Intelligent Management System for Ecological Innovative **Enterprises**

Mykola Odrekhivskyi^a, Uliana Kohut^a and Ulyana Kostyuk^b

^a Lviv Polytechnic National University, 12 S. Bandera St, Lviv, 79000, Ukraine

^b Ivano-Frankivsk National Technical University of Oil and Gas, 15 Karpatska St, Ivano-Frankivsk, 76000, Ukraine

Abstract

The purpose of the scientific work is to study problems of eco-oriented management and design of intelligent management systems for ecological innovative enterprises. The approaches to formation of the eco-oriented management process are studied. These approaches investigation additionally proofs the importance for modern business conditions to design the management model that provide economic as well as environmental and social efficiency of enterprises. At the same time, the problems of an intelligent system organizational design are relevant for ecooriented management and using of artificial intelligence approaches in order to optimize management decisions. A system model of an intelligent system of eco-oriented management for innovative enterprises has been developed to improve their environmental efficiency, sustainability and safety, as well as to improve resource and socio-economic efficiency. Based on the system model, the organizational structure of the intelligent management system of ecological innovative enterprises has been developed. It will make it possible to design, construct and restructure the intelligent management systems of ecological innovative enterprises as a whole and their units in to adapt them to modern business conditions. The study of ecological sustainability 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 eco-oriented management and design the system of eco-oriented management that are based on the using of environmental innovations. Markov chain theory was used as a mathematical tool to evaluate efficiency of eco-oriented management. Based on this mathematical tool, the software for evaluation and prediction of state of eco-oriented 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 ecological innovative enterprises and applied for the study of ecological sustainability of enterprises.

Keywords 1

Eco-oriented management, system, innovative enterprise, ecological, economic and social efficiency, sustainable development

1. Introduction

The extremely unsatisfactory environmental situation in Ukraine and in the world demands for the search for new approaches to enterprises management, focused on minimizing negative impact on the environment and ensuring sustainable development. Different forms and ways of improving production

COLINS-2021: 5th International Conference on Computational Linguistics and Intelligent Systems, April 22-23, 2021, Kharkiv, Ukraine EMAIL: Mykola V.Odrekhivskyi@lpnu.ua (M. Odrekhivskyi); Uliana I.Kohut@lpnu.ua (U. Kohut); kostyuk_u@ukr.net (U. Kostyuk) ORCID: 0000-0003-3165-4384 (M. Odrekhivskyi); 0000-0002-3847-2762 (U. Kohut); 0000-0001-8826-8084 (U. Kostyuk) © 2021 Copyright for this paper by its authors. Use permitted under Creative Commons License Attribution 4.0 International (CC BY 4.0).



CEUR Workshop Proceedings (CEUR-WS.org)

and economic activities based on introduction of eco-innovations serve s a basis of sustainable development. Under such circumstances, it is urgent to develop an appropriate of intelligent management systems (IMS) for ecological innovative enterprises (EIE) to ensure rational decisions regarding environmental, economic sustainability and security of individual economic entities and the country as a whole. The designing of the IMS EIE, use of artificial intelligence elements in the system functioning to optimize management, formation of a system of criteria and indicators to evaluate the system efficiency are considered as important problems.

Eco-oriented management (EOM) of innovative activities at all organizational levels of national innovation systems is an urgent issue in the current conditions of international socio-economic development. EOM generates and activates all enterprise resources to achieve economic goals, interrelated with purposes of sustainable nature management and development. At present, EOM is becoming the central subsystem of the management system; whereas operation of all other subsystems (personnel, financial, etc.) is based on the principles sustainable nature management and environmental protection [1].

2. Literature review

Eco-oriented management has been the subject of research by many scientists. In particular, Yasnolob I. notes that as a part of a general management system, an environmental management system, based on a system-environmental approach, ensures correlation of all management functions according to sustainable development concept and environmental justice principles [2]. The purpose of enterprise EOM is to minimize or prevent the negative impact of technological processes on the environment. It can be implemented by modernization of existing technological processes or by their replacement with innovative, environmentally-oriented processes [3].

In a broad sense, EOM can be defined as a type of management, mainly oriented at formation and development of ecological production, ecological culture and life sphere. This type of management should be considered as a complex and perspective consideration of ecological problem as a part of the economic policy of enterprises [1]. EOM shall be implemented with continuous interaction of all economic entities and combine the ecological strategy goals and management methods that are most relevant to the ecological and economic development of society as a whole. EOM covers macro-, meso- and micro-levels of environmentally sound management [4], it shall consider the environmental impact and modern approaches to innovative development regulation at all levels of economic systems organization.

The principles of an efficient ecological management system include [2]:

- target permanency;
- acquisition of high quality and safe components of production, technologies, machinery, etc.
- Process improvement and compliance with ecological management system requirements;
- use of leadership as a method of production quality assurance and safety;
- cooperation of managerial staff with employees;
- motivation to self-improvement and professional development of the personnel;
- the support of ecological management system by chief executive officers.

