Lecture Notes in Networks and Systems 996

Mykola Nechyporuk
Volodymir Pavlikov
Dmytro Krytskyi *Editors*

# Integrated Computer Technologies in Mechanical Engineering - 2023

## Synergetic Engineering, Volume 2

Springer

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Mykola Nechyporuk · Volodymyr Pavlikov ·
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# Preface

The International Scientific and Technical Conference “Integrated Computer Technologies in Mechanical Engineering”—Synergetic Engineering (ICTM) was established by the National Aerospace University “Kharkiv Aviation Institute.”

The Conference ICTM’2023 was held in Kharkiv, Ukraine, during December 2023. During this conference, technical exchanges between the research communities were carried out in the forms of keynote speeches, panel discussions, as well as special sessions. In addition, participants were treated to a series of receptions, which forged collaborations among fellow researchers. ICTM’2023 received 202 papers submissions from different countries.

All of these offer us plenty of valuable information and would be of great benefit to the experience exchange among scientists in modeling and simulation. The organizers of ICTM’2023 made great efforts to ensure the success of this conference. We hereby would like to thank all the members of ICTM’2023 Advisory Committee for their guidance and advice, the members of program committee and organizing committee, and the referees for their effort in reviewing and soliciting the papers, and all authors for their contribution to the formation of a common intellectual environment for solving relevant scientific problems. Also, we are grateful to Springer-Janusz Kacprzyk and Thomas Ditzinger as the editor responsible for the series “Lecture Notes in Networks and Systems” for their great support in publishing these selected papers.

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# Project Management and Business Informatics

# Methodology for Assessing the Processes of the Occupational Safety Management System Using Functional Dependencies

Olena Cherniak[1](✉), Roman Trishch[2], Romualdas Ginevičius[2], Olesia Nechuiviter[1], and Victoriia Burdeina[3]

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**Abstract.** The existing functional dependencies between the measured values of quality indicators and their assessment on the dimensionless scale that were used to assess qualimetry objects of various nature have been analyzed. It has been shown that, as a rule, non-linear dependencies should be used for the objective assessment of qualimetry objects. The main task of the researcher is to choose the type of nonlinear dependence, this requires additional scientific research. The tool for choosing one or another non-linear dependence is the understanding of the physical essence of the qualimetry object, that is, the understanding of the regularities of the relationship between the measured value of qualimetry indicators and their assessment. For this, it is important to use methods of expert assessments, because, as a rule, such regularities are unknown. The functional dependence that is used to obtain assessments of indicators of the state of occupational safety in production is stepwise and includes a shape parameter. When the shape parameter changes, the curvature of the dependence changes, thereby changing the assessment on the dimensionless scale. This feature of the applied dependence makes it possible to develop a universal technique, that is, by changing the shape parameter, this dependence can be applied to various indicators of labor safety in any production. As an example, the article examines the machine-building industry and assesses the most dangerous factors. A step-by-step technique for determining a complex indicator of occupational safety in production has been developed, and its effectiveness and universality have been shown by an example of measured numerical values of dangerous factors.

**Keywords:** Functional Dependence · Management System · Multi-criteria Assessment · Object of Qualimetry · Complex Indicator · Occupational Safety

## 1 Introduction

An important factor in the sustainable economic development of the organization is ensuring the quality, safety and competitiveness of products. The implementation of management systems based on the requirements of international standards such as ISO 9001,


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ISO 45001, ISO 14001 and others contributes to improving the enterprise's performances [1–3].

One of the vectors of the sustainable development strategy is the safety of human life and health that is impossible without an effective system of occupational health and safety management. Occupational safety management involves the development of a system of measures aimed at obtaining objective information about the object of management that allows making management decisions on the improvement of its condition from the point of view of safety. To achieve effective management, more sophisticated and economical methods of collecting and processing information are needed.

It is known that in the process of work, a person is affected by the factors of the production environment and the work process that may affect health. For proper forecasting and minimization of harmful and dangerous factors, their assessment is required, and such assessments should have quantitative values.

