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Innovations and Enterprises: Sustainable Development and Ways to Achieve It

At all levels of management of the company's activities, the main goal is to achieve sustainable development, which is characterized by an increase in the dynamics of the company's performance indicators. The introduction of innovations at enterprises leads to the renewal of the nomenclature of manufactured goods, improvement of product quality to meet consumer demand and maximize profits, therefore, there is an increase in the efficiency of the business entity. However, in order to achieve sustainable innovative development, enterprises need to provide for the potential for possible growth and further development.

In the first issue of the 2023 Sustainable development and engineering economics journal, the authors examined various aspects of sustainable development of enterprises and territories and ways to achieve it.

The first section named Economics of engineering and innovation decisions as a part of sustainable development is presented by the article "Automation of Investment and Project Management Based on the Introduction of an Enterprise Resource Planning System in the Power Grid Company" by Eremina, I, Degtereva, V., Kobulov, Kh., Yuldasheva, N. In this study, authors consider the automation of the asset management of a power grid company based on the introduction of an Enterprise Resource Planning system. The results obtained show that the system developed involves the most ergonomic user interfaces that meet the requirements for convenience and speed.

The Enterprises and the sustainable development of regions section presents two articles. The first work "Applying of self-organizing maps for risk assessment of mining and metallurgical enterprises" by the authors Pishchalkina, I., Tereshko, E., Suloeva, S., the subject of which is to develop a risk factors prioritization neural network model for a vertically integrated mining and metallurgical company. In order to attain this goal, authors identify risk factors by the mining and metallurgical enterprises key activities and allocate into key groups by forming a risk register. The second work – "Implementation of digital tools in the operational management of material procurement at machinery enterprises" by Dubolazov, V., Simakova, Z., Chua, C. presents scientific findings from domestic and international research to consider the most urgent challenges that the machinery industry faces in its ongoing digitalisation. Specific attention is paid to the external and internal environment of machinery enterprises, their ability to adapt to dynamic fluctuations in demand, and unpredictable changes in supply and consumption.

To solve the problems of Sustainable development of regional infrastructure, the authors Victorova, N., Karpenko, P., Mirazizov, A., Radzhabova, I. the article "Holistic approach to managing socially secure development of a regional socio-economic system" clarify the concept of the socially secure development of a regional socio-economic system and elaborated a methodology for quantifying the state of human resources when the socially secure development of a regional socio-economic system is managed.

In the final section named Management of knowledge and innovation for sustainable development, the authors Lomakin, N., Maramygin, M., Kuzmina, T., Tudevdagva, U., Vimalarathne, K., Lomakin, I. in the article "The decision tree neural network as part of a cognitive model for forecasting the sustainability of the Russian economy" address the problem of sustainable economic growth, a subject that is highly relevant in the current conditions of market uncertainty. This study aims to test whether using a cognitive model with the application of the AI system decision tree can afford a more accurate forecast of GDP than known forecasting methods.

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

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Research article
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Automation of Investment and Project Management Based on the Introduction of an Enterprise Resource Planning System in the Power Grid Company

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Abstract

Today, there is no universal software product that can fully cover the need for automation of management in all areas of a large company. The purpose of this study is to consider the automation of the asset management of a power grid company based on the introduction of an Enterprise Resource Planning (ERP) system. The subject of the study is the automation of investment and project management in a power grid company. This study uses abstract-logical and economic-statistical methods of information analysis. The automated system for managing investment activities and capital construction through the ERP system was introduced in the work of Rosseti Lenenergo PJSC. Here, the subsystems for project management and investment programme management are considered. The scientific novelty of the study is the fact that the results of the study provide insights for increasing the efficiency of the assets management processes of the power grid company, that is, the process of managing investment and project activities and the process of managing technical inspections and maintenance through automation based on the introduction of an ERP system. Of practical importance is the new integrated solution developed for the process of managing the investment activities of the power grid company, which takes into account the current requirements for project development. The results obtained show that the system developed involves the most ergonomic user interfaces that meet the requirements for convenience and speed.

Keywords: automation, management process, power grid company, ERP system

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Научная статья
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Автоматизация Процесса Управления Инвестиционной и Проектной Деятельностью в Электросетевой Компании на Основе Внедрения Системы Управления Предприятием

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Аннотация

В настоящее время не существует универсального программного продукта, способного полностью покрыть потребности в автоматизации управления не только всех областей деятельности крупной компании, но даже какой-либо одной ее области. Целью настоящего исследования является автоматизация процесса управления активами электросетевой компании на базе внедрения ERP-системы. Предмет исследования - процесс автоматизации бизнес-процесса управления инвестиционной и проектной деятельностью в электросетевой компании. Научная новизна проведенного исследования заключается в повышении эффективности основных процессов управления активами электросетевой компании: процесса управления инвестиционной, проектной деятельностью и процесса управления техническими осмотрами и ремонтами оборудования, посредством автоматизации на базе внедрения ERP-системы. В ходе исследования применялись абстрактно-логический, экономико-статистический методы анализа информации. В ходе исследования была разработана и внедрена в работу ПАО «Россети Ленэнерго» автоматизированная система управления инвестиционной деятельностью и капитальным строительством с помощью ERP-системы, подробно рассмотрены подсистемы управления проектами и управления инвестиционной программой. Практическая значимость проведенного исследования заключается в том, что для процесса управления инвестиционной деятельностью электросетевой компании разработано новое интегрированное решение, в полной мере учитывающее требования современного проектного развития. Полученные результаты показывают, что в созданной системе реализованы максимально эргономичные пользовательские интерфейсы, отвечающие требованиям пользователей к удобству и быстродействию.

Ключевые слова: автоматизация, процесс управления, электросетевая компания, ERP-система.

Цитирование: Еремина, И., Дегтерева, В., Кобулов, Х., Юлдашева, Н., 2023. Автоматизация процесса управления инвестиционной и проектной деятельностью в электросетевой компании на основе внедрения системы управления предприятием. Sustainable Development and Engineering Economics 1, 1. https://doi.org/10.48554/SDEE.2023.1.1

1. Introduction

The tasks of boosting the Russian economy and import substitution are associated with an increase in power consumption, the volume of its transmission, and the connection of an increasing number of new consumers to the power grids. The solution to these problems is complicated by a high degree of equipment wear. In the power generation industry, the share of equipment operating for more than 30 years is about 40%; in the grid complex, it is more than 50%. As noted by leading economists, the duration of consumer outages due to accidents will only increase unless decisive measures are taken to improve the reliability of the power grid complex (Hadidi et al., 2020; Kriswanto et al., 2021). The successful implementation of investment programmes and projects, as well as the quality management of equipment maintenance, directly affects the performance of companies and the achievement of their strategic goals. In the current challenging environment, effective investment and maintenance management in power grid companies is no longer possible without special software. The problem is not only selecting the software but also integrating it into the company's business processes, taking into account their specifics.

Studies have indicated that the software used for management should not only meet the requirements of the company's business but should also be an integral part of business processes and ensure their high-quality implementation (Lebedev, 2019; Lin, 2021). Only in this case can the automation of management and the effective use of software with the competitive advantages it creates become possible. Further, companies expect to obtain a customised system that takes into account their requirements and has the most convenient interface. Currently, there are a small number of products of the required quality on the market. Thus, the largest Russian Enterprise Resource Planning (ERP) systems "1C" and "Galaktika ERP," do not have any components for the development of investment portfolios and programmes, although their practical application in various business processes was substantiated in a number of scientific works (Danilczuk, et al., 2020; Roslan. et al., 2017; Wang. et al., 2020).

The study pursued the following goals: the analysis of the current state of the enterprise's business processes, the analysis of the possibility of integrating ERP systems into the business processes of the enterprise, the selection of an ERP system that best meets the strategic goals of the enterprise, the development of design solutions for the implementation of the selected ERP system, and the analysis of the possibility of using the developed universal technical solution for the automation of asset management in power grid companies.

The automation of investment management implies a certain extension of the standard functionality of the SAP PPM system and the use of the functionality of SAP ERP modules already implemented in the company. These systems must be integrated with each other and with BusinessObjects BI, as well as with the technological connection management system (on the 1C platform). The developed subsystems implement the most ergonomic user interfaces that meet the requirements for convenience and speed.

2. Literature Review

We analysed the extent of knowledge concerning the automation of asset management based on the implementation of an ERP system. Most authors consider automation as a process of developing various technical means and mathematical methods aimed at facilitating production, technological, managerial, and other processes, as well as reducing the role of a human worker in these processes and reducing the labour intensity of work performed by human workers (Babkin et al., 2021; Alekseeva et al., 2020). However, most scientists pay attention to the fact that automation is a natural process of enterprise development (Kozlov et al., 2019; Kudryavtseva et al., 2020; Mizanbekova et al., 2020). Automation allows us to optimise management and technological processes and reduce risks by removing human workers from hazardous life and health industries. Thus, it is possible to improve the quality of manufactured products, increase management efficiency, increase labour productivity, and, consequently, increase business productivity (Rudskaia et al., 2017). The introduction of automation systems allows for an increase in sales and profits and strengthens the competitiveness of the company. In recent research, economists have noted that automation paves the way for business expansion and scaling (Wellmann et al., 2020; Schepinin et al., 2018).

The most effective tool for automating a company's business processes is the introduction of information systems, such as systems in the enterprise resource planning (ERP) class. ERP belongs to the class of accounting and transactional computer enterprise management systems designed to plan and manage all enterprise resources vital for the production, sale, and accounting of products (Locatelli et al., 2020). ERP has a dual nature: on the one hand, it is an information system, and on the other hand, it is a management standard (concept) that is implemented in this information system. ERP, as an information system, integrates the information used by multiple functional units of an organisation into a unified computer system. This means that instead of using isolated databases for each individual department (such as personnel, customers, orders, equipment, finance, warehouses, etc.) to manage information, the same database is used, which will allow the company's management and employees in different departments to have up-to-date information (Zaytsev et al., 2021).

The unified nature of an ERP system can lead to significant benefits, including reduced error rates, greater speed and efficiency, and better access to information. With better access to information, workers, and their managers can gain a better understanding of enterprise performance and make better decisions in terms of business development. The ERP system was chosen in this study according to the following main criteria: comprehensive functionality covering all existing business processes; ease of use; integration of various components of the system; performance; scalability; availability of means of integration with other applications; compatibility with other office applications; ease of management; availability of training technology for working with the system; sustainability of the system manufacturer; and availability of the system on the market, in the industry, and in the region.

Many researchers have indicated that modern software should not only meet the requirements of the company's business, it should also be an integral part of business processes and ensure their high-quality implementation (Zhu, 2021; Arbabi et al., 2020; Dubey et al., 2021; Korotkevich et al., 2019). Only in this case can the automation of management and the effective implementation of the software product with the competitive advantages it creates become possible. In the largest Russian companies, investment management at the level of individual projects is quite effectively automated (Zaborovskaya et al., 2019; Voliket al., 2021). However, there are still many unresolved issues of automating investment management at the company level, primarily control over the implementation of strategic investment plans, including operational and regulated reporting. The reason lies in the small number of products of the desired quality in the market. Thus, the largest national ERP systems, 1C and Galaktika ERP, do not yet have a special component for the development and maintenance of investment portfolios and programmes. Galaktika ERP, which positions itself as a full-scale management information system, considers the absence of excessive functionality to be its advantage over Western systems.

Despite all the advantages of ERP systems offered by the market, there is no universal software that can fully cover the needs for automating the management of all areas of a large company. For the purposes of the most complete and efficient automation of portfolio management functions that no longer fit within the old IM module, these functions were separated from the SAP ERP system into a separate specialised SAP RPM product (currently SAP PPM). Today, methods of investment management make it possible to form an optimal pool of projects (investment programme), taking into account funding restrictions, to determine the rules for ranking these projects and criteria for their effectiveness (such as net present value, payback period, internal rate of return, and energy efficiency), as well as the principles of their calculations. At the beginning of the introduction of special software, these methods should be developed and put into practice in the company. The problem of internal regulation of the investment planning process in power grid companies has not been resolved.

In accordance with current regulatory documents, the power grid company develops a five-year investment programme and submits it for approval by Rosseti PJSC and the Russian Ministry of Energy. The approved investment programme is subject to annual adjustments. The company develops a draft of the adjusted programme, which also reflects its actual implementation for the current year, with subsequent approval by PJSC Rosseti and the Russian Ministry of Energy. To provide real assistance and support to its users, an automated investment management system is designed to perform a number of specific tasks: registration of the hierarchical structure of investment programme modules and flexible management. This is achieved by changing the structure itself, reassigning projects (titles) to the modules, bringing the planned values up in the hierarchy, and registering and grouping (creation of pools) of investment applications of applicant divisions for new projects and for changing current projects. Further, the responsible employees of the executive office are provided with the opportunity for a comprehensive analysis of incoming applications and bringing the decision on each of them to the applicants (in case of rejection, indicating the reasons or requirements for revision). There is also the opportunity for the divisions to obtain the necessary information on the progress of the implementation of each of the projects of the current investment programme, including data on the concluded contracts.

Since all the above procedures involve the processing of significant amounts of data, the system must have all the necessary tools to provide its convenience and reliability. These are mass-processing tools that are often missing in a standard solution. If it is required to enter and process large amounts of data within a short time, the convenience of the work actually means its feasibility. The problems stem from the fact that during the examination stage, the requirements of businesses and end users to the system were not clarified. As a result, the goals are not relevant to the tasks that need to be fulfilled.

Thus, the analysis of modern literature on the automation processes inspired the formulation of tasks that should be fulfilled by using the automated system for managing investment activity and capital construction (AS MIACC) based on the ERP system. These tasks include information support and automation of coordination and subsequent adjustment of the investment programme; automation of the operational, analytical, and external reporting on the investment programme; access to up-to-date information on the implementation of the projects of the investment programme to all interested employees of PJSC Rosseti Lenenergo; decision-making support; integration of several software systems into a single information environment; and completeness, relevance, and consistency of information.

3. Materials and Methods

The theoretical and methodological bases of the study are the works of Russian and foreign researchers, the works of researchers on the theory of project management and strategic management, and the works of specialists in the fields of automation and reengineering of business processes, information technology, and production management. The following methods were used during the study:

- abstract-logical method for studying the phenomenon and its processes through abstract logical reasoning of the process of automation of investment and project activities in the power grid company based on the implementation of an ERP system;

- economic and statistical methods of information analysis to build a functional architecture subsystem of project management and investment programme management;

- method of innovative business modelling of the process of managing investment and project activities in the electric grid company based on the implementation of an ERP system (which is a priority of this study);

- optimisation methods for creating types of reviews and versions of initiatives that are used for preparing documentation and reporting in the investment programme management subsystem at various stages of its formation, approval, and implementation.

The following materials were used: programmes, concepts, and financial and accounting statements of PJSC Rosseti Lenenergo. The project was developed according to the notations indicated in Table 1.

Table 1. Variables used for modelling

Source: compiled by the authors

№	SAP ERP PS	AS MIACC	Coding	Economic meaning
1.	***New construction and renovation projects***			
	Project Definition	Initiative	IXXXXXX	Title
	WBS element of level 1	Initiative	IXXXXXX	Title
	WBS element of level 2		IXXXXXX-AA	Start-up complex number
	WBS element of level 3		IXXXXXX-AA-ZZ	Construction project
	WBS element of level 4		IXXXXXX-AA-ZZ-YY	Consolidated cost estimate/Future Fixed Asset
2.	***OS procurement projects***			
	Project Definition	Initiative	IXXXXXX	Title
	WBS element of level 1	Initiative	IXXXXXX	Title
	WBS element of level 2		IXXXXXX-AA	Equipment group

From the point of view of methodology, the designed software should not only meet the requirements of the company, but it should also be an integral part of business processes and ensure their effective performance. Only in this case can the automation of management and the effective implementation of the software product with the competitive advantages it creates become possible. To date, in the largest Russian companies, the management of investment activities has been automated at the level of individual projects. However, there are still many unresolved issues of automating investment management at the company level, primarily control over the implementation of strategic investment plans—investment programmes, including operational and regulated reporting. These problems are likely to be caused by a small number of related products of the desired quality. Thus, the largest Russian ERP systems, 1C and Galaktika ERP, do not yet have a special component for the formation and maintenance of investment portfolios and programmes. Galaktika ERP, which positions itself as a full-scale management information system, considers the absence of excessive functionality to be its advantage over foreign systems.

Despite all the advantages of ERP systems offered by the market, there is no universal software that can fully cover the needs for automating the management of all areas of a large company. Therefore, for the most complete and efficient automation of portfolio management functions that no longer fit within the old IM module, these functions were separated from the SAP ERP system into a specialised SAP RPM product (currently SAP PPM). It turns out that applied tasks, such as portfolio and programme management, are more efficiently solved using special software (with the allocation of separate hardware capacity) designed to solve these tasks than the so-called universal software.

To date, one of the most advanced solutions in the field of investment and project management has been developed by the German company SAP AG, namely, PS (Project System) modules, which are a component of the ERP system, and a separate PPM (Portfolio and Project Management) application. The PS component is deeply integrated with other ERP system modules, such as FI, CO, MM, SD, and PM. SAP PPM also has built-in integration tools. Unfortunately, software manufacturers do not offer a ready-made solution for automating the management of the assets of electric grid companies and the management of investment activities in particular that would take into account all the features of projects in this industry (primarily grid connection projects).

Based on the experience of leading economists in automation methodology, work on the development and implementation of an ERP system will be carried out within the framework of successively implemented stages:

stage 1 – preparation and survey of the current business processes. At this stage, a survey of the enterprise's current business processes is carried out;

stage 2 – conceptual design. At this stage, decisions are made to determine the subsequent appearance of the system, and the research and coordination of the parameters of the created technical solutions with their possible implementation are carried out;

stage 3 – implementation of the solution. This stage involves development in accordance with the conceptual design solutions prepared. The functional architecture of AS MIACC includes four functional subsystems: data management, project management, investment programme management, integration subsystem, and reporting subsystem;

stage 4 – testing of the system. At this stage, the system and its final preparation for commercial launch are tested;

stage 5 – industrial operation of the system. At this stage, the system is fully operational;

stage 6 – replication of the solution. This stage involves the development and transfer of the solution or its parts to other enterprises.

4. Results

Based on a detailed study of the investment management processes in PJSC Rosseti Lenenergo, the decision was made to develop a new integrated solution that takes into account the requirements of the company. The solution provided for a certain extension of the standard functionality of the SAP PPM system with the help of further developments and the use of the functionality of SAP ERP modules already implemented in the company. These systems must be integrated with each other and with BusinessObjects BI, as well as with the technological connection management system (on the 1C platform). As a rule, the subdivisions that manage the investment and project activities of power grid companies belong to either investment management block or capital construction management block. The former are involved in the formation and control of the investment programme, while the latter are involved in the implementation of the projects included in the investment programme. The purpose of building AS MIACC was to create convenient working tools for executive office divisions and branches so that each block would perform its own functionality adapted to its specific tasks. Thus, SAP ERP was intended for capital construction departments (in terms of financial and logistics modules), which includes operational reports on projects with analytical data about costs, payments, receipts, supplies of materials and services, and control over the execution of contracts. The functionality of SAP PPM (formation and maintenance of the investment programme) and SAP BusinessObjects BI (formatted reports on the investment programme) corresponded with the tasks of investment management departments.

A shift was initially made from the WEB to the SAP GUI interface due to the slowness of the Java technology used in it. In the SAP GUI interface, users are offered a single-screen operation mode—a single entry point—to perform all operations. To do this, a report is created using ALV Grid (Enjoy Controls) technology with the ability to enter data and edit most of the displayed fields. The report displays the data of system objects (reviews, initiatives, and versions of initiatives) in accordance with the criteria specified by the user. The report screen contains panels and buttons with drop-down menus. Thus, everything the user needs for work is always at hand on one screen. Using the same technology, an additional report was created to work with the reviews.

Based on the applications approved by the executive office of PJSC Rosseti Lenenergo, a draft of a new long-term investment programme for a five-year period and a draft of the adjusted investment programme of the company are formed. Each project is approved once a year by the parent organisation (PJSC Rosseti) and approved by the Russian Ministry of Energy. Prior to this, documents of the investment programme of the established form are prepared. In the process of implementation during the year, changes are accumulated in the working version of the programme, which are then reflected in the adjusted investment programme for the next year. The project is closed in the system by setting the appropriate status on the project cards, which prohibits performing any operations except for viewing and using them in reports. The status is initially set for the project card in the Project Management Subsystem (PS SAP ERP module) (hereinafter referred to as the IP management subsystem) and transferred to the card of the same project in the Investment Programme Management Subsystem (SAP PPM) (hereinafter referred to as the IPR management subsystem). The signing of final acts of acceptance of work is a necessary prerequisite. The absence of an unaccomplished construction—that is, the complete commissioning of all the reconstructed and modernised facilities—is a necessary condition for closing the project.

The functionality of SAP BusinessObjects BI was used in our version of AS MIACC to prepare the planning and reporting documents for the investment programme. The SAP NetWeaver BW platform was used as the data store. All the necessary project master data and planning data are loaded daily into the SAP BW data warehouse from SAP PPM, and the actual data on the development of capital investments (costs), financing (payments), and the cost of fixed assets put into operation are loaded from SAP ERP. SAP BusinessObjects BI tools allow us to generate the necessary regulatory reporting forms and carry out a user-flexible analysis of all data of the investment programme and its actual execution. The two main subsystems are described below.

1. IP Management Subsystem

The IP management subsystem (SAP ERP system, PS module) is designed to control the life cycle of investment projects, and includes automatic creation of an investment project from the SAP PPM system, detailing of the investment project structure, cost collection, periodic, and final calculations, and closing of the investment project. The functional scope of the data management subsystem includes the following main business processes: detailing the structure of projects, reflection of costs on WBS elements (structural plans of the project), project closure, and reporting.

When the list of initiatives is approved and included in the IPR in the SAP PPM system, investment projects with the original structure are automatically created in the SAP ERP system (PS module). When automatically creating investment projects, the master data fields of the project definition and the parent WBS element are filled in by copying from the PPM initiative. When a project is closed, a final settlement rule (one or more) is entered, specifying recipients in the final settlement of the WBS element. An asset can be entered (partially or completely) to account 01, transferred between company codes, or written off (disposal). At each stage of the life cycle of an investment project, analytical reporting is available that allows us to evaluate the actual costs, structure, statuses, and basic data of the investment project. The functional architecture of AS MIACC includes four functional subsystems: IP data management, IPR management, integration subsystem, and reporting subsystem. The place of the IP data management subsystem in the functional architecture of AS MIACC and its connections with other subsystems are shown in Figure 1.

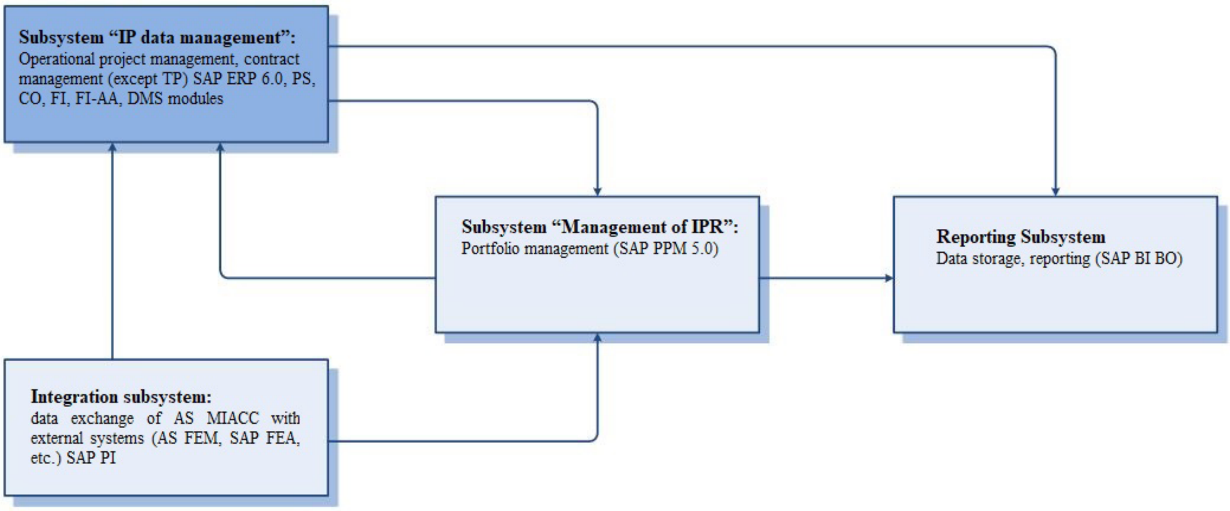

Figure 1. Functional architecture of the subsystems: IP management and IPR management

Compiled by the author

After creating a project and including it in the IPR in AS MIACC, an investment project is automatically created in the SAP ERP (PS module). When performing a purchase under the project for the purchase of fixed assets that do not require installation (Project Profile 2030), an additional WBS element is assigned at the lower level. A WBS element can correspond to an individual fixed asset or a group of purchased fixed assets. The WBS element will be created by employees of the capital construction department of the branches. Statistical key figures are used as a reference for internal allocations (for example, for cost allocation) as well as for key figure analysis. Planned and actual values of statistical key figures can be assigned to cost centres, internal orders, and WBS elements.

