevier, thereby identifying unified keywords that Russian scientists should use when publishing scientific articles on regional economics.

Digital bibliographic and abstract databases, which allow the tracking of citations and other indicators of articles, are used to store data on scientific publications and their full texts. Such databases are also one of the main sources for obtaining scientometric data to conduct evaluation studies of subject areas. The largest international bibliographic databases are Web of Science and Scopus. In the Russian Federation, the most complete digital bibliographic and abstracting base is the "Scientific Electronic Library" (or elibrary.ru). This is the largest electronic library of scientific publications in Russia, integrated with the Russian Science Citation Index (RSCI)—a free public tool for measuring and analysing the publication activity of scientists and organisations created by the Ministry of Education and Science of the Russian Federation.

Scientometric research on the subject area of engineering economics is the study of the subject area "engineering economics" through the study of this science by quantitative methods. In world practice, there is a wealth of experience in the application of scientometric analysis of data obtained from the international abstract databases Web of Science and Scopus (Hossfeld et al., 2017). To conduct scientometric analysis, files of various formats can be downloaded from database systems containing brief information (author, title, source, abstract) about the paper (so-called article metadata). The resulting text file can be used in various applications capable of performing complex analyses based on downloaded data. In the process of working and using specialised software, various methods of information processing are used: clustering, grouping, identifying the most common elements, etc. (Sahil and Sood, 2021).

Scientometric research on the subject area of engineering economics is devoted to certain aspects. For example, Boltürk (2020) conducted bibliometric analysis on the subject area of the evaluation of investment projects in engineering economics. Heutel et al. (2016) considered the mastery of studies in

economics of climate engineering subject area, and as a result came to the conclusion that climate engineering technologies should become a fundamental part of future domestic and global climate policy. They also proposed several directions for future research. Interestingly, engineering and economics are quite often considered together in articles devoted to "green" technologies (Clark, 2014).

Based on the analysis of existing studies, the present study attempts to fill the research gap associated with the study of the subject area of engineering economics. The study addresses the following questions:

(1) What subject areas do engineering economics cover?

(2) Which authors and resources are the most popular in this area? Which articles are the most cited?

(3) What representative keywords are found in different periods? Which keywords are currently relevant?

In general, this article is a large-scale literature review and systematisation of the subject area of engineering economics. We expect the findings from this investigation to help new researchers choose the most relevant journals, articles, keywords, and popular authors, which, in turn, will help them determine the directions of future research.

2. Methodology

To conduct scientometric and bibliometric research, researchers often use electronic scientometric databases, such as Web of Science, Scopus, Google Scholar, and eLibrary.ru. This study used scientometric methods to assess the current situation in engineering economics research and to study trends in the development of engineering economics based on literary data on articles obtained from the Scopus database, as well as by empirical analysis of textbooks on engineering economics. Many specialised software designed for automated processing of arrays of information downloaded from bibliographic databases have been developed and upgraded for scientometric analysis. Although each of the presented databases has built-in capabilities for conducting analytics, it is necessary to have specialised software to conduct a deeper analysis and visualisation of the results obtained. To date, the main programs for conducting scientometric analysis and visualisation are the following: IN-SPIRE (1999), VantagePoint (2004), HistCite (2004), BibExcel (2009), CiteSpace (2004), Sci2 Tool (2009), Leydesdorff's Software (2004), Publish or Perish, VOSViewer (2010), InterDisciplinary Research, Network Workbench Tool (2007), SciMAT (2011). Some are commercial (paid) programs, whereas others are freely available. The VOSviewer program was chosen for this study because it is the most frequently used and freely available program.

VOSviewer[1] is an open-access program that can be used for various purposes. VOSviewer can be used to create data network-based maps. VOSviewer is a map creation and cluster allocation technologies. VOSviewer can be used for viewing and exploring maps. The program builds the map in various ways, each of which highlights its different aspects. Features such as zoom, scroll, and search, which facilitate a thorough study of the map, are offered. Initially, VOSviewer was designed for the analysis of bibliometric networks. The program, for example, can be used to create maps for publications, articles, or journals that are based on the social network, or to create keyword maps based on their simultaneous appearance on the network. VOSviewer is easy to use, and is also considered the most suitable for the analysis of bibliographic communication and cartography (Shah, 2020).

In this study, keyword analysis and document co-authorship analysis were carried out using VOSviewer. The following types of documents were included in the analysis: articles, abstracts from conferences, literary reviews, and textbooks, as these types of documents are mainly used to present scientific results. The phrase "engineering economics" was used to search the title, annotation, or keyword sections of VOSviewer. Articles with anonymous or unidentified authors were excluded from the

1 VOSviewer [Electronic resource]. URL: http://www.vosviewer.com/

analysis.

3. Results and discussion

We analysed 14 English-language textbooks on engineering economics (Table 1) to identify the main topics and concepts considered part of engineering economics.

