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Intelligent Management of Enterprise Business Processes

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Abstract: The article develops the conceptual foundations of natural and artificial intellectualization of the enterprise, as well as the combination of artificial and natural intelligence in managing business processes in the context of modern challenges of the business environment. Based on the methods of structural design, a system model of the enterprise is developed as the basis for intelligent management. Quantitative and qualitative effects of human–cyber–physical systems, which are the result of management intellectualization, are highlighted. The possibilities of using deviation and perturbation management methods in managing the state of enterprise development with the support of decision-making and implementation of an intelligent information system are considered. The features of making managerial decisions during intelligent enterprise management are considered. The place of the human factor in such intellectual management is highlighted, in particular, in terms of improving the intelligence of employees and the natural intellectualization of the enterprise. The problem of assessing and forecasting the state of enterprise development in the context of intellectual management is highlighted. In this context, the expediency of using mathematical methods of Markov process theory, using systems of Kolmogorov differential equations and their solutions, using numerical methods and applied software products is justified. This made it possible to study the dynamics of probabilities of states and stability of development of enterprises and their employees; the dynamics of probabilities of states of innovative and technological processes; scientific and technological, environmental, social and economic efficiency of a business. To test the proposed mathematical models for assessing and predicting the state of development of enterprises and their employees, appropriate studies were conducted on the sanatorium–resort complex in Truskavets (Ukraine).

Keywords: business process; business intellectualization; intelligent management; deviation management; perturbation management; system approach; Kolmogorov system of differential equations; management solution

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1. Introduction

The vital activity of any enterprise is largely determined by its resistance to external and internal destructive forces, as well as a fairly high rate of its development, which most fully and accurately affects the development of intelligence. The high rate of development of the company, including intellectual development, helps it to stay at the forefront of evolution, as well as successfully compete with other enterprises both in the domestic and foreign markets. Intelligent enterprise management [1] can provide it with a flexible, and at the same time stable, balance of behaviour in a dynamic environment, which has a changeable, but at the same time adaptive nature. Industry 4.0 determines today the intellectualization of everything: business models, environments, production systems, machines, operators, products, and services, and also encourages the unification of digital and physical worlds through the creation of managerial human–cyber–physical systems that can combine natural and artificial intelligence [2–4]. Such challenges require modern enterprises to use new approaches to building management systems, in particular, to widely apply natural and artificial intelligence in their organizational management structure. It is the combination of natural and artificial intelligence that will contribute to the creation of new business models [5–7], the use of observations, data, analysis, evaluation and forecasting for making optimal management decisions on the implementation of tasks to ensure the development of enterprises. Developed based on a combination of natural and artificial intelligence, intelligent information systems allow businesses to [8–11] model and automate decision-making processes; to model and automate organizational management of enterprises; to take into account the possibilities of automating all stages of management activities; to build integrated intelligent information systems for making optimal decisions on the use of innovative adaptogenic business models [12,13], etc. All this will contribute to the adaptation of enterprises to environmental conditions by redesigning and reorganizing their activities, as well as by building innovative business models. Therefore, the work aims to develop a conceptual framework for the natural and artificial intellectualization of the enterprise, as well as a combination of artificial and natural intelligence in the management of its activities, so that the development of the company meets modern challenges. In addition, the work aims to develop software for intelligent information systems for assessing and forecasting the development of innovative enterprises, supporting the adoption and implementation of appropriate decisions.

2. Literature Review

Many scientists have studied the problems of intellectual management of enterprises through their natural and artificial intellectualization, the combination of natural and artificial intelligence, the creation of managerial human–cyber–physical systems and the construction of smart enterprises [14], which are predetermined by Industry 4.0. In particular, Tanajura et al. [15], Dipalokareswara et al. [16], Chakir et al. [17], Kamble [18], and Wang et al. [19] indicate that self-organizing, adaptogenic multi-agent and expert systems should be used on the way to building smart enterprises, which can form new business models [20–22] based on a large amount of data and knowledge [23]. As noted by Brown [24], Marr [25], Dalenogare et al. [26] and other modern scientists, these are modelling, industrial internet, vertical and horizontal integration, intelligent technologies, manageability and augmented reality, the autonomy of production systems based on big data, analytics, and machine learning. Pereira et al. [2] and Alcácer et al. [4] believe that Industry 4.0 leads to the intellectualization of everything: business models, environments, production systems, machines, operators, products and services, to the unification of digital and physical worlds through the creation of human–cyber–physical systems that can combine natural and artificial intelligence. In turn, Johnson [27], Daugherty et al. [28] and Fourtané [29] concluded that due to the combination of natural and artificial intelligence, we are on the verge of expanding intelligence through the creation of intelligent systems. This allows one to overcome the limitations on the development of cognition and decision-making processes and, accordingly, on improving work efficiency. Intelligent decision-making, as noted by Zhou et al. [11] and Abbasi et al. [30], is one of the key positions in decision-support systems and is largely associated with modern business development.