However, the problems of a mechanism formation for eco-oriented management of innovative enterprises are not sufficiently addressed and need further research, development and implementation in compliance with requirements and challenges of industry 4.0.

EOM at the level of innovative enterprises (IE) can be ensured by development of an appropriate eco-oriented management system (EOMC). EOMC can promote IE to maintain and strengthen its stable position at the market, form and meet eco-oriented consumer needs, respond adequately and promptly to changes in the environment, provide sustainable development. Changes in the environment, high competition and intensive development of eco-oriented demand force IE leaders to reorganize and improve the organizational and economic mechanism of IE management to provide IE eco-oriented activities to get, on the one hand, their profit, and on the other, preserve the environment and human health. That is, nowadays, all IE shall become ecological, by ecological innovating enterprise (EIE) we mean an enterprise of various organizational and legal forms, engaged in eco-innovation activities, focused on the production of environmental products (provision of environmental services) in various

fields life. The EIE business strategy is aimed at profit earning with a focus on environmental conservation and sustainable development [5].

EIE can be described as follows [6]: these are nature-oriented IE, providing wildlife habitat conservation, eco-tourism and other nature-related activities using economic and human resources to improve the environment; manufacturers of innovative eco-technologies - production of such technologies is under the impact of legislative pressure on communities or industrial enterprises to reduce their environmental, water, air and soil load; providers of innovative ecological management services are aimed at consultations of companies on use of environmental skills as a source of competitive advantage; manufacturers of eco-friendly innovative products, differentiated from existing products due to better ecological life-cycle indices as compared with existing ones.

EIE identification criteria are based on [7, 8]: Compliance with principles of socially responsible innovative business; consideration of changes in the increasing (but not dominating) significance of environmental factors; environmental conservation as an integral part of IE management and marketing system; achievement of economic, social and environmental impact by introduction of innovative technologies using natural resource potential. That is, EIE shall adhere to sustainable innovative practices to minimize negative social and environmental consequences, obtain the optimal corporate performance, and be responsible for sustainable development in products, services, processes and business models [9].

3. Methods

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 eco-oriented management and design the mechanism of eco-oriented management that are based on the using of environmental innovations, greening the activities of innovative enterprises for ensuring the sustainable development. The obtained scientific results are based on the implementation: a systematic approach, logical analysis and synthesis for researching the reference sources to determine approaches for the problem solving of forming IMS EIE; structural design methodologies for the analysis of various aspects of IMS as a complex organizational and economic system that implements eco-oriented management of EIE; methods of multilevel and multi-stage decomposition of IMS for construction of its model; the concept of hierarchical management and methods of functional analysis of IMS, for determination of the multiplicity of its functions, the heterogeneity of structural elements at all levels of the hierarchy, the diversity of forms of existence throughout the life cycle of EIE; formalization methods - economic-mathematical models of queuing theory, methods of hierarchical structures theory, set-theoretic models, differential equations, models of Markov processes - for quantitative evaluation, comparative analysis and forecasting of EIE states in general and its structural components; graphical method - for a visual representation of the dynamics and statics of the development of EIE or their structural units; decision-making methods - for decision-making on EIE states and the choice of methods for managing these states; methods of cognitology - for development the organizational structure of intellectual IMS. These aspects will allow the design, construction and reconstruction of IMS EIE in general and their units with the purpose of their adaptation to modern business conditions.

4. Results and discussion

4.1. Intelligent management system designing for EIE

It is important to decide on the strategic vector of EIE development to form IMS EIE. For this, it is relevant to perform: structural analysis of the IMS EIE as a complex system and consider its results; to use quantitative evaluation, comparative analysis and prediction of EIE conditions in general and its structural elements; functional consideration of IMS EIE, determined by the multiplicity of functions, heterogeneity of structural elements, variety of forms of IE life cycle. That is, the analysis of IMS EIE various aspects as a complex system, implementing IE eco-oriented management, it is recommended to provide by multilevel and multi-stage decomposition of its model [10].

Analysis of systems, using decomposition methods, allows to break down their models into subsystems and determine their structure and functions. The complexity that generated decomposition and aimed efforts of scientists to get further knowledge about certain aspects of phenomena, also caused the problem of the studied components integration into a complex system - the problem of synthesis [11, 12]. Synthesis involves use of integration methods to reproduce a system by its functional elements (subsystems) to study processes of these functions implementation. That is, analysis and synthesis methods can serve as a basis for the methodology of IMS EIE formation and provide IE adaptive capacity to solve problems of sustainable development, caused by modern environmental challenges [13, 14].