Table 1. Textbooks on engineering economics

	Name	Author(s)	Year
1	Schaum's Outline of Engineering Economics	Jose Sepulveda, William E. Souder, Byron S. Gottfried	1984
2	Foundations of Engineering Economics	Eugene L. Grant, W. Grant Ireson, Richard S. Leavenworth	1990
3	Advanced Engineering Economics	Chan S. Park, Gunter P. Sharp	1990
4	Engineering Economic Analysis	Donald G. Newnan, Jerome P. Lavelle	1998
5	Engineering Economy: Applying Theory to Practice (Engineering and Technology)	Ted G. Eschenbach	2003
6	Foundations of Engineering Economic Analysis	John A. White	2012
7	Fundamentals of Engineering Economics and Decision Analysis	David L. Whitman, Ronald E. Terry	2012
8	Fundamentals of Engineering Economics	Leland Blank, Anthony Tarquin	2013
9	Contemporary Engineering Economics	Chan Park	2015
10	Engineering Economics	J. K. Yates	2016
11	Engineering Economics	Leland Blank, Anthony Tarquin	2017
12	Engineering Economics	William Sullivan, Elin Wicks, C. Koelling	2018
13	Engineering Economic Analysis	Don Newnan, Ted Eschenbach, Jerome Lavelle, Neal Lewis	2019
14	Engineering Economic Analysis	John A. White, Kellie S. Grasman, Kenneth E. Case, Kim LaScola Needy, David B. Pratt	2020

Table 2 presents the topics covered in the textbooks under study. The textbooks were analysed in chronological sequence. Topics are ranked by frequency of mention.

Table 2. Topics and frequency of mention

Topic	Frequency of mention
Replacement analysis	85.7%
Amortisation	85.7%
Taxation	85.7%
Present/future value	78.6%
Percentages and equivalences	71.4%
Techniques for choosing an investment alternative	71.4%
Introduction to Engineering Economics	64.3%
Profitability	64.3%
Sensitivity analysis	64.3%
Cost-benefit analysis	57.1%
Break-even analysis	57.1%
Time value of money	57.1%
Analysis of the equivalent annual value	57.1%
Inflation	57.1%
Risks and uncertainties	50.0%
Pay-off period	42.9%
Decision-making in engineering economics	42.9%

Cash flow calculation and estimation	42.9%
Risk analysis	42.9%
Public sector in engineering economics	42.9%
Investment attractiveness analysis	35.7%
Investment budget	35.7%
Nominal and effective interest rates	35.7%
Determination of the minimum acceptable rate of return	28.6%
Decision tree	21.4%
Economic analysis in the service sector	21.4%
Cost calculation	21.4%
Annual cash flow analysis	14.3%
Lending, loans, bonds, investing	14.3%
Multiple factors in the problems of engineering economics	14.3%
Accounting in engineering economics	14.3%
Compounding	7.1%
Preparation and submission of a feasibility study	7.1%
Transformation methods in cash flow modeling	7.1%
Utility theory	7.1%
Measurement of investment value under risk conditions	7.1%
Incremental analysis	7.1%
Spreadsheets in economic analysis	7.1%
Internal rate of return	7.1%
Mutually exclusive alternatives	7.1%
Project evaluation methods	7.1%
Financial leverage	7.1%
Analysis of real options	7.1%
Arithmetic and geometric gradients	7.1%
Project financing and non-economic attributes	7.1%
Independent projects with limited budget	7.1%
Equivalences for recurring cash flows	7.1%

The first chapters of most textbooks are devoted to the theoretical aspects of engineering economics: its significance and relevance, scope of application are considered, a brief overview of topics is given, and the basic foundations are described. Further, we identified a block of topics that provide insight into the essence of engineering economic analysis. We considered in detail the topics related to decision-making, as well as techniques for choosing among alternatives. Each textbook includes a chapter covering the topic of the time value of money. The basic concepts of this block are present and future value, nominal and effective interest rates, discounting, and cash flows. The types of cash flows, calculation methods, and management methods are described, as well as methods for calculating and justifying the discount rate. The block includes topics describing the methodology for evaluating the efficiency of engineering solutions (or projects). Some authors emphasise project management in a separate chapter in which a significant part is given to project financing. Concepts such as profitability (invested capital, equity, etc.), pay-off period, net present value, and internal and minimum acceptable rates of profitability are considered. A significant number of topics are devoted to risk analysis and management (in particular, project risks). Modelling is described under conditions of certainty, under conditions of risk, and under conditions of uncertainty. Sensitivity analysis, decision tree building, and scenario methods are considered in detail. Among the specific tools of engineering economics in the study materials are descriptions of cost-benefit analysis, break-even analysis, the option method, and analysis of the equivalent annual cost and annual cash flows.

Notably, many authors have addressed replacement analysis, which is found in more than 85%

of textbooks. When equipment wears out due to age, it leads to a decrease in deposition costs and an increase in operating and maintenance costs. As a result of increased operating and maintenance costs, it is often cost-effective to replace equipment after a certain period of use. The classical problem of equipment replacement is aimed at finding a replacement policy that minimises the total discounted value of equipment costs in conditions when the interest rate and cost structure remain constant over an infinite horizon (Hartman and Tan, 2014). The chapters on reporting cover reporting standards, cost calculation, and cost calculation methods, as well as cost accounting and cost management. As a rule, the final three chapters are devoted to accounting for depreciation, taxes, and inflation. In some textbooks, there are topics devoted to the public sector in engineering economics, investment budget preparation, and economic analysis in the service sector. Topics on business valuation, production theory, aspects of microeconomics and macroeconomics, utility theory, inventory management and logistics, asset valuation, outsourcing decision-making methods, and linear programming (simplex and graphical methods) are less frequently covered.