Based on the analysis of recent research and publications, it can be concluded that the natural and artificial intellectualization of enterprises, as well as a combination of natural and artificial intelligence for intelligent enterprise management, meets the challenges of the time. Intelligent systems as human-cyber-physical systems, in which human and artificial intelligence interact and facilitate the process of making optimal decisions, will contribute to the creation of smart enterprises; the transition of enterprises from centralized to decentralized management; the adaptation of business processes, business structures, and technologies to environmental conditions; the use of self-organized, adaptogenic, multi-agent and expert systems that can form new business models.

3. Methods

The problem of intelligent management of enterprises is proposed to be solved by methods of their intellectualization, through increasing the natural intelligence of employees, creating artificial intelligence systems, and through a combination of natural and artificial intelligence, as well as the formation of appropriate human–cyber–physical systems. The effectiveness of these systems is determined by methods for assessing quantitative and qualitative effects. Quantitative effects are formed by methods of automating routine operations of diagnostic experiments, which increase the level of standardization, accuracy, and speed of obtaining initial data and solutions. Qualitative effects are provided by the ability of modern computers to implement new methods of technology and other changes, the use of the latest achievements in the field of information technology, maintaining databases and knowledge bases, image recognition algorithms, and artificial intelligence methods based on knowledge manipulation due to modern technologies.

Based on the methods of structural design, it is proposed to develop a system model of the enterprise, which will include a physical subsystem (managed subsystem), a management subsystem (which includes a cybernetic (virtual) subsystem), as well as a person (manager) who makes decisions. To manage the state of enterprise development with the support of decision-making and implementation using an intelligent information system, as a human–cyber–physical system, deviation and perturbation management methods are used. Assessment and forecasting of the state of development of employees and enterprises, which are stochastic in nature, to make optimal management decisions are proposed to be carried out by mathematical methods of the theory of Markov processes using systems of Kolmogorov differential equations. As a result, the corresponding systems of algebraic equations were solved using the software of an intelligent information system. This software was developed by the authors based on the methodology of structural programming and the numerical methods of Gauss and Runge–Kutta of the fourth order. Professional development of employees of enterprises is implemented through the use of modern methods of teaching knowledge, skills, and abilities. Visual representation of dynamic and static characteristics of probabilities of states of professional development of employees of enterprises is carried out by graphical methods and computer tools.

4. Results

4.1. System Model of an Enterprise as a Basis for Intelligent Management

The solution to problems of intelligent management of enterprises is proposed to be carried out based on the concept of their natural and artificial intellectualization, a combination of natural and artificial intelligence by creating managerial human–cyber–physical systems. This is since the main indicator of the sustainability of enterprises' development is the level of their natural and artificial intellectual potential, as well as the speed of their growth. Therefore, the problem of intellectualization of diagnostics of the state of development of the individual and the enterprise is extremely urgent to further create favourable conditions for the intensification of their development on an innovative basis, as well as the formation of appropriate innovation environments. These innovative environments must be able to provide themselves with appropriate resilience and adaptability to entropic environmental conditions and thus survive. The problem of sustainability and adaptability of enterprises is proposed to be solved by methods of their intellectualization through increasing the natural intelligence of employees, creating artificial intelligence systems and through a combination of natural and artificial intelligence, as well as the formation of appropriate human–cyber–physical systems. Such systems can synthesize natural and artificial intelligence, comprehensively analyze, clearly display information, form and accumulate knowledge and make optimal decisions on this basis.

The effectiveness of these systems is determined by quantitative and qualitative effects. Quantitative effects are mainly associated with automating routine operations of diagnostic experiments, which increase the level of standardization, accuracy, and speed of obtaining initial data and solutions. The efficiency of computer information processing makes it possible to conduct mass observations in a short time. Qualitative effects are provided by the ability of modern computers to implement new methods of technology and other changes, the use of the latest achievements in the field of information technology, maintaining databases and knowledge bases, image recognition algorithms, and artificial intelligence methods based on knowledge manipulation due to modern technologies. To obtain quantitative and qualitative effects by constructing human–cyber–physical systems, we will first consider the enterprise as a complex system, the model of which was developed by the authors based on the analysis of literature sources [3,4,8] and presented in Figure 1. The enterprise system model includes:

- A physical subsystem (managed subsystem) that includes input resources, an innovative (technological) process, and output products;
- A management subsystem, which includes a cybernetic (virtual) subsystem that contains a feedback loop, diagnoses the states of the physical system, and supports the making and implementation of management decisions;
- Person—a manager who makes the decision.