When performing the procurement of services for an investment project (R&D, construction, commissioning), both the top-level WBS element corresponding to the title (if it is impossible to allocate costs to deeper analytics) and the WBS element corresponding to more detailed analytics can be used as an account assignment object. The costs of depreciation of used fixed assets, wages, and settlements with persons accountable are collected at the production units (cost centres). Later, these costs are allocated to the WBS elements of projects in an economic way. Indirect costs can also be assigned to WBS elements for the maintenance of the structured plan of the project (SPP), in accordance with the general rule for the distribution of costs for the SPP. During the given period, the accountants of the branches and the executive office perform cost postings with the analytics of the capital construction departments.

Further, when closing the period at the branches, the accounting department starts automatic recalculation of costs from the capital construction units of the branches to the titles. As a result of this recalculation, the system automatically distributed the costs of the capital construction department (CCB) in proportion to the costs reflected in this period. Interest is distributed to WBS elements with a non-zero balance in the distribution period in proportion to current costs. Implementation is carried out with the help of a programme—a report. The final stage is the "Execution of documents for the project," after which the project is closed, while the initiative receives the status "Completed" in the system. When generating reports, reviews and alternative hierarchies of areas are used, which represent different options for classifying and grouping titles. Data exchange within AS MIACC is allowed between SAP ERP (PS) and SAP PPM systems. SAP PPM is external to SAP ERP (Figure 2).

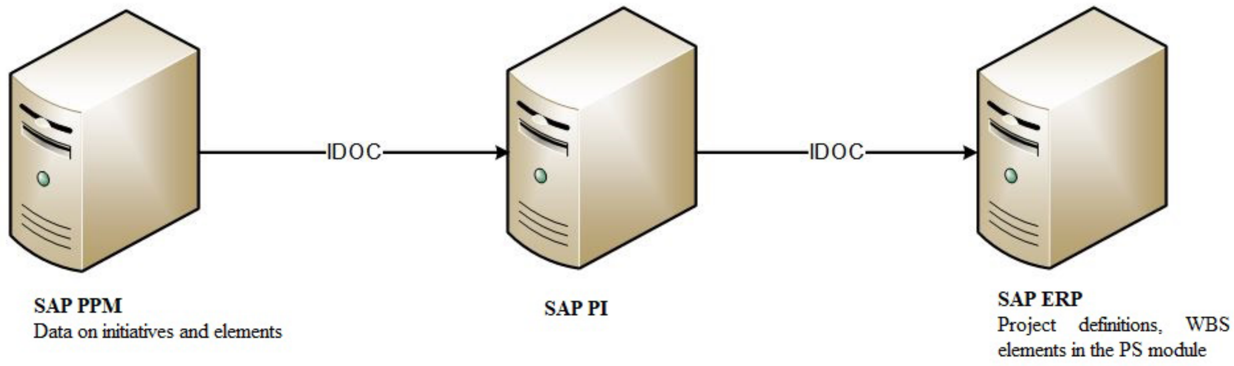

Figure 2. Interface for creating project definitions and root WBS elements
Compiled by the author

The reporting subsystem collects data directly from the ERP system using a trust connection. Integration with external systems is described in more detail in the DMS module on the integration subsystem. Cost planning takes place in the PPM system (IPR management subsystem) in the context of the main cost items on the initiative, whose code is the definition of the project and the top-level WBS element in the ERP (PS module). A detailed description of cost planning is given in the DMS module for the IPR management subsystem. Planned costs are not maintained in the IP data management subsystem. A comparative plan-fact analysis is performed in the reporting subsystem.

WBS elements are used to accrue costs for current activities, materials, and equipment, allocate costs of the capital construction department of branches and the executive office, and capitalise interest on loans and borrowings.

2. IPR Management Subsystem

The IPR management subsystem is designed to solve all the problems associated with obtaining summary data on IP within the IPR.

The functional scope of the IPR management subsystem includes the following main business processes:

- formation and approval of IPR;

- implementation of IPR;

- analysis and closing of IPR.

The formation and adjustment of the IPR should be carried out on the basis of the following principles:

- IPR is formed by including/excluding IP in/from it. The functionality of including/excluding a project from the IPR is implemented by changing the corresponding IP status. At the same time, completed IP should be automatically excluded from the current version of the IPR (despite the fact that the project is excluded from the current version of the IPR, information on the IP itself should be available for viewing through the appropriate reports);

- all numerical indicators of the IPR (financial, technical) are formed on the basis of IP data by direct summation of the corresponding indicators of individual projects included in the IPR;

- adjustment of IPR is a separate version of IPR, which includes corrected IP, and which is formed on the basis of data from the adjusted IPs.

Approval of the IPR will be carried out in the form of launching a standard approval flow, with the possibility of choosing the approval route. Upon approval of the IPR, the reports “Memorandum for inclusion / adjustment of projects in the IPR” and/or “Order for the inclusion of projects in the IPR” will be automatically generated. At each approval step, it will be possible to attach various supplementary documents (external files: protocols, orders, technical documentation, etc.). Attached documents will be stored in the system and linked to the objects to which they refer.

The functional architecture of the IPR control subsystem consists of the following blocks (Figure 3): IPR formation block, IPR correction block, IPR coordination block, and IPR versioning block.

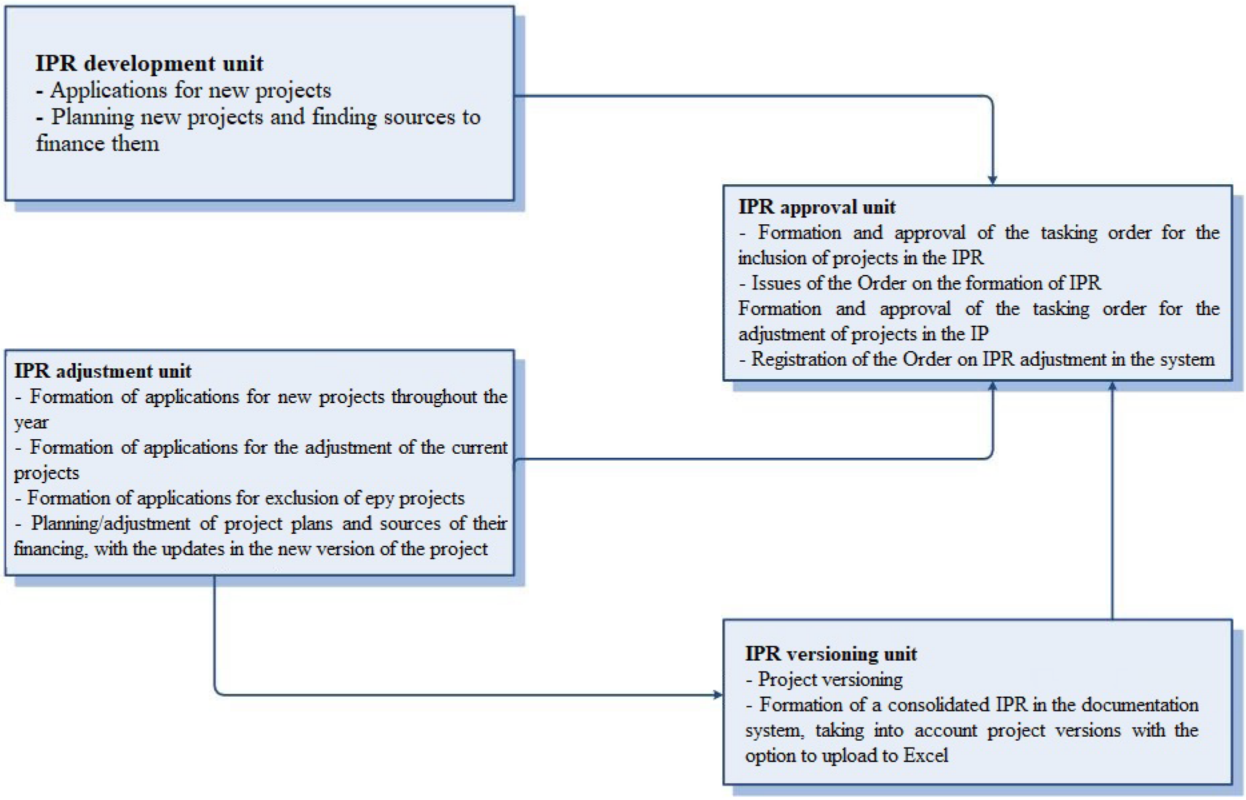

Figure 3. Functional architecture of the IPR control subsystem

Compiled by the author

Development of new reviews and initiatives/correction and deletion of initiatives/creation of new versions of initiatives is performed using a special interface procedure that allows you to enter and change object data in the most convenient way and with an acceptable processing speed. A new project in the system is created in the form of an initiative for future planning (development, financing of capital investments, commissioning, and decommissioning of fixed assets). IPR is corrected by making changes to the main data and/or data of planning initiatives with the obligatory creation of new versions of initiatives. Input is performed using the interface or by loading it from an external Excel file.

The system provides the following opportunities:

- fixing within the system the fact of inclusion in the IPR, exclusion from the IPR, suspension or change of the project at various stages of coordination, and approval of the IPR, which consists of the following:

- memo to correct the IPR;

- the result of the consideration of the Memo in the EO;

- order to adjust the IPR;

- instructions for the inclusion of RAB projects in the IPR (for the purposes of immediate implementation);

- approval of a long-term IPR by the executive office in PJSC Rosseti Lenenergo;

- approval of a long-term IPR by the board of directors of PJSC Rosseti;

- approval of the long-term IRP by the Ministry of Energy;

- approval of the IPR adjustment for the current year by the executive office in PJSC Rosseti Lenenergo;

- approval of the IPR adjustment for the current year by the board of directors of PJSC Rosseti;

- approval of adjustments to the IPR for the current year by the Ministry of Energy.

At each approval step, it should be possible to attach various supplementary documents (external files: protocols, orders, technical documentation, etc.). Attached documents must be stored in the system and have a connection with the objects to which they relate.

The analysis of the IPR and its projects is carried out by means of reporting in AS MIACC. The reporting was generated by means of SAP PPM and BI BO (Business Objects and Business Intelligence). For the purposes of reporting in BO, the actual data from SAP ERP and SAP PPM will be uploaded periodically to BW storage. The project is closed in the system by setting the appropriate status on the project card. A necessary condition for closing the project is the absence of construction in progress and the full commissioning of all created (reconstructed, modernised) facilities.

The data exchange of the control subsystem of the IPR AS MIACC is provided by the following systems: SAP ERP and an automated system for the collection and analysis of reports on the investment activities of PJSC Rosseti (based on the IBM Cognos platform). From the IPR management subsystem (SAP PPM) to the ACS of FEA (SAP ERP, PS module), the main data of initiatives and changes in them are transferred. Based on these data, SAP ERP (PS) creates project definitions and WBS elements at the three levels of the project structure hierarchy. Planned and actual data on managerial and regulated reporting on IPR in the established format are transmitted from the reporting subsystem of AS MIACC to AS to collect and analyse reports in terms of investment activities.

AS MIACC uses several hierarchies of IPR articles: The main one corresponds to the basic classification of articles of the investment programme in PJSC Rosseti Lenenergo. Alternative hierarchies correspond to classifications of investment projects that are different from the basic ones. These are used in the formation of documents and reports on IPR. The creation of the main and alternative hierarchies of IPR items is implemented in AS MIACC through the creation of a portfolio of projects and a hierarchy of areas. The portfolio corresponds to the investment programme of the company as a whole. One portfolio is used for one IPR for which the basic parameters of the IPR are set. Areas are related to the structure of IPR articles, which form a hierarchy. Initiatives can be assigned to areas at the last level of the structural hierarchy (both main and alternative). The initiative corresponds to an application for the inclusion of a project in the IPR or a project included in the IPR. The status of the project in relation to the IPR is determined by the status of the initiative. The assignment of an initiative to an area belonging to the main and alternative hierarchies is done at the moment the initiative is created.

AS MIACC provides for the creation of reviews and versions of initiatives that are used for the preparation of documentation and reporting on IPR at various stages of its formation, approval, and execution. Each initiative is included in a new version when it is created, or any changes are made to it in terms of basic data or planned values. Each new review is created for the purposes of forming, coordinating, and approving the IPR/adjusting the IPR by higher authorities or making current adjustments to the scope and plans of ongoing projects. When any review is saved from the list, the system automatically creates a version of each initiative included in the review. The initiative version code is exactly the same as the review code under which this version was created. Review versions are created regardless of the type of initiative and the status set for it at the time the review was created.

Table 2 presents the review statuses implemented in AS MIACC.

Table 2. Review statuses
Source: compiled by the authors

Number	Status name	Comments
1.	<Empty>	It is used for reviews that do not correspond to any IPR documents created by users to solve operational problems
2.	To be considered	It is used for reviews of AMW
3.	Approved	It is used for reviews of: AMW(R), FPC, RSP, IPR-EO, IPR-SD, IPR(K)-EO, IPR(K)-SD
4.	Approved	IPR-ME, IPR(K)-ME

Table 3 presents statuses of initiatives grouped into four groups are implemented in AS MIACC.

Table 3. Initiative statuses
Source: compiled by the authors

Number	Status group name (a field in the initiative card)	Status name	Method of implementation	Conditions of implementation	Where it is implemented
	Status of the application for IPR adjustment				
1.		Initiation	Automatically	At the time of the creation of the initiative. Initial status	
2.		Inclusion	Manually	When an initiative is included in the Memo review. The initiative was never included in the IRP by order	Branch
3.		Adjustment	Manually	When an initiative is included in the Memo review. An adjustment is required to the initiative previously included in the IPR by order	Branch
4.		Suspension	Manually	When an initiative is included in the Memo review. The actual execution of the initiative previously included in the IPR has begun (a work contract has been concluded), but its continuation is not required.	Branch

Number	Status group name (a field in the initiative card)	Status name	Method of implementation	Conditions of implementation	Where it is implemented
		Exclusion	Manually	When an initiative is included in the Memo review. The execution of the previously included initiative is no longer required, the work has not actually begun, the contract has been terminated, there are accepted “junk” costs	Branch
	Status of the decision of the EO on the application (Memo)				
		<empty>	Automatically	At the time of the creation of the initiative. Initial status	
		Approved	Manually	It is set for initiatives/ adjustments of initiatives approved for inclusion in the IPR adjustment order	EO
		Rejected	Manually	It is set for initiatives/adjustments of initiatives not included in the IPR adjustment order	EO
	OS input status				
		< empty>	Automatically	At the time of the creation of the initiative. Initial status	
		Partial input	Automatically	It is implemented in SAP ERP PS project and given to SAP PPM initiative	
		Full input	Automatically	It is implemented in SAP ERP PS project and given to SAP PPM initiative	
	IPR status				
		<Empty>	Automatically	At the time of the creation of the initiative. Initial status	
		Approved by EO	Automatically	When saving the corresponding review in AS MIACC	
		Approved by the Board	Automatically	When saving the corresponding review in AS MIACC	

Number	Status group name (a field in the initiative card)	Status name	Method of implementation	Conditions of implementation	Where it is implemented
		Approved by the Ministry	Automatically	When saving the corresponding review in AS MIACC	

During the approval process, users are given the opportunity to generate reports “Memo for inclusion/adjustment of projects in the IPR” and “Order on the formation/adjustment of the IPR”. At each approval step, it is possible to attach various supplementary documents (external files: protocols, orders, technical documentation, etc.). The attached documents will be stored in the system and linked to the objects to which they refer.

A user interface is created in AS MIACC to work with reviews, initiatives, and IPR documents. It is a screen with initiative fields displayed on it that will be available in both viewing and editing modes. The interface is designed to perform the following functions:

- creation of new initiatives;
- adjustments to the master data of existing initiatives;
- input and correction of planned data of initiatives;
- removal of initiatives;
- creation of reviews with the inclusion of selected initiatives;
- creation of versions of the initiatives included in the review;
- formation of documents on IPR in accordance with the established format (Memo, Order, IPR);
- formation of flexible reports of any format;
- uploading reports with subsequent saving on the user’s personal computer.

Further, the possibility of creating and modifying objects using batch input (uploading Excel files) is retained. Batch input programmes are redesigned, taking into account changes in the composition of the initiative fields, planning indicators, the emergence of new directories, etc. In the financial planning view, all analytics by funding sources and all indicators of economic efficiency are excluded.

5. Discussion

In the course of the study, it was scientifically substantiated that the strengths of the SAP PPM functionality (which determined its choice and success of implementation) included the following:

- ability to work with multiple portfolios of projects. Each of the portfolios can have one main hierarchy of areas (positions, articles), and several so-called classification hierarchies. Each project can be simultaneously assigned to several hierarchies of one portfolio, which opens up wide opportunities for analysis, generation of planning, and reporting documents with the necessary detail. In previous studies (Zaytsev et al., 2021; Korotkevich et al., 2019), only one portfolio of projects was considered. In our opinion, a systematic approach can reduce the risk of production disruptions;

- the ability to maintain versions of projects that are necessary for playing various scenarios for the implementation of the investment programme as a whole, as well as saving the history of changes An attempt to introduce such a workflow has already been made in the automation of project activities (Kozlov et al., 2019; Kudryavtseva et al., 2020). Our proposal is fundamentally different. Thus, according to our decision, each document generated in the system corresponds to a separate version of the investment proposal or project. As a result, the existing or planned data of the project included in the memo and the order, and the adjusted investment programme may differ significantly, but all these documents are stored in the system and are available for analysis at any time;

- the functionality of reviews, which are essentially containers and allow us to create various sets of investment proposals or ongoing projects (including options for an investment programme) to solve specific business problems. The prerequisites for introducing reviews of investment proposals or ongoing projects (including options for an investment programme) to solve specific business problems have already been discussed in scientific works (Zaborovskaya et al., 2019; Volik et al., 2021). Reviews are an additional and more independent means of grouping projects than areas (which make up the hierarchy of investment programme items). In the proposed solution, we strictly regulated the process of creating and using reviews, providing for each selected business process a separate type of review, a rule for generating an identifier, and limiting the user's ability to work with reviews of each type. Each review is a document stipulated by the company's internal regulations for the formation and execution of the investment programme. This document can be downloaded, saved, and printed at any time as an Excel document of the established form. Examples of such reviews are the following: a tabular appendix to the memorandum of the branch for the adjustment of the investment programme, the decision of the executive office on the memorandum of the branch, and the order of the head on the adjustment. Applicants in the branches are able to track the life cycle of their investment proposals, results, and reviews at various levels of management and the progress of the projects in one system, without resorting to other sources of information.

6. Conclusion

The introduction of AS MIACC in PJSC Rosseti Lenenergo, based on the SAP ERP system, allowed us to:

- raise the level of automation of strategic investment planning and ensure high accuracy and consistency of investment program data while significantly saving time and money;

- improve the management of projects and the Investment Program as a whole, which have become transparent and clear. Due to the flexible analytical reporting of SAP BusinessObjects BI, investment programmes can now be viewed from different angles and get up-to-date data on their actual implementation;

- receive full analytical information about all completed, launched and proposed projects at any time;

- identify unwanted changes and quickly respond to them;

- get an easy way to control consolidated investment costs, subject to tight budget constraints across the entire investment program;

- obtain a tool for rapid preparation of documentation for the investment program for submission to higher organisations, taking into account changing requirements;

- ensure the preservation of the history of investment programs, their formation, adjustment, implementation, and easy access to archived data;

- retrieve information concerning personnel more efficiently, reduce the administrative burden associated with tracking the execution of tasks and forms.

Thus, a new integrated solution was developed to manage the investment activities of a power grid company that takes into account the requirements of the company. The solution provides for the expansion of the standard functionality of the SAP PPM system with the help of developments as well as the use of the functionality of SAP ERP modules already implemented in the company. It is necessary to set further areas of research into the automation of managing investment and project activities in a power grid company based on the introduction of an ERP system. It is planned to rationalise and streamline data flows between the subsystems of AS MIACC and external systems based on the use of artificial intelligence, to bring the profiles of investments and objects into line capital construction in progress, and to expand practical testing in power grid companies in other regions.

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SECTION 2

ENTERPRISES AND THE SUSTAINABLE DEVELOPMENT OF REGIONS

РАЗДЕЛ 2

ПРЕДПРИЯТИЯ И УСТОЙЧИВОЕ РАЗВИТИЕ РЕГИОНОВ

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Application of Self-Organizing Maps for Risk Assessment of Mining and Metallurgical Enterprises

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Abstract

Investigation of risk factor assessment and grouping is relevant because ranked risk groups help companies to navigate achieving their strategic development goals while minimizing the impact of external risk factors. Grouping, carried out with neural network modelling, enables the formation of a self-learning model that can be changed by rearranging the vectors of cluster groups under the influence of turbulent external factors. The aim of this research was to develop a risk factor-prioritizing neural network model for a vertically integrated mining and metallurgical company. To attain this goal, the authors identified risk factors by the mining and metallurgical enterprises' key activities and allocated them into key groups by forming a risk register. In accordance with the risk register, the degree of influence and probability of each risk factor was assessed using the expert assessment method that allows for calculating the significance of each risk factor. The formation of risk factor groups by significance was carried out using the method of Kohonen self-organizing maps. The DataBase Deductor Studio Academic 5.3 software was used to simulate the results and build the artificial two-layer neural network. The study proved to be effective for (1) identifying the major risks and risk factors inherent in vertically integrated mining and metallurgical companies based on annual company reports; (2) assessing the impact and probability of risk factors using an expert computational method; (3) graphically presenting a two-layer neural network for further simulation; (4) forming five groups using neural simulation based on Kohonen networks; and (5) interpreting the simulation results, identifying the most significant risk in management decision-making and putting forth brief recommendations on using artificial neural networks for risk analysis and assessment. Based on the research results, recommendations on the use of artificial neural networks for risk analysis and assessment for vertically integrated mining and metallurgical companies are provided. The proposed algorithm allows large vertically integrated companies with a complex organizational structure and technological processes, as well as a wide list of risks affecting their activities, to quickly identify the most significant risks.

Keywords: risk management, neural networks, mining and metallurgical industry, digital transformation, risk analysis

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Применение Самоорганизующихся Карт для Оценки Рисков Предприятий Горно-металлургической Отрасли

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Аннотация

Изучение вопроса оценки и группировки факторов риска является актуальным, так как ранжированные группы рисков в дальнейшем помогают ориентироваться компаниям при достижении стратегических целей развития, минимизируя влияние внешних факторов риска. Группирование, выполнено с применением нейросетевого моделирования, позволяет сформировать самообучающуюся модель, которая сможет изменяться, перестраивая векторы кластерных групп при влиянии действующих внешних факторов. Целью исследования является разработка нейросетевой модели приоритезации факторов рисков для вертикально-интегрированной горно-металлургической компании. Для достижения поставленной цели в статье идентифицированы факторы рисков в ключевых сферах деятельности предприятий горно-металлургической отрасли и распределены по ключевым группам – сформирован реестр рисков. В соответствии с реестром рисков произведена оценка степени влияния и вероятности каждого фактора риска посредством метода экспертных оценок, что позволило рассчитать значимость каждого фактора риска. Формирование групп факторов рисков по значимости осуществлено с помощью метода самоорганизующихся карт Кохонена. Для моделирования результатов использован функционал программного обеспечения DataBase Deductor Studio Academic 5.3, с помощью которого строится искусственная нейронная сеть с двумя слоями. На основе результатов исследования сформулированы рекомендации по использованию искусственных нейронных сетей в целях анализа и оценки рисков для вертикально-интегрированных горно-металлургических компаний.

Ключевые слова: управление рисками, нейронные сети, горно-металлургическая отрасль, цифровизация, анализ рисков

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1. Introduction

Uncertainties are growing, and the external environment is rapidly changing. Today, enterprises have to use modern and powerful analytical tools that allow them to consider risks and make management decisions quickly. Risk is one of the most important economic phenomena. In current circumstances, risk management to minimize possible financial losses is paramount. The economy as a whole is affected by various factors, such as globalization, recurring global crises, the economic downturn of recent years, increased competition, the destruction of national borders, and the COVID-19 pandemic, which has become a turning point for the economy and society as a whole. In terms of market relations, these are key external factors influencing enterprises' operations. Modern companies need to quickly adapt their management objectives and functions, including production methods, given the volatile business environment (Pukała, 2016). Consequently, the growth potential of enterprises in each specific case depends on the effectiveness of this adaptation to the new externalities and internalities, including the needs of a market economy.

"Black swans" affect all enterprises, including vertically integrated mining and metallurgical companies (VIMMCs) (Taleb, 2009), which need to structure their various business practices in a timely and transparent manner. The mining and metallurgical industry is one of the key sectors of the modern global economy (Korneeva, 2016). The metallurgical sector consists of enterprises engaged in the extraction, enrichment, and processing of ferrous and non-ferrous ores and is a type of heavy industry that negatively influences the environment. The environmental impact can worsen VIMMCs' reputation if their management does not take swift actions to alleviate the negative impact. In addition, now, the metallurgical industry is influenced by some downward trends, including high depreciation of fixed assets, strict environmental requirements for products, insufficient supply of the domestic market, high production costs of metals and metal products, a high level of production concentration, and underdevelopment of the system of small and medium-sized enterprises (Pishchalkina, 2021). It should be noted that today, as the flow of information is practically unlimited, any enterprise that tries to increase its competitiveness or maintain its current position in the market must be constantly involved in technical improvements. Most VIMMCs define the following main objectives of risk management: (1) increasing the probability of achieving the company's strategic and operational goals; (2) improving the efficiency of resource allocation; and (3) increasing the company's investment attractiveness and shareholder value.