The methodology of quantitative assessment is regulated by the subject of science - qualimetry. In qualimetry, there are a number of scientific directions of research concerning all objects regardless of their nature - these are tasks related to multi-criteria assessment. One of these directions is the problem of bringing various quality indicators of objects to a single dimensionless scale. The second direction is the unification of quality indicators into a single (comprehensive) assessment of the object of qualimetry. Let us consider the system of harmful and dangerous factors as the object of qualimetry.

## 2 Literature Review

Over the past decades, multi-criteria assessment has become a necessary tool for making complex decisions, as it promotes the active participation of stakeholders in the joint decision-making process and allows taking into account a wide range of criteria that may be both measurable and non-measurable. This approach combines quantitative and qualitative aspects that allows taking into account various aspects of the problem and the importance of each of them when making a decision. In addition, multi-criteria assessment helps to achieve consensus and increases the level of trust between participants in the decision-making process [4–8].

In qualimetry, mathematical dependence is an integral part of many processes of assessment and comparison of various indicators [9–13]. For example, the article [14] discusses the problems of quantitative assessment and ranking of economic development in countries using indicators and indices. To assess the quality of investments, mathematical relationships between the actual values of investments and their assessments on the dimensionless scale are used.

The scientific work [15] examines the psychological effects of the COVID-19 pandemic on various professional groups and uses qualitative methods to quantify the psychological stress experienced by these groups and identifies seven main signs of stress. In work [16], mathematical dependencies are used to compare the economic development of the European Union countries, and in work [17], they are used to study the economic indicators of the countries' development.

The authors [18] used various functional dependencies between the measured indicators of dangerous factors and their evaluation on a dimensionless scale to assess the indicators of occupational health and safety processes. In the study [19], to obtain estimates of process quality indicators, it is proposed to apply the error function, which provides requirements for quality indicators, allows to effectively obtaining estimates on a dimensionless scale, which makes it possible to obtain and increase the amount of statistical information.

Thus, techniques that apply mathematical dependencies are an effective tool for assessing, comparing and solving complex problems in various fields. They have a more accurate application of the values of various indicators and ensure objectivity and scientific accuracy in the conducted studies [20–25].

## 3 Research Methods

The analysed assessment methods are used to assess product quality and its influence on various processes of the quality management system; therefore, we believe that the literature review has confirmed the relevance of research aimed at the development of methods for assessing the state of occupational safety. It is proposed to apply a type of dependencies that will allow assessing the state of occupational safety in production:

$$F(x) = \frac{1}{1 + nm^{-kq_i}}, \tag{1}$$

where the coefficients n and m are found as follows:

$$m = m_1^{\frac{1}{(q_{\min} - q_{\max})k}}, \tag{2}$$

where

$$m_1 = \frac{(1 - q_{\max})q_{\min}}{(1 - q_{\min})q_{\max}}. \tag{3}$$

$q_{\min}$ and $q_{\max}$ are the minimum permissible and maximum permissible value of the indicator of the harmful factor.

Thus, after normalization, the coefficient n is found as follows:

$$n = \frac{(1 - q_{\min})}{q_{\min}} m^{kq_{\min}}. \tag{4}$$

The $k$ parameter influences the steepness of the function along the OX axis. By changing $k$, it is possible to control the curvature of the function (1) and thus obtain different assessments with the same results of measurements of the harmful factor indicator.

Figure 1 shows a series of three dependencies (1), where the coefficient k varies from 1.2 to 0.8 in steps of 0.2 from left to right. On the OX axis, the scale corresponds to the scale of measurement units and can be changed for each individual indicator of the harmful factor. The extreme left value on this scale (0) corresponds to $Q_{\min}$ – the minimum permissible value of the indicator of the harmful factor. The extreme right value on this scale (1) corresponds to $Q_{max}$ – the maximum permissible value of the indicator of the harmful factor. They correspond to the respective values of each individual indicator of the harmful factor. Therefore, if working conditions have n indicators of harmful factors, then it is necessary to determine the coefficients *n* and *m* for each of them according to Formulas (4) and (2), respectively. Regardless of the units of measurement and the digits of the value of the indicator of the harmful factor on the OX axis, the type and form of the dependence will not change. A change in the shape parameter *k* will lead to a change in shape.