Thus, it is proposed to use decomposition methods for formation of IMS EIE (*S*) [15, 16]. The system model of IMS *S*, according to decomposition methods, will have the form as shown in Fig. 1, where SS_1 is a subsystem for diagnostics of EIE current state and their environment; SS_2 is a subsystem for evaluation and prediction of EIE states; SS_3 is a subsystem to support decision-making on EIE states; SS_4 is a decision support subsystem on selection of main effects on EIE; SS_5 is a subsystem for simulation of EIE states; SS_6 is a subsystem for implementation of main effects on EIE. E is a set of elements of each subsystem, from SS_1 to SS_6 ; *V* is a set of indicators inherent in set *E* elements; V_1 is a subset of names for the indicators characterizing states of subsystems; V_2 is a subset of values of indicators from subset V_2 , according to their names from subset V_1 , at a fixed moment in time - set *T*; *F* is a set of functions (actions, operations), providing transition of subsystems from the initial state to the main purpose of subsystems functioning for EIE management; *G* is a set of purposes for subsystems functioning; *R* is a set of relations, containing subsets of the relations between the sets themselves and between each set elements.

The following types of relations are observed between these sets of system model of IMS EIE: R_1 (E, Vj) – correspondence relation that puts into correspondence to each sample of set E a sample of Vj, that is, from V_{Ij} i V_{2j} ; $R_2(V_{Ij}, V_{2j})$ – correspondence relation between a given indicator name and its specific values at time moment t; $R_3(Vj, W)$ – relation, which puts into correspondence to each element of set Vj Πa subset of values of set W elements at time moment t; $R_4(W,F)$ – relation of order that sets the sequence of functions (actions, operations) in the process of achieving main goal G_0 .



Figure 1: Decomposition model of intelligent management system for ecological innovative enterprises

Source: own elaboration.

The goal, in turn, can be formed as a requirement for achievement of specific values of indicators or states of performance for subsystems of IMS EIE and effective performance of certain functions of IMS EIE as a whole. That is, when simulation IMS EIE, it is necessary to distinguish such mandatory sets of components that would ensure the model completeness (1), where i = 1, 2, ..., N, N = 6.

$$P_{M} = \{E^{SS_{1}}, E^{SS_{2}}, E^{SS_{3}}, E^{SS_{4}}, E^{SS_{5}}, E^{SS_{6}}, V^{SS_{1}}, V^{SS_{2}}, V^{SS_{3}}, V^{SS_{4}}, V^{SS_{5}}, V^{SS_{6}}, W^{SS_{1}}, W^{SS_{2}}, W^{SS_{3}}, W^{SS_{4}}, W^{SS_{5}}, W^{SS_{6}}, K^{SS_{5}}, F^{SS_{5}}, F^{SS_{5}}, F^{SS_{5}}, F^{SS_{6}}, G^{SS_{1}}, G^{SS_{2}}, C^{SS_{3}}, G^{SS_{4}}, G^{SS_{5}}, G^{SS_{6}}, R^{SS_{1}}, R^{SS_{2}}, R^{SS_{3}}, R^{SS_{4}}, R^{SS_{5}}, R^{SS_{6}}, K^{SS_{6}}, K^{SS_{6}}, R^{SS_{6}}, R^{SS_{$$

The above patterns of structuring and functioning of IMS EIE subsystems are the initial rules for allocation of a system of elements and its model attributes. Regarding completeness of the mechanism system model, consideration is required at the upper levels of decomposition relative to the following objects:

$$E = \left\{ E^{SS_1}, E^{SS_2}, E^{SS_3}, E^{SS_4}, E^{SS_5}, E^{SS_6} \right\}.$$
(2)

During decomposition of set E elements, for each element $(E^{SS_1}, E^{SS_2}, E^{SS_3}, E^{SS_4}, E^{SS_5}, E^{SS_6})$ from set (2), it is proposed to select the entire set of system components $-\{V, Z, W, F, G, R\}$. Next decomposition of elements (2) and their components depend on the analysed subsystem type SS_i , where i = 1, 2, ..., 6. Hierarchy of structuring is a common feature. It can be formalized by a description in a theoretical and multiple language in the form of a relation tree, which can be an abstract level of a hierarchical model of subsystems, where the units of their characteristics and the mutual relations are specified. Here we propose a six-stage decomposition that can be represented as a model (Fig. 1), where the first stage is represented by graph (G_E) – graph of elements, the second (G_{V1}) – indicators graph, the third (G_{V2}) – graph of indicator values, the fourth (G_W) – graph of states, the fifth (G_F) – graph of functions (actions and operations), the sixth (G_G) – tree (graph) of goals functioning of the IMS EIE. That is, the presented six-stage decomposition can set the rules for IMS EIE system model formation.

