New trends in Measurement Theory: Bayesian Intelligent Measurement and its Application in the Digital Economy

Svetlana Prokopchina[a]

[a] *Financial University under the government of the Russian Federation, 49 Leningradsky Prospekt, GSP-3, Moscow, 125993, Russian Federation*

Abstract

The paper proposes the concept of Bayesian Intelligent Measurement (BIM) and Soft Measurements (SM) as one of the promising directions for creating a methodological basis and technologies of new branch of Measurement Science. Within this concept, soft measurements are implemented using the Regularizing Bayesian approach (RBA) and Bayesian intelligent technologies (BIT). A generalized equation of BIM and SM based on RBA are given. The main principles and properties of BIM and SM, that are important for solving practical problems of measurement theory, artificial intelligence, and digital economy, are formulated. Examples of developed application systems of such types of measurements, focused on functioning in conditions of information uncertainty, are given.

Keywords 1

Bayesian intelligent measurement, soft measurements, regularizing Bayesian approach, digital economy

1. Introduction

Measurement is an integral part of any modeling and cognition tasks for control, decision-making, and management. Therefore, the measurement methodology is continuously improved in accordance with the complexity of the tasks, being solved. One of the modern directions of the Measurement Science theory is the methodology of intelligent measurements. This direction includes Bayesian intelligent measurements, which are based on the use of the Bayesian approach in the formation of a measurement solution [7, 19-22] and soft measurements , based on making measurement decisions in accordance with artificial intelligence approaches and Zade logic [1, 5].

The main principles and methodology of BIM were developed in 1995-1997 by the author of this article. The main theoretical basis of BIM is Bayes approach, adopted to condition of uncertainty.

The term “soft measurement” was suggested by author of this article in 1997 and can be interpreted in a broad and narrow sense.

In a broad sense, soft measurements are understood primarily as fuzzy measurements whose result is not determined by a specific number.

In the narrow, strict sense of this term, soft measurements are fuzzy, multi-alternative, conditional (the measurement result is reliable within certain experimental conditions) measurements with soft logic. Behind the formation of a solution to the measurement problem and a complete metrological justification of the measurement results.

If the criterion for choosing measurement solutions is the Bayesian criterion for the minimum average risk of solutions, then such measurements are called Bayesian intelligent measurements (BIM). They are based on the methodology of the regularizing Bayesian approach (RBA) and Bayesian intelligent technologies (BIT) [1, 3, 7, 19-22].

Russian Advances in Fuzzy Systems and Soft Computing: selected contributions to the 8-th International Conference on Fuzzy Systems, Soft Computing and Intelligent Technologies (FSSCIT-2020), June 29 – July 1, 2020, Smolensk, Russia

Soft measurements, like BIM, are designed to measure properties, states, dynamics, and trends of characteristics of complex objects, processes, and systems under conditions of their continuous development and active interaction with the environment.

Almost all real modern economic systems can be attributed to complex objects that operate under conditions of uncertainty under the powerful influence of environmental factors. Therefore, the concept of soft measurements (SM) and BIM is adequate to the nature of economic systems, that is important for digital economy methods and means implementation.

2. Basic principles of BIM and SM

Let's consider some methodological aspects of soft measurements and BIM.

Measurements of the BIM and SM types are made under conditions of significant uncertainty regarding the exact knowledge about the model of the measurement object, measurement conditions, and measurement tools, which can be either instrumental or expert knowledge, which introduces instability in the measurement process and the resulting solutions, and it is necessary to implement measurements within a single regularized solution space.

As a model object, in particular reference points of measurement scales, there can be not only numerical values, but also functions, situations, images of objects, scenarios, which together represent a conditionally complete group of events reflected by the reference points of the measurement scale carrier. Such scales can be parametric, functional, or system scales with corresponding reference points in the form of parameter values, model functions, and systems.

The problem of measurement under uncertainty is set as the problem of restoring values or metrological classification of images, which determines the need to ensure the stability of its solutions. Therefore, for complex measurement situations, the representation of the measurement problem is used as a set of inverse problems for restoring values, states, and situations based on the received information.

The measurement technique can be a complex information technology.

For each measurement solution, metrological justification of models, algorithms, and solutions is provided in the form of indicators of accuracy, reliability, reliability, risk, and information content of solutions.

3. Generalized equation of BIM and SM

For the purpose of methodological formalization, a generalized measurement definition was obtained for all types of measurements, including BIM and SM measurements. The equations of measurements for all types of classical measurements, as shown in [21], are special cases of this generalized equation.