It can be seen from Fig. 1 that with an indicator of 0.5 measured in units of measurement, its assessment on the dimensionless scale varies from 0.88 at k = 1.2 to 0.3 at k = 0.8. Therefore, having one valid value of the indicator of the harmful factor, we can obtain a range of values of its assessments on the dimensionless scale. In this way, one can choose one of the degree indicators in function (1) and change the assessment of the valid indicator of the harmful factor on the dimensionless scale.

The choice of a particular parameter k is made by a group of experts - experienced professionals who have knowledge of the degree of impact of a particular harmful factor on the health of employees. For example, if, according to experts, any harmful factor has a minor negative impact on human health, the parameter $k = 1.2$ can be used. In this case, the assessment of the harmful factor on the dimensionless scale will be significantly high relative to the others. If experts assess the impact of a harmful factor on human health as significant, it is proposed to use the parameter $k = 0.8$. In this case, the assessment of the harmful factor on the dimensionless scale will be significantly lower than the others. The choice of this or that parameter *k* allows the manager to adjust the goals for occupational safety in the workplace.

It is known from the theory of qualimetry that quality is a set of characteristics of an object that relate to its ability to meet the established needs of the consumer in accordance with its purpose. Therefore, when choosing the parameter *k*, either a group of experts or a consumer can be used. In this case, the consumer is also an expert. If the consumer is an expert, then subjectivity is levelled out when choosing the parameter *k*, otherwise the group of experts applies the theory of expert judgement. With the right choice of the expert evaluation method and its application, subjectivity is minimised.

Since the assessments of single indicators of harmful factors have the same measurement scale (0–1), it is possible to find a comprehensive indicator of the state of occupational safety by applying one of the average values (arithmetic, geometric, harmonic) that make it possible to combine individual assessments. In this case, the comprehensive indicator of the occupational safety state is calculated according to the formula:

$$Q = \frac{1}{n}\sum_{i=1}^{n} F_i. \tag{5}$$

where n is the number of unit indicators of the harmful factor; $F_i$ is the value of the *i*-th unit indicator of the harmful factor on the dimensionless scale.

We offer a step-by-step technique for determining the comprehensive indicator of the occupational safety state:

Step 1. To determine the list of harmful and dangerous factors in production.

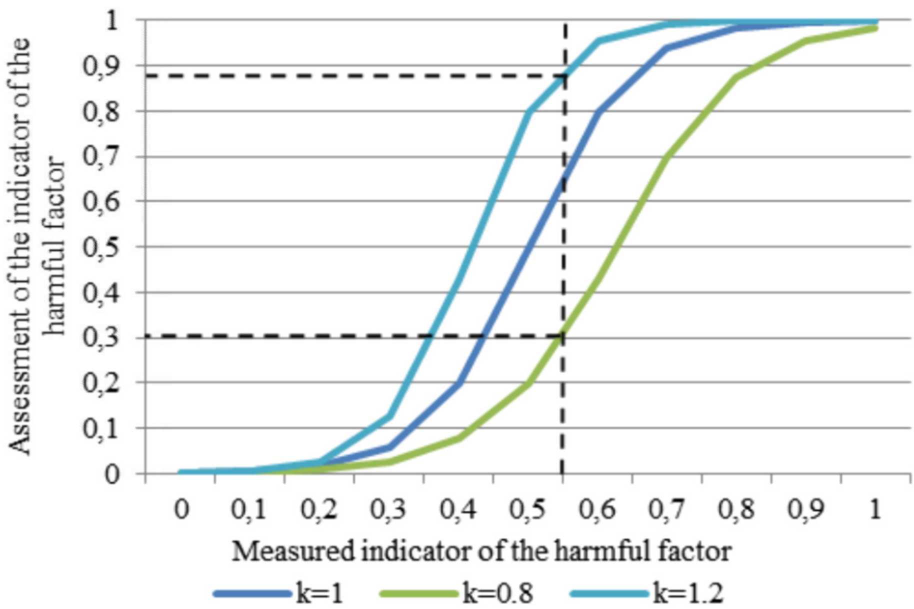



**Fig. 1.** Series of dependencies (1) at k = 1.2–0.8 with a step of 0.2 from left to right.

Step 2. To determine the maximum permissible, minimum permissible and optimal (best) values for each harmful and dangerous factor according to regulatory documents.