Engineering economics, as a separate field of research, has developed relatively recently. This does not mean that earlier economic laws were not taken into account when making engineering decisions. Final economic efficiency has always been one of the top priorities for engineers. The beginning of the engineering interest in economic assessment was in 1887 with The Economic Theory of the Location of Railways by the civil engineer A. M. Wellington, who wrote about what, in his opinion, was ignored by many engineers during railway locations: the expected costs and revenue.

The founder of engineering economics is Eugene L. Grant. The first edition of his textbook, Foundations of Engineering Economics, was published in 1930. The eighth edition of this textbook states that the formulation of the investment budget (of a company or state) is one of the vital tasks for the implementation of strategic management decisions (Grant et al., 1990). Each project is the result of a multitude of management decisions, each of which has been evaluated for efficiency. In many cases, economists need engineering expertise to make decisions. When implementing engineering solutions, the technological components and the analysis and estimation of expected costs and benefits are important. They form the essence of engineering economics.

Blank and Tarquin (2017) indicated that the need for an engineering economy is primarily conditioned upon the work that engineers do, analysing, synthesising, and coming to a conclusion while working on projects of any scale. In other words, engineering economics is at the heart of decision-making. These decisions involve the fundamental elements of cash flows—money, time, and interest rates. Blank and Tarquin (2017) identified the following as the main tasks of engineering economics: the formulation, evaluation, and analysis of the expected economic outcomes of alternatives designed to achieve certain goals. Mathematical methods simplify the economic estimation of alternatives (Blank and Tarquin, 2013). Eschenbach (2003) stated that engineering economics estimates the economic results of the products, projects, and processes that engineers develop. These products, projects, and processes often require significant investments and have a long service life. When comparing several options for project execution, a question arises: "Which of the alternatives is more profitable in the long run?" There are cases when one alternative may be cheaper in construction, and the other in operation. The task of engineering economics is to evaluate the effectiveness of all options and choose the most profitable alternative (Newman et al., 2019).

Newnan and Lavelle (2019), in their book Engineering Economic Analysis, interpreted the essence of engineering economics through the concepts of problem- and decision-making (problem solving). The authors identified three criteria for the problem, referring it to the subject area of engineering economics (Newnan et al., 2019). First, the problem must be significant enough to deserve the effort to solve it. Second, the problem cannot be solved at a time "in the head", but requires careful analysis and systematisation of influencing factors and possible outcomes. Third, the problem contains economic aspects that are critically important for analysis and decision-making. If the problem satisfies the three criteria considered, then engineering economic analysis is suitable for its solution. White et al. (2012)

described engineering economics as a set of methods for applying economic analysis techniques to compare engineering alternatives. The authors defined engineering economic analysis as a combination of quantitative and qualitative methods for analysing differences in the economic efficiency of engineering alternatives. The authors believe that the possibility of using economic analysis for decision-making in the public sector of the economy has given a serious impetus to the development of engineering economics. Whitman and Terry (2012), in their textbook Fundamentals of Engineering Economics and Decision Analysis, defined the purpose of engineering economics as providing engineers with all the necessary economic functionality for decision-making (to choose among alternatives). The authors noted that there are always at least two alternatives. In cases where there is one project (or one implementation method), inaction is considered the second alternative.

In his textbook Contemporary Engineering Economics, Park (2015) focused on the increased role of engineers in making economic decisions. This is because the design and production processes are becoming more comprehensive and complex. For example, it is difficult to evaluate the equipment's condition and make a decision about its replacement without a technical specialist. Engineers are involved in all stages of the production cycle and are familiar with all the subtleties of production, which allows them to more accurately estimate the cost of a particular solution. Yates (2016) revealed the essence of engineering economics through the need for engineers to analyse the cost benefit of their proposed solutions. If there are multiple alternatives, then it is necessary to evaluate each and choose the most efficient one. For private projects, the most profitable alternative is chosen, whereas for public projects, the alternative with the greatest positive effect on society should be selected.

In the textbook Engineering Economics by Sullivan, Wicks, and Koelling (2018), Newnan and Lavelle reveal the work of engineers through the concept of problem solving. Engineers are finding new ways to make their work more efficient in economic terms. Engineering solutions do not exist in a vacuum but in an economic environment. Since there are many possible solutions to each problem, a question arises: "Which of them will be the most cost-efficient?" Engineering economics can answer this question. Engineering economics provides a system for evaluating the economic effects of implemented engineering solutions. Regardless of the scope of implementation, engineers should remember the "economic exhaust" from their solutions. There is an opinion among engineers that they do not need to think about the financial component; however, in real life, projects should not only be physically feasible but also economically attractive, and even the most advanced engineering developments may not be in demand if they are not profitable. Therefore, in the current era, in which technological solutions are becoming more complicated every day, engineering economics is more relevant than ever before.

We found 2,480 publications in the bibliographic database Scopus[2] when we queried "Engineering Economics." Figure 1 shows the distribution of the number of publications by year.

