Problems of Construction of Smart Innovative Enterprises

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Abstract

The purpose of the scientific work is to study problems of smart management and design of integrated intelligent information management system of smart innovative enterprises. The approaches to formation of the smart management process are studied. These approaches investigation additionally proofs the importance for modern business conditions to design the management model that provide economic efficiency of enterprises. The interpretation of the concepts of digital factory, smart factory and virtual factory has been further developed. To perform the tasks of the "virtual factory" for the management of smart innovative enterprises in general, it is proposed to use the intelligent information management system of innovative enterprises as part of integrated intelligent information management system of smart innovative enterprises. Based on the system model, the organizational structure of the intelligent management system of smart innovative enterprises has been developed. It will make it possible to design, construct and restructure the intelligent management systems of smart innovative enterprises as a whole and their units in to adapt them to modern business conditions. The study of smart and sustainable manufacturing of enterprises based on its integral index was tested. The methodological basis of the investigation is a set of general and special methods of scientific researches. The implementation of these methods is caused by the goal and logic of problems solving for smart management and design the system of smart innovative enterprises that are based on the using of Industry 4.0 concept. The theory of Markovian stochastic processes using the Chapman-Kolmogorov equation systems was used as a mathematical tool to evaluate efficiency of smart management. Based on this mathematical tool, the software for evaluation and prediction of state of smart innovative enterprises development was presented and tested for adequacy. The prediction results can be used to support managerial decision-making, developed software can be incorporated into the structure of the intelligent management system of smart innovative enterprises and applied for the study of sustainable manufacturing of enterprises.

Keywords

Smart innovative enterprises, smart management, sustainable manufacturing, digital factory, smart factory, virtual factory, integrated intelligent information management system, Industry 4.0

1. Introduction

Smart enterprise today is Smart Management, IT data platforms and real management knowledge, sources of business processes (production, distribution, sales) combined. Knowledge management IT platforms provide: read measurement values from all data sensors and import data from the database; processes, calculates all indicators and models of business/production/sales; evaluates the results and condition of business facilities (products, customers, suppliers, technology, finance, social networks, environment, quality and enterprise in general); corrects results in smart management on regular mobile devices with clear identification and if "yes", then "where" and "why". Smart management

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takes into account real events and, if something is "wrong" in accordance with the planned goals, analyzes business processes and implements management influences aimed at achieving goals. It is worth noting that over the past few decades, production has progressed rapidly, it has become more automated, computerized and complex, thanks to improved information technology, production methods and technologies, equipment and facilities, new and improved materials, improved understanding of process characteristics through analysis big data. This allowed the use of new production methods (cyber production and distributed production), new production processes (production of various additives and hybrid production) [35]. Modern methods of production and organization of technological processes equipped with sensors, computational methods, new materials, data analytics, artificial intelligence, organizational management and communication technologies form a smart manufacturing [3]. That is, smart manufacturing is a new form of production that combines today's and tomorrow's production assets with sensors, computing platforms, communication technologies, modeling, intelligent engineering, data intensive modeling, and management. It uses the concepts of cyber-physical systems, the industrial Internet of Things, cloud and service-oriented computing, artificial intelligence and data science [2, 41]. Smart manufacturing systems are fully integrated production processes that respond in a timely manner to the changing requirements and conditions of the enterprise, supply chain, consumer needs [38]. Smart manufacturing allows you to get all the information about the production process, when it is needed, where it is needed, and in the form in which it is needed throughout the production chain, to make optimal decisions [4]. Such technological progress will allow a wide range of industries to reduce costs, improve quality, increase productivity, improve material management, increase efficiency, reduce energy consumption and improve the health and safety of workers [3, 40]. Continuous monitoring and improvement of key performance indicators (KPIs), improvement of sustainability indicators of smart manufacturing systems will help in this. Sustainable manufacturing requires a KPI balance, covering economic, environmental and social efficiency [11]. However, smart and sustainable manufacturing systems are complex in nature, often due to diverse, heterogeneous technological processes that form quantitative indicators of the production process, ensuring data integrity, so to establish the relationship between systems and subsystems is extremely difficult [1, 39]. The evolution of manufacturing, new processes, materials and assistive technologies are developed based on the needs of today. Additional efforts are being made to quantify metrics, model systems and subsystems, and to develop methods for quantifying performance indicators. To address these shortcomings, the US National Institute of Standards and Technology (NIST) is working on [53]: developing standard intelligent methods of measuring production; modeling and characterization of smart manufacturing; developing guidelines on methods, metrics and tools that enable production stakeholders to assess and ensure the cybersecurity of smart manufacturing systems; developing methods and approaches to the integration of smart manufacturing systems. In addition, the developed standards of ASTM (American Society for Testing and Materials) led by NIST (National Institute for Standards and Technology) [42, 43] guide companies to assess and characterize the sustainability of manufacturing processes and supply chains. That is, the essence of smart manufacturing is based on intelligent technologies and production processes, its monitoring, materials, data, sustainability, resource and network sharing. Since today smart enterprises are divided into smart manufacturing, digital and virtual enterprises [37, 44], in the work, based on the concept of smart manufacturing, digital and virtual enterprises, it is proposed to develop projects to build smart innovative enterprises. The structure of the innovation process is proposed to be based on the structure of the innovation process, which includes: idea generation, knowledge transfer, research (basic and applied research), design and research work, diffusion of innovations and technologies, technological preparation of production, production, marketing and commercialization of innovative products, its implementation, use, modernization and renovation. This will help build smart innovative enterprises (SIE) through the effective integration of digital, smart and virtual enterprises.