Step 3. To measure these harmful factors and enter the results in a specially prepared table.

Step 4. To determine the assessment of the indicator of the harmful factor on the dimensionless scale according to Formula (1). To do so, it is necessary to use Formulas (2–4) and assign the shape parameter *k*. The form parameter is assigned by a group of experts.

Step 5. To determine the generalized index of occupational safety in accordance with Formula (5) taking into account all individual indicators.

## 4 Application of the Methodology for Determining a Comprehensive Indicator of Occupational Safety

In order to check the efficiency of the methodology for assessing the occupational safety state, a study was conducted at a machine-building enterprise. To conduct the assessment, hazards at the turner's workplace were considered. During work, employees of machine-building enterprises may be affected by such harmful production factors as: noise, monotony of work processes, injury by moving parts of production equipment, insufficient lighting of the work area, electric shock, etc. It was determined that the main harmful production factors at the workplace of turner are: air temperature, relative air humidity, air movement speed, noise and lighting.

The values of harmful production factors were measured and recorded at workplaces and in the work area for three weeks. The FLIR EM54 combined device was used to measure air temperature, relative air humidity, and air movement speed. The noise level was measured with the GM1351 digital sound level meter. Illumination was measured with the DE-3350/DE-3351 digital lux meter. The optimal norms of harmful factors are determined at the enterprise in accordance with current regulatory documents.

The obtained experimental values of the above indicators of harmful factors and results of mathematical transformations are shown in Table 1.

**Table 1.** Results of implementing the technique for assessment of occupational safety conditions at the workplace of turner.

| No. | Indicators of harmful factors | $q_{min}$ | $q_{max}$ | $q_{opt}$ | $q_i$ | k | F |
|---|---|---|---|---|---|---|---|
| 1 | Air temperature, °C | 18 | 27 | 23 | 23 | 1.2 | 0.99 |
| 2 | Relative humidity, % | 30 | 75 | 55 | 65 | 1 | 0.84 |
| 3 | Air speed, m/s | 0.2 | 0.4 | 0.3 | 0.25 | 1 | 0.8 |
| 4 | Noise, dBa | 60 | 80 | 70 | 77 | 0.8 | 0.64 |
| 5 | Lighting, lx | 300 | 750 | 750 | 650 | 1.2 | 0.96 |

Graphical representations of dependencies for the assessment of harmful factors at the workplace are presented in Fig. 2.

Figure 2 shows the dependencies (1) for different parameters of the form k. To obtain estimates of the indicators of harmful factors on the dimensionless scale OY, where the dimensional scale OX has the corresponding dimension of the measured indicator of harmful factors (air temperature, °C; relative humidity, %; air velocity, m/s; noise, dBA; lighting, lux).

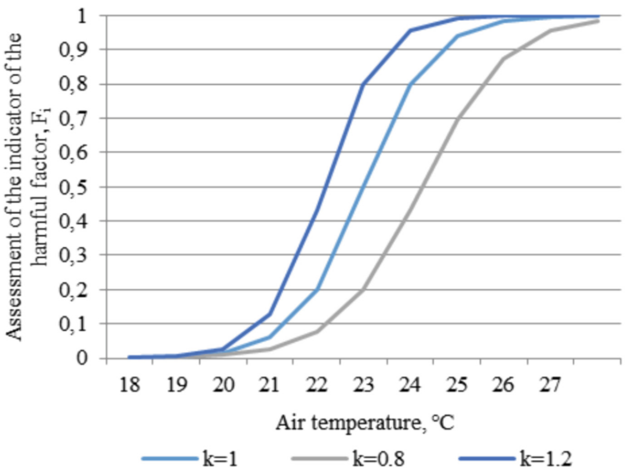
According to the proposed methodology, it is necessary to measure harmful factors using established methods and determine the standard values. A group of experts, depending on the importance of the harmful factor indicator (hazard and impact on the worker), determines the parameters of the form k for each of the harmful factor indicators and enters them into Table 1. According to Formula 1, the assessment of a single indicator of a harmful factor on a dimensionless scale is determined and entered into Table 1.

A complex indicator determined by one of the formulae of average values. In this case, the arithmetic mean value is used.