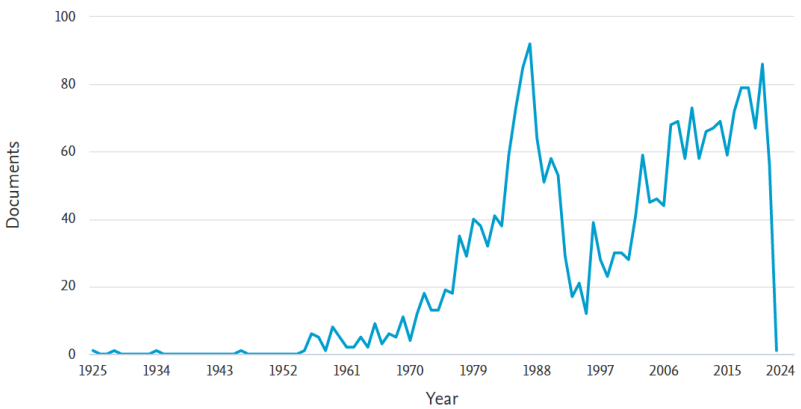

Figure 1. Distribution of the number of publications on engineering economics by year

2 Scopus bibliographic database [Electronic resource URL: https://www.scopus.com

The two peak points in the number of publications are 1987 and 2020 (92 and 86 publications, respectively). In 1987, this was associated with the meeting of the Association for the Advancement of Cost Engineering (AACE), for which most of the publications (25%) were prepared. AACE is the world's largest community of professionals in value engineering. The association is the organiser of a number of educational programmes aimed at improving professional and technical skills and holds annual meetings, seminars, exhibitions, presentations, and social and certification programmes. The organisation also publishes a monthly international magazine, Cost Engineering Journal, which contains the latest information on value engineering[3]. The main topics discussed at the annual meetings of the association include project management, accounting, cost management and estimation, risk assessment and risk management, decision-making, and quality management.

The graph of the distribution of published documents on engineering economics by source (Figure 2) also shows the above-mentioned meeting. The figure shows that currently, the main magazine publishing articles on engineering economics is Engineering Economist.

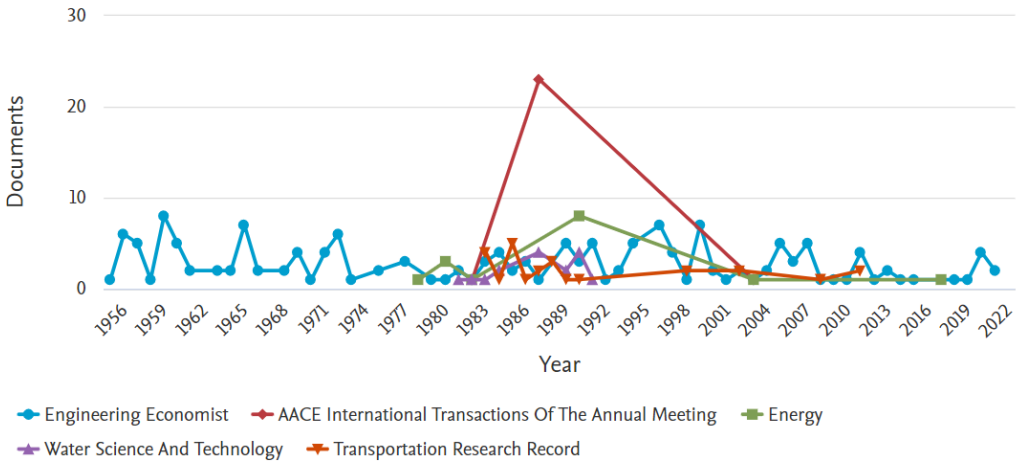

Figure 2. Distribution of the number of publications on engineering economics by source

Engineering Economist is devoted to the problems of capital investments. It is an international magazine that publishes research on capital investment, including financial risk management, project solution economy, and education in engineering economics[4]. Figure 3 shows the most published authors. It is worth noting that the textbooks of five of them (Chan S. Park, Jerome P. Lavelle, Ted G. Eschenbach, John A. White, and William Sullivan) were analysed in the first part of this article.

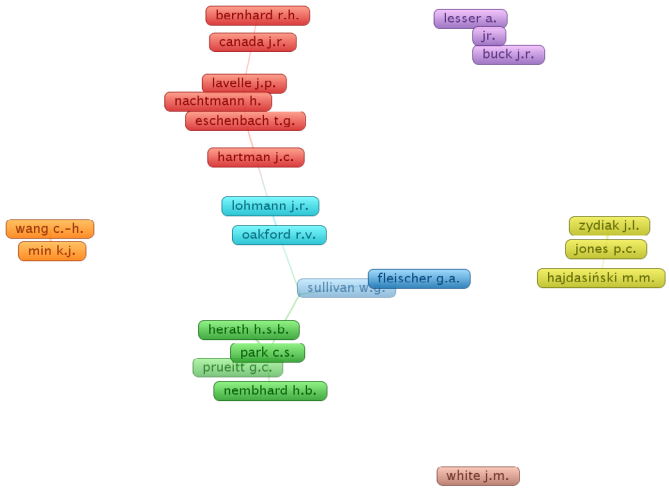

Figure 3. The most published authors in Engineering Economist

3 AACE Conference [Electronic resource]. URL: https://web.aacei.org/
4 The Engineering Economist [Electronic resource]. URL: https://www.tandfonline.com/toc/utee20/current/

Take, for example, the subject area of articles in Engineering Economist. Figure 4 shows the most common keywords, which we conditionally divided into four clusters. The first cluster is dedicated to investment and investment projects. It also includes the concepts of cash flow, profitability, internal rate of return, discount rates, profit, and net present value. In the second thematic block, it is possible to highlight the budgeting of capital investments, budget control, and inventory management. The third block of keywords includes project management, cost accounting, and decision-making. Mathematical models, risk management, cost-benefit analysis, Monte Carlo method, sensitivity analysis, and real options are also mentioned in the third block. The fourth cluster includes keywords on the topic of engineering economic education. Thus, we can distinguish four broad topics: investment design, economic analysis, budgeting, and engineering economic education.