For graphical representation of IMS EIE (S) hierarchical levels it is proposed to perform three-level and two-stage decomposition and build a system S model in the form of three-level structure using system (macro), subsystem (meso) and micro-level (element level). That is, system S model is proposed to be presented in the form of a graph, where, after the first stage of system S decomposition as a complex system (macro-level), the second (meso) levels can accommodate hierarchical structures of all system S components, in our case, these are the following subsystems: SS_1 , SS_2 , ..., SS_6 . Elements of sets E^{SS_1} , E^{SS_2} , E^{SS_4} , E^{SS_5} , E^{SS_6} (graph G_E) indicate the second stage of system S decomposition and, accordingly, to the third (micro) level of system S hierarchical structure. Similarly, further decomposition of all elements of set E of system S is performed, if they can be regarded as complex hierarchical structures.

The evaluation of system S efficiency can be performed based on the evaluation of EIE functioning efficiency, in particular, on results of economic, environmental, scientific, technical, social, resource, organizational and managerial types of efficiency, etc. [17-20]. At the same time, the focus will be on a high level of economic and environmental efficiency, which is a priority.

That is, next graph (G_{v_1}) is indicators graph and the third (G_{v_2}) is a graph of indicator values can represent, for example, a graph of EIE performance and, accordingly, a graph of performance. Based on EIE performance values, it is possible to analyse efficiency of system S functioning of eco-oriented management of EIE activities in general and its components and to make appropriate decisions on this

The fourth graph (graph G_w) can be represented by EIE development stages and, accordingly, implementation states of EIE functions, actions and operations and, accordingly, efficiency states EIE and IMS.

basis.

Study of functions, actions and operations of IMS EIE is relevant, contributing to achievement of the EIE goal, and during decomposition IMS EIE may be the fifth graph (graph G_F). IMS EIE management functions, actions and operations are proposed to include: collecting, storing, processing and transmitting management information, forecasting and supporting the adoption and implementation of management decisions.

A goal tree of IMS EIE decomposition is proposed as the sixth stage (Fig. 2). This tree defines the main goal of G_0 EIE and the ways to achieve it, that is, includes the goals of all elements and subsystems of EIE, in particular:

 G_{I} – production of intelligent ecological products; G_{II} – generation of ecological ideas; G_{I2} – scientific research work; G_{I3} – design work; G_{I4} – pilot work;

 G_2 – production of innovative ecological products; G_{21} – transfer of innovative eco-technologies; G_{22} – technological preparation of ecological production; G_{23} – ecological production; G_{24} – marketing;



Figure 2: EIE goal tree Source: own elaboration.

 G_3 – ecological training of personnel; G_{31} – formation of ecological competence of staff; G_{32} – training in ecological knowledge; G_{33} – ecological skills training (operations and operations); G_{34} – provision of eco-innovation certificates; G_{35} – acquiring eco-innovation skills; G_{36} – study of educational process and decision making;

 G_4 – implementation and use of eco-innovation; G_{41} – resource; G_{42} – process; G_{43} – product; G_{44} – market; G_{45} – managerial; G_{46} – organizational;

 G_5 – management; G_{51} – prediction; G_{52} – goal formation; G_{53} – planning; G_{54} – coordination; G_{55} – organization; G_{56} – stimulation; G_{57} – control; G_{58} – regulation; G_{59} – operational management.

IMS EIE analysis, using multilevel and multi-stage decomposition allows to break up IMS EIE model into subsystems and study the EIE functioning states at different levels of their organization, IMS EIE structure, its function, actions and operations. It causes the synthesis problem of studied IMS EIE components, involving use of integration methods to reproduce IMS EIE from its functional elements to study implementation processes of IMS EIE functions in general to meet present challenges of EIE development. That is, the analysis and synthesis will allow the design of IMS EIE, IMS EIE general construction and reconstruction and their subsystems, to adapt IMS EIE to modern business conditions.

4.2. Structure of the intelligent management system for ecological innovative enterprises

The tools, required for IMS EIE formation and operation, can be based on object-oriented integrated and distributed databases and knowledge bases, hybrid expert systems, decision support systems (DSS), integrated neural networks and fuzzy logic tools. DSS allow you to model and automate decision-making processes, model and automate EIE organizational management. Distributed artificial intelligence, integrated intelligent information systems (IIIS) as multi-agent systems [21-23] is the most suitable class of models for IMS EIE implementation, its structure is presented in Fig. 3.

The structure of decision support subsystems (SS_3 and SS_4 subsystems) that are capable of decision making support and explanation include: the first and second generation knowledge subsystems, knowledge base, user interface, decision making subsystems and explanation. Necessary decisions, when using IMS EIE, will be made based on expert knowledge, which, respectively, can be highly qualified specialists in specialized fields of knowledge (knowledge of the first kind), as well as the knowledge obtained based on a priori information and the research results of EIE activities (knowledge of the second kind). This knowledge can be formalized and entered into the knowledge base as knowledge, on its basis SS_3 subsystem supports decision-making on the states of EIE activities, SS_4 subsystem - main effects implemented by SS_6 subsystem.