2. Literature Review

Many scientists have studied the problems of building smart enterprises based on the concept of smart manufacturing, digital and virtual enterprises, which is the basis of Industry 4.0 [8, 10]. Andrew

Kusiak [2, 3], Shreyanshu Parhi, Kanchan Joshi, Milind Akarte [38], Zakoldaev D.A., Korobeynikov A.G., Shukalov A.V., Zharinov I.O. [54] explore concepts "smart factory", "smart manufacturing" and "factory of the future". D. Kibira, M.P. Brundage, S. Feng, and K.C. Morris [12], Hugh Boyes, Bil Hallaq, Joe Cunningham, Tim Watson [21], Sathyan Munirathinam [37], Steve Ranger [45] argue that "smart manufacturing" and "industrial Internet of Things" are at the heart of Industry 4.0 today. Y. Lu, K.C. Morris, and S.P. Frechette [54] point out that attempts are being made today to divide the factories of the future into three main types – digital factory, smart factory and virtual factory. Stephen Furber [44] emphasizes the use of artificial intelligence, machine learning and the Internet to construct smart enterprises. Erum Mehmood, Tayyaba Anees [14], Saeed Shahrivari, Saeed Jalili [36], Tongya Zheng, Gang Chen, Xinyu Wang, C.Y. Chen, Xingen Wang, Sihui Luo [50] explore intelligent big data processing technologies that provide new knowledge for decision making in the form of more objective and scientifically sound smart decisions. David Tegarden, Barbara Haley Wixom, Alan Dennis [5], Maria Rashidi, Maryam Ghodrat, Bijan Samali and Masoud Mohammadi [6], Deepika Verma [7] think that distributed artificial intelligence, integrated intelligent information systems as multi-agent systems are the most suitable class of models for the implementation of smart management functions.

Based on the analysis of recent research and publications, it can be concluded that the key aspect of constructing a SIE can be attributed to:

- the concept of smart industries, digital and virtual enterprises, their effective integration;
- intellectualization of all SIE activities;
- big data mining and multicriteria decision analysis;
- construction of an integrated intelligent information system (IIIS).

3. Methods

To construct smart innovative enterprises in the work used: the concept of smart manufacturing, digital and virtual enterprises; methodology of structural design, which combines natural and artificial intelligences and allows: to intellectualize all the processes of SIE; to carry out intellectual analysis of big data and multicriteria analysis of decisions; intellectualize the organizational management of the SIE in general; take into account the possibilities of intellectualization of all stages of management and, accordingly, to build an integrated intelligent information system (IIIS).

The theory of Markovian stochastic processes using the Chapman – Kolmogorov equation systems, based on them dynamic and static mathematical models solved by computer technology, used to support decision-making on the condition of development of SIE or any element of their hierarchy and on the choice of managerial influences on these states.

Cognitology methods have been used to develop the intelligent information system (IIS), according to which IIS is proposed to be considered as a logical-cognitive model of a social agent, and integrated IIS as multi-agent systems based on synthesis of natural and artificial intelligence and take into account adequate formalization of decision-making processes.

4. Results and Discussion

It is proposed to build smart innovative enterprises on the basis of the concept of smart industries, digital and virtual enterprises, their effective integration. The concepts of "smart factory", "smart manufacturing", "factory of the future" [3, 38, 54] appeared very recently and do not yet have clear definitions. Now they are used as synonyms, although the concept of "factory of the future" is more voluminous and includes not only "smart manufacturing", but also digital and virtual enterprises.

The concept of "smart production" means fully integrated corporate production systems that are able to respond in real time to changing production conditions, supply chain requirements and satisfy customer needs. That is, in real time, as quickly as possible, the planned goals are achieved through the intensive and comprehensive use of information technology, "Industrial Internet of Things" and cyberphysical systems at all stages of production and supply products. "Smart manufacturing" and "Industrial Internet of Things" are today the basis of Industry 4.0 [12, 37, 45], which is characterized by fully automated production, where management of all processes is carried out in real time and taking into account changing external conditions. Industrial Internet of Things (IIoT) [21, 37] means a system of integrated computer networks and connected industrial (production) facilities with built-in sensors and software for collecting and exchanging data, with the possibility of remote control and management in an automated mode, without human intervention.

The concept of "smart manufacturing" is quite vague (sometimes it means active robotics, automation of most production and management processes and even just innovation), and the transition to it occurs in several stages, which takes more than one year. Today, attempts are being made to divide the factories of the future into three main types - digital, smart and virtual [46, 54].

The main task of the "digital factory" - the development of models produced using digital design and modeling [26, 34, 52]. These tools begin to be used at the stage of research and development, and end with the creation of digital mock-up (DMU), digital twin, research sample, production of small series or individual products to customer requirements.

"Smart factories" are aimed at mass production, but while maintaining maximum flexibility of production. This is ensured by a high level of automation and robotics of the enterprise. Automated control systems for technological and production processes are widely used. Industrial Internet of Things (IIoT) technologies provide machine-to-machine interoperability, integration of Digital Factory with Smart Factory [30]. The production assets of an enterprise equipped with sensors and means of communication are able to produce products almost (or not at all) without human intervention. Big Data technologies allow to cope with sharply increased information flows coming from sensors and automated control systems [14, 36, 50].