The scale of the mining and metallurgical industry and the specifics of the vertically integrated technological process of metal production result in the formation of "big data" that must be analysed promptly and accurately. Advanced digital technology can be used to algorithmize the analysis and evaluation processes, including processing a large array of corporate data. In addition, digitalization transformation helps to speed up information processing and expand the methods used (for example, simulation modelling, The program evaluation and review technique (PERT) analysis, fuzzy sets, neural networks, RiskMetrics, CorporateMetrics, heuristic methods, Bayesian analysis, Markov chains, etc.) (Damodaran, 2017).

However, large amounts of data are not always the key to resolving all problems and making the right management decisions. In many cases, statistical methods can hardly be used for risk assessment, even with the necessary amount of information collected. This is due to several factors: (1) Linear modelling methods are not applicable (for example, the simplex method) to most risk analysis problems; and (2) it is assumed that to assess risks, a multivariate statistical model with a Gaussian distribution of observations is built, but this is not common when solutions to practical economic problems are sought (Strebkova, 2014).

In risk analysis, it is necessary to identify non-linear dependencies, and one of the promising approaches to risk management is using neural networks (for example, for predicting or classifying risks). Artificial neural networks are used in many scientific fields, and because they are based on a large amount of data with non-linear dependencies and implicit relationships, they can help to determine the nature of these interdependencies and create the necessary models.

2. Literature review

The literature review reveals that researchers from all over the world use neural networks for risk assessment and apply self-learning models with a set of various factors.

Neural network modelling is actively used in medicine (Hosny et al., 2018a, 2018b; Shankarapillai et al., 2010); the automotive industry, including for crash assessment (Chinea and Parent, 2007; Elhag and Wang, 2007); the wind energy industry (Pinson and Kariniotakis, 2003); project activities, for investment risk assessment (Gaber et al., 1992; Jiang, 2009); the banking industry, for credit risk assessment (Li et al., 2017; Mohammadi and Zangeneh, 2016; Oreski et al., 2012; Yang et al., 2001). For example, Yang et al. (2001) considered artificial neural networks used in an early warning credit risk system for a commercial bank. Jiang (2009) used an artificial neural network to create a new risk assessment model for assessing investments to be made in high-tech projects and MATLAB software for performing exemplary simulations, with the BP neural network model and the RBF neural network model, respectively.

Neural network forecasting has become widespread at the level of enterprises and organizations, which model artificial neural networks to conduct an analysis of risk factors affecting the company's operations and the forecasts of its development. Ramamoorti et al. (1999), Kiseleva and Simonovich (2014), Novikov et al. (2013), Bataev et al. (2019), and Demidova (2020) described modern approaches to risk assessment and reviewed the architecture of a neural network according to different models and methods of neural network interpretation.

Some studies have focused on developing a mathematical framework for risk management of software projects (Lebedeva and Guseva, 2020) and considered various mathematical models for neural network modelling (Schwartz et al., 2004; Zhao et al., 2009). For example, in their study, Lebedeva and Guseva (2020) developed software for assessing the risks of project deadline extension, predicting the future performance of a project, and building scenarios to support decision-making.

This approach to using artificial neural networks can be applied to forecast both financial and economic indicators and to assess the degree of risk (Strebkova, 2014), which confirms the above analysis of the studies conducted by domestic and foreign researchers. Various numerical and textual data, such as estimates, expert opinions, and probabilistic estimates, can be used as input parameters of the neural network.

Compared with traditional technologies, neural networks have the following advantages (Korneev, 2017): (1) They do not depend on the properties of the input data; (2) they do not require a certain type of initial data distribution or linearity of the objective functions (these can be either linear or non-linear) (Haikin, 2006); (3) they are relatively simple, and no special training is needed to apply them in practice; (3) they solve the dimensional problem of linear modelling and are suitable for modelling dependencies with many variables; (4) they speed up the process of finding dependencies because all the neurons process data simultaneously; (5) they can learn; (6) they are suitable for representing nonlinear dependencies and solving problems where cause-and-effect relationships are difficult to establish; and (7) they have a relatively high resistance to measurement errors.

However, neural networks have some constraints (Ivanov, 2013): (1) They do not have a template solution, and a separate modelling algorithm must be found for each particular task (the type of network, the number of neurons, and the network layers must be selected specifically); (2) a neural network is a "black box", and interpreting the results is difficult; (3) the model can be retrained, after which its ability to generalize the input information is reduced; and (4) they are inclined towards "network paralysis during learning", which can occur when too much significance is attached to one of the weights.

Despite the constraints of neural networks, they have proven themselves well in solving problems related to classification, prediction, encoding, and decoding of information (Strebkova, 2014). Neural networks are mostly used if the exact type of connection between the input and output is not known but there is a known connection between the input and output data. In this case, the dependence itself will be identified by the neural network in the process of its learning. The main advantage of neural networks might be their suitability for representing non-linear dependencies and solving problems if there are difficulties in determining cause-and-effect relationships. These features make them helpful in optimizing risk management in enterprises operating in the mining and metallurgical industry. Kohonen's method of self-organizing maps (Haykin, 2006; Kohonen, 1982a, 1995b) was chosen due to the simplicity of analysing the obtained graphical information. The proposed tool makes it possible to identify the most significant risks that should be paid special attention when implementing the enterprise strategy and operational plans.

The aim of this research was to develop a neural network model for clustering risk factors to determine the impact of the key risk factors and the most significant risks for a VIMMC.

To achieve this goal, the following objectives were pursued: (1) identify risk factors in the core activities of VIMMCs; (2) make an expert assessment of the degree of influence and probability of each risk factor; (3) graphically represent a two-layer neural network of corporate risk clustering of VIMMCs; (4) cluster the risks using neural networks; and (5) make recommendations for how artificial neural networks can be used for analysis and risk assessment.

3. Materials and Methods

3.1. Rationale for the applied research methods

Neural network modelling was applied as the research method, which is suitable for clustering the risk factors faced by VIMMCs with a two-layer neural network. Clustering is widely applied to various objects and subjects of research (Babkin et al., 2020; Kudryavtseva et al., 2020; Schepinin et al., 2018; Victorova et al., 2020), but this type of grouping seems particularly effective for substantiating risk factor groups (Er Kara and Oktay Fırat, 2018; Izmalkova and Leontiev, 2018; Panjehfouladgaran and Lim, 2020; Yeo et al., 2001). In this study, clustering was used as a means for ordering and grouping. Neural network modelling is widespread, so there are many studies by domestic (Kiseleva and Simonovich, 2014; Lebedeva and Guseva, 2020; Novikov et al., 2013) and foreign authors (Elhag and Wang, 2007; Jiang, 2009; Li et al., 2017; Yang et al., 2001). This is one of the most effective ways to expand analytical capabilities when studying problems that do not have a standard solution algorithm (Zaentsev, 1999). Neural networks do not require programming but envisage that learning is done on specially selected examples (Debok and Kohonen, 2001). Neural networks are great at solving problems that are somehow related to the processing of data images. The list of typical tasks for neural networks is as follows (Zaentsev, 1999): (1) regression (approximation of functions according to a set of points); (2) recognition (classification of data according to a given set of classes); (3) data clustering and identification of previously unknown prototype classes; (4) information compression; (5) lost data recovery; and (6) associative transformation of information.

Artificial intelligence-based clustering is possible with genetic algorithms (Kalmykov et al., 2011; Sastry et al., 2005; Sivanandam and Deepa, 2008), the C-means fuzzy clustering method (Bezdek, 1981; Jang et al., 1997; Wu and Yang, 2002); the Kohonen neural network (Gorshkov et al., 2009; Haikin, 2006; Kohonen, 1982a, 1995b), and random forest (Shi and Horvath, 2006; Speiser et al., 2019). It is worth highlighting clustering approaches that are not based on artificial intelligence: the probabilistic approach, logical approach (Rakićević et al., 2019), k-means discriminant analysis (Lloyd, 1982; MacQueen, 1967), k-medians (Bradley et al., 1997; Pandit et al., 2011), the EM algorithm (Dempster and Laird, 1977; Zhong and Ghosh, 2003), the hierarchical approach (Pestunov et al., 2015; Zhang et al., 2018), and the graph-theoretic approach (Koontz et al., 1976; Pavan and Pelillo, 2003). Neural network modelling implies choosing a method based on artificial intelligence and able to self-learn. The Kohonen self-organizing map method was chosen to group the risk factors (Haikin, 2006; Kohonen, 1982a, 1995b). Kohonen maps organize data in such a way as to identify unknown structures, serve as a clustering tool, and allow for identifying patterns, as well as visually presenting the data. A self-organizing map consists of components called nodes or neurons. The analyst sets the number of neurons. Each node is described by two vectors (Kohonen, 1982a, 1995b): (1) the M-vector, with the same dimensions as the input data, and (2) the R-vector, representing the coordinates of the node on the Kohonen map.

The Kohonen map can be visually displayed using rectangular or hexagonal cells (Kohonen, 1995b). A hexagonal Kohonen map is built in the paper so that the distance between the centres of neighbouring cells is the same, and the interpretation of the map result is the most correct.

The self-organizing map method has a number of advantages if it is used for solving a specific problem of clustering the risk factors by significance (W): (1) Unlike other networks devised for solving problems with supervised learning, the method is suitable for solving problems with unsupervised learning ("without a teacher"), where the learning outcome depends only on the structure of the input data; and (2) input learning data is sufficient for modelling (output values are not required or, if present, are ignored).

For neural network modelling, we used the free functionality of DataBase Deductor Studio Academic 5.3 to build an artificial neural network with two hidden layers.

3.2. Research algorithm

In this study, to solve the economic and statistical problem, we sequentially modelled an artificial neural network based on a two-layer model of risk clustering factors, in which the input is the risk register of the VIMMCs and the output is a map of neurons with cluster groups of the risk factors. Thus, the following logical steps were taken in the study:

Stage 1. Determine the total number of risk factors that can characterize the analysed VIMMCs, based on the following sub-stages:

1.1. Analyse the annual reports of the mining and metallurgical companies, in particular the risk analysis section.

1.2. Group the risk factors according to their semantic load and form a consolidated register of the risks faced by the VIMMCs.

Stage 2. Form a learning sample for the neural network that includes the values of the indicators generated at the previous stage for a period of time. The corporate risk factors of the VIMMCs are ranked given the estimated significance of each risk factor; the significance is based on the impact and probability of the risk factor. The estimator algorithm involves the following steps:

2.1. Prepare a questionnaire.

2.2. Carry out an online survey of respondents.

2.3. Analyse and rank the results of the survey by risk factors in accordance with the impact and probability assessments.

Stage 3. Form a self-organizing Kohonen map and cluster the risk factors.

3.1. Prepare the input parameters for data clustering.

3.2. Build a Kohonen map using the free version of DataBase Deductor Studio Academic 5.3.

3.3. Interpret the results.

4. Results and Discussion

In the mining and metallurgical industry, risks are inherent in all operations due to the complex organization and scale of production. Companies have to be very careful at the risk identification stage. The best method for identifying risks is to create a risk map based on risk analysis carried out by internal risk managers or risk controllers of the company.

To identify the risks specific to the industry, we analysed the annual reports of metallurgical companies, such as PJSC Norilsk Nickel[1], PJSC RUSAL[2], PJSC EVRAZ[3], PJSC NLMK[4], PJSC Severstal[5], Glencore Plc.[6], Vale S.A.[7], and China Hongqiao Group Ltd.[8] These companies were selected as major VIMMCs, some of which have been operating successfully in the ferrous and non-ferrous metallurgical sector for more than half a century.

The risk factors (x1-x37) were grouped according to the key risks specific to the VIMMCs (N1-N12). The resulting indicator is the corporate risk (R), which considers the impact of all risk factors, given their significance. The impact of corporate risk can be assessed on EBITDA (Earnings Before Interest, Taxes, Depreciation), FCF (Free Cash Flow), or SVA (Shareholder Value Added), as well as on changes in investment attractiveness that depend on the goals of each company. The weight (rank of significance) was estimated using an expert calculation method so that the possible impact of each risk factor on the entire activity of the enterprise could be measured. To assess the significance of risk factors (W.N), expert assessments were considered in terms of the degree of influence of the factor (x.n.i), as well as the probability of the occurrence of the risk (x.n.p).

Three experts in the field of corporate risks of the mining and metallurgical industry were involved in the expert assessment. They were asked to assess the degree of influence and probability for each risk factor that was chosen from VIMMCs' annual reports. Table 2 shows the expert assessment scale.

Table 1. Scale of impact and probability of risk factors for VIMMCs

Expert assessment scale	Impact	Probability
1	1	0.95
2	0.7	0.7
3	0.4	0.3
4	0.1	0.05

After assigning scores to all risk factors, an average score was calculated for each risk. Furthermore, the average values were converted into more accurate values of impact and probability in accordance with the ranges proposed in Table 2. The ranking range for impact was from 0.1 to 1.00, with a minimum progressive step of 0.1; for probability, it varied from 0.05 to 0.95, with a minimum progressive step of 0.01. The averaged expert assessments were converted into updated values of the impact and probability of the risk factors using an interpolation method. The calculation was made using the MS Excel FORECAST function.

Table 2. Scale for assessing the impact and probability of risk factors faced by VIMMCs

Range	Range validation
Graded impact	
1-0.7	It is assumed that 70% to 100% of the assessed risk indicators (in monetary terms) have the greatest impact on the enterprise operations.
0.7-0.4	It is assumed that 40% to 70% of the assessed risk indicators have an average impact on the enterprise operations.
0.4-0.1	The lowest limit is defined by the materiality threshold. Values in monetary terms below this threshold are not included in the scope of the detailed analysis.

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Range	Range validation
Graded probability	
0.95-0.7	Risk is assumed to represent uncertainty, so the upper limit is 95%.
0.7-0.3	If the occurrence of an event is expected within the range of 30% to 70%, it is an event of medium probability.
0.3-0.05	If the occurrence of an event is expected within the range of 5% to 30%, it is an event of low probability. If the probability of a risk event is below 5%, the risk is not within the perimeters of a detailed analysis.

After this stage, the final assessment of the weight of each risk factor (W1-W37) is calculated according to Formula 1:

$$W_n = x_{ni} * x_{np} \tag{1}$$

where x_{ni} is the impact of each risk factor and x_{np} is the probability of each risk factor.

Table 3 presents the results of the risk analysis given in the annual reports. A risk register illustrates the types of risks associated with the operation of VIMMCs. The names of the risks and the key risk factors are the compilation of the most mentioned risks in the reviewed annual reports of the firms analysed earlier. The risk register was chosen as a method for structuring and ranking risks, approved by the National Standard of the Russian Federation, “Risk Management. Risk Register. Construction Rules”[9]. The risks were grouped according to the proposed categories, and each one’s the degree of influence on the whole company was determined.

Table 3. Key business risks of VIMMCs

Risk (N)	Major risk factors (x)		Significance (W)
Price risk (N1)	- Falling demand for metals	x1	0.59
	- Slowdown of global economy as a whole and in countries consuming metals	x2	0.36
	- Imbalanced supply and demand in metal markets	x3	0.69
Market risk (N2)	- Stricter requirements for environmental, social, and corporate governance and product quality on the part of the consumer and the market	x4	0.78
	- Competition from other manufacturers of metal products that sell metals at a lower price	x5	0.68
	- Changing patterns in consumption of high-tech products	x6	0.39
	- Limitation of product exports due to an increasing intensity of decarbonization programs	x7	0.78
	- Introduction of foreign trade restrictions by foreign regulators: tariff and non-tariff regulation	x8	0.87
FX risk (N3)	- Increase in Russia’s balance of payments, increasing stock oil prices and decreasing imports	x9	0.13
	- Change in country macroeconomic indicators	x10	0.22
	- Changing rankings	x11	0.13

[9] GOST R 51901.22-2012. December 05, 2022. Available at: https://docs.cntd.ru/document/1200100075

Risk (N)	Major risk factors (x)		Significance (W)
	- Decreasing volatility in the financial markets of Russia, as well as in the markets of other developing countries	x12	0.07
Tighter environmental regulations (N4)	- Greater focus of the international and domestic communities on sustainable development and the environment	x13	0.33
More rigorous environmental standards (N4)	- Stricter environmental supervision and active law-making in the environmental field	x14	0.52
	- Introduction of technological restrictions associated with industrial wastewater and mine water treatment	x15	0.26
Climate change risk (N5)	- Climate changes leading to abnormal natural phenomena (droughts), an increasing average annual temperature over the past 15–20 years, and a growing depth of seasonal thawing	x16	0.13
Investment risk (N6)	- Changes in the deadlines of investment projects	x17	0.39
	- Changing budgets of investment projects and revisions of technological indicators in the process of project implementation	x18	0.22
	- Changes in forecasts for the volume, quality, and properties of ores during supplementary exploration	x19	0.33
Work-related injury risk (N7)	- Unsatisfactorily organized execution of work	x20	0.17
	- Disrupted technological process and impact of hazardous factors	x21	0.22
	- Failure to comply with the legal requirements for occupational health and safety	x22	0.14
Epidemic risk	- Spread of virus infections	x23	0.26
(N8)	- Restrictive anti-epidemic measures taken by international, federal, and regional government bodies	x24	0.34
Information security and	- Growing external threats, including unfair competition	x25	0.27
digital efficiency risks (N9)	- High growth rates of the IT infrastructure of the mining and metallurgical complex and automation of business processes	x26	0.39
	- Illegal actions on the part of employees of enterprises and (or) third parties aimed at obtaining material gain or influence	x27	0.07
	- Failure to introduce new IT capacities in due time	x28	0.07
Technical and production risk	- Difficult natural and climatic conditions: low temperature, storm wind, snow load	x29	0.22
(N10)	- Unscheduled shutdowns of the main equipment caused by depreciation of fixed assets, collapse of buildings and structures, or failure of infrastructure facilities	x30	0.24
	- Emission of explosive gases and flooding of mines	x31	0.10
Risk of changing legislation and	- Instability of the legal system and the lack of consistent regulatory legal acts in various fields	x32	0.05
law enforcement	- Frequency of changes in legislation	x33	0.14
practice (N11)	- Complex foreign political situation	x34	0.28
	- Deficit of the budget system (the need to increase revenues through tax and other deductions)	x35	0.17

Risk (N)	Major risk factors (x)		Significance (W)
Compliance risk	- Inconsistency in legislation	x36	0.11
(N12)	- Scope of power and special attention on the part of oversight bodies	x37	0.10

Next, a graphical interpretation of the two-layer neural network of clustered corporate risks of VIMMCs was formed (see Figure 1).

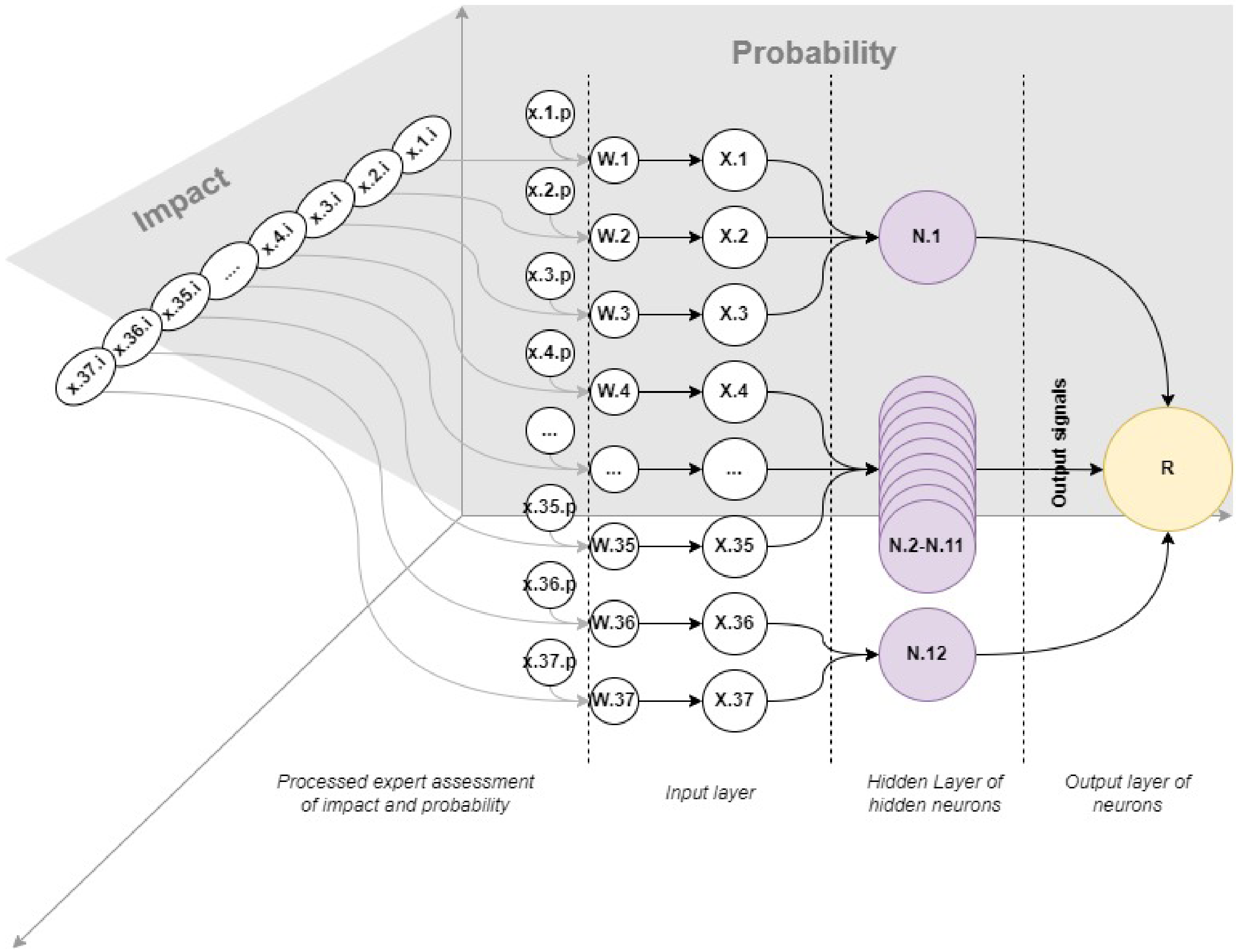

Figure 1. Two-layer neural network of clustered corporate risks of VIMMCs

Figure 1 shows distinctive neuron layers: a layer of hidden neurons and an output layer of neurons[10]. With output signals, the output layer of neurons forms the corporate risk of VIMMCs (R). Corporate risk represents a complex risk that is aimed at protecting the company's assets and also combines all types of risks inherent in the VIMMCs and discussed in Table 1. The layer of latent neurons forms cluster groups of the risk factors for VIMMCs (G1-G5) in accordance with the levels shown in Table 4. The input layer is formed by processing expert assessments on the impact and probability indicators of a particular risk factor (x1-x37). The risk factors of the input layer (see Table 1) belong to the corresponding risk groups (N1-N12). The aggregated data will be used as input (vector) data for further analysis, which is performed using artificial neural networks. The input data collected at the level of the input layer of neurons represent a combination of the influence and probability degree of the identified risk factors in Table 1, which reflect the significance of risk factors.

It follows from the above study that there are 37 types of risk factors inherent in mining and metallurgical enterprises (Table 1). In addition, all the identified risk factors are divided into 12 risk groups. Furthermore, an artificial neural network is modelled to formalize the description of the risk assessment

[10] How to configure the number of layers and nodes in a neural network. December 05, 2022. Available at: https://www.machinelearningmastery.ru/how-to-configure-the-number-of-layers-and-nodes-in-a-neural-network/

of VIMMCs (Kachalov et al., 2019). At the first stage of modelling, the designations of the variables (N1-N12) are introduced to characterize an event as a manifestation of the risk factor of the corresponding group, which has a significant impact on the corporate risk of VIMMCs (R), and the risk factors themselves (x1-x37).

As part of the study, the method of self-organizing Kohonen maps (Kohonen networks) was applied. The network formed with DataBase Deductor Studio Academic 5.3 can be defined as having the following parameters: 1) 37 values of weights (W) of factors were taken as input parameters, and the information layers are risk groups (N1-N12) and risk factors (x1-x37); 2) the sample is broken down into training and test subsets in the following proportions: 95% of the weights of risk factors were included in the training subset, and 5% were included in the test sample; 3) the size of the map was set according to the software developer's recommendation as 12*9; 4) the number of clusters was 5, which corresponds to the following ranking of levels of risk impact on the activities of VIMMCs: low, below average, medium, above average, and high; and 5) the defined conditions for stopping training were 500 by the number of iterations (epochs), the average normalized error for the training set does not exceed 0.05, and the average normalized error for the test set is not higher than 0.05.