Managerial decisions on EIE states in general, or any element of their hierarchy, in IMS EIE with proposed structure can be supported, using Monte Carlo simulation, discrete simulation, system dynamics and statics [24, 25], digital business models and visual simulation, operations research (simulation modelling, business games, stochastic programming), decision trees, impact diagrams, fuzzy logic tools, agent and multi-agent simulation [26-29].

Study of dynamic and static characteristics of real states of EIE development and their efficiency with subsequent decision-making is performed by means of IMS EIE. Data collection, their initial processing, to state an environmental problem, is performed using SS_1 subsystem - diagnosing subsystem of EIE states. The storage and collected data processing and further evaluation and prediction of EIE states and their efficiency are performed using SS_2 subsystem. If real studies fail to be implemented, then it is proposed to use virtual information from the information block and modulate virtual states and business processes of EIE using SS_5 subsystem. It will promote further evaluation and prediction of possible states, make situational decisions and implement them using SS_6 subsystem. If ecological problem is well-structured, then mathematical methods are used to process environmental information about it and subsequent choice of management decisions, and if the problem is poorly structured or unstructured, expert judgement is proposed to prepare options [30-32] and evaluations.

To evaluate and predict EIE states in general or their components, it is proposed to use a mathematical tool of Markov chain theory; applying systems of differential equations of Kolmogorov

type. Based on this mathematical tool the corresponding software was developed and tested in the study of petroleum products concentration on biogeocenosis elements around wells operated in Boryslav-Skhidnytske oil deposit [33, 34]. This mathematical tool can also be used to study IE environmental friendliness of before and after introduction of eco-innovations, allowing to evaluate their efficiency.





Source: own elaboration.

These studies are proposed to be performed based on calculation of integrated ecological indicators of enterprises [35-37], namely, integral indicator I_{PEVS} , represented as formula (1) [35].

$$I_{PEVS} = \sqrt[7]{K_A \cdot K_{VO} \cdot K_B \cdot K_Z \cdot K_{BB} \cdot K_{ZB} \cdot K_N} ; I_{PEVS} \longrightarrow 1, \quad (1)$$

where K_A – emission coefficient; $K_A \rightarrow 1$;

 K_{WB} - coefficient of discharge into water bodies; $K_{WB} \rightarrow 1$;

 K_W – waste coefficient; $K_W \rightarrow 1$;

 K_{LP} – coefficient of land production capacity; $K_{LP} \rightarrow 1$;

 K_{WU} -waste utilization FACTOR; $K_{WU} \rightarrow 1$;

 K_{LR} - loss ratio of products; $K_{LR} \rightarrow 1$;

 K_{WH} – waste hazard factor; $K_{WH} \rightarrow 1$.

As information support for calculation of integral indicator (1) and its components, it is possible to take data from environmental balances and EIE reports.

To study dynamic and static characteristics of the impact of eco-innovation on enterprise activities, it is proposed to use an integral indicator of their environmental friendliness (ecological sustainability) (1). Table 1 provides this indicator interpretation [31, 35].

Table 1

Interpretation of integral ecological indicator (ecological sustainability) of enterprises

Stability states	Indicator value	State description
S ₅ - absolutely sustainable development (very good state, VG)	0.91	All ecological issues of enterprise production activity are solved (considering development prospects)
<i>S₄</i> - high sustainable development (good state, G)	0.70.9	Provision of environmental safety and minimizing environmental impact
S₃ - sustainable development (satisfactory state, S)	0.50.7	Payments for environmental pollution within the established limits
S 2 – unstable development (poor state, P)	0.30.5	Poor ecological sustainability
S ₁ – crisis situation (very poor situation, VP)	less than 0.3	Ecological sustainability is not ensured

Source: own elaboration based on data from [31; 35].

4.3. Formation of mathematical software for IMS EIE

To evaluate and predict the EIE states of ecological sustainability based on the study of its integral index, these states are proposed to be presented as a graph with vertices (Fig. 4), identifying the states (Table 1): S_1 – "very poor"; S_2 – "poor"; S_3 – "satisfactory"; S_4 – "good"; S_5 – "very good".