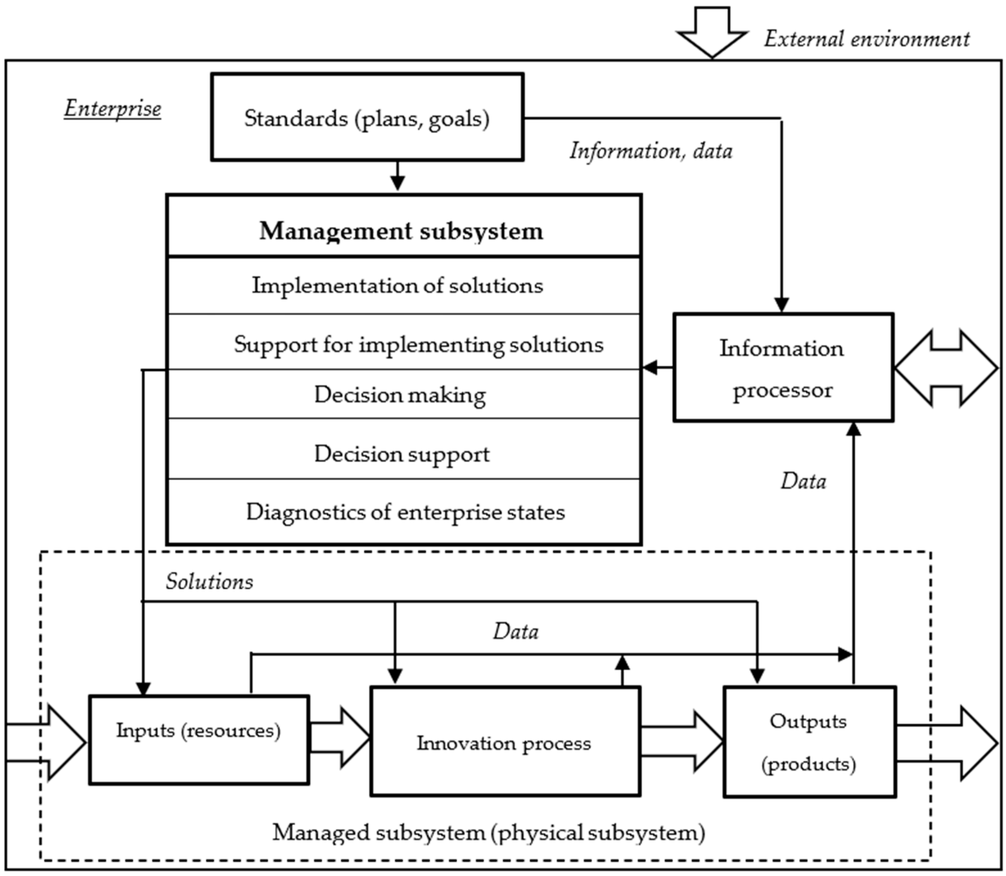


Figure 1. Enterprise system model.

The lower part of Figure 1 shows a physical subsystem of an enterprise that converts incoming resources into outgoing innovative products. Input resources come from the external environment; they are transformed, and output products are returned to the external environment. A physical subsystem of the enterprise is an open subsystem that interacts with the environment through material flows. Within the enterprise, resource and product material flows function, since input resources are transformed through the innovation process into inventions, know-how, experimental samples, and goods and services (innovative products). The virtual (information, cybernetic) subsystem [8,31,32] of the enterprise ensures the functioning of the physical subsystem, based on the adopted strategy. Management is achieved through a cycle that is built into the enterprise. In the feedback loop, data is sent from the managed subsystem (resources, innovation process, products) to the management subsystem, and vice versa. Managerial influences formed based on decisions made, return to the managed system.

The control subsystem is external to the physical subsystem. It uses feedback signals to diagnose the state of the enterprise, assesses the level of its effectiveness, and determines whether corrective action is necessary. Outgoing (feedback) relationships are important for the manager as a decision-maker. The manager also needs to know the input status of the managed subsystem and the transformation processes in it (for example, the manager wants to have a description of whether suppliers are meeting the company's resource needs well, as well as the level of efficiency of technological operations, etc.).

Information may not always be transmitted directly from the physical subsystem to the manager. Many managers may not process information physically. They must receive information from a managed subsystem or a specific device that processes the collected data (in particular, from a computer). The information creation mechanism is an information processor. When managers determine their need for data that the information processor should provide, they consider four main characteristics of information [33–36]: relevance, accuracy, timeliness, and completeness. The manager can best describe the properties of the information he needs. If necessary, the systems analyst can make this task easier for them.

To ensure control over the manager's responsibility link, there should be information that describes what this link produces and what standards should be followed. A standard is a measure of acceptable performance, ideally described in specific terms. The manager uses standards to monitor the state of the physical subsystem by comparing the actual performance (efficiency) reported by the information processor with standard values. The results of the comparison determine whether a certain guiding influence is needed.

Therefore, the management subsystem that controls the physical subsystem consists of the following key components:

- Decision makers (managers);
- A virtual subsystem that diagnoses enterprise states and supports decision-making and implementation;
- Information processor and standards (plans, goals).

As shown in Figure 1, standards are available for the information processor in the same way as for the management subsystem. This allows the information processor to assist the manager in pre-processing and controlling data. The enterprise state diagnostics subsystem can evaluate the information received and notify the manager about deviations from the standards. Based on deviations, decision-making on the state of the enterprise and management impact is supported.