"Virtual factory" is an integrated structure for the design and analysis of production systems [47], which is a network of digital and "smart" factories, which also includes suppliers of materials, components and services. A number of automated enterprise management systems are used in such a factory to manage global supply chains and distributed production assets. With the right degree of integration, they allow you to develop and use a virtual model of all organizational, technological, logistics and other processes that take place not only in the enterprise but also at the level of distributed production assets and global supply chains, up to after-sales service. This provides integrated management of business processes, products and development of production systems, the implementation of the functions of smart management.

With the emergence of digital ecosystems, manufacturing enterprises from isolated systems, which independently perform all the necessary business processes for production, will be transformed into open systems that connect different market participants. The means of production of such systems will be managed not by personnel, but by cloud services. The ultimate goal of all these transformations is not production, but the provision of services to consumers [37, 45]. Therefore, today, based on the concept of digital factory, smart factory and virtual factory, it is advisable to develop projects to build new enterprises and such enterprises could be SIE.

Smart innovative enterprise (SIE), therefore, is a management approach focused on the use of new technologies for the development of innovative enterprises. Because today, entrepreneurs need new creative ideas and solutions that would accord the requirements of a world that is changing every second. We are talking about the use of artificial intelligence, machine learning and the Internet [44, 46] – all the latest technologies that help to more effectively implement innovative processes of innovative enterprises. All this will provide employees of the innovative enterprises: the ability to automate innovation processes and implement machine learning algorithms in all areas of the innovative enterprises; digital platform that will facilitate data management and integration of components of the innovation process; intelligent technologies that analyze data and provide the most accurate real-time results for the required transactions. It should be noted that the use of artificial intelligence in the innovative enterprises will help to more quickly analyze a variety of situations and make more informed decisions, closely link analytics with semantic and logical processes of information processing.

Because only information based on reliable data is the basis for a variety of tactical and strategic operations, this leads to lower costs, reduced risks and reliable data that provides a deeper understanding of the innovation process. Therefore, the structure of the SIE is proposed to be based on the structure of the innovation process, which would be managed at all stages of its organization by an integrated intelligent information management system of smart innovative enterprises (IIIMS SIE) (Fig. 1).

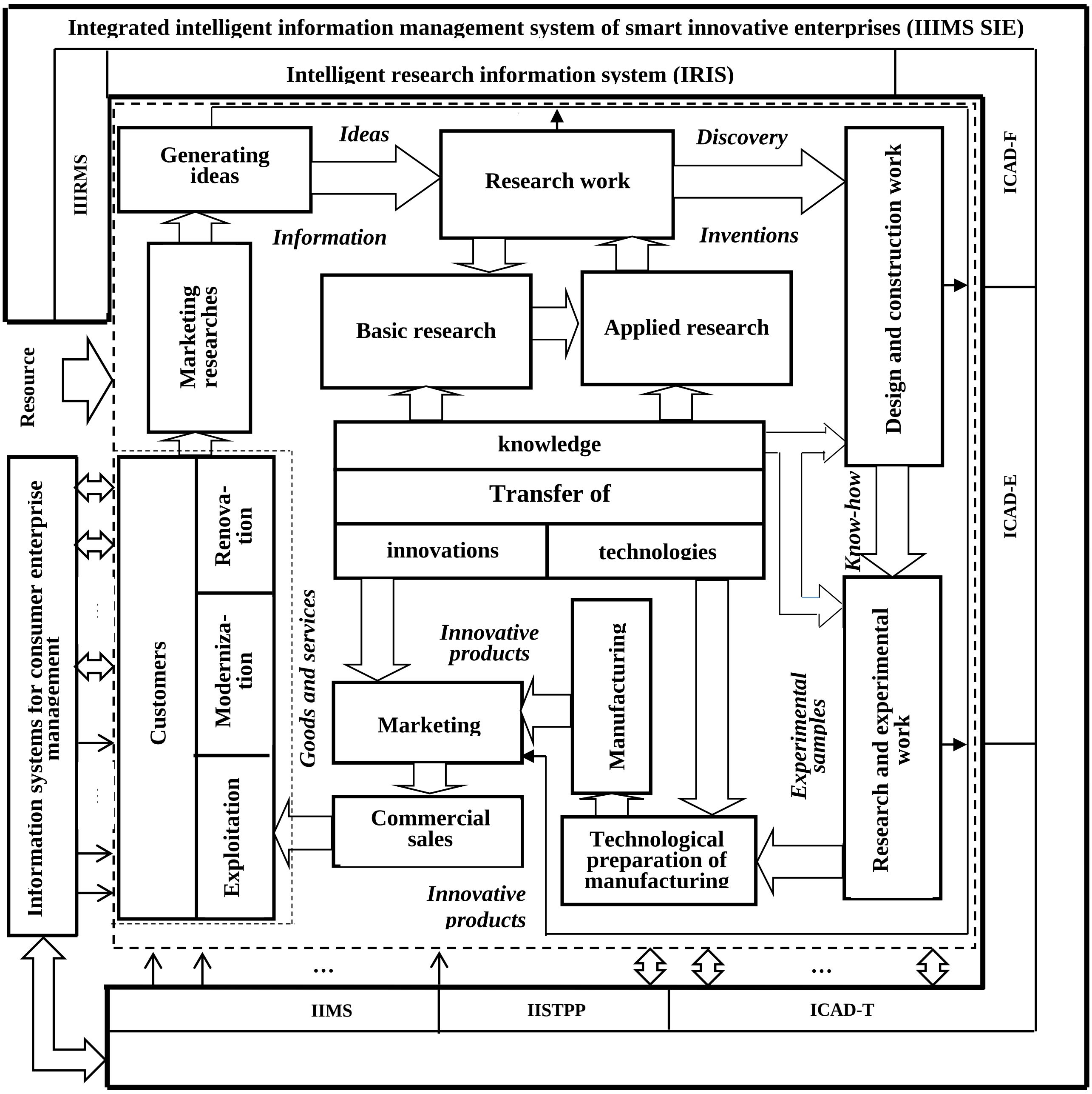

Figure 1: Organizational structure of a "smart innovative enterprise"
Source: own elaboration.