Figure 4: Graph of ecological sustainability states

This graph can be described by the system of Kolmogorov differential equations (1), and as $t \to \infty$ and dP/dt = 0, by the system of algebraic equations (2), where λi , j are the intensities of the transition from state i to state j, i, j = 1, 2,..., 5; i \neq j; Pi is the probability of i states.

$$\frac{dP_1}{dt} = -\lambda_{12} \cdot P_1 + \lambda_{21} \cdot P_2$$

$$\frac{dP_2}{dt} = \lambda_{12} \cdot P_1 - (\lambda_{21} + \lambda_{23}) \cdot P_2 + \lambda_{32} \cdot P_3$$

$$\frac{dP_3}{dt} = \lambda_{23} \cdot P_2 - (\lambda_{32} + \lambda_{34}) \cdot P_3 + \lambda_{43} \cdot P_4$$

$$\frac{dP_4}{dt} = \lambda_{34} \cdot P_3 - (\lambda_{43} + \lambda_{45}) \cdot P_4 + \lambda_{54} \cdot P_5$$

$$\frac{dP_5}{dt} = \lambda_{45} \cdot P_4 - \lambda_{54} \cdot P_5$$
(1)

The value of transitions from one state to the other, directly affected by eco-innovations, is the statistical information that can be obtained during the functioning of studied EIE. To evaluate and predict EIE ecological sustainability state, it is recommended to collect information at the beginning and at the end of the eco-innovation implementation. For the purpose of automated study of the dynamics of ecological sustainability states, the numerical solution of the differential equation system (1) is proposed to be performed by software tools, based on the fourth-order numerical Runge-Kutta method, included in the structure of the IMS EIE (Subsystem SS₄). An automated study of EIE ecological sustainability state in static when $t \rightarrow \infty$, a dP/dt = 0, is proposed to be performed based on computer solution of the system of algebraic equations (2) using software developed on the basis of the Gaussian numerical method. Based on the obtained dynamic and static characteristics of the state of ecological sustainability of enterprises can make appropriate forecasts and make optimal management decisions.

$$-\lambda_{12} \cdot P_1 + \lambda_{21} \cdot P_2 = 0$$

$$\lambda_{12} \cdot P_1 - (\lambda_{21} + \lambda_{23}) \cdot P_2 + \lambda_{32} \cdot P_3 = 0$$

$$\lambda_{23} \cdot P_2 - (\lambda_{32} + \lambda_{34}) \cdot P_3 + \lambda_{43} \cdot P_4 = 0$$

$$\lambda_{34} \cdot P_3 - (\lambda_{43} + \lambda_{45}) \cdot P_4 + \lambda_{54} \cdot P_5 = 0$$

$$\lambda_{45} \cdot P_4 - \lambda_{54} \cdot P_5 = 0$$
(2)

The proposed mathematical tool and the developed software to solve systems of differential (1) and algebraic (2) equations, were tested for relevance in real studies of the state of ecological sustainability of 100 enterprises in the Western region of Ukraine.. Graph of virtual states of ecological sustainability is shown in Fig. 5.

Prior to the introduction of eco-innovation, 30 enterprises were in state S_1 , 40 enterprises were in state S_2 , 15 enterprises were in state S_3 , 10 enterprises were in state S_4 and 5 enterprises were in state S_5 , that is, the initial values of state probabilities (initial conditions of the studied process) were as follows:

$$P_1 = 0.3; P_2 = 0.4; P_3 = 0.15, P_4 = 0.1, P_5 = 0.05$$



Figure 5: Graph of ecological sustainability virtual states

When solving differential equations system (1), describing the state graph of the integral indicator of ecological sustainability (Fig. 5) and algebraic equations systems (2), we obtained dynamic and static characteristics of virtual state probabilities of ecological sustainability, presented in Fig. 6.



Figure 6: Dynamic and static characteristics of virtual states of enterprise ecological sustainability Source: developed by the authors based on own calculations

In this case, state of S_5 is most likely, since value of P_5 in statics is 0.9342, and $P_4 = 0.0467$, $P_3 = 0.0093$, $P_2 = 0.0092$, $P_1 = 0.0006$. Since S_5 is a very good state, characterizing the absolutely sustainable development of the EIE, it can be considered that most EIE where eco-innovations are implemented, belong to enterprises where ecological issues of industrial activities are resolved.

Based on the computational experiment, it can be concluded that this mathematical tool and the software developed on its basis can find application as a mathematical and software IMS EIE to evaluate, predict and support environmental decision making.

Thus, the proposed approach to designing of IMS EIE, the study of EIE state in general and their structural elements, goals, efficiency, functions, actions and operations, indicates that IMS EIE should be considered as a complex system with a set of interdependent elements, their structure, strategic and operational activities aimed at achievement of EIE interim goals and overarching goals in a market environment and the constant impacts of a changing environment.

5. Conclusions

Designing of IMS EIE as a complex system is aimed at greening of production and technological processes of economic entities of different spheres and activities, industries, regions and the country as a whole in compliance with modern challenges. Use of IMS EIE will allow to make optimal management decisions on ecological and economic activity and increase the efficiency of enterprises functioning, increase their environmental and economic security, which is a practical effect of work.

The studied approaches to IMS EIE designing can be widely used for IMS EIE and EIE design, construction and restructuring in general and their structural elements, to adapt EIE to current economic conditions.