Thus, the standards combined with data output by the information processor allow the manager to control the deviation [37–39], that is, to act according to the style due to which the manager adheres to the rule: processing of an individual indicator begins only when its value falls beyond the acceptable interval. For practical implementation by the deviation management manager, there must be standards in the form of upper and lower limits of controlled indicators. Deviation control can be provided by an intelligent information system [31,32] as a human–cyber–physical system. In this case, the intelligent innovation system becomes responsible for controlling the physical subsystem, and the manager can use his time more efficiently.

Another control method that is similar to deviation control is the method of critical success factors, which can be considered as perturbations of the system, and control can be considered control on perturbations [40–42]. Critical success factor as a perturbation of the physical subsystem is one of the opportunities for businesses that has a strong impact on their ability to achieve a goal. Several such factors may affect the company. The virtual subsystem allows the manager to monitor critical success factors by receiving notifications about them.

The method of critical success factors is relatively stable, while special situations can change over time.

The advantage of the proposed approach is that the overall system model of the enterprise can be modified: adapted to changes in the external environment, and management decisions can change the physical subsystem. The manager can collect data from all elements of the physical subsystem (input, processing, and output) and make changes to the states of all three elements. In other words, a "solution" is added to the feedback from the manager to the physical subsystem to reflect how the manager changes system states. Feedback consists of signals from a physical subsystem, which are of three types [9,43,44]: data, information, and solutions. Data here refers to a formalized representation of information about the states of a physical subsystem, suitable for interpretation, forwarding, or processing with human participation or by automatic means (according to the ISO/IEC 2382:2015 standard). In other words, the data itself is not information. Data processed and interpreted according to a pre-agreed scheme becomes information. Therefore, in this case, the data is converted into information by the information processor, and the information is converted into a solution by the management system. The information processor and management system together turn data into solutions.

An enterprise operates in an environment, with resources coming to it from the environment, and products coming from it to the environment. Physical resources move through the physical subsystem (at the bottom of the model). Virtual resources (information and data) are entered into the information processor, where they are stored or made available to the management subsystem. There is bidirectional information and data flow between the information processor and the environment.

4.2. The Features of Making Managerial Decisions during Intelligent Enterprise Management

The features of making managerial decisions during intelligent enterprise management. The scientific basis for proper research and management of various systems is a systematic approach [45,46]; the understanding that the entire organization is a system, each part of which has its own interests. Therefore, achieving the overall goal of an organization is possible only if we consider it as a single system, trying to understand and evaluate the interaction of all its parts and combine them on such a basis that would allow the enterprise as a whole to effectively achieve the goal. The success of applying the system approach in the study and improvement of economic systems requires understanding the provisions of system analysis [43,47].

System analysis is a set of special procedures and measures that ensure the implementation of a systematic approach when studying specific situations [48,49]. It includes:

- Methods and procedures for operations research that allow you to develop recommendations for quantitative analysis necessary for planning and organizing targeted actions;
- Methods of system analysis used to determine tasks and choose the direction of action, to assess how systems act under conditions of uncertainty;
- Methods of system engineering used for the design and synthesis of complex systems based on the study of the features of the functioning of their elements.

System analysis also provides for systematic research and mutual comparison of those alternative actions that make it possible to achieve the desired results; evaluation of each alternative in terms of the cost of resources spent and benefits achieved; accounting and detailed analysis of uncertainties.

Since planning by its very nature requires consideration of changes in events in the future, and such a future is always characterized by uncertainty, one of the most important aspects of system analysis is that it provides a clear understanding of the place and significance of uncertainty in decision-making. The task of the decision-maker and the person who performs the analysis in their best interests is to take into account the ambiguity inherent in strategic decisions in advance. To do this, one can apply several methods developed in system analysis; in particular, operations research (simulation modelling, business games, stochastic programming), a decision tree, influence diagrams, fuzzy logic tools, etc. [50–52].

Decision-making is one of the most important elements of organizational management and consists of three main stages [46,47,53]:

- Assessment of circumstances to determine the conditions that you need to know for making decisions;
- Search, develop, and analyze possible alternative actions;
- Choosing one direction of action from possible alternatives in such a way that a certain goal is achieved.

Among a significant number of decisions, we can distinguish the so-called managerial ones, which require certain actions of certain persons. Therefore, the essence of such decisions is the separation of decision-making and implementation processes (or the separation of decision-making entities and those who implement them), which means that there are two categories of managers in this context: those who make and implement decisions, between which there are subordination relations. The success of management decisions depends on a number of parameters:

- Qualifications of the decision-maker, who determines its quality;
- Preparation level of the person who implements the solution, which determines the quality of its implementation;
- The degree of improvement of the information system (clarity, efficiency), which determines the quality of feedback between these categories of managers and the environment.

Thus, the intellectualization of enterprises is carried out through conscious human activity. That is, conscious, intellectual actions of employees are actively involved in the formation of the company's intelligence.