According to the given structure, the components of the innovation process include: generating ideas; knowledge transfer; research work, which includes basic and applied research; design and research work; technological preparation of manufacturing and manufacturing; marketing and support of innovative products for consumers during its operation, modernization and renovation; audit of innovative goods and services in order to complete i $(i = 1, 2,...)$ innovation cycle $(ІЦ_i)$, start $ІЦ_{i+1}$ and ensuring the spiral development of innovative enterprise (Fig. 2), where I_1, I_2, ...– idea *1*, idea *2*, ..., idea *i*, ...

It is impossible to organize a full innovation cycle in some enterprises, so it is proposed to include innovation units in the structure of such enterprises, which would be engaged in the transfer of knowledge, technology and innovation (resource, process, product, marketing, management, organizational, diffusion etc.).

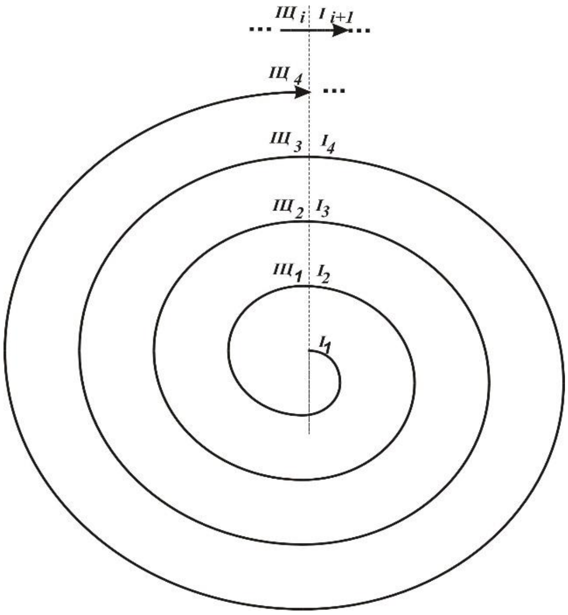

Figure 2: Spiral model of development of innovative enterprises
Source: own elaboration.

IIIMS SIE of the proposed structure should intellectualize the automation of all stages of the innovation process, so it is proposed to include: intelligent information resources management system (IIRMS); intelligent research information system (IRIS); intelligent design automation system (ICAD), the components of which may be an intelligent automation system of functional design (ICAD-F); intelligent system of automation of design engineering (ICAD-E) and intelligent system of automation of technological design (ICAD-T) or intelligent information system of technological preparation of production (IISTPP); intelligent information production management system (IIPMS) and intelligent information marketing system (IIMS).

In the development of IIIMS SIE it is advisable to use innovative methodologies and tools inherent in Industry 4.0 [12, 37, 45]. In particular, those that would provide all stages of the innovation cycle: generating ideas and research; designing; production planning and preparation; manufacturing; marketing; implementation; installation, commissioning and operation; technical support and modernization, diffusion of innovations, utilization and recycling. That is, the tasks of "digital factories", "smart factories" and "virtual factories" can be implemented by means of IIIMS SIE.

The tasks of the "digital factory" here can be performed by IRIS, ICAD-F, ICAD-K and ICAD-T based on the following systems and technologies [9, 46]:

- systems CAD/CAM/CAE as computer-aided design systems (CAD), where CAE (Computer Aided Engineering - computer systems of engineering analysis) - CAD-F computer systems for automation of engineering calculations, analysis and functional design; CAD (Computer Aided Design - design with the help of a computer) - CAD-K system of geometric modelling, drawing and design works; CAM (Computer Aided Manufacturing) - CAD-T technological preparation of production;
- PDM (Product Data Management) – product data management system;
- PLM (Product Lifecycle Management) – application software for product lifecycle management.

IIPMS are able to perform the tasks of "smart factories", which can use the following basic systems and technologies:

- IISTPP – intelligent information system of technological preparation of production;
- MRP-2 (Manufacturing Requirement Planning) – manufacturing planning and material requirements;

- APS (Advanced Planning and Scheduling) – synchronous (advanced) manufacturing planning;
- MES (Manufacturing Execution Systems) – manufacturing executive system designed to solve operational tasks of design, production and marketing management;
- SCADA (Supervisory Control and Data Acquisition) – a system that performs dispatching functions (collection and processing of data on the state of equipment and technological processes) and helps to develop software for embedded equipment;
- CNC (Computer Numerical Control) – system of direct software control of technological equipment on the basis of controllers (specialized (industrial) computers) built into technological equipment with numerical software control;
- IIoT (Industrial Internet of Things);
- Big Data.

The tasks of the "virtual factory" can be implemented by IIRMS and IIMS based on the following systems and technologies:

- AEMS – automated enterprise management systems;
- ERPII (Enterprise Resource Planning) – supports all business processes of the enterprise: planning, financial management, sales, production, logistics, operations, relationships with customers and suppliers, reporting, etc., developed on the basis of ERP (Enterprise Resource Planning) – enterprise planning and management and includes SCM (Supply Chain Management) and CRM (Customer Relationship Management).