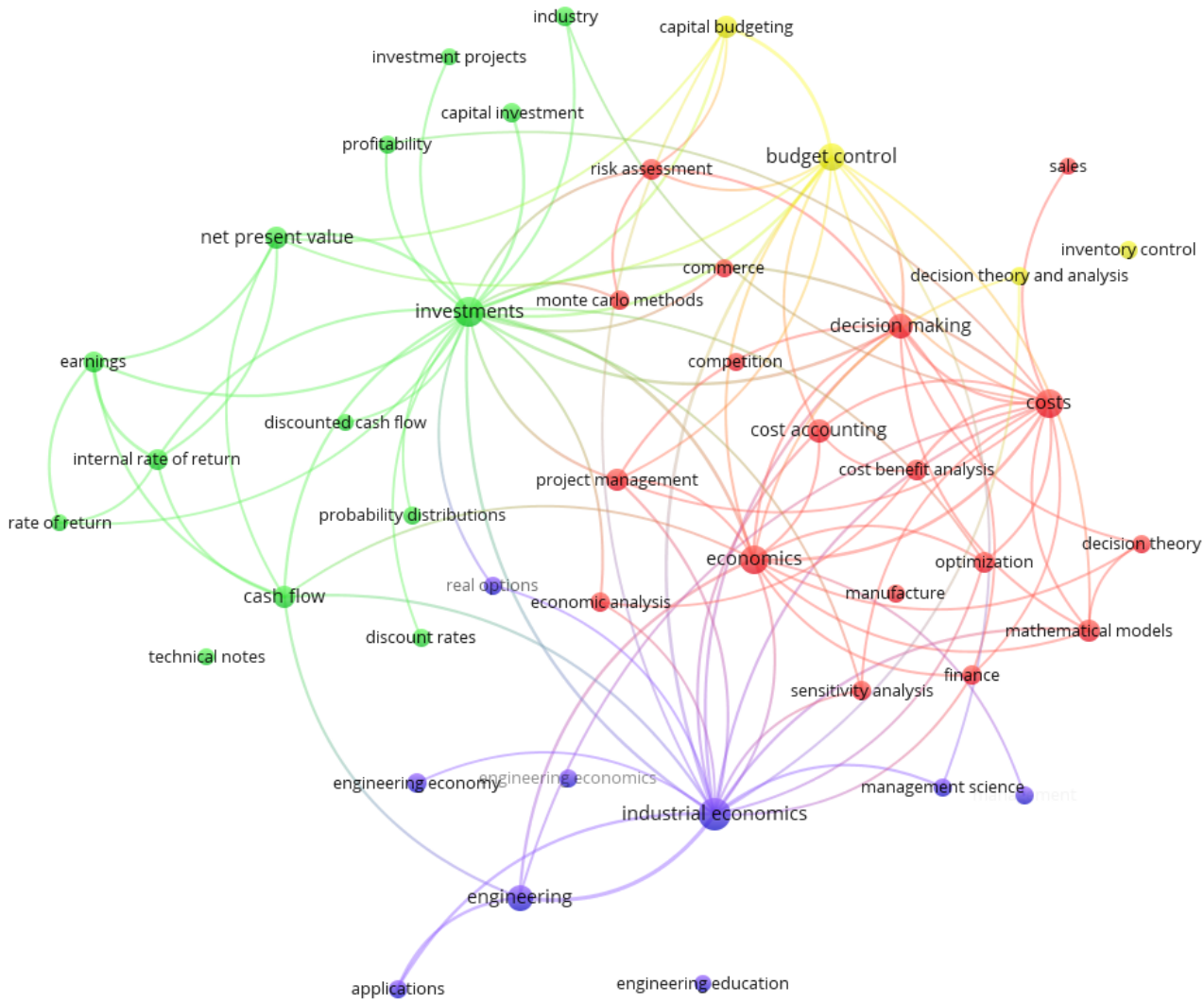

Figure 4. Keywords in Engineering Economist

Figure 5 shows the top 10 authors publishing in the field of engineering economics. It is worth noting that seven of them are also authors of textbooks on engineering economics: T. G. Eschenbach, Sullivan, J. C. Hartman, N. Lewis, G. J. Thuesen, J. P. Lavelle, and C. S. Park.