The self-organizing map method enabled visualization of the clustering of the initial set of risk factors (Figure 2).

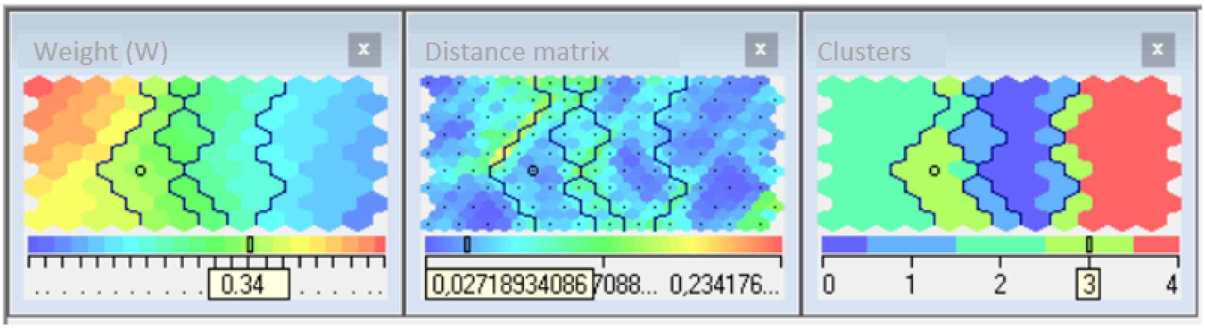

Figure 2. Clustering of risk factors of VIMMCs

The colour of a cell indicates the approximate value of the objects that fall into it. On the component projections, red is the highest value, blue is the lowest, and the intermediate values are represented by a colour gradient. In the context of the self-organizing map method, clusters are the collections of vectors, with the distance between them being less than the distance to the vectors of neighbouring groups. All elements of the map that fall into an area of the same colour (cluster) have similar properties. Based on the maps, it can be inferred which objects have the highest values of a particular indicator (a group of objects, marked in red) and which have the smallest values (a group of objects, marked in blue).

Table 4 shows the results of clustering, from which it can be seen that five clusters were formed and include the following number of risk factors: Cluster 0 has 7 factors, cluster 1 has 2 factors, cluster 2 has 10 factors, cluster 3 has 4 factors, and cluster 4 has 14 factors.

Table 4. Risks and risk factors of VIMMCs distributed by cluster

Item No.	Cluster number	Risk (N)	x	Value (W)
1	0	N3	x10	0.22
2	0	N4	x15	0.26
3	0	N6	x18	0.22
4	0	N7	x21	0.22
5	0	N8	x23	0.26
6	0	N10	x29	0.22
7	0	N10	x30	0.24

Item No.	Cluster number	Risk (N)	x	Value (W)
8	1	N9	x25	0.27
9	1	N11	x34	0.28
10	2	N1	x1	0.59
11	2	N1	x3	0.69
12	2	N2	x4	0.78
13	2	N2	x5	0.68
14	2	N2	x6	0.39
15	2	N2	x7	0.78
16	2	N2	x8	0.87
17	2	N4	x14	0.52
18	2	N6	x17	0.39
19	2	N9	x26	0.39
20	3	N1	x2	0.36
21	3	N4	x13	0.33
22	3	N6	x19	0.33
23	3	N8	x24	0.34
24	4	N3	x9	0.13
25	4	N3	x11	0.13
26	4	N3	x12	0.07
27	4	N5	x16	0.13
28	4	N7	x20	0.17
29	4	N7	x22	0.14
30	4	N9	x27	0.07
31	4	N9	x28	0.07
32	4	N10	x31	0.10
33	4	N11	x32	0.05
34	4	N11	x33	0.14
35	4	N11	x35	0.17
36	4	N12	x36	0.11
37	4	N12	x37	0.10

Based on the clusters obtained and the analysis performed, it was possible to determine the scale for assessing the factors' significance (Table 5) and highlight those factors that should be paid special attention when management decisions are made.

Table 5. Scale of risk factor significance assessment

Cluster	Level	Range	Description of impact
4	Low	0.05-0.17	Risk factors that have the lowest impact on decision-making
0	Below average	0.22-0.26	Risk factors with a below-average impact on decision-making
1	Average	0.27-0.28	Risk factors that have no significant impact on decision-making
3	Above average	0.33-0.36	Risk factors that have to be considered in management decisions
2	High	0.39-0.87	Risk factors that have to be paid a lot of attention when management decisions are made

Thus, the results of the neural network modelling of cluster groups of risk factors have practical applications. According to the obtained clusters, the following conclusions can be made:

1. When making management decisions for VIMMCs, first, attention should be paid to the risk factors included in the second cluster, in particular to the following ones: (1) any imbalance of supply and demand on metal markets; (2) stricter requirements for environmental, social, and corporate governance and product quality on the part of the consumer and the market; (3) competition from other manufacturers of metal products selling metals at a lower price; (4) limitation of product exports due to an increasing intensity of decarbonization programs; and (5) introduction of foreign trade restrictions by foreign regulators.

2. The analysis perimeters exclude risk factors that are included in clusters 0, 1, and 4 because they do not have any direct or significant impact on managerial decision-making.

Thus, the use of this algorithm makes it possible to quickly identify the most significant risks for large vertically integrated companies with a complex organizational structure, a separate method of organizing technological processes, and a wide list of risks affecting their activities.

We also propose using the capabilities of artificial neural networks not only for clustering issues but also for identifying implicit patterns when processing a large data sample. This study emphasizes grouping the risk factors to exclude minor factors from the perimeters of a detailed risk analysis when management decisions are made. It is important to note that as the number and significance of factors change, the ranges of the factors will shift, which will result in a subsequent revision of the list of risk factors for detailed analysis.

5. Conclusion

Today, the problem of risk management in VIMMCs is attractive in light of the risks inherent not only in these enterprises but also in their turbulent external environment. By clustering the risk factors, one can quickly reduce the list of factors to be analysed and concentrate on the most significant factors when making management decisions. The research methodology is suitable for obtaining data that clearly indicate that the methods are effective and can be successfully applied in risk management processes.

In addition, the literature review indicates that although each of the scientific fields necessary for achieving the goal of the current study is covered at the national and international levels, the ties between all these disciplines must be investigated further. This research study is of practical importance, and the results obtained indicate that it is possible to combine various areas of research and draw interdisciplinary conclusions.

This study relied on the method of self-organizing Kohonen maps built with the DataBase Deductor Studio Academic 5.3 software to cluster the risk factors of mining and metallurgical companies.

The study proved to be effective for (1) identifying the major risks and risk factors inherent in the VIMMCs based on annual company reports; (2) assessing the impact and probability of the risk factors using an expert computational method; (3) graphically presenting a two-layer neural network for further simulation; (4) forming five groups using neural simulation based on Kohonen networks; and (5) interpreting the simulation results, identifying the most significant risks in management decision-making and putting forth brief recommendations on using artificial neural networks for risk analysis and assessment.

Overall, artificial neural networks can be applied not only for solving clustering problems but also for assessing specific risks or identifying dependencies between the analysed independent factors. The direction of the further research is to analyse the potential of neural networks in identifying risks using the capabilities of big data analytics.

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Implementation of Digital Tools in the Operational Management of Material Procurement at Machinery Enterprises

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Abstract

Operational management of material resources has become a major concern for machinery enterprises. Growing interest in this issue rests on multiple reasons, primarily increasing the costs of material resources, their significant effect on efficiency and competitiveness, the complexity of cutting-edge processes involved in resource management, and economic and political turbulence worldwide. In an era when new business processes are emerging, and the older ones are being improved and accelerated, digitalisation is becoming one of the major drivers for innovation in enterprise management. Readjustments also occur in the infrastructure and fabric of departments and staff, alongside the methods of motivation and performance assessment. This paper presents scientific findings from domestic and international research to consider the most urgent challenges that the machinery industry faces in its ongoing digitalisation. Specific attention is paid to the external and internal environment of machinery enterprises, their ability to adapt to dynamic fluctuations in demand, and unpredictable changes in supply and consumption. Further, the authors develop a range of methods and tools aimed at improving efficiency of calculation, and integrating a whole-scale approach to provide an enterprise with materials of the required quantity and quality in a timely manner, with the lowest costs and optimal reserves.

Keywords: material supply, dynamic multi-type production, digitalisation, engineering

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Применение Цифровых Инструментов в Оперативном Управлении Поставкой Материалов на Машиностроительных Предприятиях

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Аннотация

Оперативному управлению обеспечением материальными ресурсами (ОУОМР) предприятий, традиционно, а в последнее время в возрастающей степени уделяется большое внимание. Объясняется это их возрастающей ролью в бизнесе, ростом затрат на них, влиянием их на эффективность и конкурентоспособность предприятий, усложнением ОУОМР в связи с ускорением научно-технического прогресса, ростом динамики внешней и внутренней среды предприятий, экономической и политической нестабильностью в мире. Цифровизация становится одним из приоритетных направлений инновационного развития управления предприятием, появляются новые и трансформируются старые бизнес-процессы, которые оптимизируются, насыщаются информационными потоками и ускоряются. Модернизируется инфраструктура предприятий, функции подразделений и работников, методы оценки и мотивации их деятельности. В статье на основе отечественных и зарубежных публикаций, собственных разработок авторов рассмотрены проблемные вопросы цифровизации ОУОМР для разнотипного машиностроительного производства при динамике внешней и внутренней среды предприятия, в первую очередь к динамичному изменению спроса на продукцию предприятий, непрогнозируемым изменениям поставки и потребления материалов. Предложены методы и инструменты, направленные на повышение оптимальности, оперативности, детализации расчетов, комплексного подхода с целью своевременного обеспечения предприятия материалами необходимого количества и качества в требуемые сроки с наименьшими затратами и оптимальными запасами.

Ключевые слова: поставка материалов, динамичное разнотипное производство, цифровизация, машиностроение

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1. Introduction

In recent years, an enterprise's ability to compete and stay afloat has begun to rely heavily on the efficiency of its procurement activities and their management. Reduction of purchasing costs is one of the most evident and long-standing ways to boost profitability, ensure high quality, and stimulate innovation. A variety of material assets and inventory items at a large machinery enterprise amount to tens and hundreds of thousands of units. About 20–60% of a prime cost is taken by semi–finished and finished componentry (hereinafter, materials). The development of an effective system for procurement management will reduce these costs and subsequently create a prerequisite for the sustainability of an enterprise. The market economy depends on expansion and rapid changes in product range demanded by consumers, harsh timing for introduction of newly designed items into production, cuts in production cycle, and growing competition. All these trends create grounds for enterprises to improve their material and technical supplies, and strengthen quality control in procurement logistics.

Logistics has become a major sufferer in the conditions of economic and political turbulence, pandemics, and military operations. Among other things, Russian logistics is vastly affected by a weak ruble, traditional trade and industrial ties between countries disrupted by sanctions and embargoes, sky, ports, and borders closed by "unfriendly countries", transport routes either getting closed or changed, decrease in volumes of cargo transportation and passenger traffic, impeded labour migration, etc. The major outcome is that the population is losing its purchasing power. Trade flows are getting weaker, logistics costs and commodity prices are skyrocketing, businesses are suffering, and suppliers are incapable of forecasting their prospects. As a result, many of them, especially small and medium enterprises, are either closing or reducing production. Consequently, supply chains were destabilised for almost all enterprises because the borders were closed. Serious disruptions in supply and logistics occurred; thus, many enterprises were forced to quickly look for new suppliers and diversify production and supply chains. Therefore, logistics and staff are becoming two major concerns for machinery enterprises.

The global background is experiencing significant changes as well, with the World Trade Organization (WTO) losing its leadership due to economic, political, and military pressure from a number of countries. As a result, considering economic reasons exclusively is no longer a viable strategy for designing logistics projects. Due consideration is currently supposed to refer to political and even military outcomes.

Digitalisation is becoming one of the priorities in the innovation of enterprise management, including the operational management of material resources. In this regard, new business processes are emerging, and old ones are being transformed, updated, and accelerated. Readjustments also occur in the infrastructure and fabric of departments and staff, alongside the methods of motivation and performance assessment. Most importantly, digitalisation should be aimed at the following results: acceleration of business processes, improvement of decision-making, ability to adjust to changes in supply and demand, development of a personalised approach to consumers, transparency of data throughout the supply chain, and high efficiency of business processes. The entire supply chain (supply-finished product-consumer) calls for integrated digitalisation, which is only possible when a common information and communication space is ensured. Digital production is associated not only with the introduction of new technologies but also with a profound transformation of development strategy, corporate structure, management, and interaction with contractors. In other words, whole-scale rewiring requires new methods for the development of enterprise architecture and management models (Dubolazov, 2021).

This study aims to identify methods of operational management of materials supply that focus on increasing the efficiency of decision making at machinery enterprises, with all due consideration of planning and production specifics. The study strives to define instruments and digital tools for boosting the transparency of supply, cutting costs, and improving processes associated with resource planning, etc.

2. Literature review

Wide discussion of digital tools and their implementation in economics and production started in 1995, when American computer scientist Nicholas Negroponte came up with the term "digitalisation" or "digital economy" (Negroponte, 2000). His ideas sparked widespread and whole-scale use of data, information, and digital resources in the industry. In 2016, K. Schwab introduced the notion of Industry 4.0 (Schwab, 2016), aimed at improving the competitiveness of manufacturing enterprises. At this point, traditional production processes have begun to change, with a new architecture of industrial systems being built, and a digital approach affecting all stages of the product life cycle.

Supply chain management took the leading position among the areas that actively implemented digital tools. Therefore, it came as no surprise that the concept of digital logistics developed rapidly. However, back then, multiple definitions of this newly-coined term concerned the issues of digitalisation in transport logistics and other functional industries. (Moldabekova et al., 2021; Barykin et al., 2021; Negreeva, 2020). Sergeev, Lukinsky, and Sherbakov are Russian researchers who considered classical models of calendar planning in material resources on the basis of average daily demand (Sergeev, 2019; Lukinsky, 2019; Shcherbakov, 2020). In their works, Sokolitsyn and Dubolazov (1980) assessed the features of the operational management of machinery enterprises, emphasising the importance of integrated planning. Konovalova (2019) examined the methodology of the operational management of digital production in machinery enterprises from a slightly different perspective. She focused mostly on the influence of various factors on the production complex and assessed the effects of digitalisation on the accuracy of production tasks and improvement of inventory potential. It is worth mentioning that her research "Provision of material resources at industrial enterprises" from 2019 is still highly relevant.

Figure 1 presents the range of scientific papers that have largely shaped the grounds for this research (collected from the Scopus database, 2000 to 2022). As shown in the figure, the topic of supply management for material resources has become increasingly relevant since 2019. This trend is primarily associated with in-depth research and the implementation of digital tools in enterprise management.

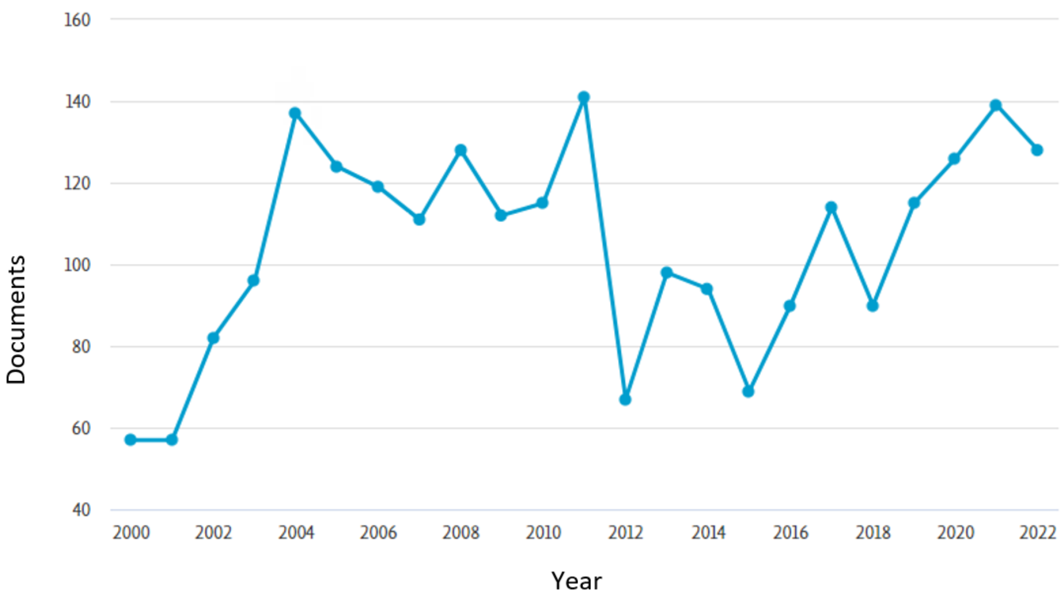

Figure 1. Collection of Scopus articles examined for this study. Search key term: "supply management industrial enterprises"

Many of the studies mentioned above have considered various models of material resource management used for a certain type of production. However, they seem to be of little use for different types of machinery enterprises, as they do not take into account the increasing dynamics of production and the constantly updated range of products that are being manufactured. Neglecting these factors impedes accurate planning of materials in demand, and inevitably leads to disruptions in supply, materials shortage, low-quality or costly materials being supplied, order declines, higher working capital, etc.

3. Materials and methods

Methodologically, this study rests on modern theories and guidelines of domestic and international scientists. The information bank for this study includes legislative and regulatory acts of the Russian Federation, resolutions of the Government of the Russian Federation, data from the Federal State Statistics Service, research materials, analytical reviews on the development of machinery, material resources at industrial enterprises, internet resources, etc. Fundamental theoretical and empirical methods were implemented in the research process. These primarily include observation, system analysis, synthesis, complex analysis and grouping, and economic and mathematical methods.

Efficiency and quality of operational management, especially regulation, are largely determined by the timely recorded deviations from a preplanned course of production, and accurate collecting, transmitting, and processing of operation-related data. Automated control systems that are now applied to a large extent are restricted to maintaining daily operational records and shift planning. Clearly, these systems improve the efficiency of operational management. However, they lead to a time lag in regulating production in terms of emerging deviations. Hence, it is necessary to develop an automated real-time control system, which is currently a real ambition due to the development of the internet of things (IoT) and other digitalisation means (Dubolazov, 2021).

Further, there is a whole range of challenges that impede effective demand planning and make it rather unpredictable, including ruble fluctuations, difficulties in international trade relations, particularly sanctions, import-export embargoes, multiple closed borders, restricted bank operations for Russia, etc. Many manufacturers and distributors note that the difference between planned and actual production volumes amounts to 10%, often 20%, or even more (Titov et al., 2017). As pointed out by manufacturers, problems associated with materials provision include excessive stocks, supply disruptions, high logistics costs, low quality of materials and logistics services, inadequate batches, and high prices of purchased materials (Dubolazov, 2017).

Therefore, these issues create an urgent task that all enterprises need to solve as quickly as possible. They must adapt to changing conditions in supply chains, including dynamic, and sometimes unexpected, changes in demand and materials supply. On the one hand, it is necessary to widen the planning time frame to establish delivery dates in advance following the main production roadmap. On the other hand, it is reasonable to shorten intervals of operational supply planning and adjust them to changes in demand for supplies and shifting schedules. This would be made possible through efficient readjustments in operational sales plans, production plans, and possibly even supply policies. Among other positive outcomes, enterprises may expect to improve planning flexibility, strengthen the reliability of supplies, and cut the costs of materials due to their shortage or excessive stocks. However, once an operational change in demand takes place, it would entail contract changes, since the previous frame is not likely to be profitable. The key solution to this issue is to find the best possible planning time frame.

4. Results

Stricter requirements for production intensity and quality rest on the number of developments, such as Industry 4.0 and Procurement 4.0, cuts in time for the introduction of products to the market, and transition to partnerships between sellers and buyers. In recent years, procurement activities around the world have largely focused on transparency and flexibility of supplies (their volume, product range, timing, transportation mode, new logistics routes, and possibility to withdraw an order). In other words, supply chain stakeholders can introduce timely adjustments to schedules when changes arise (Dybskaya, 2012).

Digitalisation 4.0 poses a set of the following changes for industrial enterprises (Kraus et al., 2021; Nyagadza et al., 2022):

- Digitalisation of products (including customisation) and services leads to an increase in qualitative and quantitative characteristics of products and services provided;

- Building and using digital business models and platforms to organise communication between counterparties;

- Ability to switch to integrated forecasting and production planning via data exchange, such as WMI;

- Digitalisation and integration of vertical and horizontal supply chains: As a result, internal and external business processes are rearranged, since a stakeholder is integrated into a single information system in real time (suppliers, consumers, intermediaries, etc.);

- Employee training in digital skills to ensure the internal transformation of an enterprise. Outstaffing seems to be one of the promising means for attracting highly qualified specialists from the outside.

Following the development of Procurement 4.0, it became easier for stakeholders to enjoy better transparency of supplies and obtain win-win contracts with suppliers. New technologies enable enterprises to manage costs in real mode, quickly negotiate via smart contracts, select preferred suppliers, automatically determine demand for material resources, eliminate duplicate orders and transactions, and monitor risks on site. Another benefit is that supplier management will allow the purchasing department to focus on ways to optimise procurement. Loss of leadership is an inevitable outcome for those companies who neglect the importance of digitalisation, Industry 4.0, Procurement 4.0, digital technologies, and the entire call for rearranging business processes and interaction with counterparties.

Notably, traditional models of calendar planning for material resources are based on average daily demand. However, the demand for materials tends to vary throughout a month, a week, or even a day. Therefore, when a fixed volume or frequency of supplies takes place, enterprises run the risk of excessive stocking. Further, these models were designed for a time when operational deviations of actual data from the preplanned were not taken into account. Nonetheless, modern machinery enterprises need the concept of an operational management system that would imply single methods and algorithms to perform—operational planning, accounting, control, assessment, and regulation of material resources. Such a concept should consider dynamics and combine single-unit and mass production (Figure 2).

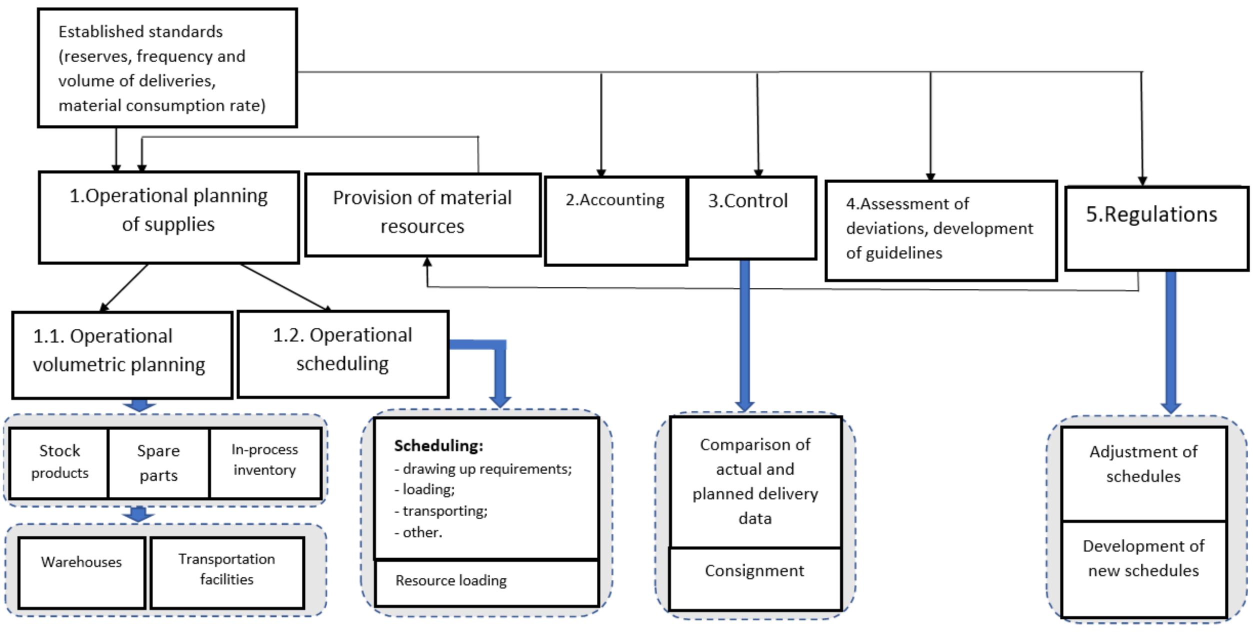

Figure 2. Operational management of procurement

In practice, deviations of actual indicators from the preplanned ones are potentially possible for various reasons, including changes in intensity of consumption, delivery of materials by a bigger or smaller batch, errors in data on the amount of stocking, materials in transit, etc. Most likely, various combinations of these reasons would occur. An important factor to pay attention to is that in mechanical engineering, different types of production prevail, and the output may differ by working days (weeks). The methodology developed in this study considers this factor and makes it possible to achieve more accurate supply planning, identify emerging deviations in time, and regulate further deliveries. The scientific novelty of this methodology is in its systematic approach, which accounts for the specifics of managing the provision of material resources at a machinery enterprise. This new approach is characterised by efficient plan adjustments to ensure timely supplies.