It is important to formulate criteria to evaluate efficiency of the IMS EIE and use of an integral indicator for evaluation and prediction of ecological sustainability of enterprises. Approaches to the study of dynamic and static characteristics of EIE ecological sustainability states, its evaluation and prediction, are relevant, for further optimal management decisions to improve the IMS EIE functioning and the EIE as a whole.

6. References

- Sadekov A.A. 2002. Mechanisms of ecological and economic enterprise management. Monograph. Donetsk: Donetsk National University of Economics and Trade named after M. Tugan-Baranovsky, 311 p.
- [2] Yasnolob Ilona, Gorb Oleg, Opara Nadiia, Shejko Serhii, Pysarenko Svitlana, Mykhailova Olena, Mokiienko Tetyana. 2019. The formation of the efficient system of ecological enterprise. Journal of Environmental Management and Tourism, Vol 9. N 1 (17). (Spring 2019). URL: http://dspace.pdaa.edu.ua:8080/jspui/bitstream/123456789/5229/1/%D0%A1%D0%9A%D0 %9E%D0%9F%D0%A3%D0%A1.pdf.
- [3] Reshetnikova I.L. 2009. Methodical approaches to eco-oriented management of a trading company. Economy regulation mechanism, N 4. T. 1, 42-47.
- [4] Shylo S.V. 2013. Ecological and economic management of innovation in the agricultural sphere: organizational aspect. Agroincom, N 10-12, 26-29.
- [5] Ching-Torng Lin, Yu-Hsuan Chang, Chuanmin Mi. 2017. Develop Eco-Friendly Enterprise: Aligning Enablers with Strategy. Sustainability, Vol 9. Issue 4. URL: https://www.mdpi.com/2071-1050/9/4/570.
- [6] Lassi Linnanen. 2002. An Insider's Experiences with Environmental Entrepreneurship. Greener Management International: The Journal of Corporate Environmental Strategy and Practice, Vol. Summer, Issue 38, 71-80. URL: https://ssrn.com/abstract=1495532.
- [7] Adam Luqmani, Matthew Leacha, David Jessona. 2017. Factors behind sustainable business innovation: The case of a global carpet manufacturing company. Environmental Innovation and Societal Transitions, № 24, 94-105.
- [8] Coen Bertens, Hidde Statema. 2011. Business models of eco-innovations, 67 p.
- [9] Kneipp J., Gomes C., Bichueti R., Frizzo K., and Perlin A. 2019. Sustainable innovation practices and their relationship with the performance of industrial companies. Revista de Gestao, Vol. 26. N 2, 94-111. URL: https://doi.org/10.1108/REGE-01-2018-0005.
- [10] Andrea Ettekal, Joseph L. Mahoney. Ecological Systems Theory. 2017. URL: http://dx.doi.org/10.4135/9781483385198.n94.
- [11] Agarwal N., Mukkamala R. 2005. Design of complex systems: issues and challenges. URL: https://ieeexplore.ieee.org/document/1563486.
- [12] Andrew P. Sage, William B. Rouse. 2014. Handbook of Systems Engineering and Management 2nd Edition. Wiley-Interscience, 1504 p.
- [13] Rika Preiser, Reinette Biggs, Alta De Vos, Carl Folke. 2018. Social-ecological systems as complex adaptive systems: organizing principles for advancing research methods and approaches. Ecology and Society, Vol. 23. No. 4. URL: https://doi.org/10.5751/ES-10558-230446.
- [14] Zundong Zhang, Limin Jia, Yuanyuan Chai. 2010. A New Kind Methodology for Controlling Complex Systems. International Journal of Natural Sciences and Engineering, Vol. 4. No. 8/1369
- [15] Nicole Fortin, Thomas Lemieux, Sergio Firpo. Decomposition Methods in Economics. 2010. Handbook of Labor Economics, No. 4. 118p. URL: https://www.researchgate.net/publication/46467022.
- [16] Nestor Shpak, Mykola Odrekhivskyi, Kateryna Doroshkevych and Włodzimierz Sroka. 2019. Simulation of Innovative Systems under Industry 4.0 Conditions. Social Sciences. MDPI AG, Basel, Switzerland, Vol. 8, Issue 7. URL: https://www.mdpi.com/2076-0760/8/7/202 https://doi.org/10.3390/ socsci8070202.
- [17] Smol M., Kulczycka J. & Avdiushchenko A. 2017. Circular economy indicators in relation to ecoinnovation in European regions. Clean Technologies and Environmental Policy, Volume 19. Issue 3 (April 2017), 669–678. URL: https://doi.org/10.1007/s10098-016-1323-8.
- [18] Gunarathne, A.D.N. & Peiris, H.M.P. 2017. Assessing the impact of eco-innovations through sustainability indicators: the case of the commercial tea plantation industry in Sri Lanka. Asian Journal of Sustainability and Social Responsibility, Volume 2. Issue 1. (September 2017), 41-58. URL: https://doi.org/10.1186/s41180-017-0015-6.
- [19] Katarzyna Tarnawska. 2013. Eco-innovations tools for the transition to Green economy. Economics and Management, 18 (4), 735-743.