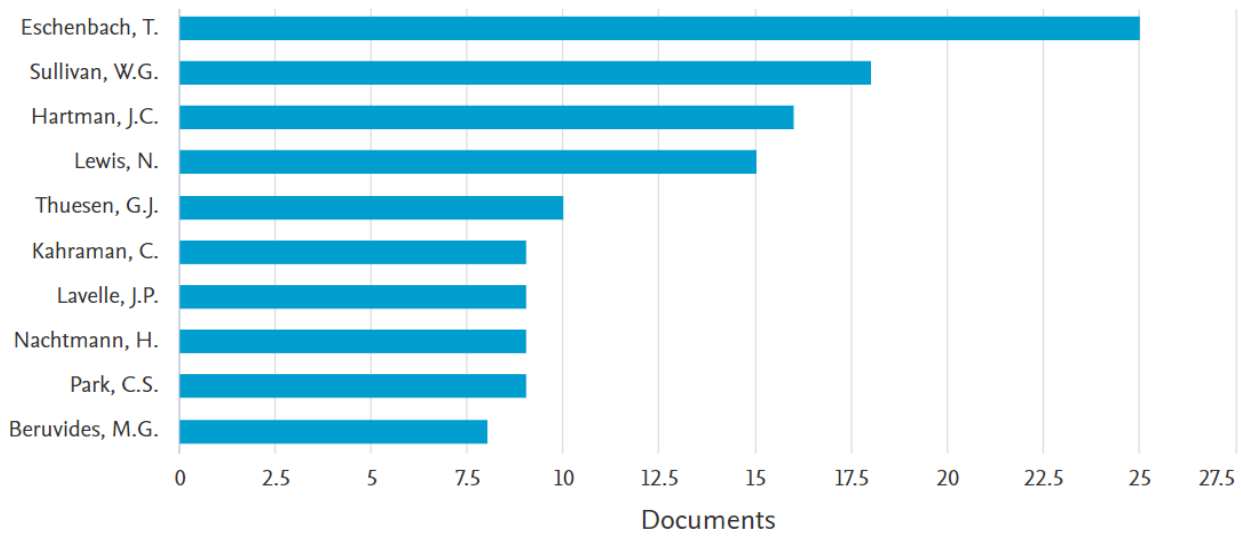

Figure 5. Distribution of the number of publications on engineering economics by author

One of the key topics of works by T. G. Eschenbach is engineering economic education. His most cited article is devoted to the same topic: Empirical Analysis of Teaching Engineering Economics (Needy et al., 2000). This paper presents the results of a two-part study on the teaching of engineering economics at US universities. Eschenbach's top five most cited articles include three articles describing sensitivity analysis: tornado diagrams (Eschenbach, 2006), stochastic sensitivity analysis (Eschenbach and Gimpel, 1990), and the use of graphs for sensitivity analysis (Eschenbach and McKeague, 1989). A bias towards finance is visible in his recent works. In particular, in 2017, together with J. P. Lavelle and N. Lewis, Eschenbach presented the work Personal Finance Coverage in Engineering Economics Courses (2017) at the ASEE conference. Another recent article (jointly with N. Lewis) is devoted to teaching students the importance of diversification (Eschenbach and Lewis, 2015). The content of most texts on engineering economics implies that a relatively small number of courses in engineering economics include investment issues. However, according to the authors, students should be taught financial literacy. A brief discussion of the investment model helps to understand the relationship between risk and return, and the importance of diversification.

In the works of W. G. Sullivan, two main directions can be distinguished: automation of production (his most cited article is devoted to this) (Sullivan, 1986) and new technology implementation in the process of engineering economic education. There are also articles covering the historical component (Thuesen and Sullivan, 1999) and the new paradigm of engineering economics (Sullivan, 1991). A significant part of the works of J. C. Hartman is dedicated to real options. The author writes about their application for real engineering projects (Eschenbach et al., 2007), the specifics of using various interest rates—discrete and continuous (Eschenbach et al., 2009)—risk-free and market-based (Eschenbach et al., 2008), the integration of real options with a decision tree and risk modelling (Eschenbach, 2008), expected costs, and different views on the implementation of projects using real options (Lewis et al., 2010).

Most of the literature on real options is devoted to the mathematical details of how to perform real options analyses and does not take into account real applicability for engineering projects. Since engineering economic analysis has long included decision trees, sensitivity analysis, modelling, and other tools, a key question is: Does real options analysis add anything significant to this set? Most analysis methods do not take into account the corresponding costs to the proper extent and provide an inflated option value, which leads to overly optimistic conclusions. Specialists from different fields tend to look at solutions to one problem in different ways. Articles devoted to finance usually consider theoretical solutions that can be mathematically justified. In articles written by economists-engineers, as a rule, they look for solutions that can be applied to solve real problems. As for real options, theoretical prescriptions exceed the number of real cases, which limits the possibilities of their application to solving engineering

problems. Works by J. C. Hartmann offer insights into teaching engineering economics at different levels of education.

N. Lewis published multiple works together with the above-mentioned authors: teaching finance in the course of engineering economics, with J. P. Lavelle and T. G. Eschenbach; engineering education, with T. G. Eschenbach; and real options, with J. C. Hartman and T. G. Eschenbach. G. J. Thuesen published several works in collaboration with W. G. Sullivan and C. S. Park. These works are devoted to engineering and economic education (historical aspects, evolution, and new trends). His independent publications also cover this area, and his most-cited work describes the methodology for choosing the discount rate. As mentioned above, J. P. Lavelle worked in collaboration with T. G. Eschenbach, J. C. Hartman, and N. Lewis. His subject areas are decision-making, engineering, and economic education, finance in engineering economics, and personal finance (investing). The works of C. S. Park are devoted to economic analysis. The author writes about the theory of fuzzy sets (Chiu and Park, 1994), decision-making under uncertainty (Miller and Park, 2002), real options (Park and Herath, 2000), and R&D projects (Herath and Park, 1999). Several articles have also been published in engineering and economic education (together with G. J. Thuesen and W. G. Sullivan).