For example, for Bayesian intelligent measurement, the measurement equation is written as follows [21]:

$$\{hkt(Q)|\{MX\}kt\ (Q)\} \mid (Yt\ (O\}\ *Yt\ (OE)*Gt(OE)\ )\} = \{argexstr\ C(L)\ [\ \varphi j(fit\{Xit\ \}*\{Xit(st)\} \mid (Yt\ (Q)\ \}\ *Yt\ (OE)\ Gt(OE)]\}, \qquad (1)$$

where {hkt(Q)|{MX}kt (Q)} | (Yt (O} *Yt (OE)*Gt(OE))} – fuzzy solution of the problem in terms of Yt, (defined a priori information, requirements, constraints, and assumptions) of the object; in terms of influencing environmental factors Yt (OE); in the compact set of object properties

Gt(O) and environment Gt(OE); {MX}kt(Q) – a set of metrological characteristics of solutions containing indicators of accuracy, reliability, reliability, solution risk, entropy, and Fisher information; C – a criterion that specifies the logic of solving the problem; in Bayesian intelligent technologies, it is the Bayesian criterion of the average risk of solving; in soft dimensions, it is the Zadeh logic; in classical type of measurement it is the Lukasevich logic; φj – Bayesian intelligent technologies, that define and implement regularization of solutions; fit-computational or algorithmic technologies, used to process existing primary information; {Xit} – a set of information flows (data and knowledge), used to obtain solutions.

The equation for fuzzy measurements differs in that, in General, it can have non-Bayesian criteria for inferring solutions, but its result, as in equation (1), is represented by a list of alternative solutions with different degrees of confidence, which is calculated for any indicator, for example, for evaluating environmental factors, using the modified Bayes formula [21]:

$$P\left(h_{kt}^{F_t}\middle|G_t^{(OE)}\right)=\frac{P^a\left(h_{kt-1}^{F_t}\middle|G_{t-1}^{(OE)}\right)*P\left(G_t^{(OE)}\middle|h_{kt}^{F_t}\right)}{\sum_{j=1}^{J}P^a\left(h_{jt-1}^{F_t}\middle|G_{t-1}^{(OE)}\right)*P\left(G_t^{(OE)}\middle|h_{jt}^{F_t}\right)}. \quad (2)$$

Differences from the measurement equation according to the classical scheme of measurement of physical quantities are: the introduction of the criterion for choosing a measurement solution in the equation, information technology transformations in accordance with the methodology and methodology of measurements, influencing external factors, as well as conditions that formalize the measurement situation.

The main differences from the classical methodology for measuring physical quantities are also the following.

1. Ensuring the development of measurement methods, models, and algorithms depending on changing measurement conditions.
2. Cognition and interpretability are provided directly in the process of forming a measurement solution.
3. In the process of measurements, it is possible to use, process and convolution both numerical and qualitative, linguistic information.
4. Ensuring the stability of the resulting solutions during integration, identification of system models and their characteristics
5. Obtaining measurement solutions not only in the form of numerical parameter values as in classical measurements, but also in the form of models, audit decisions, recommendations, estimates, conclusions, and scenarios.
6. The conditional nature of the resulting solutions, that is, the measurement solutions will be valid only if the conditions of the experiment are met, namely: within this compact of solutions, the set restrictions, metrological requirements, and the available a priori information.

The SM and BIM measurement process has several other differences from the classical measurement scheme. They are as follows.

Measurement is implemented as a decision-making process on conjugated numerical and linguistic scales, called dynamic constraint scales (DCS). Such scales are multidimensional metric compacts that can change their structure over time. The type of DCS is shown in Figures 1, 2.

Each value of the measured parameter corresponds to the value of its reliability (probability or possibility). Thus, the scale for measuring the value of a quantity has the form of a two-dimensional scale, in which the values of the quantity are deferred along the abscissa axis, and the ordinate axis – their probability or possibility, (see Figures 1, 2). Moreover, the measurement solution can be obtained both on a numerical and conjugate linguistic scale.

Each SM and BIM solution are a multi-alternative set of values with their corresponding verities.

The DCS may include criteria scales that are associated with the main scales, as illustrated in figure 1. Simultaneously with the determination of the measurement solution on the linguistic scale, the solution is checked against the norm criterion. It is possible to use several criteria-based conjugate scales to perform leg-criteria verification.

Models of measurement objects have the form of models with dynamic constraints (MDC), whose properties can change over time, according to which the DCS scales will also change. A detailed description of the MDC models and DCS scales is given in [1-7].

In the process of forming a measurement solution of BIM and SM, the knowledge and assessments of experts can be used.