Figure 3 demonstrates this methodology by showing a proposed schedule for materials provision. Each stock item is controlled by three parameters. The first indicates the daily need for material resources. The second tracks daily demand on an accrual basis from the beginning of the month. The third shows the delivery schedules of the batches. The numerator indicates the size of a batch, and the denominator refers to the planned volume of delivered material resources on an accrual basis from the beginning of the month. Delivery of the next batch should take place on a working day when the amount of material resources supplied is equal to the required (from the beginning of the month, accrued total).

Type-size of a res-ce	Stock reserve	Size of batch	Indicators of schedule	Daily supply schedule for material resources, one month																							Total, mnth	Opening balance
			Working days	1	2	3	4	7	8	9	10	11	14	15	16	17	18	21	22	23	24	25	28	29	30	31		
			Daily demand, actual	10	10	10	15	15	2	3	5	0	8	12	15	10	10	3	3	5	0	4	8	9	10	2		
			Daily demand, accrued total	10	20	30	45	60	62	65	70	70	78	90	105	115	125	128	131	136	136	140	148	157	167	169	169	
			Schedule	50/	70				50/	120				50/	170								50/	220				
0533-01	20	50																									200	51

Figure 3. Schedule for the provision of material resources

This methodology enables stakeholders to keep records of the actual materials provision, monitor the implementation of a plan for provision by time frame and quantity, assess the degree and causes of deviations, promptly adjust daily demand by the accrued total from the beginning of the month, determine delivery date for the next batch, and consider the actual progress of supplies. This table illustrates the methodology, which is highly complex and thereby practically implementable only when IT systems are used. Thus, delivery dates of material resources are more accurately determined, with excess or shortage excluded (Simakova, 2022).

When the described methodology for developing a provision schedule is implemented, a daily demand (or another planned period with constant daily consumption, for example, a week) for them is determined by the release date. In turn, this date is scheduled in accordance with marketing requirements (consumer needs for products in terms of quantity and timing), logistics (transportation), and production (volume of continuous production of mass products).

The actual inventory data, accounting records, and IT data determine the amount of material resources at the beginning of the month. Based on these data, plus the daily (variable) demand of an enterprise for material resources, the delivery time of the first batch D 1 is specified as (Formula 1):

$$M_{st} = \sum_{k=1}^{d} Md_K, \tag{1}$$

where M_{st} is the amount of stored material resources at the beginning of the month, units; k is the average daily demand for the k–*th* day; $k = 1, \ldots, K$ is the index of a working day.

In this case, the volume of supply is taken as specified (fixed). The delivery time for the second and subsequent batches is defined as (Formula 2):

$$n_2 = \sum_{K=D1}^{D2} \mathrm{M}d_K \tag{2}$$

$n_3 = \sum_{K=d2}^{d3} Md_K$ etc., where n_i is the batch number equal to the specified volume.

Considering the fact that supplies are measured in batches, the monthly amount of material resources that must be delivered is specified as (Formula 3):

$$M_m = K_n{*}n, \tag{3}$$

where K_n is the number of batches to be delivered per month, and n is the batch volume, units.

Today, most enterprises cooperate with reliable suppliers via framework contracts. Therefore, the issue of determining batch size is important when planning working capital and costs for supply and storage. Although in practice, volumes of batches are most often specified on the grounds of previous experience, knowledge, or even hunch of management, more palpable factors should be taken into consideration. They include capacity of vehicles or containers (transit rate), tight budget, maximum batch size limited by the warehouse capacity, suppliers limiting the batch size by setting minimum and maximum orders, all batches not splitable (rolls, packaging, etc.), fluctuations in demand for materials with dynamic production, supplier running out of the necessary volume, discounts for large volumes, changing prices and possible interruptions in supply, damage, loss, normal wastage, and outdating of materials when a long-term storage of a large batch takes place (Hennet, 1999).

Inevitably, production also suffers from the untimely provision of material resources. For orders to be processed on time, companies have to go with parts made from scarce materials, which entails additional costs for overtime, urgent production of lacking parts in smaller batches, violation of schedules for other productions, etc. Overall, this results in a last-minute rush that is likely to affect the quality of the products. Further, companies may start to run the risk of failing to process the order, which would result in penalties, fines, and the loss of consumers who may flock to competitors.

The predominant criterion for choosing suppliers is not the price or the possibility of deferred payment, as is often the case currently in Russia. Rather, it is the supplier's ability to provide material resources in a timely manner, taking into account all the specifics of consumers: the potential necessity to change their orders by volume, range, completeness, timing, transportation mode, routes, and even order withdrawal. The guidelines presented below were designed on the basis of expert opinions shared by the researchers, including Lukinsky and Strimovskaya (2016), Zharinov (2022), and Dybskaya (2012). To develop a comprehensive system of operational management, it is necessary to:

1. Integrate and synchronise management of material resources with production and sales; efficiently respond to changes in production programmes and adapt to dynamics in demand.

2. Reduce the period of release planning (up to a quarter instead of a year) and, accordingly, the period of demand planning, since an annual contract is likely to lead to excessive purchasing and subsequent penalties for nonacceptance, as provided by the contract. It is essential to provide for quarterly adjustment of supply volumes and/or revision of the delivery schedule in case of significant market changes.

3. Broaden demand planning for integrated product groups, since a drop in demand for some products can be offset by a growing demand for others.

4. Outsource personnel for planning. Provide contracts that would set fines or compensation fees for various types of loss, including lost profits or deviations from the preplanned demand, by a specified %.

5. Negotiate the planned demand with suppliers who can see the bigger market picture in terms of demand and potential fluctuations.

6. Expand the range of supplies to eliminate the risk of disruptions.

7. Increase the frequency of stock control, preferably from once a year to quarterly checks, or even more often.

8. Arrange operational tracking (accounting, control, assessment) and operational regulation of supplies; develop a framework of supplier liability (penalties, payment of damages) for failures.

9. Constantly monitor the emergence of innovative materials.

10. Promptly monitor the financial conditions of suppliers. It may even be appropriate to provide temporary financial assistance in a rough patch. For example, by purchasing a larger batch, acquiring a share in their authorised capital, or purchasing bonds. (Dubolazov, 2017).

To achieve these goals, it is necessary to introduce modern management systems for materials supply, for instance, material requirements planning (MRP), just in time (JIT), vendor managed inventory (VMI), and lean production (LP).

There are two ways to meet the demand for materials. The first is to order them at the exact time they are required. The MRP system operates within that framework. Such a system is applied to plan the purchase of expensive materials, as well as those that are used for manufacturing individual orders, when the deadline is not specified. The second method is to maintain stocks. This is a so-called "at stock" model used for less expensive materials and standard components that are needed on a regular basis, in large volumes, and for different requests. These stocks should be purchased and delivered in such quantities and time that would suffice the demand for them. Typically, companies tend to use both methods.

However, without a universal operational management system for dynamic multi-type production, enterprises are forced to choose between one of the two options below:

1) Apply various systems of operational production management, which significantly impede the planning, accounting, control, and regulation of production;

2) Apply a particular system of operational production management that would allow averaging in calculations (e.g. the daily demand may be taken as a constant), and using statistical accounting units (set, group set, per-day set, conditional unit, etc.) (Konovalova, 2018).

An integrated approach to supply management requires linking operational accounting to the consumption of material resources in production. A matter of fundamental importance here is to establish a solid connection between operational decision-making and the performance of economic stimulation and completion of the processes involved. Four types of reserves to promptly eliminate potential deviations are material, organisational, moral, and time reserves. The operational control system must be flexible enough to respond correctly to any deviations, and still function appropriately with specified reservations. This perspective allows for the classification of all deviations into three groups:

1) Permissible deviations in delivery time, quantity, and quality of material delivered; this should be considered when placing the next purchase order;

2) Deviations that can be eliminated without adjusting schedules; for example, a small percentage of defects in a batch, less-than-a-day delay compensated by insurance stocks;

3) Serious deviations that require additional resources for their elimination or revision of pre-planned schedules.

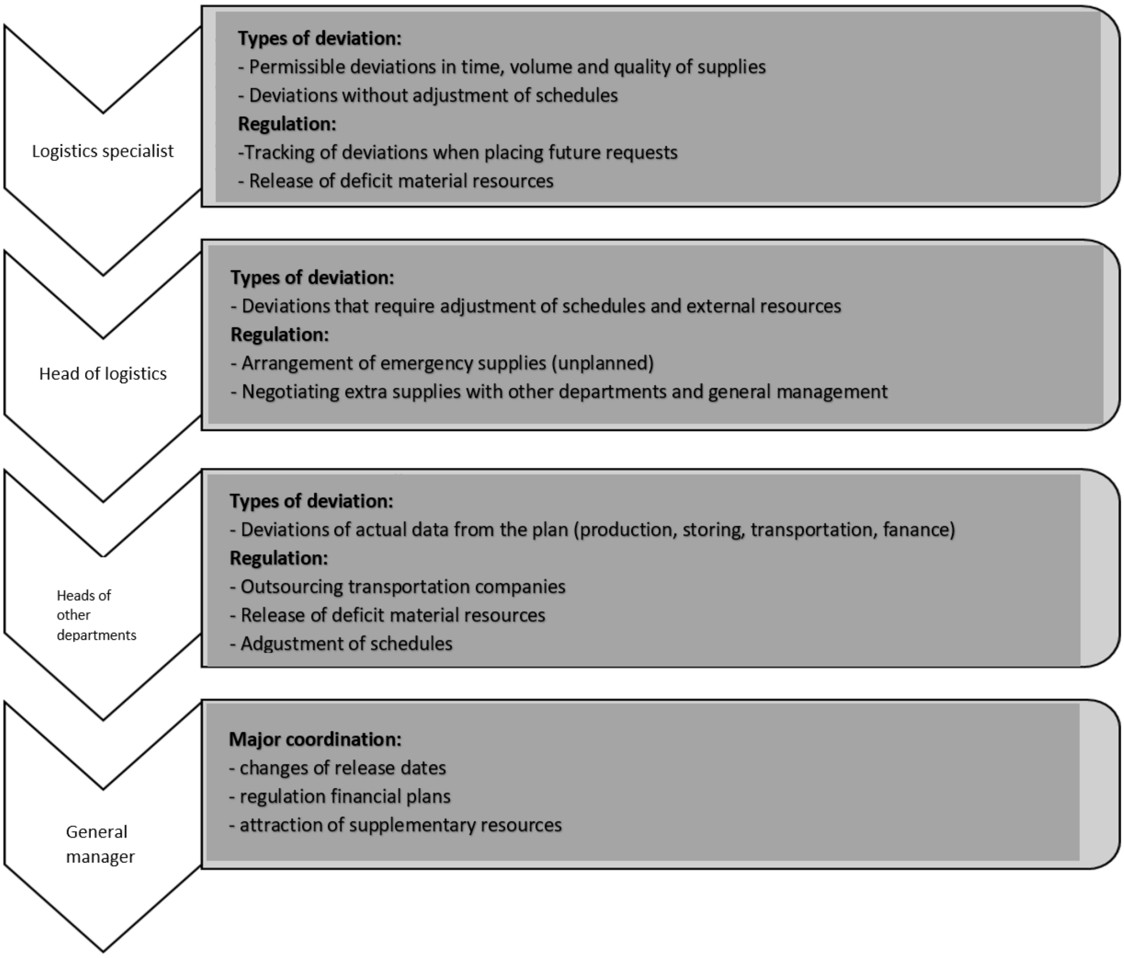

Figure 4. Hierarchical system control and regulation of operational management

This study proposes a hierarchical system of operational control and regulations (Figure 4), in which each level of management specifies types and frames of deviations, timing for their elimination, and fixed reserves (logistics specialist, head of the logistics department, heads of other departments, or general manager). Data on occurring deviations are passed on to higher levels if they cannot be covered by reserves at a lower level. This scheme reduces unnecessary information exchange between management levels, frees administrators at higher levels from current operations, and allows them to focus on long-term planning. The frequency of higher-level managers' interference in subordinates' activities decreases through the hierarchy. Thus, it encourages independence, responsibility, and improvement of the social and psychological climate.

The efficiency of operational management in logistics, especially operational regulation, is largely determined by the timely recorded deviations from the norm, and accurate collection, transmission, and processing of information. Of importance here is the fact that without providing the necessary information in real time, it will be difficult to implement the above-mentioned system and methodology in developing supply schedules. Typically, existing automated control systems are restricted to maintaining daily operational records and shift planning. Of course, it does improve the efficiency of operational management. However, at the same time, this leads to a time lag in regulating production in terms of emerging deviations. Fortunately, at present, multiple digital instruments have created solid grounds for an automated real-time control system to be implemented.

Large-scale digitalisation and the fourth industrial revolution rest on multiple tools: IoT, cyber-physical systems, artificial intelligence, neural networks, cloud and quantum technologies, robotics, 3D printing, and others. To digitalise the entire supply chain (supplier-finished product-consumer), it is necessary to create a common space for communication and information exchange. The integral stages of material supply management include planning demand and quantity of materials to order; search, examination, selection, and verification of suppliers; contract making; operational management of material resources; accounting and logistics control; and operational management of materials supply to different divisions of an enterprise. Digital tools with wide coverage can be selected at all stages (Figure 5).

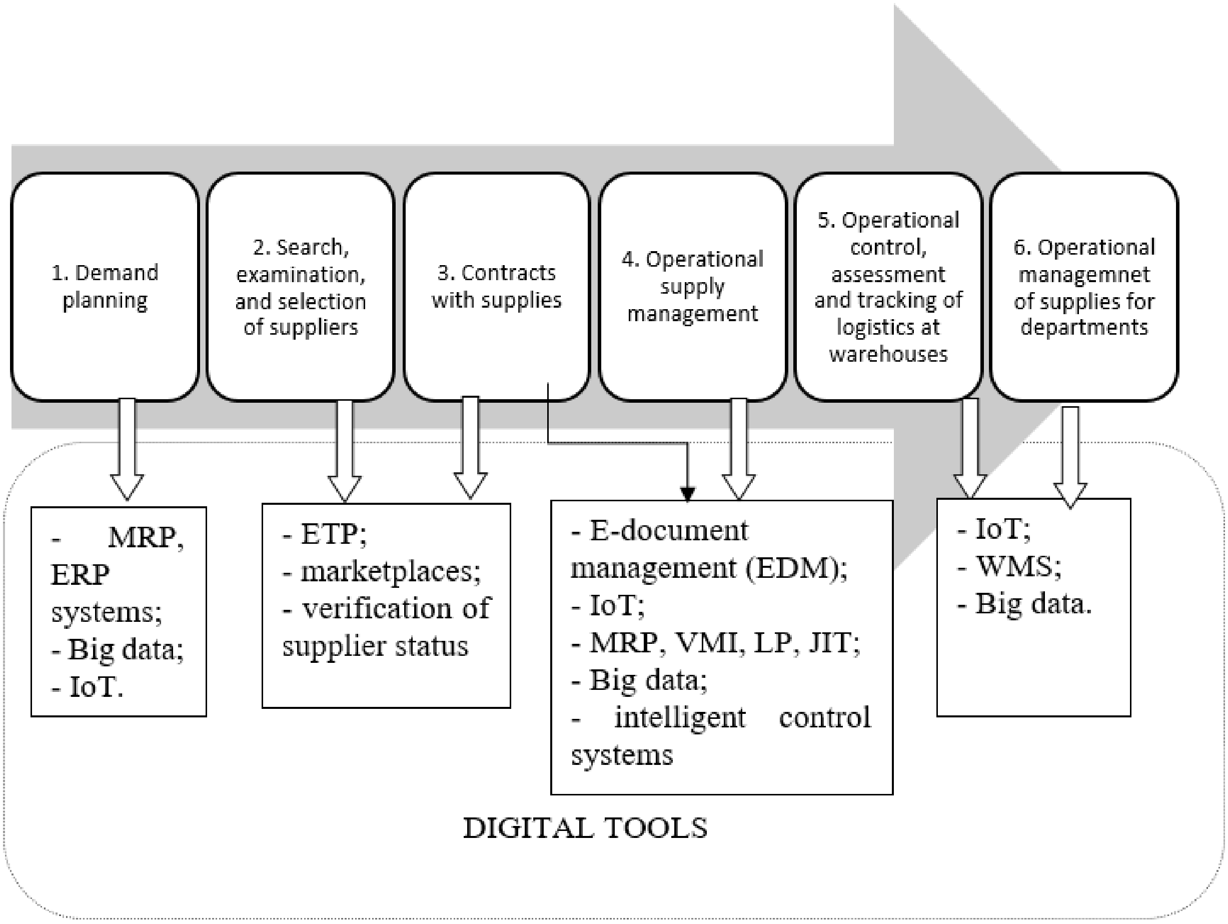

Figure 5. Implementation of digital tools at the main stages of operational supply management

Big data, IoT, electronic document management, etc. are singled out as the main digitalisation tools used in resource management. IoT, for instance, allows operational dynamic regulation of processes associated with logistics in real time. It encourages flexibility of timely response to various "disturbants", both external (new orders, changes in volume, time, or completeness of manufactured products), and internal (changes in availability of resources: materials, technology, output, or reduced equipment performance). Thus, IoT eliminates the notorious drawback of MRP—lack of efficiency and flexibility—which makes IoT a promising development in the digitalisation of logistics (Tokareva et al., 2018).

At the operational level, IoT devices use various sensors to monitor the movement and storage of materials in a warehouse, transport, and materials supply, and the use of equipment and processes associated with manufacturing itself. When combined with information systems and computer resources, IoT shapes the digital logistics system of an enterprise, as well as cyber-physical systems for managing production complexes. This is especially relevant in flexible production systems (Zaychenko et al., 2021). Here, the logistics system is tracked and managed throughout the entire supply chain in real time, which allows for responding to any minor changes as promptly as possible. Further, all stakeholders are able to receive relevant big data on problems that may arise. (Glavee-Geo, 2016). This study articulates promising directions for further comprehensive research in the areas of production, transport, warehouses, and other logistics subsystems.

Another area that is thriving due to the growth of information volumes is cloud technology. SaaS, IaaS, and PaaS cloud computing allow for the processing of huge amounts of data. In 2020, 5G entered the Russian arena. This technology is expected to fulfil the potential of big data, reduce the share of intuitive decision making, capture microtrends in consumer preferences, and ensure timely response to current changes. These all occur due to higher data transfer speeds, ultra-low costs, and heterogeneous network architecture (Grishunin et al., 2019). The implementation of 5G will allow enterprises to introduce synergetic transport systems, create smart port systems, and advance significantly in the development of smart factories.

Such developments as EDM, IoT, network technologies, cyber-physical systems, Big Data, intelligent control systems, and other digitalisation tools contribute greatly to the development of digital twins in logistics. They enable enterprises to simulate and predict the future trends and conditions of products and materials in real time (Bril et al., 2021). The biggest advantage of using digital twins is their ability to ensure the transparency and credibility of logistics operations. Generally, the market literally calls for such prospects due to an unstable competitive environment, force majeure, and COVID-19. Regarding supply management, digital twins are necessary to achieve the following goals:

- Detecting bottlenecks in supply management;

- Testing changes in the design of new supply management models, for example, VMI, JIT, or shifts in inventory management;

- Monitoring risk and predicting potential risks in the long run;

- Testing operations for the short term (Shvedenko and Mozokhin, 2020; Sergeev, 2019).

As a means to increase the efficiency of supply management, IoT seems to be most promising today. At present, Russia considers IoT at the legislative level within the national programme “Digital Economy”. However, “IoT” is only observed there in the concept of building and developing narrow-band wireless communication networks, while it is neglected in procurement management. IoT can help reduce the costs of supply, finished products, and overall costs throughout the entire supply chain.

IoT also creates a significant advantage in decision-making. It is with the help of IoT that data collection in real time becomes possible. It increases the efficiency of business processes, security, and quality. These outcomes prove to be highly relevant, since more than half of logistics employees note the lack of transparency in the supply chain. Over the past 5 years, the share of companies using IoT in supply chains has grown from 2% in 2015 to 7% in 2020. The upward trend continues (Lawal and Rafsanjani, 2022). The annual growth rate of the IoT market is predicted to reach approximately 15–20%. Thus, in 2016, IoT expenditures in various markets amounted to about $700 billion, and by 2020, they exceeded $1 trillion (Khan et al., 2021).

Digital tools allow the creation of a model of digital twins. With the help of artificial intelligence and machine learning, it is possible to create a digital copy of the entire logistics chain. Since digital twins support the whole cycle (purchase-sale), their utilisation increases the accuracy of production planning, reduces the share of defects, and prevents risks associated with some typical bottlenecks. Logically, the identification of risks at early stages reduces operational costs, including those for purchased material resources. Modelling supply chains with changing configurations allows for testing innovations painlessly. For example, it may be applicable to the replacement of suppliers and models of interaction with them (Marmolejo-Saucedo, 2020; Defraeye et al., 2021).

RPA platforms in supply management.

In recent years, the robotic automation of business processes has been experienced in a wide range of industries. Robotic process automation (RPA) is a technology that automates repetitive, long-term, routine business processes by inviting software robots capable of recording and reproducing human actions in an enterprise information system. RPA is a relatively new type of software that reproduces transactional processes based on strictly specified rules. In supply management, software robots serve as a means to reduce the time spent by humans on a large number of repetitive processes, including collecting requests, searching for price information, controlling receipts of commercial offers, checking information on counterparties, tracking the order status, etc. Processes associated with supply generate a large amount of information that could be better and quicker processed if software robots were invited. They are able to extract information about the cost of goods and services, delivery time, and payment terms from supplier documents. With the robotisation of voluminous business processes, the time spent on their implementation is reduced. Subsequently, procurement specialists can redistribute efforts to deal with strategic tasks.

Although RPA technology is often emphasised as easy to implement, in practice, this process can be accompanied by a wide range of issues. According to a survey of 400 senior managers conducted by "Supply Chain Dive", 38% of RPA implementation projects have not been completed (Anagnoste, 2018). Impediments begin at the stage of selecting the processes to be robotised. The problem is that various sources offer a range of selection criteria that, in fact, are sometimes incompatible. For example, researchers often suggest choosing the most voluminous transactions (Madakam et al., 2019). However, this strategy has been widely criticised. Some authors argue that the RPA system should not handle large-volume tasks. Instead, it should be applied by companies interested in the robotic automation of business processes for medium-sized transactions, since they have a greater business value. A common reason for the inefficiency of software robots is the lack of preliminary arrangements aimed at optimising business processes. In this case, speeding up an inefficient sequence of actions through robotics will only make matters worse. The reengineering of business processes is the most important stage in RPA implementation.

According to Figure 5, the software robot independently extracts information from specifications on the quantity and features of the purchased inventory items, and their price. Thereby, it determines the range of potential suppliers and requests for commercial offers. It is also possible to perform the latter from the procurement department database.

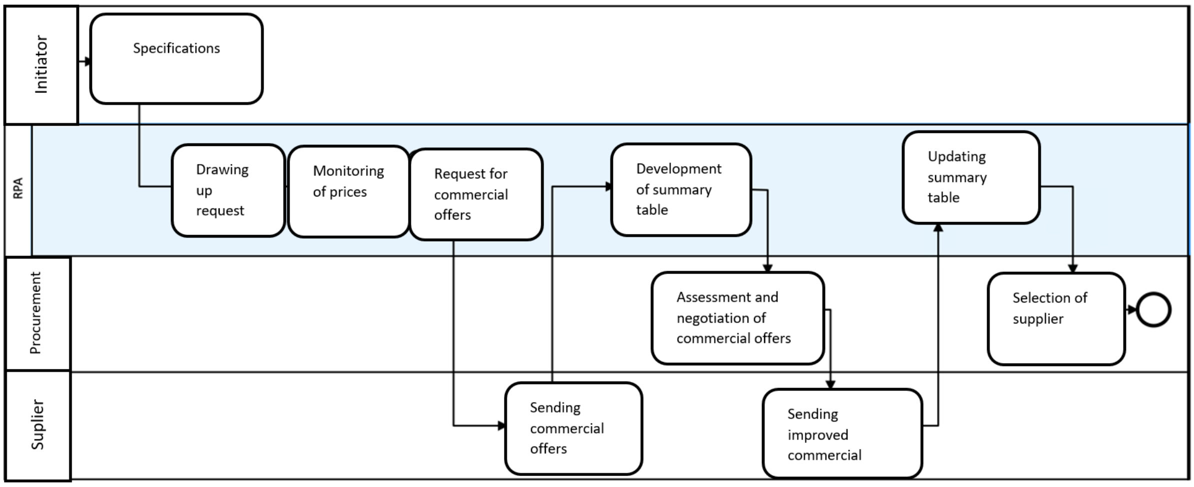

Figure 6. Modelling of supplier selection process assisted by a procurement specialist and a software robot in the BPMN notation (Shapiro, 2022)

A more effective application of RPA requires integration with artificial intelligence, since cognitive decision support systems can allow software robots to carry out more complex business processes. When applied in its traditional mode, the RPA system depends heavily on human participation.