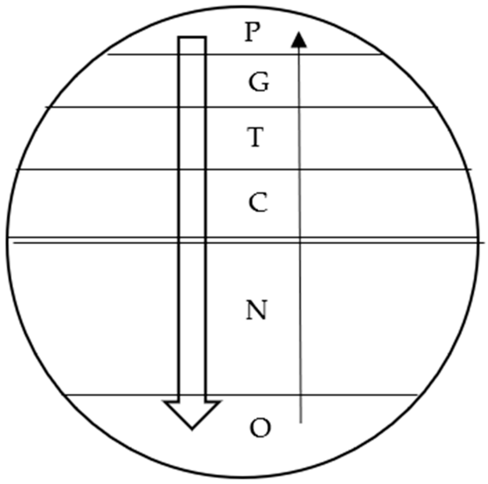
4.3. The Human Factor in Intelligent Enterprise Management

The involvement of human intelligence in the creation of mechanisms for the intellectualization of enterprises determines that these mechanisms only partially consist of people, and their main substrate is artificial elements: computers, local networks, complex systems of computers, and technical means of communication between them, etc. However, increasing the intelligence of employees or the natural intellectualization of the enterprise plays an important role in their overall development.

Throughout life, each person goes through stages of information development, which are based on the transformation of genetic information and information from the environment into its bodily, intellectual and spiritual "matter" and "energy" [54–56].

Information that brings new knowledge to society and generates information flows that excite it arises due to the duration of the system in time and space and due to the movement of the system in time and organization [55]. Therefore, all elements of the system cannot simultaneously enter the "present", that is, all members of society can be placed in a certain sequence of movement in time, and the sequence of movement in time primarily depends on the specifics of the organization of the psyche and must correlate with the hierarchy of specificity of the psyche. Given the above, elements of the social system can be displayed as a two-dimensional figure (Figure 2), consisting of areas [54]:

- P (prophets);
- G (geniuses);
- T (talents);
- C (capable);
- N (normal);
- O (others).



P – prophets; G – geniuses; T – talents; C – capable; N – normal; and O – others;
⇒ – natural movement of information flows; → - direction of person's development.

Figure 2. Model of person's development in society.

This can be determined based on statistical data on the number of members of the society belonging to the categories P, G, T, C, N, and O.

The figure is a circle divided by parallel chords to roughly correspond to the popular idea of the proportions of the categories of people who make up society. The P category should correspond to individuals who have gone far ahead in the perception of reality and significantly differ from the majority of members of society in the nature of the specialization of the psyche, and, accordingly, the ability to generate new information for the system. Such people are most able to predict the direction of development of the system, so they are called "prophets". The G category should correspond to people who can understand the first group and give out new information in a form that is more accessible to the understanding of people and, above all, gifted ones. Such people are mostly called "geniuses", and those closest to them are called "talents", which corresponds to category T. In the same order, you can interpret the plane C (capable), N (normal), and O (others). Such a graphical representation of a social system allows us to reflect the hierarchy of its elements, although it cannot reflect their quantitative ratio, which also plays an important role in the movement of information flows and the formation of system intelligence. However, it contributes to the study of the dynamics of human development, due to their possible movement from one category to another, and within the categories.

Based on the above, we can conclude that the reason for the appearance of new information and new knowledge in society should be considered the interaction of its elements with the environment. Those elements of society that have the most specialized reflective mechanism (psyche) for information interaction with the environment and that are most advanced in terms of the time coordinate of development (first of all, these are types P and G), become sources of new information, can best understand the needs of the current state of society, predict the direction of its further development. Elements of the social system that follow the representatives of the first group can understand the first ones, and generate information of such a nature and in such a form that gives grounds to associate it with the already accepted information of society. If elements of Type G are mostly limited to expressing new ideas in an abstract form, then talents are well understood by both geniuses and the practical needs of society. They transform these general theoretical, abstract ideas into a more concrete and convenient form for society to use.

Based on the talent's information activity, the information flow is further developing. In addition, the activity of elements of the fourth group—capable people—is developing dramatically. At the same time, scientific and technical knowledge is undergoing significant changes. First of all, the enrichment of these streams with new information is significantly reduced. Secondly, there is a significant expansion of these flows due to the detailing and differentiation into scientific–practical, educational–theoretical, popularization and pragmatic applied links of the information flow. Thirdly, the information flow is becoming the main source of scientific and technological progress and a source of innovative development. If at the third level (talents) new information from the external environment continues to arrive (and although it is no longer able to create a new scientific and technical information flow, can still significantly enrich and replenish the existing flow), then at the fourth level (capable) the flow of fundamentally new falls sharply. However, the flow itself does not narrow; on the contrary, it significantly expands by clarifying details, filling in the unproven, establishing connections with other flows, etc. Further qualitative transformation takes place at the level of elements of the fifth level, that is, in the most numerous group, which is called the "normal". Here the most complete and widespread use of scientific and technical information takes place, that is, society seems to absorb all the useful information. The information flow concludes that ideas, innovations and various information, in fact, long-used, which gave all the useful information to society, continue to function at the sixth level, among the members of society, which we will call "others". This information flow does not decrease, but on the contrary, expands even more; however, at this stage, it becomes harmful to society, prevents the penetration of new information, and delays the innovation process [54,55].