- [20] Tsapuk O. Yu. 2013. System of criteria and indicators for evaluation of innovative development efficiency. Marketing and innovation management, N 3, 137-145.
- [21] Antonescu, M. 2018. Are business leaders prepared to handle the upcoming revolution in business artificial intelligence? Qual. Access Success, 2018, N 19 (53), 15–19.
- [22] Boitnott J. 2019. 7 innovative companies using A.I. to distrust their industries. URL: https:// www.inc.com/john-boitnott/7-innovative-companies-using-ai-to-disrupt-their-industries.html (accessed on 1 June 2019).
- [23] Jaehun Lee, Taewon Suh, Daniel Roy and Melissa Baucus. 2019. Emerging Technology and Business Model Innovation: The Case of Artificial Intelligence. Journal of Open Innovation: Technology, Market, and Complexity, 5, 44. URL: https://www.researchgate.net/publication/334620177.
- [24] Aliyev A.G. 2014. Economic-Mathematical Methods and Models under Uncertainty. Apple Academic Press, 302 p.
- [25] De la Fuente A. 2000. Mathematical Methods and Models for Economists. Cambridge University Press, 836 p. URL: https://www.twirpx.com/file/1180529/.
- [26] Ana Paula M. Tanajura, Valdir Leanderson C. Oliveira, Herman Lepikson. 2015. A Multi-agent Approach for Production Management. Industrial Engineering, Management Science and Applications, 65-75.
- [27] Aradea Dipalokareswara, Iping Supriana, Kridanto Surendro. 2014. An Overview of Multi Agent System Approach in Knowledge Management Model. International Conference on Information Technology Systems and Innovation, 2014. URL: https://www.researchgate.net/publication/268982254.
- [28] Dhanashree R. Kamble. 2013. Architectural Review On Multi Agent Knowledge Management. International Journal of Scientific & Technology Research, Volume 2, Issue 6 (June 2013), 105 – 114.
- [29] F. Vendrell-Herrero, G. Parry, O. F. Bustinza, E. Gomes. 2018. Digital business models: Taxonomy and future research avenues. Strategic Change, Vol. 27, Issue 2. URL: https://doi.org/10.1002/jsc.2183.
- [30] Delgado M., Verdegay J.L., and Vila V. 1993. Linguistic decision making models. International Journal of Intelligent Systems, Vol. 7, 479-492.
- [31] Larysa Cherchyk, Mykola Shershun, Nina Khumarova, Taras Mykytyn, Artur Cherchyk. 2019. Assessment of forest enterprises performance: Integrating Economic Security and Ecological Impact. Entrepreneurship and Sustainability issues, Vol. 6, N 4, 1784-1797. URL: http://doi.org/10.9770/jesi.2019.6.4(17)/.
- [32] Singh S., Olugu E. U. and Fallahpour A. 2014. Fuzzy-based sustainable manufacturing assessment model for SMEs. Clean Technologies and Environmental Policy, Vol. 16 (5), 847-860. URL: https://doi.org/10.1007/s10098-013-0676-5.
- [33] Odrekhivskyy M., Kohut U., Kochan R., Jancarczyk D and Gryga V. 2019. Problems of evaluation and Forecasting of the Biosystems states. 19th International multidisciplinary scientific Geoconference SGEM 2019. Nano, Bio, Green and Space: Technologies for Sustainable Future, (30 June – 6 July, 2019), Albena, Bulgaria. Vol. 19, Issue: 6.1, 859-865.
- [34] Odrekhivskyy, M., Kohut, U., Kochan, R., Karpinskyi, V. and Bernas, M. 2019. Problems of environmental innovation systems design. 19th International multidisciplinary scientific Geoconference SGEM 2019. Ecology, Economics, Education and Legislation, 30 June – 6 July, 2019, Albena, Bulgaria. Vol. 19, Issue: 5.3, 587-594.
- [35] Rudneva H.Y., Zaglada R.Y., Chiechienieva E.R. 2012. Evaluation the ecological Component of Sustainable development of Coal-mining Industry Enterprises. Bulletin of Zaporizhzhya National University. Economic Sciences, No. 4 (16), 62 - 68.
- [36] Jurgis K. Staniskis, Valdas Arbaciauskas. 2009. Sustainability Performance Indicators for Industrial Enterprise Management. Environmental Research, Engineering and Management, N 2 (48), 42 - 50. URL: https://www.researchgate.net/publication/49941561.
- [37] Hyunkee Bae, Richard S. Smardon. 2011. Indicators of Sustainable Business Practices. Environmental Management in Practice. Edited by Dr. Elzbieta Broniewicz, 177-206.