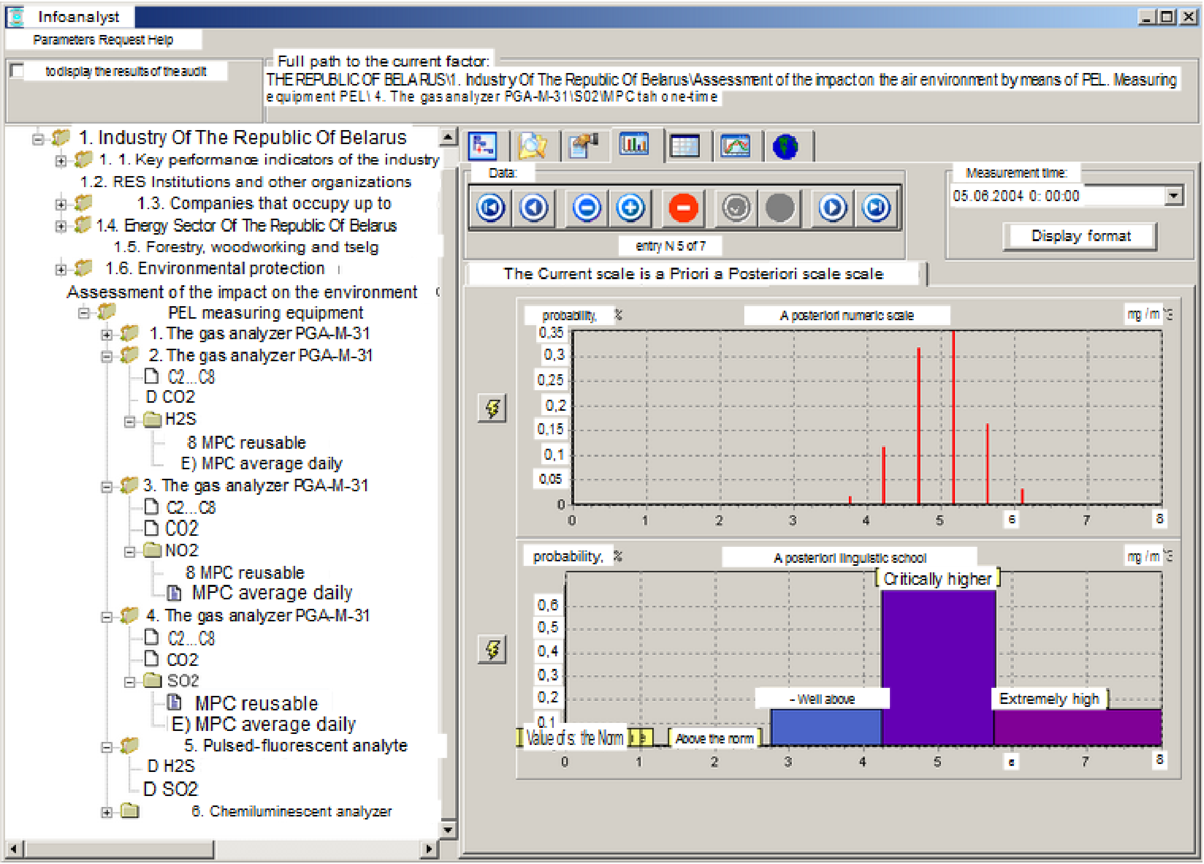

Figure 1: An example of a DCS with a measurement solution for the state of the air in the form of a multi-alternative quantitative and interpreted linguistic results