The above-mentioned movement of information flows in society reflects the natural processes of intellectualization of socio-economic systems. Based on this, we can conclude that continuous training can play an extremely important role in the intellectualization of enterprises and society as a whole. Therefore, it requires a comprehensive, systematic approach, the inclusion in educational technologies of effective diagnostic tools for the development of individuals, modern methods and teaching tools for the formation of the elite of society, generators of new ideas and knowledge, prophets of its further development, persons able to work out and implement ways to transform science and the economy of society as a whole, its branches or enterprises in particular.

Based on the above, we can conclude that human and social intelligence cannot be separated. They are two sides of the same system that functions subtly (human intelligence contains social intelligence as its external memory, and social intelligence contains human intelligence as its basic "cell"). In modern conditions, it is especially important to highlight the second, social side of the creative process; the main role in the progressive development of countries and peoples has been acquired by the exchange of ready-made knowledge and their engineering processing, which depends entirely on the structures, mechanisms, and technological and organizational levels of the logosphere (socio-intellectual environment) as a means of human intellectual work, which is the main condition for creativity and the formation of the person itself. That is, the problem of the intellectualization of society can be considered primary in relation to the problem of the intellectualization of the individual [55,57]. Therefore, diagnostics of the development of socio-economic systems is extremely relevant and requires the concentration of efforts of scientists from many branches of knowledge. In our opinion, it is advisable to study the development of society from the standpoint of ensuring the development of spiritual, intellectual and physical potential, as well as its intellectual inclinations, since there are different concepts of the development of the individual and society, but the main ones include psychological, cultural, economic and somatic.

Social intelligence, in turn, is considered not the sum of individual intelligence, but an organized system with a positive or negative synergistic effect, as if embedded in a social organism. That is, the problem of social intelligence is considered not a subjective-psychological, but an objective-social, structural and organizational problem. Therefore, the study of the level of natural intelligence and ensuring its growth is attributed to the natural intellectualization of any socio-economic system, in particular enterprises. The natural intellectualization of enterprises is extremely relevant today, meets modern challenges and allows enterprises to provide appropriate organizational development.

4.4. The Problem of Assessing and Forecasting the State of Enterprise Development in the Context of Intellectual Management

When building management intelligent information systems, the problem of assessing and predicting the state of development of the enterprise and all its links, as well as all employees, especially managers at all levels of management, is extremely relevant for making optimal decisions. Management decisions on the state of enterprises and employees in intelligent information systems can be supported by modelling using digital business models, Monte Carlo modelling, discrete modelling, agent-based simulation and multi-agents, system dynamics modelling, and visual modelling, which allows for the digital transformation of business models in creative enterprises [15,16,18,58].

Taking into account the fact that the dynamics of the states of enterprises and employees are stochastic [59,60], models based on mathematical methods of Markov process theory using Kolmogorov differential equation systems may be most suitable for diagnosing and predicting their states to further make optimal decisions [52,61–64]. Taking into account the fact that enterprises have a hierarchical structure and at each level of the hierarchy there are people (managers) who make decisions, the Kolmogorov system of differential equations when describing states of j- th element of i-th level of the enterprise hierarchy, including managers, it will look like:

$$\frac{dP_{i,j,l}}{dt} = \lambda_{i,j,l-1,l} \cdot P_{i,j,l-1} - \left(\lambda_{i,j,l,l-1} + \lambda_{i,j,l,l+1}\right) \cdot P_{i,j,l} + \lambda_{i,j,l+1,l} \cdot P_{i,j,l+1} \quad (1)$$

where $i = 1, 2, \ldots, N$—sequence number of the hierarchy level; N—number of hierarchy levels; $j = 1, 2, \ldots, M_i$—sequence number of the element of the i-th level at the hierarchy; M_i—number of elements of i-th level of the hierarchy; $l = 1, 2, \ldots, L_j$—status sequence number of j-element of the i-th level of the; L_j—number of states of j-th element; $P_{i,j,l}$—probability of l-th state, j-th element of the i-th level of the hierarchy; $\lambda_{i,j,l,l+1}$—the intensity of the transition of the studied system from the state l to the state $l + 1$ of j-th element of the i-th hierarchy level.

The values of state-to-state transition intensities for each element of the hierarchical structure are statistical information that can be obtained as a result of the functioning of the system under study. To assess and predict the states of these systems and their elements, it is advisable to collect this information at the beginning, during, and after a certain period of system operation time.