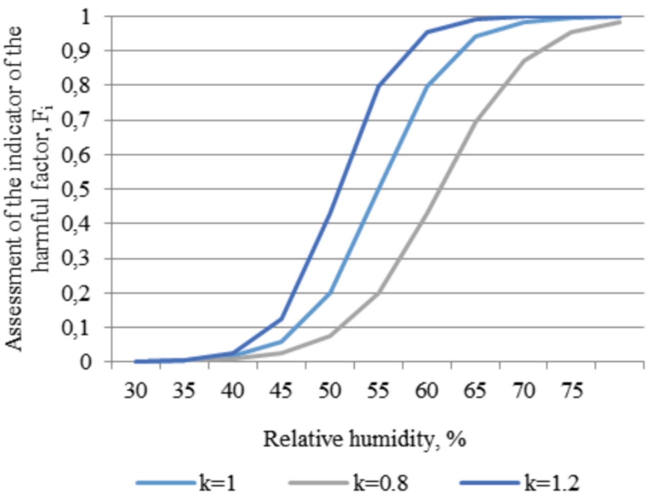
$$Q = \frac{0.99 + 0.84 + 0.8 + 0.64 + 0.96}{5} = 0.85$$

Therefore, with the help of functional dependence and experts, it is possible to obtain the comprehensive indicator of occupational safety at the enterprise. The developed technique is universal, and it can be applied to assess the occupational safety state in productions of various branches of the national economy.

The proposed methodology has been validated for assessing working conditions at a machine-building enterprise. However, it can be equally used and effective for any sector of the economy.

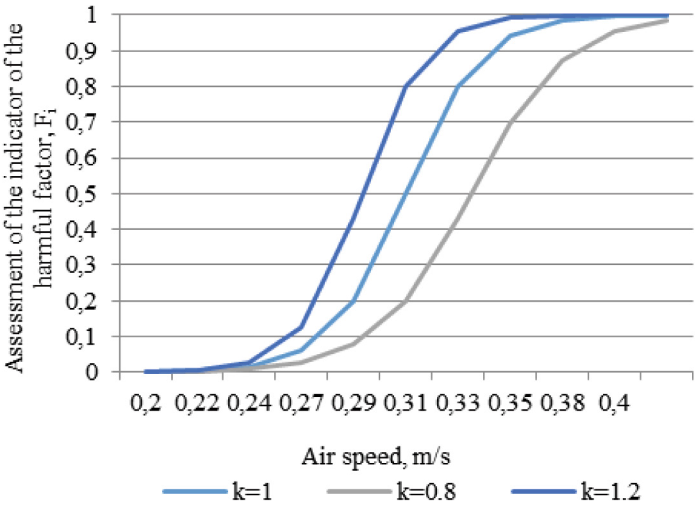



a)

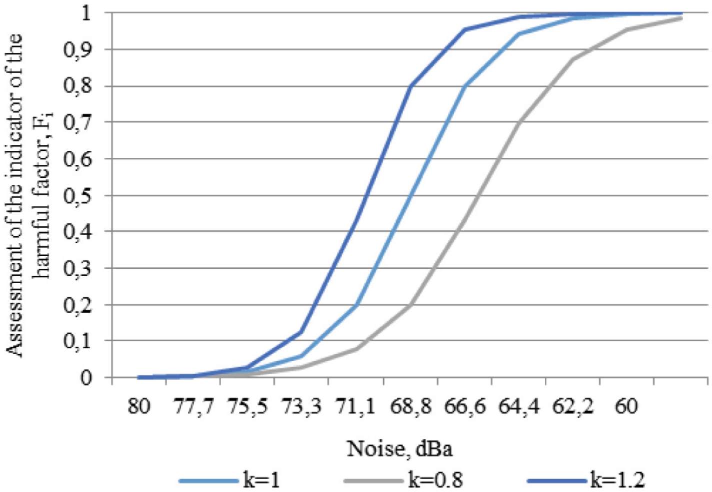



b)

**Fig. 2.** Graphical representation of dependencies for assessing indicators of harmful factors: a) air temperature; b) relative air humidity; c) air speed; d) noise; f) lighting.