To increase the efficiency of management, it is necessary to identify indicators that allow for controlling the process of provision. It is also important to motivate employees to ensure an uninterrupted supply of materials in compliance with quality and, at the same time, minimise logistics costs. Further, digitalisation is an important optimisation tool for operational management. Therefore, when calculating indicators of management for material resources, the level of digitalisation should be considered. The results of the assessment allow the authors to suggest using the indicators presented in Table 1.

Table 1. Indicators for evaluating the efficiency of digital tools applied in procurement management

Indicator	Formula	Clarification
Indicators of implementation of digitalisation tools		
Share of purchases by Internet tenders/ contests, via ETP (K_T)	$K_T = \frac{N_T}{N_Z}$, where N_t is the number of deliveries placed at the ETP, N_z is the number of deliveries for the period	Reduces time for status verification through preliminary accreditation by ETP; purchase of material resources at a minimum cost
Share of suppliers that use EDM (K_{EDM})	$K_{EDM} = \frac{N_{EDM}}{N_p}$, where N_{EDM} is the number of suppliers who use electronic document management, N_p is the total number of suppliers for the period	Reduces the number of inaccurate documents and saves time for placing an order
Share of deliveries using IoT (K_i)	$K_i = \frac{N_o}{N_z}$, where N_o is the number of deliveries using tracking	Increases efficiency of delivery tracking; checks compliance with delivery conditions
Share of suppliers verified as reliable via online services (K_s)	$K_s = \frac{N_s}{N_p}$, where N_s is the number of suppliers verified online	Reduces decision-making time dedicated to verification of a supplier

The key performance indicator (KPI) system is another hierarchical management system based on goals. KPIs of individual employees or lower-level management should be aimed at achieving the goals of higher-level units and the organisation as a whole by tracking the efficiency of each process.

Traditionally, enterprises calculate a monthly supply plan in value terms with *k* based on the demand for material resources from a monthly perspective.

$$S_k = \sum_{i=1}^{Il} N_{ik} * C_i \,, \tag{4}$$

where $i = 1, \ldots, I$ is the index of the type of material resource; I is the number of purchased units, pcs.; N_{ik} is the number of material resources of the *i*–th type to be delivered in the *k*–th month, pcs.; and C_i is the provision cost of the *i*-th material resource, rub.

Often, S_k works as a specified indicator, for instance, when it is determined by individual orders, aggregated groups of products, specific spare parts, or other types of materials. To increase management efficiency, the percentage of fulfilment of a monthly plan is calculated in value terms P_{kd} for the *d*-th working day from the beginning of the *k*-th month:

$$P_{kd} = C_{kd} / C_k * 100 \,, \tag{5}$$

Where C_{kd} is the cost of materials supply at the *d*–th working day from the beginning of the *k*-th month, equals:

$$C_{kd} = \sum_{i=1}^{I} N_{ikd} * C_i \,, \tag{6}$$

The planned percentage for the *d*-th working day amounts to:

$$P_{kd} = 100 / D_k * 100 \tag{7}$$

When efficient calculations of the above-mentioned indicators are performed, their assessment can be carried out in a timely manner. In other words, decision-making becomes simpler, and material resources are distributed among all the departments with higher accuracy.

5. Discussion

Enormous data collection that must be adequately processed is a typical side effect of digitalisation, which requires highly qualified specialists with outstanding IT skills. As a result, companies are facing the dilemma of whether they need to nurture such workers themselves, or outsource. However, either option requires impressive funds, which are out of reach for many logistics companies. Another limitation of digital solutions is the lack of supporting infrastructure. Warehouse technologies require premises for wireless networks to fix sensors on site, meaning that remote and larger warehouses will require complete or partial modernisation, which again entails impressive costs.

Despite the widely discussed positive aspects of digitalisation, a number of authors (Trittin-Ulbrich et al., 2021; Binsfeld and Gerlach, 2022; Fedotova, 2019) believe that digitalisation entails a range of significant drawbacks. The problem is that with a deeper immersion in the cyber environment when using digital tools, enterprises face new risks associated with data leakage, confidentiality, etc. Apparently, these newly found threats need to be addressed with all due precautions and large investments in updating software and operating systems. Further, all the accumulated big data must be carefully processed and classified so as not to cause incorrect source data grounds for the construction of digital twins and other mathematical and simulation models.

6. Conclusion

The Russian economy is vastly focusing on the development of machinery enterprises and strives to improve digital technologies, increase labour productivity, and enhance import substitution. In today's unstable political and economic conditions, it seems impossible to develop the industry unless operational enterprise management systems are integrated on a large scale. Since the costs of material resources can account for 60% of total costs, operational management systems prove to be key to reducing costs and, less painfully, adjusting to market changes.

Current theoretical and practical research has shown that operational management systems do not take into account the variety of production types and the dynamics of demand. To address these issues promptly, this study proposes a concept for an operational management system and a methodology for drawing up calendar schedules for materials provision in response to demand dynamics (by inventory range, quantity, completeness, and time). As a tool for reducing costs arising from deviations in delivery indicators, the authors developed a hierarchical system of operational control and regulation that specifies fixed types of deviations and defines the volume of reserves and time frame for the elimination of deviations.

Changes in the management of material resources and the implementation of digital tools are the only possible ways to address challenges posed by the fourth industrial revolution, globalisation, increasing automation, and speed to market. The digital tools that are proposed for each stage of operational management are aimed at enhancing the efficiency of control, accounting, and assessment of supply. The combination of these tools enables enterprises to perform more accurate calculations and optimise decision making. Thus, a hierarchical system of KPIs for the proposed operational system was constructed with the aim of ensuring the efficient implementation of new methods and calculation tools. In the long-time, these measures are expected to increase the efficiency of production, timing, and utilisation of material resources.

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SECTION 3

SUSTAINABLE DEVELOPMENT OF REGIONAL INFRASTRUCTURE

РАЗДЕЛ 3

УСТОЙЧИВОЕ РАЗВИТИЕ РЕГИОНАЛЬНОЙ ИНФРАСТРУКТУРЫ

Research article
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Holistic Approach to Managing Socially Secure Development of a Regional Socio-Economic System

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Abstract

This paper considers the matters of regional governance and how it can be improved in social and economic aspects to ensure that people have a socially secure life. The insights highlighted here have been aggregated through a holistic research study that includes a theoretical framework and methodological results with regard to the posed problem and determines the goal setting. We clarified the concept of the socially secure development of a regional socio-economic system and elaborated a methodology for quantifying the state of human resources when the socially secure development of a regional socio-economic system is managed. We present an economic and mathematical description of a management model that ensures socially secure development of a regional socio-economic system, and developed and tested an algorithm for managing the development of a regional socio-economic system based on the proposed tools. In this study, we used general scientific methods, as well as economic and mathematical methods, including regression analysis. To quantify the unstructured information, we applied artificial intelligence technologies. The results of the study were tested on the case study of St. Petersburg, the federal city of the Russian Federation. In particular, we proved that the construction of a logistics hub as a major infrastructure project would influence the core of the social security of this region in the near future.

Keywords: management, regional socio-economic system, social security, human resources

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Комплексный Подход к Управлению Социально Безопасным Развитием Региональной Социально-Экономической Системы

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Аннотация

Статья посвящена вопросам совершенствования управления регионами в социальном и экономическом аспектах для обеспечения социально безопасной жизнедеятельности населения. В ней агрегированы отдельные наработки автора и в этом смысле предложено целостное законченное исследование, включающее как теоретические основы, так и методические результаты применительно к решаемой проблеме, что характеризует целеполагание исследования. Так в работе уточнено понятие социально безопасного развития региональных социально-экономических систем; сформирована управленческая модель обеспечения социально безопасного развития региональной социально-экономической системы; разработана методика квантификации состояния человеческих ресурсов в контексте управления социально безопасным развитием региональной социально-экономической системы; приведено экономико-математическое описание управленческой модели обеспечения социально безопасного развития региональной социально-экономической системы; разработан и апробирован алгоритм управления развитием региональной социально-экономической системы на основе предложенных инструментов. В исследовании использованы как общенаучные методы, так и экономико-математические, включая регрессионный анализ. Для квантификации неструктурированной информации применены технологии искусственного интеллекта. Результаты исследования апробированы на примере субъекта РФ – города федерального значения Санкт-Петербурга. В частности, доказано влияние на ядро социальной безопасности данного региона строительства в ближайшей перспективе логистического хаба, как крупного инфраструктурного проекта.

Ключевые слова: управление, региональная социально-экономическая система, социальная безопасность, человеческие ресурсы

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1. Introduction

Regional economics traditionally deals with the problems of economic territorial development (Gutman, 2021). Studies on the digitalisation of regions (Yanovskaya et al., 2022) and the ecological state of territories (Liu et al., 2022) have become increasingly important. However, the development of regions is not only about the targets for the growth of the economic potential and competitiveness of a particular territory or strengthening technological advancement, including the use of technological innovations for environmental protection. The social environment of the regional system and related matters of social security are equally important (Li et al., 2021), the same as healthcare (Rodionov et al., 2022) and education. The development of the economic and social components of the region in its traditional sense does not yet mean that the functioning regional system is secure (Zaytsev et al., 2021). Security matters also concern the environment where the population of the region lives, and business is done and is of particular importance for society. According to international statistics, growing crime, suicide, and alcoholism are observed in economically and socially developed countries. Such consequences should be taken into account when territories are governed in the context of social security. In addition, the primary measure of the social security of a regional socio-economic system should be the personal security of the people in this system. This aspect is very important today for any country, as demographic problems are aggravating, resources are limited, and the influence of the social environment on the economy is growing.

2. Literature review

A literature review on the problems of the socially secure development of regions highlights the following.

First, there are a number of research studies concerning the sustainable development of territories that assign an important role to social sustainability (as a basis for social security) in connection with economic and environmental sustainability. For example, Yang Ding et al. (2014) applied a modified method for assessing coordinated regional development on the example of Hubei Province in China. The authors focused on the simultaneous stimulation of economic growth, social well-being, and preservation of the environment. Waidelich et al. (2022) proposed a science-based approach towards the creation and further development of a regional innovation ecosystem focused on the future of the economy and society in the Northern Black Forest.

This study examined the problems of sustainable agricultural development in Anhui Province in China (Liu et al., 2022). The authors relied on the theory of systems and considered three subsystems in relation to each other—economy, society, and environment. The study resulted in two models. The first model can be used to assess the coordination of interactions between the three subsystems of regional agriculture. The second model is helpful for identifying the factors that prevent sustainable development: use of pesticides, lack of achievements in agricultural science and technology, use of agricultural plastic film, lack of technical training schools for farmers, and a small share of animal husbandry. An empirical study by Pan and Misha (2022) assessed the security of sustainable livelihoods in 30 districts of the Indian state of Odisha. A composite index used in the assessment includes an environmental safety index, a social justice index, and an economic efficiency index. The authors included the following indicators in the social justice index: female literacy, student–teacher ratio in primary school, dropout rate in primary school, sex ratio, electrified households, households using clean fuel for cooking, households with improved sanitation and drinking water, and infant mortality rate. The study used a min–max normalisation method. As a result, the districts were grouped in terms of their level of sustainability.

The above-mentioned findings directly relate to the social aspect of the ESG concept. However, in some studies, this aspect is observed indirectly through the influence of economic or environmental aspects (increasing number of jobs, improved public health). For example, the work by Xiaoa et al. (2022) empirically justifies the growth in green development in Hubei Province after 2014 and the reduction of regional differences. The relationship between the balanced economic growth of regions and environmental pollution caused by industrial emissions was demonstrated in another study (Sueyoshi and Goto, 2014) conducted on sample prefectures in Japan. According to the authors, environmental problems can be solved if we invest more in technological innovations. Marine spatial planning (MSP) is the subject of another study dedicated to the regional development of the “blue economy” (Erkkilä–Välimäkia et al., 2022). This study is based on a survey of MSP members representing coastal fisheries in the Satakunta region of Finland. The survey focuses on three main topics: regional cooperation and synergy, conflicts, and threats, and interest in regional cooperation or setting up secondary enterprises. The authors indicated that MSP processes and the growth of a sustainable “blue economy” are part of regional development that require equal playing conditions and mutual trust between stakeholders.

According to Cui et al. (2022), it is possible to protect the environmental security of cities and simultaneously achieve social justice, including better quality urban environmental services and improved well-being of city dwellers. The study was conducted using the example of Wuhan (China). Marin (2021) analysed the concept of urban resilience in terms of the socio-technical markers of sustainability models and the position of Latin America in the production of knowledge related to sustainability. This work considers the problems of closed sustainability modelling and the gap between the northern and southern parts of Latin America in the production of knowledge.

Second, some studies have investigated the organisation of regional governments from the perspective of the social development of a territory and the social security of its population. For example, Chinese scientists (Wang et al., 2023) proposed a model of system dynamics that studies the relationships between water resources, energy, and food in the context of political goals for the development of a territory (a case study of Hunan Province). The time horizon of the modelling is from 2021 to 2035. The model focuses on the environmental aspect and allows regional authorities to shape a compromise policy within the framework of intersystem interactions and social effects. Another work demonstrated that the creation of economic opportunities for territorial development by the government stimulates the growth of culture and provides support for the values of the indigenous population of the Kativik region in the north of Quebec, thereby improving their quality of life (Jacobs, 1985). Uribe-Sierraa et al. (2022) considered the problems of functional regionalisation that contribute to the creation of corporate territories, which is beneficial for business but harmful to the population and the environment. The study concerns the activities of mining enterprises in Latin American countries on an intra-national and interregional scale, using a territorial and environmental approach. This proves that uneven development prevails on an interregional scale, which makes some regions isolated, impoverished, and subjected to environmental damage. One of the authors’ key proposals is that a comprehensive policy should be developed to mitigate the processes of territorial inequality and the subsequent reconfiguration of power.

Halonen et al. (2022) focused on forest bio-economics in Eastern and Northern Finland. The authors examined the ways in which regional development actors interpret dominant forest-related policies and reproduce or challenge forest-related discourses. They extensively examined the dependences between macroeconomic policy and regional development and the uncertainties caused by the practical implementation of the policy, as well as conflicts and balance of powers between policy, practice, and the actors behind them. Critical discursive analysis was used as the research method. The authors concluded that conflicts arise due to the disharmony between policy and regional needs, cultural clashes, and misunderstanding of regional prospects. Troisia et al. (2019) proposed a model of meta-management in territorial ecosystems. The empirical study touched on a specific case of the Italian non-profit association *Libera*, which fights organised crime. The study results in the elaboration of a service ecosystem that includes *Libera*, its members, and the territory. The authors show an approach to solving one of the social security problems in the region.

Third, some studies have aimed to identify the factors that influence the social security of territories, as described below.

1) Environmental factors: The problems of water security and health of indigenous American Indians are considered in the work by (Mitchell, 2019).

2) The impacts of the COVID-19 pandemic on the economic and social consequences for communities of fishermen at Oxbow Lake (Bar) due to reduced fish catch were analysed by Samad et al. (2022).

3) Political factors. Analysing 91 Spanish, French, and British colonies, as well as former colonies from 1820 to the present day, Schmitt (2015) demonstrated that the colonial legacy is a crucial factor in explaining the adaptation and form of social security programmes outside the OECD. In terms of political tension, Batniji et al. (2009) considered the problems of social security of Palestinians in occupied territories and suggested that international levers be used to influence the situation. Heydemann (2020) investigated the relationship between the state and society after the Arab uprisings in the Middle East and North Africa in the context of the possibilities provided by a social contract as a tool for reducing social threats.

4) Legal factors: Guarantees of secure land ownership as a social opportunity for people were the subject of a study by Valkonen (2021). The author pointed out that the sources of security spring from land policy and are connected with the relationships between government authorities, state policy, social dynamics, and ownership.

5) Psychological factors. De Backer (2022) analysed the factors that bind young people to a certain territory from the perspective of their social security. Ellis et al. (2020) considered the problems of the emotional security of children who stayed in territories that used to be controlled by the ISIL. This work proves that such children need systemic therapy.

6) Technological factors. Ustugova et al. (2016) assessed the problem of collecting and processing information about the state and development of the city environment using geo-information technology. They described the process of analysing people's social preferences and providing support in decision making when development problems in city districts are managed. In particular, the authors referred to the development of bicycle and pedestrian routes as an element of a healthy lifestyle that reduces social tension. The authors proposed CityRoutes, a specialised application for computer devices.

7) Geographical factors. In the concept of geographical development, Deng et al. (2022) highlighted the differentiation characteristics, diffusion state, and convergence mode as elements that underlie the investigation of specific regional development and affect, among other things, the social security of a region.

Based on this literature review, the theory of regional economics clearly lacks works that characterise territories, taking into account their socially secure development. Hence, the ***purpose*** of this study is to improve the methodological approach and tools for managing the socially secure development of regional socio-economic systems (using the example of St. Petersburg, the federal city of the Russian Federation). The main idea of the study, which is focused on the elaboration of management tools, is connected with the hypothesis of the influence of the population's responses, expressed in socially dangerous acts, on the socio-economic policy implemented by the government authorities of the region.

3. Materials and Methods

This study systematises the authors' exploratory work (Karpenko, 2021a; Karpenko, 2021b; Rodionov et al., 2021a; Rodionov et al., 2021b). As a synergy of scientific, theoretical, and methodological results on the problems of socially secure development of regional socio-economic systems, the research combines the following interconnected elements arranged in a logical sequence (with the methodology described for each element).

1. Clarification of the term "socially secure development of a regional socio-economic system" using the following algorithm of actions. First, based on the analysis of the definitions of "region" and "socio-economic system", we identified the essential features of these concepts. Second, we determined whether the essential features of the terms "region" and "socio-economic system" were reflected fully and completely in such definitions. Third, we proposed our original definition of a "regional socio-eco-

nomic system", which includes all the essential features of the concepts of "region" and "socio-economic system". Fourth, we identified the main social security and selected indicators for measuring it. Lastly, we summarised the results obtained into our ideal definition of a regional socio-economic system.

2. Formation of a management model for socially secure development of a regional socio-economic system. This model includes 1) centroid, core (human resources), 2) input factors characterising the current socio-economic state of the regional system as a result of management decisions of the regional government authorities, and 3) a system of resultant indicators reflecting the social danger of the region. Using analysis and synthesis methods for processing the data from normative legal acts and scientific literature, we select the indicators to be included in the model and propose a graphical image of the model.

3. Development of a methodology for quantifying the state of human resources for managing the socially secure development of the regional socio-economic system. This involved 1) assessment of the primary and complex characteristics of tonality regarding the state of the regional socio-economic system; 2) measurement of the human resources' response to the state of the regional socio-economic system; and 3) estimation of the indicators of the emotional gap of the information unit. The methodology was automated with Python programming language and implemented in the following sequence. First, we searched for and aggregated information. Second, we processed the aggregated information. The source of reactive information is the social media *VKontakte*. The news information hub is the community *St. Petersburg Vesti* (officially registered media that covers news information of regional significance only, unifies the most communicatively active audience, and generates a significant amount of reactive content). The tonality of the news and reactive information was evaluated using the Dostoevsky tool library. The approbation was carried out using the example of the federal city of St. Petersburg.

4. An economic and mathematical description of the management model for the socially secure development of the regional socio-economic system, which is based on regression analysis. This was partially implemented in MS Excel and IBM SPSS, with the following quality criteria for regression models:

i) The significance of the models was assessed using the F-test, with a limit value of the criterion being 0.1 or 10%;

ii) The quality of the model was primarily determined by the volume of the explained variance of an endogenous variable, which is indicated by the coefficient of determination (R2);

iii) The significance of the relationship between the endogenous variable and the exogenous variables included in the model was determined by the p-significance of each variable (the limit value was 0.2 or 20%);

iv) The applied quality of the description of the variance of an endogenous variable by the variance of exogenous variables was determined by a variety of potential indicators, namely, the average approximation error, standard deviation, characteristics of structural outliers and structural breaks, etc.;

v) The most significant binary criterion for the quality of the regression model was a logical justification for the direction of action of an exogenous variable on an endogenous one.

The official statistics for the city of St. Petersburg for 2008-2020 are used as source data.

5. Development and testing of an algorithm for managing the development of a regional socio-economic system that is based on the proposed tools and consists of three stages. In the *first stage*, we predicted that the key indicators of input influence identified during the regression analysis would change. In the *second stage*, the predicted value of the gap in the positive tonality of the information environment of the regional socio-economic system was estimated based on the regression equations. In the *third stage*, we selected decisions aimed at the socially secure development of regional socio-economic systems and offered a set of recommendations. The subject of the approbation is the federal city of St. Petersburg. The purpose of the approbation was to assess the expected impact of a logistics cluster on

the core of the region's social security.

The research used general scientific methods and economic and mathematical methods of regression analysis.

4. Results

In what follows, we consider the results of each of the five elements of the study outlined in the Methods.

Results for the first element: A key concept of the study—socially secure development of a regional socio-economic system—was clarified. This is important for further scientific and methodological work. For this, we analysed over 20 of the existing definitions and identified the essential features of concepts such as "region" and "socio-economic system" as elements of the concept of a "regional socio-economic system" (Figure 1).

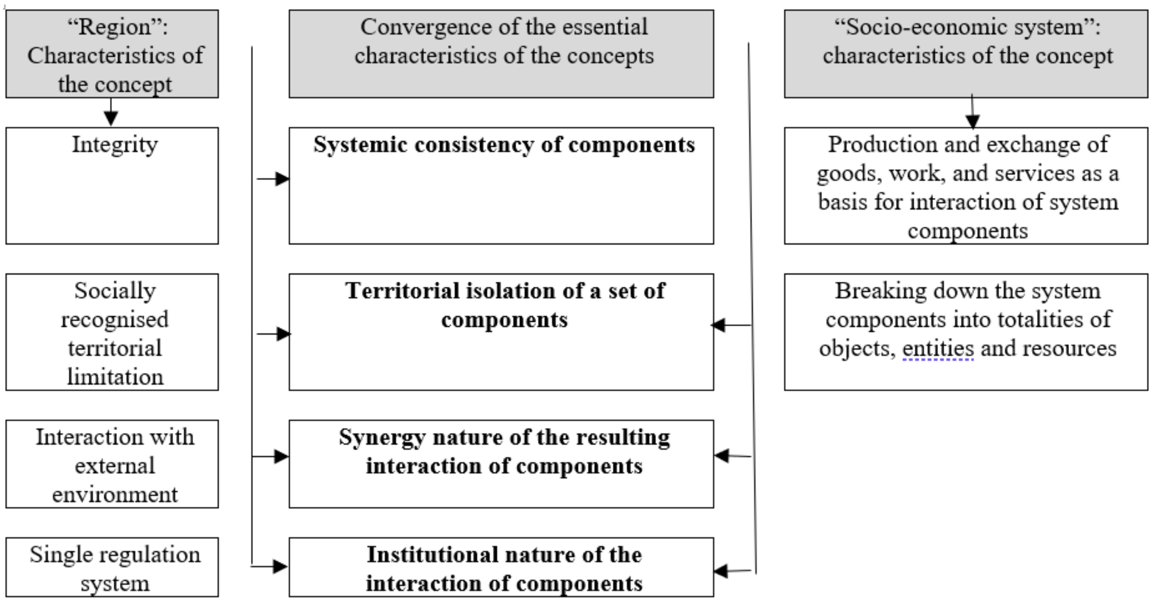

Figure 1. Convergence of essential features of the concepts of "region" and "socio-economic system"
compiled by the author

Further, the existing definitions of the term "regional socio-economic system" were analysed to identify all their essential features. We have demonstrated that the extant literature lacks a comprehensive definition of the term. We propose the following interpretation: A regional socio-economic system is understood as a socially recognised geographically limited integral set of systemically related entities and resources that are united in institutions, interact within the synergy of production and exchange of goods, work, and services and have a single regulatory system. We then singled out the main ideas in the scientific definitions of social security, in particular homeostasis (preservation) of society (Buzan et al., 1993), human risk management (Frevel, 2013), and self-sufficiency of the state in the social sphere (Doyle, 1994).

Given all the iterations, we propose the following definition: Socially *secure development of a regional socio-economic system* is such a change in the state of the system, in which the growth of economic indicators results in increased social security of the population of the region, being the basis for achieving a high quality of life. At the same time, we should highlight the core of the social security of the population of the region, which is the absence (low level) of threats to personal security (crimes against persons), and prevention of threats of a sharp loss of social status (in particular, due to unemployment).

Result for the second element: A management model of the socially secure development of a regional socio-economic system is aggregated. The model focuses on human resources (the region's pop-

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ulation). Table 1 shows the relationships embedded in the model. Input factors have an external impact on human resources that characterise the current socioeconomic state of the regional system as a result of management decisions taken by the regional government authorities.