Research on objects with a hierarchical structure in stationary mode, when $t \to \infty$, and $dP/dt = 0$, is carried out on the basis of solving a system of algebraic equations using numerical methods and computer technology:

$$\lambda_{i,j,l-1,l} \cdot P_{i,j,l-1} - \left(\lambda_{i,j,l,l-1} + \lambda_{i,j,l,l+1}\right) \cdot P_{i,j,l} + \lambda_{i,j,l+1,l} \cdot P_{i,j,l+1} = 0 \quad (2)$$

received for the j-th element of the i-th level of the hierarchy from the system of differential Equation (1), since $dP/dt = 0$.

The use of the above systems of Kolmogorov differential Equation (1), their solution using the numerical Runge–Kutta method of the fourth order [65] and the software of the intellectual information system developed by the authors on its basis using the methodology of structural programming allows us to investigate:

- Dynamics of probabilities of states and stability of development of enterprises and their employees;
- Dynamics of probabilities of states for innovative and technological processes;
- Scientific and technological, environmental, social and economic efficiency of enterprises.

Solving a system of algebraic equations obtained from the Kolmogorov system of differential equations when $t \to \infty$, and $dP/dt = 0$, using Gauss' method [65] and the corresponding software developed by the authors as a structural component of the intellectual information system allows you to study in a stationary mode the state and stability of the development of enterprises, employees, and the efficiency of their activities, set appropriate forecasts, and make decisions.

5. Discussion

The proposed approach to assessing and predicting the state of development of enterprises and their employees is recommended to be used as follows. First, information is collected about the results of experimental studies at the corresponding hierarchical level of the enterprise. Information is collected at the beginning, middle, and end of the research period. After that, the collected information is classified according to pre-defined states, for example: S_1—"unsatisfactory"; S_2—"satisfactory"; S_3—"good"; S_4—"very good". Next, the intensities of transitions from one state to another are determined, which are coefficients of systems of differential (1) and algebraic (2) equations.

Solving these systems of equations using computer technology, the values of probabilities of states of an enterprise or employees in dynamic and stationary modes are determined. Based on the results of calculations, you can analyze and predict these states and make appropriate decisions based on this.

To test the proposed mathematical models for assessing and predicting the state of development of enterprises and their employees, appropriate studies were conducted on the professional development of employees of the sanatorium–resort complex in Truskavets (Ukraine) before and after their advanced training. Such professional development was aimed at developing the professional competencies of employees by teaching them knowledge, skills, and abilities through lectures, various training, masterclasses, and seminars. Truskavets is a well-known balneological resort in Ukraine, founded in 1827. Today it is considered one of the largest European centres of the health industry and annually receives about 350 thousand vacationers.

When testing the professional competencies of employees, their levels and, accordingly, the state of their professional development was determined, in particular: $S_1(US)$—"unsatisfactory" level of professional competencies and, accordingly, the state of professional development; $S_2(S)$—"satisfactory" level of professional competencies and state of professional development; $S_3(G)$—"good" level of professional competencies and state of professional development; $S_4(VG)$—"very good" level of professional competencies and state of professional development.

Having conducted a study on the development of professional competencies of 60 employees of the sanatorium–resort complex in Truskavets before advanced training, we received the following results: there were 32 employees in the state of $S_1(US)$; $S_2(S)$ had 17 employees; 8 employees were considered $S_3(G)$; 3 employees fell under the category $S_4(VG)$. In other words, the probabilities of employee development states have the following initial values: $P_0(S_1)$ = 32/60 = 0.53; $P_0(S_2)$ = 16/60 = 0.27; $P_0(S_3)$ = 9/60 = 0.15; $P_0(S_4)$ = 3/60 = 0.05.

During professional development, the professional state of employees has changed. The intensities of transitions from state to state are represented by the corresponding values above the transition arcs of the graph (Figure 3).

In Truskavets, using the proposed mathematical apparatus, we conducted a study of the dynamics and statics of probabilities of states P_l $(l = 1, 2, 3, 4)$ by calculating using computer technology of a system of Kolmogorov differential Equation (1) and a system of algebraic Equation (2), where: $i, j = 1$, $l = 1, 2, 3, 4$.

Studying dynamic and static characteristics (Figure 4) of probabilities of states of employees' development in the sanatorium-resort complex in Truskavets, we can conclude that the most likely is a "very good" state, that is, a state in which professional competencies are at a "very good" level.

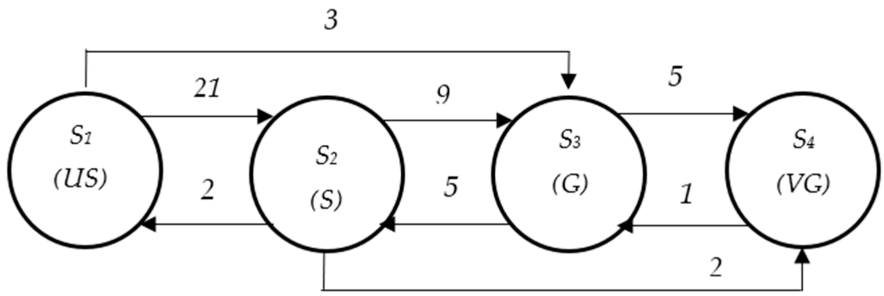


Figure 3. Graph of the development states of employees of the sanatorium-resort complex in Truskavets.