The intermediate position between automated enterprise management systems and automated process control systems is occupied by the production executive system MES (Manufacturing Execution Systems), designed to solve operational problems of design, production and marketing management. Data management in the integrated information space during all stages of the product life cycle is entrusted to the product lifecycle management system PLM (Product Lifecycle Management). A characteristic feature of PLM is the interoperability of different automated systems of many enterprises, i.e. PLM technologies (including CPC technologies, collaborative product commerce) is the basis that integrates the information space in which CAD, ERP, PDM, SCM, CRM and other automated enterprise systems operate. That is, the PLM system can be the basis for the construction of IIIMS SIE.

The world is changing faster and faster, there are no more adequate ideas and ways of working yesterday. This is due to the rapid commercialization of products and services, convergence of strategies. Firms that rely on yesterday's ideas, yesterday's products and yesterday's assumptions are very vulnerable today [49]. Creative thinking and generating ideas are at the heart of innovation today. Intelligent information systems of scientific research today must formulate qualitative ideas, expand opportunities for the formation of new questions based on available answers, including questions that have not been asked before. The ideas here should be understood as a general idea of a possible innovative product that the SIE could offer to the consumer [20].

The process of generating ideas, which in SIE should be based on modern methods of generating ideas [32, 51] on innovative goods and services, begins with their emergence (emergence, creation), constant and systematic search, accumulation, selection and formation of a portfolio or bank of ideas [23, 33] in IRIS.

The sources from which ideas can come in IRIS are proposed to be divided into two groups:

- external, which may include entities with which the SIE interacts or which influence its activities. At the SIE among the divisions that work with external sources and where they get ideas for new products, we can single out the divisions of R&D, diffusion of innovations and technologies, marketing, sales and supply;
- internal, which include processes in SIE, namely the results of the units on the basis of which employees form ideas for a new product or service. In this case, it is proposed to include in this group units of strategic planning and development, research, design and experimental work, technological preparation of production and production units. These are the most important departments that are well aware of the advantages and disadvantages of SIE, its financial, technical and production capabilities assess the current state and prospects.

Smart innovative enterprises need to constantly look for new ways to generate ideas in order to become more competitive. Researchers and practitioners advocate open approaches, involving outsiders, crowdsourcing platforms for innovation and ideas, where crowdsourcing is an opportunity to get ideas from external sources [29]. That is, IRIS with the right tools and features should not only speed up the quantity but also the quality of ideas. Outsiders in the innovation process are seen as a powerful tool to increase success and revenue from new proposals.

IRIS is an intelligent support system for research conducted in order to formulate and store ideas, their selection and implementation. IRIS can use a variety of platforms, including online platforms for crowdsourcing and identifying the best of a number of ideas. It is important here to use modern research methods to substantiate the further promotion of ideas at all stages of the innovation process. IRIS models expert opinions and takes into account the specifics of the problems to be solved. She uses advances in artificial intelligence and machine learning to conduct her chosen experiments to increase the accuracy and effectiveness of her research. This fundamentally changes the paradigm of scientific research from the search for laws based on hypotheses to the construction of empirical models based on data on the objects of study. Many systems to be studied have too many variables and are too complex for people to comprehend and use in a timely manner. Therefore, IRIS is becoming relevant as a set of automated methods for building empirical models based on intelligent processing of big data in real time.

Today, there are two categories of technologies that take into account the processing of big data, it is batch and streaming [14, 36, 50]. Streaming deals with continuous data and is a tool for converting big data into fast data. The batch model requires a set of data collected over time. Streaming requires the receipt of data in IRIS micropackets or in real time. Batch processing is often used when working with large amounts of data or legacy data sources where data cannot be delivered by streams. In both cases, all data must be uploaded to a specific type of storage, database, or file system, and then processed. Data streams can also be involved in processing large amounts of data, but batch mode works best when real-time analytics are not required. Streaming is responsible for processing data in dynamics and fast delivery of analytical results, it generates almost instantaneous results.

Both models are valuable, and each can be used to solve different situations. Therefore, IRIS is proposed to be used as an intelligent real-time data processing system based on obtaining, processing, analyzing and making real-time decisions. IRIS as an intelligent real-time data processing system must be equipped with a big data package platform, data analysis tools and machine learning models.

Research sometimes has to be conducted in areas with poorly formalized knowledge, but the analysis of empirical data in order to make optimal decisions in these areas is necessary. In this case, it is advisable to use information systems that perform intelligent analysis of empirical data, in particular intelligent systems based on the JSM-method [24, 28]. Existing intelligent JSM systems (IntJSM) are proposed to be integrated into IRIS and they should include:

IntJSM = Task solver + Information environment (fact base (BF) and knowledge base (BK) + Intelligent interface (dialogue + presentation of results + work training).

To perform the tasks of the "virtual factory" to implement the functions of smart management, it is proposed to use the appropriate intelligent information management system of smart innovative enterprises (IIMS SIE), the structure of which is shown in Fig. 3 and which can be integrated into the IIMS SIE. Object-oriented integrated and distributed databases and knowledge bases, expert systems, decision support systems (DSS), integrated neural networks and fuzzy logic tools can form the basis of the tools needed to design and operate IIMS SIE. DSS allows you to model and automate decision-making processes, model and automate SIE management processes in general. Distributed artificial intelligence, integrated intelligent information systems as multi-agent systems [5-7] are the most suitable class of models for the implementation of integrated IIMS SIE. Therefore, it is advisable to consider IIMS SIE as a logical-cognitive model of a social agent, and integrated IIMS SIE as a multi-agent system.