Table 1. A set of indicators of input influence (compiled by the author)

No.	Indicator	Symbol	Units
Environmental factors			
1.	Emissions of harmful (polluting) substances into the atmospheric air from automobile transport	N_1	tons
2.	Investments in fixed assets aimed at environmental protection and rational use of natural resources (protection of atmospheric air)	N_2	thousand rubles
3.	Investments in fixed assets aimed at environmental protection and rational use of natural resources (protection and rational use of water resources)	N_3	thousand rubles
Production factors			
1.	Use of production capacities	P_1	%
2.	Gross regional product (GRP) per capita	P_2	thousand rubles
Infrastructural factors			
1.	Automobile transport (buses)	I_1	units
2.	Automobile transport (cars)	I_2	units
3.	Length of public roads	I_3	km
Social factors			
1.	Number of students in general education institutions that provide catering	S_1	people
2.	Share of healthcare institutions using the Internet in the total number of healthcare institutions	S_2	%
3.	Real accrued wages as a percentage of the corresponding period of the previous year	S_3	%

In turn, how the population reacts to regional governance can be traced if we use a system of resulting indicators of a low-level nature (Table 2), reflecting the social danger of a region (crimes, suicides, unemployment). The low-level indicators reflect the immediate reaction of the population, which can be monitored continuously online and used in managerial decision-making.

Table 2. A set of the resulting indicators (compiled by the author)

No.	Indicator	Symbol	Units
1.	Number of crimes registered in the reporting period under Article 105 of the Criminal Code of the RF (Homicide)	R_1	units
2.	The number of crimes registered in the reporting period under Article 111 of the Criminal Code of the RF (Intended Bodily Harm)	R_2	units
3.	The number of crimes registered in the reporting period under Article 131 of the Criminal Code of the RF (Rape)	R_3	units
4.	The number of crimes registered in the reporting period under Article 213 of the Criminal Code of the RF (Disorderly Conduct)	R_4	units
5.	The number of deaths by major classes and individual causes of death per 100,000 (Suicide)	R_5	people
6.	The number of deaths by major classes and individual causes of death per 100,000 (Cases of Alcohol Poisoning)	R_6	people
7.	Total number of unemployed according to the ILO methodology	R_7	people

The input and output indicators are selected considering the current Decree of the President of the Russian Federation dated February 04, 2021 No. 68 "On assessing the efficiency of senior officials (heads of the highest executive bodies of state power) in the subjects of the Russian Federation and executive government authorities of the subjects of the Russian Federation". The strategy of socio-economic development of the region and the scientific publications dedicated to the assessment of the state of regional socio-economic systems were considered. Thus, the connection of regional socio-economic policy with the state of the social environment of the region is made through the response of the population. The above set of indicators is aggregated into a management model (Figure 2).

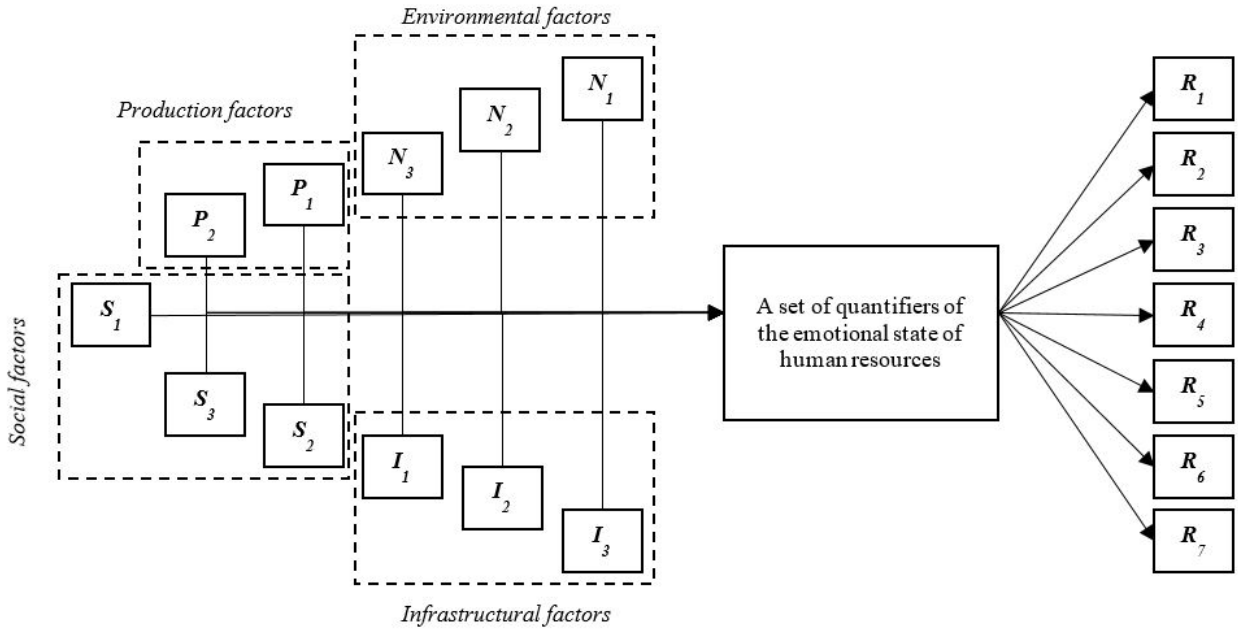

Figure 2. The management model of the socially secure development of a regional socio-economic system

compiled by the author

The central element of the model is an aggregate of quantifiers that measure the impact of management decisions on human resources in the region. These quantifiers can be aggregated based on an analysis of the comparative state of the population's communications in the region. The model can be used to determine how management action on the development factors of regional socio-economic systems indirectly influences the change in the resulting development indicators related to the core of the region's social security.

Results for the third element: A methodology was developed for quantifying the impact that management decisions about regional development have on the information environment generated by the region's population, given social security.

The study highlights the emotional characteristics of human resources as indicators of the responses that the region's population makes to management decisions that change regional development. We propose the following method of their quantification: 1) assess the primary and complex characteristics of tonality as applied to the state of the regional socio-economic system; 2) evaluate the response of human resources to the state of the regional socio-economic system; and 3) calculate the emotional gap indicators of the information unit (Figure 3). The methodology uses mathematical techniques and natural language processing (NLP) methods. Rodionov et al. (2021b) described the methodology in more detail.

The methodology was automated using the Python programming language as follows: stage 1 – search and aggregation of information; stage 2 – processing of aggregated information. The source of reactive information is the social media *VKontakte*. This information resource was chosen due to its width of coverage, which is, on average, 90% at the regional level.

The methodology was tested on the example of the federal city of St. Petersburg. The city was chosen because it demonstrates the significant information activity of the digital media and has significant network coverage of the population. The *Vesti Saint Petersburg* community was selected as a hub of news information. It is officially registered mass media that provides only news information of regional significance and concentrates on the most communicatively active audience, which results in significant amounts of reactive content.

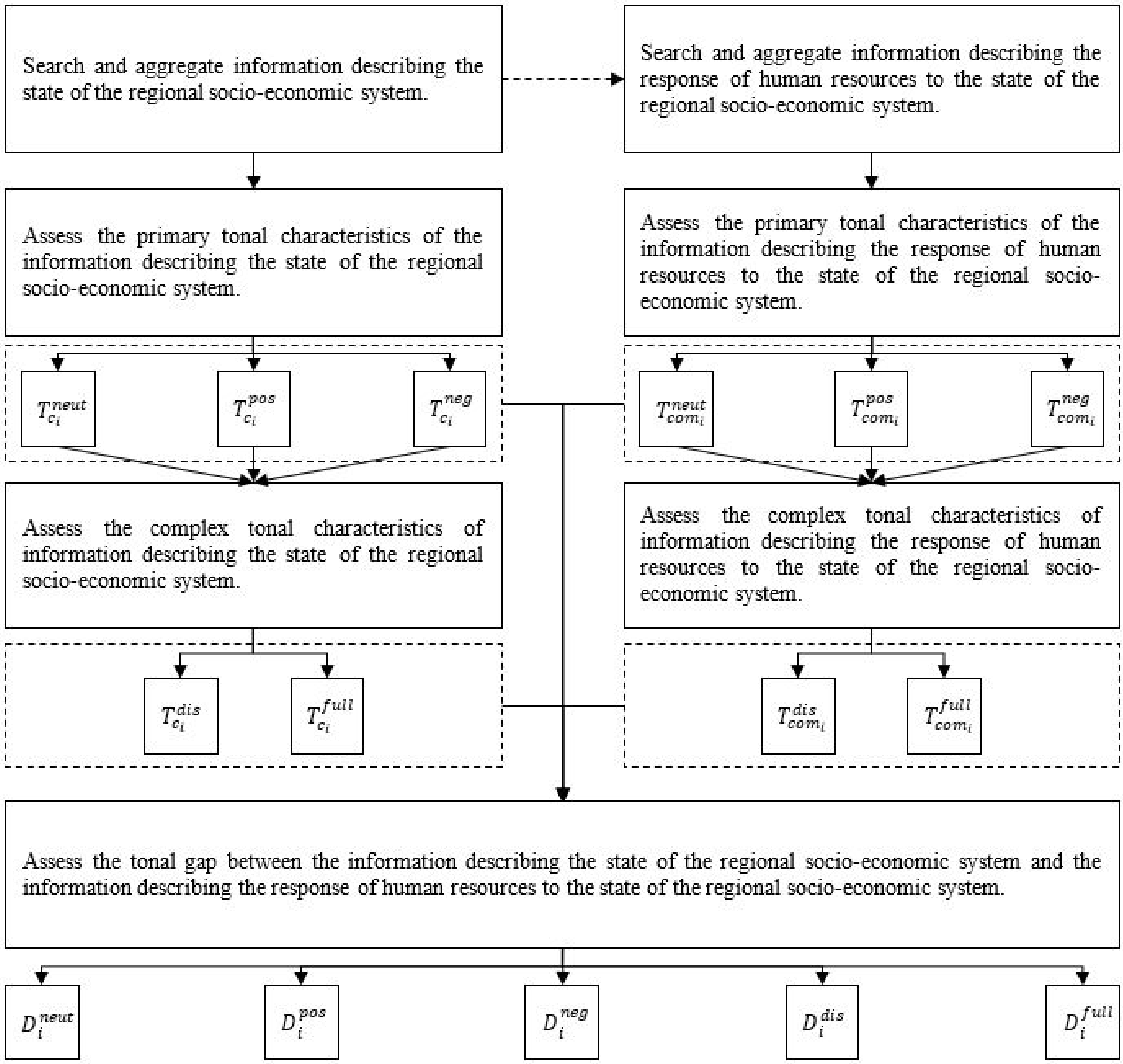

Figure 3. Methodology for assessing the impact of the state of the regional socio-economic system on the information environment generated by human resources

compiled by the author

The presented algorithm was applied to the selected web community, and 56 thousand information units were obtained. The Dostoevsky tool library was used to assess the tonality of the news and reactive information, after which a single data frame was formed. It contains both the tonal characteristics of the source information and indicators of the tonal gap. The results obtained were averaged for the purposes of searching for and describing regression relationships. This methodology, which is based on the extraction of up-to-date information generated by human resources on social media and automated through the Python programming language, can be used for continuous online monitoring of the impact that management decisions have on human resources in the region.

Results for the fourth element: We propose a quantitative tool for implementing the management model of the socially secure development of a regional socio-economic system. For this purpose, we worked out a system of regression equations that are inscribed in the model (Figure 2). Thus, a mathematical interpretation of the model (Figure 4) is provided for the federal city of St. Petersburg.

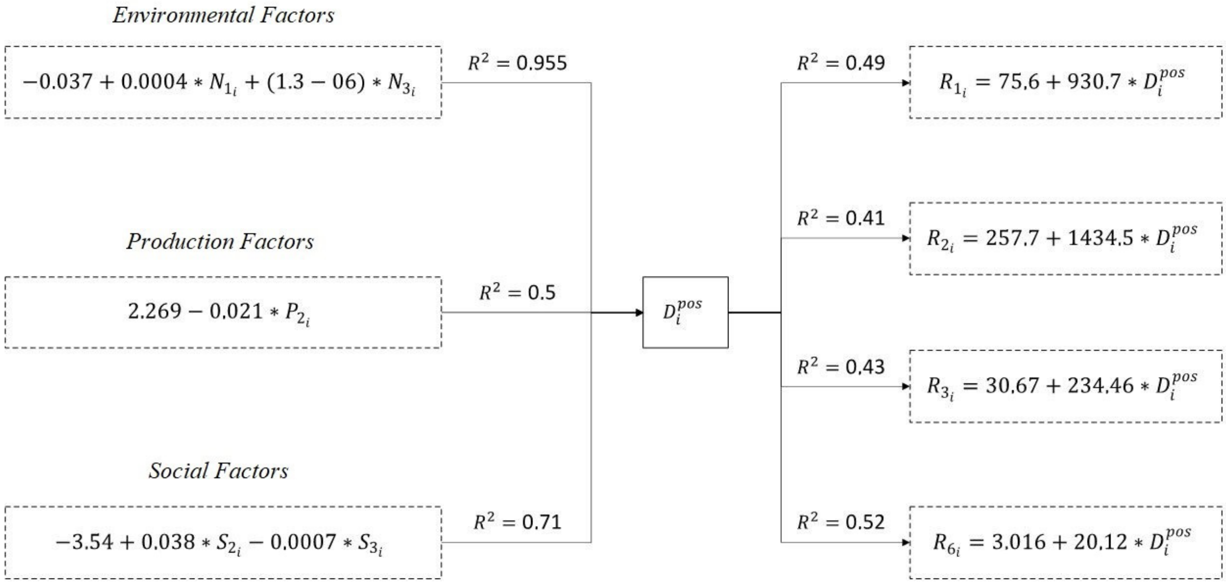

Figure 4. Formalisation of the management model of the socially secure development of the regional socio-economic system

compiled by the author

According to the results of the system of regression equations, the highest quality was achieved when the gap in the level of positive tonality of the information environment was used as a centroid (endogenous variable); therefore, the study presents the analysis of this variable only. The formalised model allowed us to interpret the mutual influence of social, environmental, production, and infrastructural factors of regional socio-economic systems, to establish a hierarchy of the factors in terms of the significance and variability of the management results and to differentiate management decisions given the regional specifics and the level of social security.

Results for the fifth element: Based on the method of online monitoring and evaluation of management decisions, an algorithm was formed for managing the development of regional socio-economic systems, given their social security. Managing the development of regional socio-economic systems implies two processes: analytical and generative. In the analytical process, the tonal gap indicators are continuously monitored, taking into account the information environment of the regional socio-economic system. In turn, the generative process influences the continuous formation of a set of decisions aimed at the development of the regional socio-economic system. Hence, the following control algorithm is proposed (Figure 5).

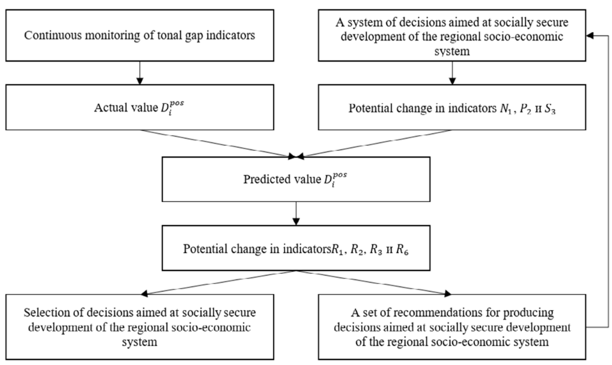

Figure 5. Algorithm for managing the socially secure development of regional socio-economic systems

compiled by the author

The management process includes three stages.

First stage. To assess the potential effectiveness of the analysed decisions, we predicted the change in the key input influence indicators, which were identified during the regression analysis: GRP per capita (P2), emissions of harmful (polluting) substances into the atmospheric air (N1), and real accrued wages as a percentage of the corresponding period of the previous year (S3). Further, we determined the hierarchy of these indicators using the coefficient of determination and the modulus of elasticity. For comparative purposes, we used a weighted approach grounded in the average percentage of change in the base value of the indicator. As a result, we formed a rating, where the indicator with the highest value of the significance coefficient had the highest position, and the indicator with the lowest value of the significance coefficient had the lowest position (Table 3).

Table 3. Conditional rating of input influence indicators

compiled by the author

No.	Influence indicator	Coefficient of determination	Modulus of Elasticity	Average percentage of change	Coefficient of indicator significance	Indicator conditional rating
1	P_2	50	16.6	0.87	954.02	1
2	S_3	71	0.52	3.23	11.43	2
3	N_1	95	1.008	19.24	4.98	3

Second stage. The predictive value of the gap in the positive tonality of the information environment of the regional socio-economic system was estimated on the basis of the previously formed regression equations. The result of the prediction illustrates the impact of the proposed system of decisions on the human resources of the region. The conversion of this change is based on the change in the key resulting indicators of the development of the regional socio-economic system that determines social security.

Third stage. We selected decisions aimed at the socially secure development of regional socio-economic systems and proposed a set of recommendations.

The algorithm we built for managing the development of regional socio-economic systems allows us to continuously monitor the effectiveness of decisions, select from these decisions, and formulate a set of recommendations to clarify the content of decisions aimed at the development of regional socio-economic systems and ensuring the social security of such systems. The algorithm was tested on the example of the regional socio-economic system of St. Petersburg. We assessed the influence that the logistics cluster is expected to have on the core of the region's social security. To determine the changes in the above input influence indicators (Table 3), we used a heuristic approach. We assume that the following changes in these indicators are possible.

The indicator of gross regional product (GRP) per capita is a complex indicator. The development of the logistics cluster means the involvement of many participants, from logistics companies to universities and research institutes. This complexity is expected to produce a synergistic effect that can significantly influence the indicator. Therefore, we should consider a change in this indicator, given the possible alternatives, and assume that the change may range from 0.1% to 0.3%.

The indicator of real accrued wages as a percentage of the corresponding period of the previous year is a pure economic indicator. The increment in this indicator is determined by the increase in demand for skilled labour. The cluster will stimulate such demand, which will also make the indicator of real accrued wages grow from 0.1% to 0.3%.

If the initiative is undertaken, the indicator of emissions of harmful (polluting) substances into the atmospheric air will increase, which will invariably have a negative impact on the regional socio-economic system. However, it can be assumed that better general logistics will prevent inefficient movement of goods, and the gradual development of vehicles powered by electric or hybrid traction will compensate for the overall increase in harmful (polluting) emissions. Thus, we can perhaps ignore the change in this indicator.

In accordance with certain potential changes in the key input influence indicators, we can establish that the actual value of the gap in the positive tonality of the information environment of the regional socio-economic system of St. Petersburg will change by a total of 1.7%. This change will reduce the number of crimes registered in the reporting period under Article 105 of the Criminal Code of the Russian Federation (Homicide) by 1.054%, the number of crimes registered in the reporting period under Article 111 of the Criminal Code of the Russian Federation (Intentional Bodily Injury) by 0.714%, the number of crimes registered in the reporting period under Article 131 of the Criminal Code (Rape) by 0.85%, and the number of deaths by major classes and individual causes of death per 100,000 people (Cases of Alcohol Poisoning) by 0.799%. This example demonstrates the potential effectiveness of the proposed decision aimed at the socially safe development of the regional socio-economic system.

5. Discussion

The findings of this study are logical and consistent. The theoretical results are the basis for obtaining practical scientific results. The study focused on one aim of investigating the socio-economic regional system from the perspective of its social security. This aspect is analysed via the prism of the state of human resources. It is a human being that is the end recipient of the regional socio-economic policy, and it is he who expresses his attitude to what is going on around, doing this unconsciously through his reactions and thus influencing the social situation in the region. The main message of the region's socio-economic policy is to improve the quality of people's lives. Ensuring social security in the region is one of the conditions for implementing this message. It is one of the key ideas of this research study that is put into practice with specific tools.

The state of human resources has been evaluated using non-structured information from social sources, which is not very common in economic scientific research and is usually grounded on structured financial and non-financial information, for instance (Xiaoa et al., 2022: Wang et al., 2023). This information was quantified (turned into quantity expression) using Python. Artificial intelligence technologies have allowed us to include continuous online monitoring of the state of human resources in the management model. Progressive technologies are increasingly utilised to obtain scientific results. For example, Ustugova et al. (2016) applied geo-information technology. However, most studies use traditional economic and mathematical tools for modelling processes (Halonen et al., 2022; Samad et al., 2022). Quite often, researchers work out integral indicators (Pani and Mishra, 2022) that offset some specific features of individual economic entities. To justify the results obtained, given the growing flow of information, we should move to tools that combine classical methods and modern technologies.

The question of selecting input and output indicators for the management model may be debatable in this study. The input indicators are included in four groups: environmental, industrial, infrastructural, and social. The number of indicators is limited in each group (2–3 indicators) and does not fully reflect the state of regional development in each area. This is done so that the model is correct, while these very indicators have been chosen due to their universality, regardless of the specifics of the region and their connection with human resources (the central element of modelling). In the future, input indicators may have to be selected, considering the specifics of a particular region, but this will be another study with a different purpose. In this study, the model was tested on the example of the federal city of St. Petersburg because the development of human resources in this region is a showcase due to a serious scientific and educational base. In this respect, it is one of the reference subjects of the Russian Federation. The resulting indicators were selected due to their low-level nature, which is important in terms of the speed of management of human resources' responses to the socio-economic policy pursued in the region. However, not all social problems common to today's society are included in the modelling with indicators that characterise them. Thus, there are good prospects for improving the management model of the socially secure development of the regional socio-economic system. It is important that such problems be studied by the scientific community (Troisia et al., 2019) so that practical solutions needed by the state and society are elucidated.

6. Conclusion

The findings of the study present the following conclusions:

1. To manage the socially secure development of regional socio-economic systems in an effective way, we need methods that combine traditional approaches and modern technologies based both on the analysis of statistics and non-structured data from the internet about the activities of the region (reactionary and news components).

2. This study proposes a management model for the socially secure development of a regional socio-economic system based on a comprehensive methodological approach. It presents a methodology for quantifying the impact of management decisions on human resources in the region and on social security. Quantitative tools were developed for modelling, and an algorithm for using these tools was suggested. The tools were tested on data about a specific region.

3. The suggested methodological provisions can be used in the process of managing the development of regional socio-economic systems for evaluating and choosing management decisions, given their impact on the core of the social security of the region's population.

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SECTION 4

MANAGEMENT OF KNOWLEDGE AND INNOVATION FOR SUSTAINABLE DEVELOPMENT

РАЗДЕЛ 4

УПРАВЛЕНИЕ ЗНАНИЯМИ И ИННОВАЦИЯМИ В ИНТЕРЕСАХ УСТОЙЧИВОГО РАЗВИТИЯ

Research article
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The Decision Tree Neural Network as Part of a Cognitive Model for Forecasting the Sustainability of the Russian Economy

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Abstract

This study addresses the problem of sustainable economic growth, a subject that is highly relevant in the current conditions of market uncertainty. Given the importance of having an accurate forecast of GDP in uncertain market conditions, this study proposes a digital cognitive model that includes an artificial intelligence (AI) system decision tree for forecasting GDP values. This study aims to test whether using a cognitive model with the application of the AI system decision tree can afford a more accurate forecast of GDP than known forecasting methods. To achieve this goal, this study: 1) investigated the theoretical fundamentals of sustainable economic growth; 2) identified the development trends of AI systems in economics and finance to create the model's dataset; and 3) calculated the forecast value of GDP using the digital cognitive model that included the AI system decision tree. The methodology involves the formation and use of a cognitive model that uses a decision tree neural network based on the Python language in the Google Collab cloud environment. Further, monographic, analytical, and computational-constructive methods were used. The results showed that the developed digital cognitive model, which included an AI system decision tree, was capable of forming GDP forecast values under changing external parameters.

Keywords: digital cognitive model, AI system, decision tree, GDP forecast

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Научная статья

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Нейросеть «дерево решений» в составе когнитивной модели для прогнозирования устойчивости экономики РФ

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Аннотация

Предметом исследования является проблема устойчивого роста экономики. Актуальность в том, что в условиях рыночной неопределенности важно иметь точный прогноз ВВП, который может быть получен на основе применения Digital когнитивной модели, составной частью которой используется AI-система «дерево решений», что обуславливает практическую значимость полученных результатов. Целью исследования является доказать или опровергнуть гипотезу о том, что, используя когнитивную модель, с применением AI-системы «дерево решений», можно получить прогноз величины ВВП. Для достижения поставленной цели были решены следующие задачи: 1) исследовать теоретические основы устойчивого роста экономики; 2) изучить тренды развития систем искусственного интеллекта в сфере экономики и финансов, сформировать датасет модели; 3) рассчитать прогнозное значение ВВП с использованием Digital когнитивной модели, составной частью которой выступала AI-система «дерево решений». Методология, положенная в основу исследования, предусматривает формирование и использование когнитивной модели, которая использует нейросеть «дерево решений», при этом используется язык Python в облачной среде Collab. Кроме того, в ходе проведения научного исследования использовались монографический, аналитический, расчетно-конструктивный методы. Результатами исследования являются: прогнозное значение ВВП, полученное на основе Digital когнитивной модели, составной частью которой использовалось AI-система «дерево решений», способная формировать прогнозные значения при изменяющихся внешних параметрах.

Ключевые слова: цифровая когнитивная модель, AI-система, дерево решений, прогноз ВВП

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1. Introduction

The objects of this study are the economic sphere and the financial sector. One of the important problems with their development is ensuring financial sustainability, which is impossible without an accurate GDP forecast for the next year. To fill the gap, we offer a novel approach to a cognitive model to formulate accurate GDP forecasts to achieve sustainable development of the domestic economy. This is relevant because in conditions of market uncertainty, it is important to have an accurate numerical forecast of GDP, which can be obtained through the use of the digital cognitive model, an integral part of which is the AI system decision tree. The study tested the hypothesis that a cognitive model with the application of the AI system decision tree can offer an accurate forecast of GDP value. To achieve this goal, this study:

- Investigated the theoretical fundamentals of sustainable economic growth.