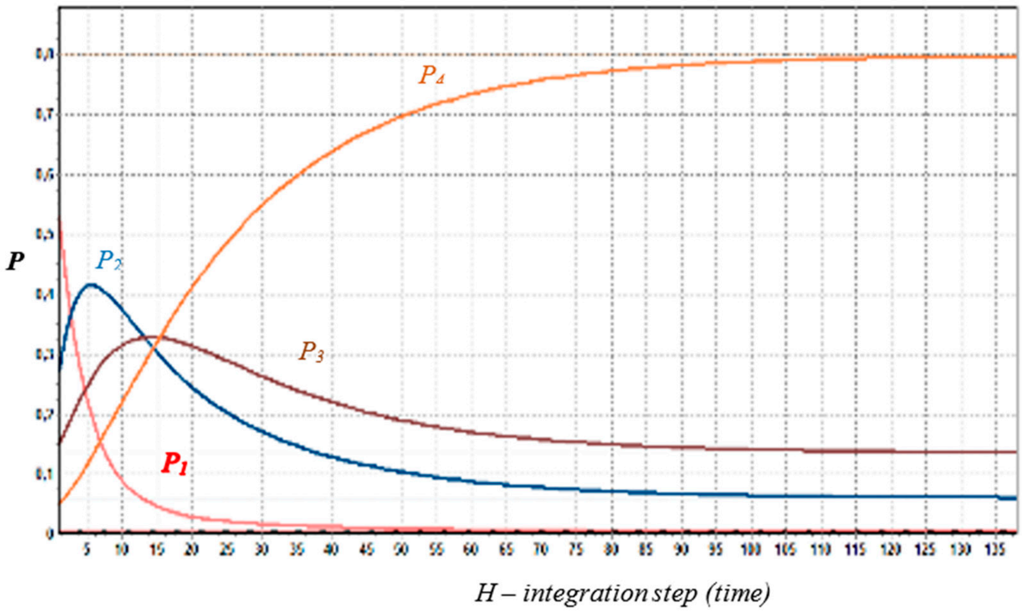


Figure 4. Probability characteristics of the development states of employees of the sanatorium–resort complex in Truskavets.

Thus, by improving the skills of employees, it is possible to improve their professional competencies and ensure their professional development.

In this case, as a result, the professional development of employees, based on the values of probabilities of states in statics, can be considered: "unsatisfactory" with a probability of 0.005; "satisfactory" with a probability of 0.06; "good" with a probability of 0.136; and "very good" with a probability of 0.799.

6. Conclusions

The solution to problems of intelligent management of enterprises should be carried out based on the concept of their natural and artificial intellectualization, a combination of natural and artificial intelligence, by creating managerial human–cyber–physical systems.

The system model of the enterprise should include a physical subsystem (managed subsystem), which includes input resources, an innovative (technological) process and output products; a management subsystem, which includes a cybernetic (virtual) subsystem, which contains a feedback loop and diagnoses the states of the physical system and supports the adoption and implementation of management decisions; as well as a person (manager) who makes decisions.

Decision-making is one of the most important elements of organizational management and consists of three main stages: assessing circumstances to determine the conditions that need to be known for decision-making; searching, developing, and analyzing possible alternative actions; and choosing one direction of action from possible alternatives in such a way that some important and desirable for the decision-maker goal is achieved. The success of management decisions depends on the qualification of the decision-maker which determines the quality of decision-making; the degree of improvement of the information system (clarity, efficiency), which determines the quality of feedback between the selected categories of employees and the environment. Thus, the intellectualization of enterprises is carried out through conscious human activity. The involvement of human intelligence in the creation of mechanisms for the intellectualization of enterprises determines that these mechanisms only partially consist of people, and their main substrate is artificial elements: computers, local networks, complex systems of computers, and technical means of communication between them.

Human and social intelligence are inseparable. They are two sides of the same system that functions subtly (human intelligence contains social intelligence as its external memory, and social intelligence contains human intelligence as its basic “cell”). Therefore, the study of the level of natural intelligence and ensuring its growth is attributed to the natural intellectualization of any socio-economic system, in particular enterprises.

For diagnosing, evaluating, and predicting the state of development of enterprises and employees, which are stochastic in nature, to further make optimal management decisions, the most suitable models (as confirmed by computational experiments) can be built based on mathematical methods of the theory of Markov processes using systems of differential equations of Kolmogorov, which are tested in the study of the state of professional development of employees of the sanatorium-resort complex in Truskavets.

Professional development of employees of enterprises, focused on the formation of their professional competencies through training in knowledge, skills, and abilities through lectures, various training, master classes, and seminars, can provide employees with professional growth.

Thus, we should focus further research on a more in-depth study of approaches to improving the efficiency of management decisions. Such decisions may relate to decision makers; the quality of training of decision makers; the level of improvement of intelligent information systems.

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