A modular structure was chosen to build the IIMS SIE, which will provide it with flexibility, adaptability to environmental conditions and survivability. The structure of decision support modules (modules M_3 and M_4), which are able to support decision making and explanation, is proposed to include: subsystems of knowledge accumulation of the first and second kind, knowledge base, user interface, subsystems of decision making and explanation. Necessary decisions when using IIMS SIE will be made on the basis of expert knowledge, which, respectively, can be highly qualified specialists in relevant fields of knowledge (knowledge of the first kind), as well as knowledge obtained based on a priori information and research results of SIE (knowledge of the second kind).

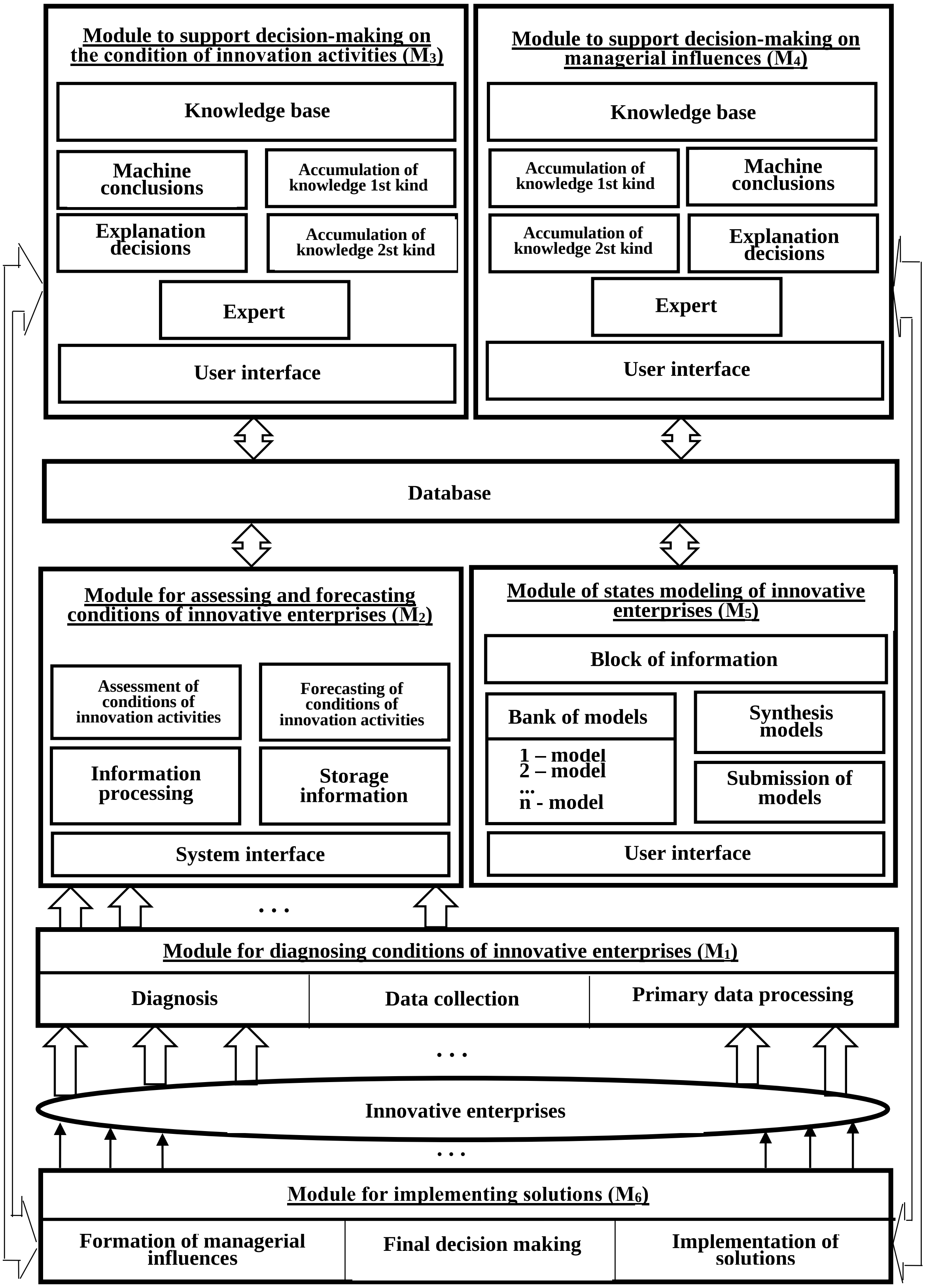

Figure 3: Structure of intelligent information management system of smart innovative enterprises (IIMS SIE)

Source: own elaboration.

This knowledge can be formalized and entered into the knowledge base as knowledge on the basis of which the M_3 module supports decisions about the state of SIE, and the M_4 module - about the managerial influences on them, which are implemented by the module. M_6.

Management decisions about SIE states in general, or any element of their hierarchy, in IIMS SIE with the proposed structure can be supported by using Monte Carlo modeling, discrete modeling, modeling dynamics and statics of systems [7, 10], digital business models and visual modeling, operations research (simulation, business games, stochastic programming), decision trees, impact diagrams, fuzzy logic tools, agent-based and multi-agent modeling [12, 13, 16, 17].