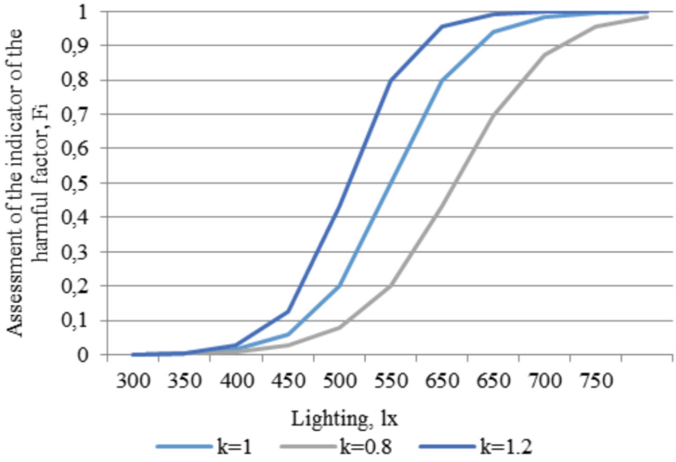



c)




d)

**Fig. 2.** (*continued*)




f)

**Fig. 2.** (*continued*)

## 5 Conclusions

Qualimetric tools are used to assess the state of occupational safety, as they allow to obtain a quantitative assessment of harmful ones. It has been determined that the system of harmful factors as an object of quality measurement has a number of features that should be taken into account when solving the task of quantitative assessment of occupational safety at production facilities.

Thus, the application of functional dependence between individual indicators of harmful factors and their values on the dimensionless scale provides a quantitative assessment of the state of occupational safety in production. With the help of the proposed technique, it is possible to make management decisions that lead to the minimization of the deviation of the actual values of harmful factors from the optimal ones.

A mathematical dependency consists of sequential arithmetic operations, but with Microsoft Excel, the decision maker enters the minimum, maximum and actual (measured) values and gets the result. This allows you to automate the calculation process. The simplicity of the dependence (1) makes it suitable for use in industrial applications.

The proposed mathematical dependence can become a practical tool for assessing the state of occupational safety, and can also be implemented in regulatory documents at the level of an organization or enterprise in order to implement the assessment procedure of the occupational health and safety management system.

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# Cognitive Component of Development of the Innovative Diffusion of the Socio-Economic Systems

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**Abstract.** The concept of the innovative diffusion is associated with the dissemination of innovations through the system of information, social and economic connections between the elements of the socio-economic system. The chapter is devoted to the cognitive component of the development of the innovative diffusion of such systems. The aim of the work is to study the issues of cognitive representation of the development of the innovative diffusion of the socio-economic systems and to design the theoretical base of the use of cognitive technologies for the making the relevant managerial decisions. The factor of cognitiveness, as the ability to perceive and process data to turn them into knowledge, will ensure stimulating the development of innovative sectors of the economy. The peculiarity of the cognitive approach is the possibility of qualitative modeling of complex weakly structured situations that are not subject to severe mathematical analysis. The attention is paid to examples of using the structural-analytical method of pattern recognition to predict the innovative development of the business entity. The authors demonstrated an original cognitive model, which allows to investigate problems that arise in the conditions of developing the innovative diffusion of economic systems. The relevant software complex has been created by the authors.

**Keywords:** Socio-economic System · Innovative Diffusion · Cognitive Modeling · Decision Trees · Patterns Recognition

## 1 Introduction

The creation and development of the innovative environment of the socio-economic systems is aimed at obtaining an economic effect. This process is carried out by updating traditional, technically obsolete and environmentally hazardous industries and is based on fundamental scientific knowledge and research. Within the framework of the innovative development concept, the phenomenon of the innovative diffusion, which is


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associated with the dissemination of a wide range of innovations through the system of information, social and economic ties between all elements of the socio-economic system occupies the central place.

Investigation of the functional capabilities of existing forms of organizational innovative structures in the socio-economic systems allows us to conclude that in this system the function of innovation distribution control is implemented insufficiently fully. This fact is largely restraining the innovation activity of business entities. In the presence of a weak demand for innovation from organizations, there is a need for management of distribution of innovations, taking into account the relationship between the processes of their perception and commercialization. This contributes to the occurrence of systemic effects that arise during the innovative diffusion.