Figure 6 presents the keywords most commonly found in articles on engineering economics. Depending on the year of publication, the words are in different colours (purple – earlier articles, and yellow – later ones). The figure shows that the topics presented in the publications almost completely duplicate the topics covered in the textbooks on engineering economics. The following blocks are distinguished: engineering and economic education, decision-making and engineering economic analysis, cost accounting and cost efficiency, production optimisation, and software development and implementation. The tools that are considered in publications include calculation of net present value, sensitivity analysis, cost-benefit analysis, etc. There are also topics dedicated to investment. Notable works include those on ecology and sustainable development, since this topic is not presented in textbooks but is quite popular in articles.

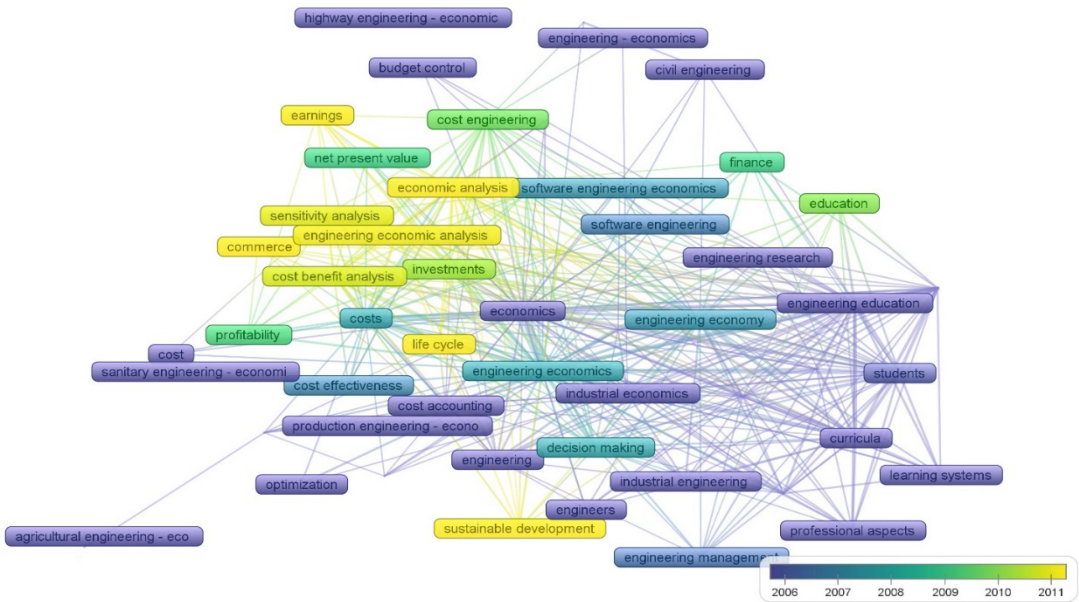

Figure 6. Keywords in articles on engineering economics

Regarding current topics in engineering economics, we analysed the keywords in publications over the past seven years (Figure 7).

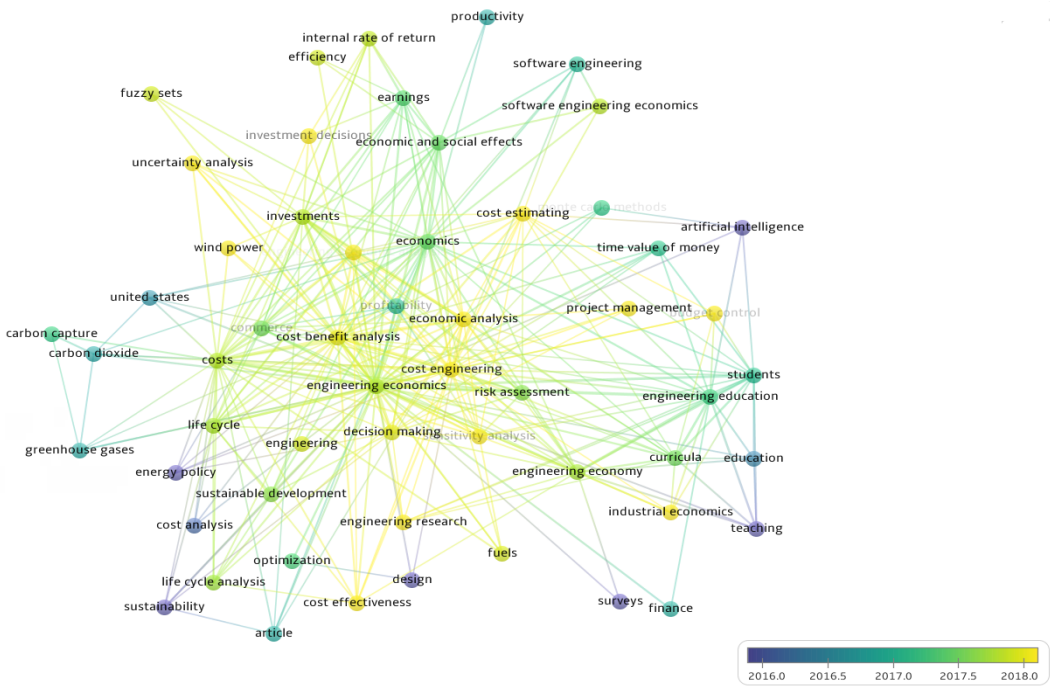

Figure 7. Keywords in articles on engineering economics for 2015–2021

The figure shows that traditional topics related to engineering and economic education, decision-making, engineering economic analysis, investment efficiency evaluation, risk modelling, and cost estimation remain popular. As mentioned above, a significant portion of the articles are devoted to sustainable development as well as software implementation. Concepts such as fuzzy sets and uncertainty analysis have been mentioned more often in the last couple of years. There are also articles on artificial intelligence.