Research of dynamic and static characteristics of real states of SIE with the subsequent acceptance of administrative decisions is carried out by means of IIMS SIE. Data collection, their initial processing, in order to clarify management problems, is carried out by means of the M_1 module - the module for diagnosing SIE conditions. Storage and processing of collected data, further assessment and forecasting of SIE conditions is carried out by means of the M_2 module. If real research cannot be implemented then it is proposed to use virtual information from the information block and modulate virtual states of SIE by means of the M_5 module. This will facilitate further assessment and forecasting of possible conditions, situational decision-making and their implementation by means of the M_6 module. If the information on SIE states is well structured, mathematical methods are used to process this information and further choose management solutions, and if the problem is poorly structured or unstructured, it is suggested to use expert judgments and evaluations to prepare solutions [15, 18, 19]. Given that the dynamics of SIE conditions is stochastic [31], to predict SIE conditions in order to further make optimal decisions, the most suitable models may be based on mathematical methods of the theory of Markovian stochastic processes using systems of the Chapman–Kolmogorov differential equations [22, 25 , 27, 48].

This mathematical apparatus was tested in the study of the sustainability of the Public Joint Stock Company "Concern Electron" (PJSC "Concern Electron", Lviv) on the index of sales of innovative goods and services (% compared to the previous year, 2017-2021). In a study of 9 enterprises, we found that 2 enterprises in 2017 were in status $S_1(BC)$, 4 enterprises - in status $S_2(C)$, 3 enterprises - in status $S_3(HC)$. In this case: *BC* - the number of enterprises in which the index of sold innovative goods and services was higher than average; *C* - the number of enterprises in which the index of sales of innovative goods and services was within the average value; *HC* - the number of enterprises in which the index of sold innovative goods and services was less than average. Thus, the initial conditions of the studied process will be the following values of the probabilities of statuses: $P_0(S1) = 2/9 = 0{,}222$; $P_0(S2) = 4/9 = 0{,}444$; $P_0(S3) = 3/9 = 0{,}333$. During the study period, the status of development of enterprises of PJSC "Concern Electron" changed according to the index of the volume of sold innovative goods and services. Intensities of transitions of enterprises from status to status, indicated by the corresponding values over the arcs of transitions of the graph presented in Fig. 4.

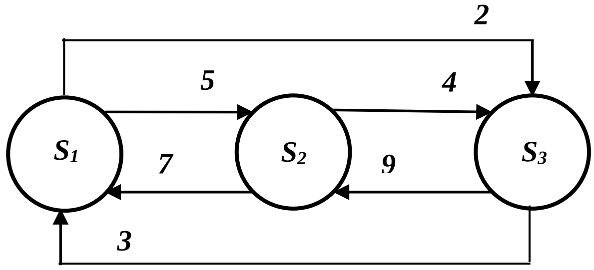

Figure 4: Graph of sustainable development of PJSC "Concern Electron" (according to the index of the volume of sold innovative goods or services, % to the previous year)
Source: own elaboration.

Studies of the dynamics of development of PJSC "Concern Electron" on the index of the volume of sold innovative goods and services were conducted by calculating with the help of computer technology system of the Chapman–Kolmogorov differential equations (1), where λ_{ij} ($i, j = 1, 2, 3; i \neq j$) – intensity of transitions from status *i* to status *j*. For $t \to \infty$ and $dP/dt = 0$, the system of differential equations (1) is transformed into a system of algebraic equations. This allows us to study the state of development of PJSC "Concern Electron" in a stationary mode and make appropriate forecasts.

$$
\begin{aligned}
dP_1/dt &= -(\lambda_{12} + \lambda_{13}) \cdot P_1(t) + \lambda_{21} \cdot P_2(t) + \lambda_{31} \cdot P_3(t); \\
dP_2/dt &= \lambda_{12} \cdot P_1(t) - (\lambda_{21} + \lambda_{23}) \cdot P_2(t) + \lambda_{32} P_3(t); \\
dP_3/dt &= -(\lambda_{31} + \lambda_{32}) \cdot P_3 + \lambda_{13} \cdot P_1(t) + \lambda_{23} \cdot P_2(t).
\end{aligned} \tag{1}
$$

When analyzing the obtained dynamic and static characteristics of the probabilities of the enterprises of PJSC "Concern Electron" on the index of sold innovative goods and services (Fig. 5) we can conclude that the most likely for PJSC "Concern Electron" is an increase in sold innovative goods or services, since the dynamics of characteristics revealed that the probability of the first status, in which the index of sold innovative goods and services is greater than the average value, becomes the largest and reaches a static value of 0.444. That is, the development of PJSC "Concern Electron" is projected to be relatively stable.