Scientific work is devoted to the cognitive component of the innovative diffusion of the socio-economic systems. The cognitive approach will directly simulate the relationship between factors (elements) of complex systems, and the values of indicators are considered secondary. This is determined by the originality and practical importance of elaboration.

The aim of the work is to study the issues of cognitive representation of the development of the innovative diffusion of the socio-economic systems and to design the theoretical base of the use of cognitive technologies for the making the relevant managerial decisions.

## 2 Cognitive Presentation of Development the Innovative Diffusion of the Socio-Economic Systems

The motivation for the innovative diffusion of socio-economic systems is the driving force and prerequisite for a qualitative technological breakthrough in the development of the national economy. A meaningful assessment of this process is of particular importance in the context of modern challenges of globalization and leads to the growth of the openness of the economy of Ukraine.

To date, there are no perfect mechanisms and tools for such motivation, which makes it impossible to fully and integrally realize the internal market potential and significantly reduces the socio-economic efficiency of transformations on the way to building a market economy capable of withstanding the changing conditions of the external environment.

In works [1–4] the socio-economic system is considered as a coherent set of interconnected and interacting social and economic institutions (subjects) and relations on the distribution and consumption of material and intangible resources, production, distribution, exchange and consumption of goods and services.

For the cognitive representation of the development of the innovative diffusion of the socio-economic systems, the chain of notations will been installed: the development of the socio-economic system, the innovative diffusion, cognitive approach to modeling of development the innovative diffusion of the socio-economic system.

The socio-economic system is inevitably localized in the economic time and space, as well as alternative variants in relation to them. It has certain historical, geographical, ethnic, spiritual, political and economic borders. Thus, the socio-economic system, which can be understood by civil society, business entity (enterprise), integrated business structure, has two main trends in existence: functioning and development. Exactly the acquisition of a new quality about the progressive modifications of the socio-economic system, as well as adaptation to the new environmental conditions is implemented through development. Conscious changes in the components of the socio-economic system are the results of the emergence and development of economic innovations.

The essence of the economic category "innovation" is defined in [5]. This is combination into a comprehensive definition of its essential characteristics as a process, as a result, as a change and as a system. The meaning of the term "innovation" depends on the specific purpose of the research, measurement or analysis of the object. New products, indicators of new activity, payment systems are economic innovations.

It is necessary to indicate another feature of the development of the socio-economic system, which relates to complex nonlinear systems. In [4–6] the general theory of evolution of systems and the idea of the possible bifurcation nature of their behavior is given. This situation leads to the appearance of diffuse properties, when the behavior of the system is evaluated by sets of basic economic parameters and the regularity of interconnection between them.

In the socio-economic systems, the objects of diffusion may be information, pattern (model) of behavior, norms, innovations. As defined by E. M. Rogers [7], diffusion is a process during which the innovation over time due to certain channels extends among members of the social system. Such diffusion is named innovative. Its research was carried out by foreign and domestic scientists, namely H. Karlsson, V. Ruttan, R. Byers, J. Emrick, J. Pope, D. Kondratieva, H.M. Chamota and others.

As for the above, the complex the socio-economic system includes a set of elements that are in ambiguous and contradictory interaction. The innovative diffusion is a special type of communications, because a new idea is laid down in the transmitted message. Novelty involves the presence of the uncertainty.

The uncertainty is characterized by a number of alternatives in relation to a certain event with a relative probability. Thus, in the problem of the innovative diffusion, a factor of the uncertainty plays a special role. This factor should be taken into account when choosing instrumental research methods. Therefore, when studying the regularity of the development of the innovative diffusion of the socio-economic system, it is advisable to use systems analysis methods.

Methods of system analysis allow directly to simulate the relationship between factors (elements) of complex systems, and the values of indicators are considered secondary. There is their main advantage that increases due to the need to take into account the factor of the fundamental uncertainty.

One of the most powerful methods of system analysis is a cognitive approach.

The peculiarity of the cognitive approach is the possibility of qualitative modeling of complex weakly structured situations that are not subject to strict formal mathematical analysis. Cognitive modeling is a cyclic process and contains several interrelated stages (see Table 1).