- Identified the development trends of artificial intelligence (AI) systems in economics and finance to create the model's dataset.

- Calculated the forecast value of GDP using the digital cognitive model, part of which was the AI system decision tree.

- Analysed the obtained results, both from a methodological perspective (what are the limitations, the problems of applying this method, how to eliminate them), and from a mathematical perspective (how big the forecast error is, how it changes).

The application scope of the results is the economic system, the credit and financial sector, the real economy, the business community, investors, and higher education. The use of the results will be of interest to anyone interested in accurate forecasting of the country's GDP for the annual forecast horizon, particularly decision makers who make strategic decisions. Economic and financial systems can become consumers of information generated by the digital cognitive model, an element of which is the AI system decision tree. The formation of forecasts of the GDP value when the input parameters of the model vary in the changing global economic landscape under conditions of market uncertainty is of great importance.

2. Literature review

The Russian economy faces the problem of sustainable development in the environment of increasing market uncertainty and a number of factors caused by the effects of the COVID-19 pandemic, increased economic sanctions by the United States, escalating global military and political confrontation, the appearance of the new technological paradigm "Industry 4.0", and others. Studies show that economic sustainability is a complex and multifaceted concept. Many works of Russian and foreign scientists have been devoted to researching the problems of economic system stability. These problems are reflected in the works of economists such as Gurvich, Prilepsky, Bobylev, M.A. Konishchev, and others (Abdrakhmanova et al., 2019). Improving the mechanism of fiscal policy is certainly an important aspect of the proper work of a financial and economic system. Thus, Nizhegorodtsev et al. (2018) attempted to identify the logic of the system paradigm in the economy, considering Kleiner and Rybachuk's position in *Systemic Balance of the Economy*. Kleiner and Rybachuk proposed a normative model of the distribution of role functions in subsystems by stages of the economic crisis cycle.

The problem of developing a cognitive model of the national financial market with the peculiarities of its structure and the possibility of using it to assess the security of its functioning was studied by Loktionova (2022). The author developed a "target loop with negative feedback" that includes a mechanism of foreign capital inflow to the national financial market, which in its essence demonstrates the interaction between the financial market and the real sector of the economy. Badvan et al. (2018) studied issues of financial market sustainability on the basis of cognitive modelling. The cognitive modelling of factors for financial market sustainability and the construction of cognitive maps were considered by

Emelianenko and Kolesnik (2019).

As research has shown, the use of AI systems is important in solving problems of economic sustainability. Mohammed et al. (2020) found that many industries are in the midst of a digital transformation that emerged as a result of advances in information and data technologies, increased use of computers, and automation through intelligent and autonomous systems based on data and machine learning. This revolution has become widespread in the industry through the use of digital technology, sensor systems, intelligent machines, and intelligent materials in their processes (Mohammed et al., 2020).

In modern conditions, it has become relevant to study the use of AI to ensure the sustainable development of the economy, reducing financial risks in the context of increasing market uncertainty. Abdalmuttaleb and Al-Sartawi (2021) reviewed recent research in the field of the application of AI for stable financing and sustainable technologies. Burova et al. (2021) proposed a cost management mechanism for an industrial enterprise that (1) takes into consideration the high level of environmental volatility inherent in the digital economy and the impact of risks on cost management; (2) can be used to control the level of target costs and make timely adjustments to costs in accordance with changing external and internal conditions to ensure target profitability; and (3) is based on the use of modern and highly accurate tools and methods to assess risks and their impact on the costs and profitability of an IS.

The developed neural network model presented by Lomakin et al. (2019) allows forecasting of the profit of real sector enterprises. The analysis showed that the risk of financial income of enterprises increased in chronological sequence, unstably from the level of 0.4 in the second quarter of 2015 to the maximum of 3.1, with subsequent consolidation to 2.8 billion rubles, with its average value of 2.09 billion rubles. Nadezhina (2021) assessed the risks of integration processes in the EU. Two indicators were used for the quantitative assessment of convergence: 1) convergence and 2) divergence. This is very important in today's environment.

Some aspects of the use of neural networks in the financial sphere intersect with the issues of economic analysis in the financial management system, as noted by Morozova et al. (2017). In the context of the development of the modern economy, for effective operation of an enterprise in conditions of constantly increasing competition, it is necessary to respond to various changes of all factors affecting the enterprise in a timely manner (Morozova et al., 2017). The reliability of the banking sector is an important factor in the financial stability of the economy, and prevention of overdue debt increases is one of the most urgent issues in ensuring reliability. To prevent the development of overdue debts in the credit sector, it is important to assess the creditworthiness and financial stability of an enterprise. Rybyantseva et al. (2017) considered some approaches to assessing the financial stability of an enterprise. The deep risk model proposed by Hengxu et al. (2021) offers a solution for deep learning and the analysis of hidden risk factors while improving the variation matrix estimation. Experiments were conducted on stock market data and demonstrated the effectiveness of the proposed solution. This method allows for obtaining 1.9% more revealed variance and reducing the portfolio risk of the global minimum variance (Hengxu et al., 2021).

An important aspect of financial sustainability, such as the formation of an investment portfolio, remains of interest. Zhan et al.'s (2021) analyses on the development of graphical models of financial time series and portfolio selection are of practical utility. The authors investigated various graphical models for creating optimal portfolios. Graphical models, such as PCA-KMeans, automatic encoders, dynamic clustering, and structural learning, can capture time-varying patterns in the covariance matrix and allow for an optimal and reliable portfolio. By comparing portfolios derived from different models with the methods of the strategy of plotting graphs underlying them, the authors showed steadily increasing returns at a low risk that outperformed the S&P 500 index using the models. This work suggests that diagram plotting models could effectively examine time dependencies in time-series data (Zhan et al., 2021).

Financial risk assessment using the VaR model provides high performance to support managerial decision making in the financial sector. Nakagawa et al. (2020) proposed an approach based on the RM-CVaR model. Variance is known to be the most fundamental measure of risk that investors seek to minimise, but it has a number of drawbacks. Conditional value at risk (CVaR) is a relatively new measure of risk that overcomes some of the shortcomings of well-known measures of variance risk and has gained popularity because of its computational efficiency (Nakagawa et al., 2020).

3. Materials and methods

In the present work, we used research methods such as monographic, analytical, statistical, and cognitive models, including the AI system decision tree, as well as the Graphviz program, which is a package of utilities developed by AT&T Labs for the automatic visualisation of graphs. The main research method applied was the cognitive model. Modelling financial and economic sustainability based on the cognitive model allowed the author to model the problem of supporting managerial decision making in conditions of financial and economic sustainability of the financial system of Russia, the most important prognostic parameter of which is the GDP value.

The study proposes the hypothesis that under conditions of uncertainty and the increase of all types of risk, application of the digital cognitive model that includes an AI system decision tree can accurately forecast the GDP value to support managerial decision making to ensure sustainable economic development. The practical significance of the study lies in the fact that it formed the prerequisites for solving an important national economic problem: forecasting the value of GDP and ensuring sustainable development of the country's economy. Managerial decision making requires the assessment of global risks and the identification of many disparate factors, which can be successfully achieved using the capabilities of the AI system decision tree as an element of cognitive modelling. To achieve this goal, the following tasks were set and accomplished: 1) Theoretical foundations of the financial sustainability of the country's economy and the formation of GDP were studied. 2) The factors determining the stability of economic development were identified. 3) Forecast values of the GDP were calculated using the digital cognitive model, an integral part of which was the AI system decision tree.

As is known, the economic development of countries depends to a large extent on exports. Exports of goods and services provide an impetus for national production, income, and employment, contributing to the economy and GDP growth. The coronavirus pandemic led to an 8% decline in trade in goods and a 21% year-on-year decline in trade in commercial services in 2020. Thus, global exports of manufactured goods declined by 5.2% in 2020, and total exports of goods declined by 7.7% in total. Russia's goods turnover for 2021 was $784.4 billion (of which exports = $491.2 billion, imports = $293.1 billion), which increased by +38.1% compared to the same period of the previous year. Exports from Russia in 2021 amounted to $491.2 billion, which increased by +46% compared to the previous year period.

Studies have shown that the sustainability of the Russian economy is largely influenced by partner countries. The economies of different countries have shown different levels of economic sustainability. Exports of goods from Russia remained below the two-year ago level (-8%), whereas China's exports rose sharply (+31%). The standard deviation calculated from the results of fluctuations in quarterly parameters of the countries' gross domestic product for 2020 reflects the value of financial risk, which can be used to assess the sustainability of a country.

The cognitive model acts as a kind of trigger, which in turn triggers methods as independent modular programmes, in particular the decision tree, which allows for obtaining a forecast value of GDP. The dataset of the decision tree model is shown in Table 1.

Table 1. The set of data for the formation of the dataset of the decision tree neural network (fragment)

Year	Key rate	Increase in bank assets, %	Share of overdue loans, %	GDP, billion rubles	RTS Index	USD exchange rate
2021	8.5	16	23.5	131015	1608	73.7
2020	4.25	16.8	17.8	1073015	1376	73.8
2019	7.25	10.4	5.9	109241	1549	61.9
2018	7.75	6.4	7.5	103861	1157	69.8
2017	8.25	-3.5	9.3	91843	1154	57.6

Table 1 (continued)

Year	Investment in assets to GDP, %	Share of robots in the exchange, %	Capital outflow, billion rubles	Risk (VaR) of the banking system, billion rubles	Banking assets, trillion rubles	GDP forecast, billion rubles
2021	21.2	58	72	-108.5	120	131015.0
2020	16.5	55	53	-72.7	103.7	107315.5
2019	20.6	55	25,2	-77.5	92.6	109241.5
2018	20.6	51	60	-77.1	92.1	103861.7
2017	21.4	51	33,3	-58.8	85.2	91843.2

The data presented in the table were collected manually, but the process can also be automated using a data parsing program. The neural network was generated in the cloud of Google Collab using Python programming language.

4. Results

4.1. Digital cognitive model

To visualise the digital cognitive model, it is reasonable to use the Graphviz program, which is a package of utilities developed by AT&T Labs, for the automatic visualisation of graphs presented in the form of text descriptions. The package is distributed with open-source files and works on all operating systems, including Windows, Linux/Unix, and Mac OS. The code script in the Dot language is shown in Figure 2.

```
digraph G {
Algorithm_for_GDP_AI_forecast ->
Data_collection -> Dataset_for_AI_desicion_tree ->
Decision_tree_architecture->GDP_neuroforecast;
Dataset_for_AI_desicion_tree -> Data_collection;
Decision_tree_architecture-> Dataset_for_AI_desicion_tree;
Error_level -> Dataset_for_AI_desicion_tree;
GDP_neuroforecast->Error_level;
Error_level->Forecast_use }
```

Figure 2. Code script of the digital cognitive model in the Dot language

The visualisation of the digital cognitive model is shown in Figure 3.

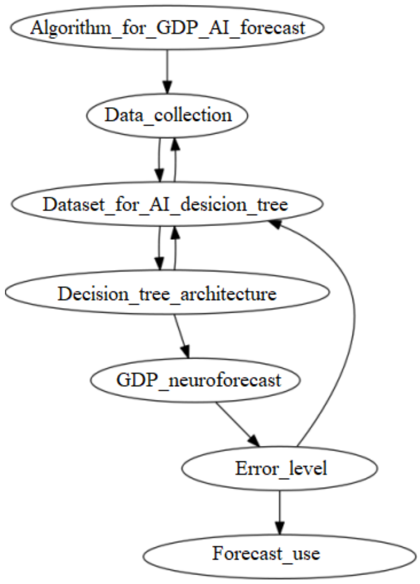

Figure 3. Digital cognitive model

A component of the digital cognitive model is the AI system decision tree, which forms the neuroforecast of the GDP.

4.2. AI system decision tree

Decision trees are based on a non-parametric, teacher-assisted learning method that is used for classification and regression. The goal of this method is to create a model that predicts the value of the target variable on the basis of learning simple decision-making rules derived from the characteristics of the data. The tree can be viewed as a piecewise constant approximation. The deeper the tree, the more complex the decision-making rules and the more accurate the model will be. Decision trees are used for both classification and regression problems. Understanding the importance of variables in random forests has been presented in many works, including that of Louppe et al. (2020).

A binary classification tree (according to regression) (Breiman et al., 1984) is an input-output model represented by tree structure T from random input vector ($X_1 \ldots X_p$), taking its values in ($X_1 * \ldots * X_p$)=X to random output variable Y ϵ *Y*. The tree is constructed from a training sample of size *N* taken from P($X_1 \ldots X_p$,Y), using a recursive procedure that identifies the partition $s_t = s^*$ at each node *t*, for which partitioning the samples of node N_t into t_L and t_R maximises the reduction of some impurity measure *i*(t) (e.g. the Gini index, Shannon entropy, or the variance of Y),

$$\Delta_i(s,t) = i(t) - p_L i(t_L) - p_R i(t_R) \tag{1}$$

where $p_L = Nt_L/N_t$ and $p_R = N_{tR}/N_t$. The construction of the tree stops, for example, when the nodes become pure by *Y* or when all the variables X_i are locally constant.

The AI system decision tree included indicators reflecting the dynamics of the domestic economy: banking assets, in trillion rubles, and the GDP forecast, in billion rubles. Using the code presented below, the initial data were input into the model (Figure 4).

```
import numpy as np
import pandas as pd
# Creating a 2 dimensional numpy array
data = np.array(
[['2021', 120, 131015],
['2020', 104, 107315],
['2019', 93, 109242],
['2018', 92, 103862],
['2017', 85, 91843],
['2016', 73, 85616],
['2015', 77, 83087],
['2014', 49, 79030],
['2013', 50, 72986],
['2012', 47, 68103],
['2011', 42, 60114],
['2010', 25, 44491],
['2009', 29, 38807],
['2008', 28, 41276]
])
print(data)
```

Figure 4. Input of initial data into the AI system decision tree

Using the command "from sklearn.tree import DecisionTreeRegressor", the library "DecisionTreeRegressor" was used, which was imported into Google Collab. The decision tree neural network was successfully generated. Visualisation of the results is shown in Figure 5.

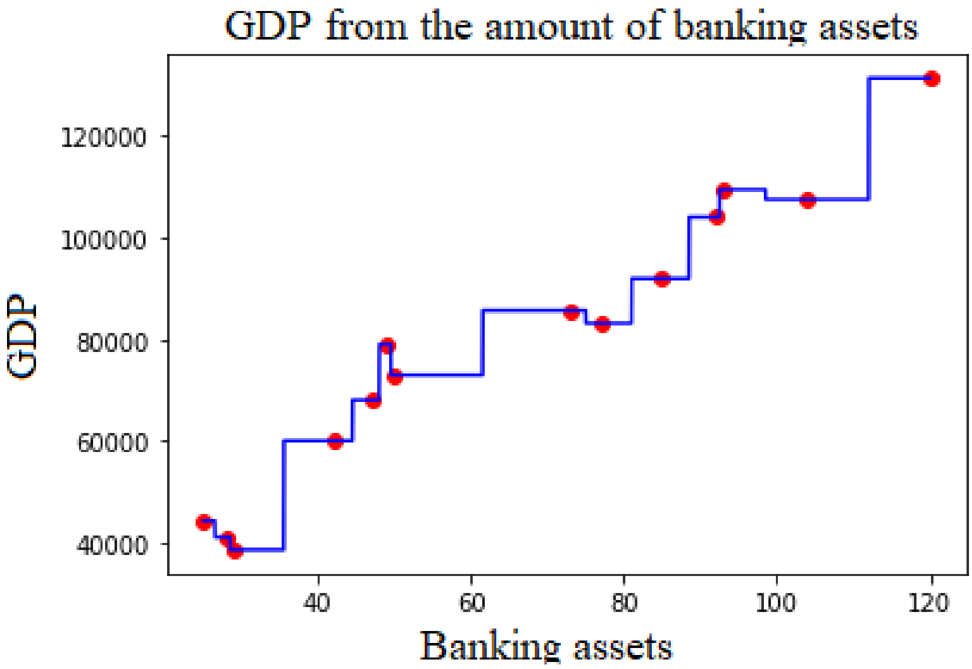

Figure 5. Visualisation of the results of the decision tree neural network

The tree is finally exported and displayed in the tree structure below, visualised using WebGraphviz[1] by copying data from the tree. Below is the first level of the decision tree (Figure 6).

[1] WebGraphviz. Available at: http://www.webgraphviz.com

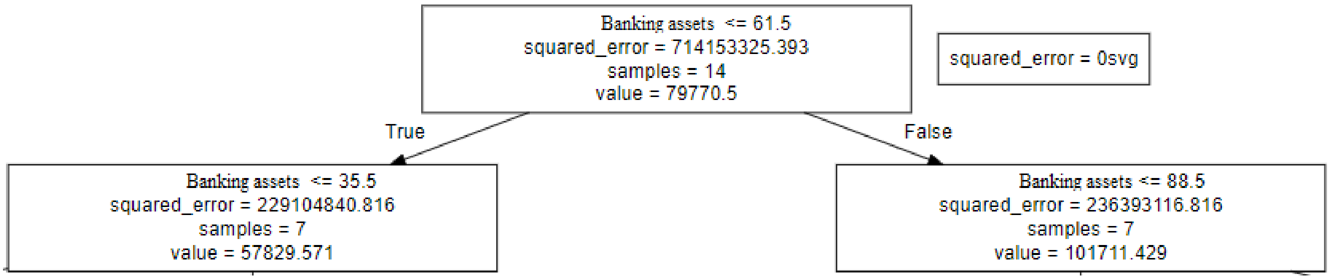

Figure 6. The first level of the decision tree

In full format, the generated decision tree neural network has five levels. To obtain the forecast value of the Russian GDP for the next year, we should use the following code, substituting the recent value of the “banking assets” input parameter. Since, according to experts’ forecasts, banking assets may lose 7 trillion rubles, the value of 113 trillion rubles was used as the input parameter (Figure 7).

```
# predicting a new value

# test the output by changing values, like 3750
y_pred = regressor.predict([[113]])

# print the predicted price
print("Predicted price: % d\n"% y_pred)
```

```
Predicted price:  131015
```

Figure 7. Script for calculating the forecast value of GDP with the AI system decision tree

The forecast value of Russia’s GDP, calculated by the AI system decision tree in 2023, may be 131015 billion rubles, which coincides with the actual value in the previous year. The neural network forecasts a stable level of GDP. In this case, we can assume that the neural network has “learned” all values, and even if the input parameter changes, it “outputs” the value corresponding to the closest value of the GDP on the given leaf of the tree. The overlearning of the model can be explained by some limitations of the dataset, including its small number of values (14 years) in the learning sample. When analysing the obtained results from the methodological point of view, it should be noted that in contrast to well-known classical methods, such as extrapolation and correlation-regression modelling, the use of the forecasting algorithm with decision tree regression has certain advantages. This is because the decision tree is a tree, the leaves of which are the values of the target function, and in the other nodes, the transition conditions (for example, “sex is male”), which determine which of the edges to follow. If, during classification, the resulting classes are in the leaves, then during regression, some value of the target function is in the leaves.

Decision tree models are based on the use of machine learning, which goes beyond the competitions in comparison with classical ones. Machine learning is typically applied to problems such as forecasting, classification, regression, clustering, and association, and various algorithms are used in this analysis, such as logistic regression, simple linear regression, support vector machine, and the naive Bayes algorithm. A prime example is the model based on decision tree regression, which makes a forecast of housing prices in Boston (Sanyal, 2023).

The root mean square error was used to evaluate the quality of the forecasts. This parameter measures the standard deviation of prediction errors (residuals). Notably, the level of the standard deviation of prediction errors varies in different models. For example, the simple linear regression model showed a value of 4.329, the polynomial regression model (degree = 2) showed 4.279, and the ridge regression had an error of 2.888.

5. Discussion

The results obtained in the present study are certainly related to other studies presented in the international scientific arena. By correlating the obtained results with the issues presented in the introduction, we can recommend other advanced neural network models for further research. The convolutional neural network (CNN) is a deep learning algorithm that can take input parameters and assign importance (convenient weights and offsets) to different areas/objects depending on the research goal. The development of the computational power of modern cloud clusters makes it possible to use advanced CNN-based neural algorithms, using parallel computations of the open-source frameworks Hadoop and Spark, to generate complex forecasts in the economic and financial fields.

The concept of the sustainability of the financial and economic system is receiving increasing attention from domestic and international scientists. This is due to the fact that, in the past, the market systems of various countries did not have the degree of volatility and connectivity experienced in the current market, which together lead to the threat of their overall destabilisation and significantly complicate carrying out effective financial and macroeconomic policies. This category is quite complex, so economic science has not yet developed a clear and unambiguous definition of it. Problems related to financial sustainability have been the subject of research by many Western scientists. Among them are John Chant, Andrew Crockett, Wim Duisenberg, Roger Ferguson, Michael Foot, Sir Andrew Large, Frederick Mishkin, Garry Schinasi, and others. For example, Michael Foot identified four criteria of financial sustainability, stating that it occurs when "(a) the monetary system is functioning stably; (b) the level of employment is close to full employment; (c) there is confidence in the stability of key financial institutions and markets; and (d) there are no relative price fluctuations in property and financial resources within the economy which undermines (a) or (b)". The Financial Conduct Authority is the financial regulator in the United Kingdom but operates independently of the UK government and is funded by fees from representatives of the financial services industry (Foot, 2022).

The application of the AI system decision tree and the random forest model is impossible without AI. The use of AI is increasingly evident in the use of robo-advisors, and the financial sector is no exception. Catherine D'Hondt, Rudy De Winne, Eric Ghysels, and Steve Raymond conducted a study on the use of the AI system "Alter Ego" in the robotic investment industry. The authors introduced the concept of AI Alter Egos, which are shadow robot investors. Using a unique dataset covering the brokerage accounts of a large number of investors in the sample from January 2003 to March 2012, including the 2008 financial crisis, the benefits of robo-investing were evaluated (D'Hondt, 2019). One promising area is the use of deep neural networks in banking. For example, Krzysztof et al. (2022) proposed a neural risk assessment in networks of unreliable resources.

In the opinion of the authors, it is reasonable to use an algorithm based on GNN, which is trained only on random graphs generated using the Barabasi–Albert model. Clarkson et al. (2022) proposed the neural network DAMNETS, which is a deep generative model for Markov chain time series. Time series chains are found in many fields, such as trading and payment networks in economics. The use of generative models is helpful for Monte Carlo estimation and for improving the dataset, which is of interest for both data privacy and model fitting. Bingyan (2022) studied the distribution-resistant estimation of expected function values on temporal data. He approximated test functions using neural networks and proved the sampling complexity using Rademacher complexity. Neufeld (2022) proposed the use of reliable statistical arbitrage strategies based on data using deep neural networks. A promising area of research is the risk reduction of a bank's loan portfolio. It is of interest to develop approaches to the study of model risk in loan portfolio models. Meyer (2022) studied model risk in loan portfolio models. His approach suggests a way to deal with uncertainty in all parameters of the model in a comprehensive but easy-implementing way.

The use of the proposed cognitive model provides ample opportunities to use the whole variety of AI systems for supporting managerial decision making to improve economic and financial sustainability. In prospect, the random forest model should be used. A random forest is a learning algorithm with a teacher. It can be used for both classification and regression. It is also the most flexible and easy-to-use algorithm. A forest consists of trees. The more trees are in a forest, the stronger it is. A random forest creates decision trees for randomly chosen data samples, gets a forecast from each tree, and chooses the best solution by voting. Random forest, according to Tongtian Zhu, is a flexible algorithm with a wide range of applications that works well with a large number of datasets (Tongtian, 2020). In addition, random forest is immune to statistical assumptions as well as pre-processing load and can handle large datasets with high dimensionality and missing values.

6. Conclusion

Several conclusions can be drawn from the findings of this study. First, at least in Russia, AI technologies, machine learning decision trees, data management, and others are just beginning to enter the phase of interest and demand. In particular, this trend is confirmed by the growing demand for DataOps engineers and the state trend towards digitalisation. Second, the use of the digital cognitive model, an integral part of which is the AI system decision tree, is important for achieving sustainable economic growth based on the forecast of GDP of the country because it contributes to improving the mechanism of fiscal policy and competitiveness of the domestic economy as a whole, providing a high accuracy of the forecast. Third, the use of the results of the digital cognitive model, an integral part of which is the AI system decision tree, offers a wide range of applications of the whole variety of AI systems to provide managerial decision support to improve the sustainability of the economy and the financial sector. Lastly, the results obtained are of practical importance; the developed algorithm can be used for GDP forecasting. The areas of the result application are the economic system, the credit and financial sector, the real sector of the economy, the business community, investors, and higher education. Researchers investigating the problems of obtaining accurate forecasts of the domestic GDP value for the annual forecasting horizon, particularly stakeholders of strategic decisions, will be interested in the use of the results from this study.

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