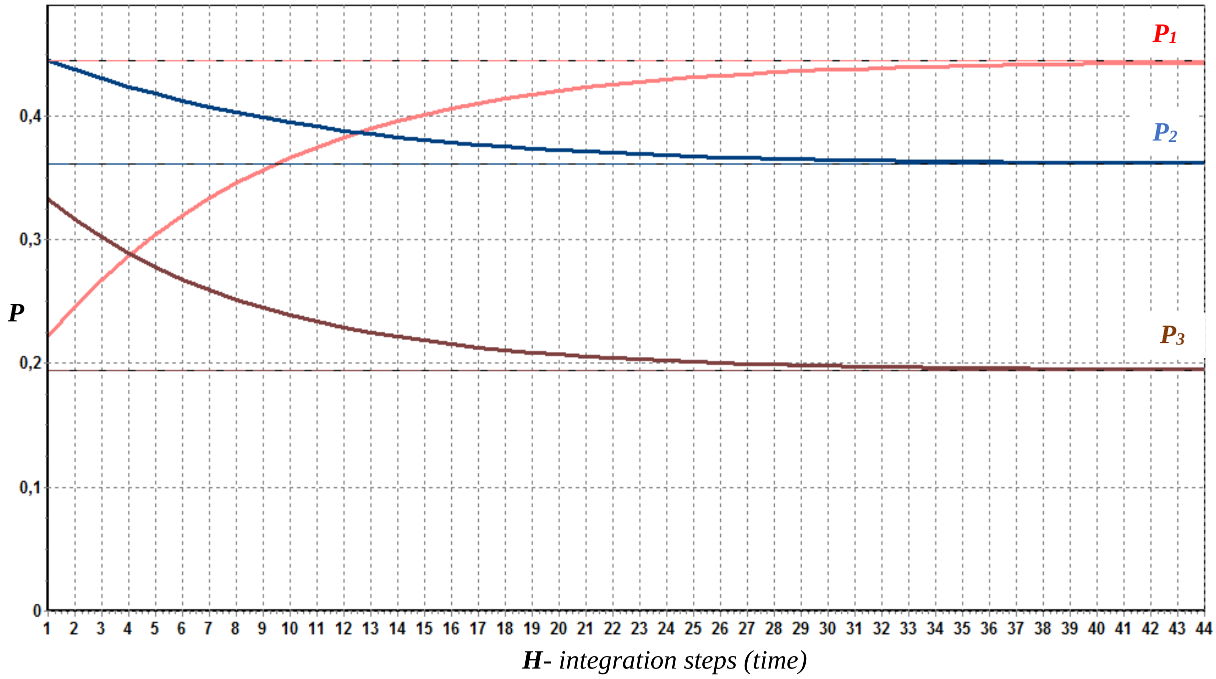

Figure 5: Characteristics of probabilities of sustainable development statuses of PJSC "Concern Electron"
Source: own elaboration.

Thus, the proposed mathematical apparatus and developed on its basis mathematical and software IIMS SIE adequately describe the status and sustainable development of the studied PJSC "Concern Electron" and can be widely used in the study of statuses and sustainability of innovative enterprises in general.

5. Conclusions

A smart innovative enterprise (SIE) is a management approach focused on the use of new technologies for the development of innovative enterprises. As individual entrepreneurs today need new creative ideas and solutions that would meet the requirements of a changing world, the structure of the SIE is proposed to be based on the structure of the innovation process, which would be managed at all stages of its organization by integrated intelligent information management system of smart innovative enterprises (IIIMS SIE).

In the development of integrated intelligent information management system of smart innovative enterprises it is advisable to use innovative methodologies and tools inherent in Industry 4.0. In particular, those that would provide all stages of the innovation cycle: generating ideas and research; designing; production planning and preparation; production; marketing; implementation; installation, commissioning and operation; technical support and modernization, diffusion of innovations, utilization and recycling. In other words, integrated intelligent information management system of smart innovative enterprises can be used to implement the tasks of "digital factories", "smart factories" and "virtual factories". The tasks of the "digital factory" can be performed by IRIS, ICAD-F, ICAD-E and ICAD-T, and the tasks of "smart factories" can be performed by IIPMS.

The generation of ideas in the CEE should be based on modern methods of generating ideas for innovative goods and services. It begins with their emergence (emergence, creation), constant and systematic search, accumulation, selection and formation of a portfolio or bank of ideas in IRIS. Therefore, the sources from which ideas can come from IRIS are proposed to be divided into: external, which include entities with which smart innovative enterprise interacts or which influence its activities; internal, which include processes in smart innovative enterprise.

IRIS is proposed to be considered as an intelligent support system for research conducted in order to formulate and store ideas, their selection and implementation. IRIS should be used as an intelligent real-time data processing system based on obtaining, processing, analyzing and making real-time decisions. Therefore, IRIS must be equipped with a big data package platform, data analysis tools and machine learning models. Since research sometimes has to be conducted in areas with poorly formalized knowledge, it is advisable to use information systems that perform empirical analysis of empirical data, in particular intelligent JSM systems.

To perform the tasks of the "virtual factory" for the management of innovative enterprises in general, it is proposed to use intelligent information management system of smart innovative enterprises (IIMS SIE) as part of integrated intelligent information management system of smart innovative enterprises. The tools needed to design and operate IIMS SIE can be based on object-oriented integrated and distributed databases and knowledge bases, expert systems, DSS, integrated neural networks and fuzzy logic tools. Since distributed artificial intelligence, integrated intelligent information systems as multi-agent systems are the most suitable class of models for implementing integrated intelligent information management system of smart innovative enterprises, it is advisable to consider IIMS SIE as a logical-cognitive model of a social agent, and integrated IIMS SIE as a multi-agent system. Therefore, a modular structure has been proposed for the construction of IIMS SIE, which will provide it with flexibility, adaptability to environmental conditions and survivability.

To predict the statuses of smart innovative enterprise in order to further make optimal decisions, the most suitable models may be based on mathematical methods of the theory of Markovian stochastic processes using systems of the Chapman–Kolmogorov differential equations. The proposed mathematical apparatus and developed on its basis mathematical and software IIMS SIE adequately describe the status and sustainable development of the studied PJSC "Concern Electron" and can be widely used in the study of statuses and sustainability of innovative enterprises in general.

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