Based on these analyses, the questions posed at the beginning of the study were answered. Concerning the first research question, engineering economics covers many subject areas: engineering and economics education, decision-making methods, finance in engineering economics, personal finance, investing, economic analysis, and R&D projects. Accordingly, engineering economics is a multifaceted subject area that combines various economic issues related to engineering areas (Amadi-Echendu et al., 2010). Our literature review revealed that most scientometric analyses have included the subject areas of engineering economics; however, there has been no scientometric analysis of engineering economics. With regard to the most popular authors and resources, the most popular and frequently cited authors are T. G. Eschenbach, W. G. Sullivan, J. C. Hartman, N. Lewis, G. J. Thuesen, J. P. Lavelle, and C. S. Park.

In answer to our third research question, we identified the most representative keywords that can guide the identification of the topics relevant for research in this subject area. The following blocks of topics were prominent: engineering and economic education, decision-making and engineering economic analysis, cost accounting and cost efficiency, production optimisation, software development and implementation. Calculation of net present value, sensitivity analysis, cost-benefit analysis, investments, etc. are popular tools used in academic studies in the subject area. We highlighted a separate stream of research on the topic of ecology and sustainable development, which is not presented in textbooks but is quite popular in scientific studies. In recent years, the concepts of "fuzzy sets" and "uncertainty analysis" have been mentioned more often, and studies on artificial intelligence have also emerged.

The concept of engineering economics is interpreted through decision-making (Simon, 1966). The company's activities are based on a variety of solutions, each of which should pass through a feasibility study (Tirachini, 2020). Engineering developments do not exist by themselves; they face a competitive environment. Thus, it is very important to choose the best possible solution. Projects should not only be

feasible but also be economically attractive. Engineering economics deals with evaluating alternatives and choosing which will be better in the long run (Li et al., 2019). However, engineers need the help of economists to make decisions and choose among alternatives; by contrast, the role of engineers in making economic decisions has been growing. This is because technologies are becoming more complex, and certain concepts cannot be evaluated without the participation of technical specialists. For example, this applies to decisions on equipment replacement or disposal to make which it is necessary to evaluate equipment conditions.

Our results reveal that the central position in the engineering economy is occupied by engineering economic analysis, which is a combination of quantitative and qualitative methods for analysing differences in the economic efficiency of engineering alternatives (Dźwigoł et al., 2018). We can conclude that the most popular tools of engineering and economic analysis presented in scientific papers are risk analysis, cost-benefit analysis, replacement analysis, break-even analysis, method of option valuation, analysis of equivalent annual cost, and annual cash flows. A significant part of scientific studies in engineering economics are devoted to engineering and economic education (Rudskoy et al., 2018), and its main task is also revealed—to teach students of technical specialties all the necessary functionality to make cost–benefit decisions. The real world of engineering economics includes such components as uncertainty, risk, and productiveness tradeoffs (Simonovic, 2020), the cost of which cannot be measured in monetary terms. Engineering economics also takes into account the time value of money in order to balance current and future income and expenses. Summing up, we can single out the main task of engineering economics – the evaluation and comparison of alternatives as a basis for making decisions that minimise costs and maximise profits for business. Nevertheless, further investigations are needed to analyse the spread of engineering economics, its specifics in different countries, the stages of its development, and its relationship with other disciplines.

4. Conclusion

The basis of engineering economics is the integration of engineering and economic knowledge. As an independent area, engineering economics was formed relatively recently (1930), but the economic return from technical solutions has always been taken into account by engineers. The concept of engineering economics is interpreted through decision-making, but engineering developments do not exist by themselves; they face a competitive environment, so it is very important to choose the best possible solution. Therefore, engineering economics deals with evaluating alternatives and choosing which will be better in the long run. On the one hand, engineers need the help of economists to make decisions and choose among alternatives; on the other hand, the role of engineers in making economic decisions has been growing.

The central position in engineering economics is occupied by engineering and economic analysis, which is a combination of quantitative and qualitative methods for analysing differences in the economic efficiency of engineering alternatives. The most popular tools of engineering and economic analysis presented in the scientific papers in question are risk analysis, cost-benefit analysis, replacement analysis, break-even analysis, method of option valuation, analysis of equivalent annual cost, and annual cash flows. A significant part of scientific works in engineering economics are devoted to engineering and economic education, given the current necessity of teaching students of technical specialties all the necessary functionalities to make cost-benefit decisions.

This study revealed that engineering economics takes into account the time value of money to balance current and future income and expenses, and its main task is to evaluate and compare alternatives as a basis for making decisions that minimise costs and maximise business profits.

Acknowledgements

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