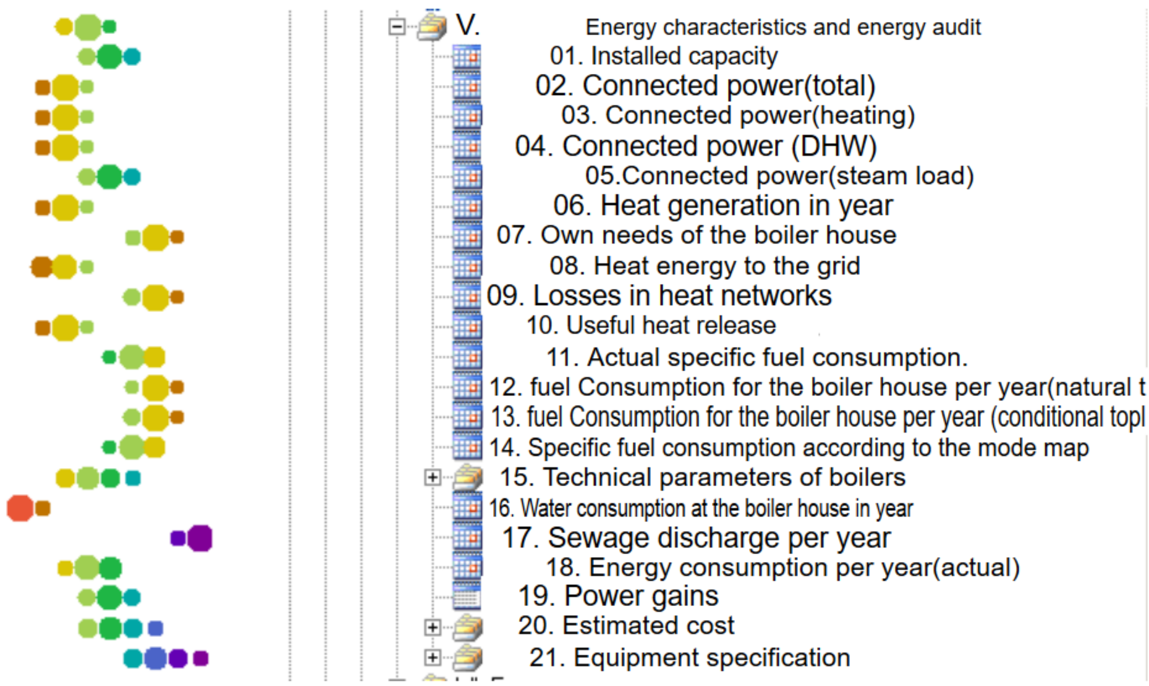

Figure 2: Cognitive interpretation of measurement solutions for the boiler house by means of the “IRM-Energetik”

4. Application of BIM and SM methodology and technologies in the digital economy

The use of methods and tools of RBA, BIT, BIM and soft measurements has proved effective in solving many basic problems of the modern economy, Some of them will be given below, others will be covered in the works of the author and his scientific school, as the results of completed projects in Russia and abroad [3-5]. In fact, these works are convincing examples of solving the problems of the main directions of the digital economy.

Artificial intelligence is one of the five basic areas that make up the technological basis of the digital economy. Its methods and tools are designed to provide full-scale solutions to new economic problems that arise in the formation of the information society. As noted in [2], "the formation of the digital economy is the result of technological development , and its theory is the fruit of the theory of the information society and the information economy" (knowledge economy).The so-called "super-smart" or "5.0 society" (in the terminology proposed by Japanese scientists) is formed in the Wake of the fourth industrial revolution, which is based on digital technologies. Post-industrial society (in the terminology of American sociologists D. Risman and D. Bell), which is part of the digital economy, is characterized primarily by the fact that it is the main driving force of development is knowledge-intensive.

The effectiveness of modern business is largely determined by the skillful use of the latest information technologies and means of communication, information collection and processing, management decision-making, sales policy, marketing and advertising. At the same time, the most popular information is presented in the form of profiled knowledge of an economic, environmental, social nature, as well as investment orientation .It is quite clear that attracting reliable and up-to-date knowledge speeds up the business management process, makes it efficient and profitable, reduces the need for physically produced labor (and, therefore, the cost of it), increases the competitiveness, safety of running and sustainable business development.

The main requirements for information support of business processes include:

- getting system solutions in the form of ready-made recommendations and alternatives. scenarios for the development of business processes and business situations;
- ability to work with information presented in a variety of numerical and linguistic data and knowledge arrays;
- flexibility and dynamism of information systems, which refers to the ability of application software to easily adapt to changing business conditions, requirements and situations;
- the calculation of risks decisions and management;
- development of investment proposals and projects;
- fast solution of production, marketing and supply, investment and personnel tasks;
- reliable assessment of influencing factors and the situation in the business environment;
- ease of communication with the information system, clarity of conclusions and recommendations of the system;
- reliability, objectivity, and completeness of business solutions.

All these requirements of modern business determine the transition of the economy of post-industrial society to the maximum consumption of knowledge, that is, they form an economy based on knowledge as a production resource, an additional powerful productive force, a "knowledge economy". The concept of the knowledge economy is presented in the works of domestic and foreign scientists.

It will be explained in the following examples that all these requirements are met by methods and tools based on RBA, BIM, and SM.

Knowledge generation, as the main resource of the digital economy and society as a whole, is determined by the effectiveness of intellectual methods and tools used to obtain it. Advanced 5G telecommunications technologies, as noted in various articles of mobile communication companies, will provide a significant number of advantages for the economic development of society. But the main issue is actually not so much a question of "how fast to transfer information" as the question "what information to convey", the question of the content of the transmission, determining the essence and efficiency solve socio-economic problems, the question of «compression» of the data to the level of useful knowledge. This knowledge can be transmitted over the network many times faster than data, which will reduce the transmission speed requirements.

For the digital economy, as for any economy, it is important not only and not so much transactions, but the generation of effective analytical, evaluation and management decisions. These problems are solved by methods and tools of artificial intelligence, which include methods and tools of Bayesian intelligent measurement and soft measurements.

All these systems were essentially systems of the digital economy, since they solved the problems of digitalization of the activities of economic entities. The methodological and technological bases for these systems were the technologies and tools of RBA and BIM, which were implemented on the "Ecoanalytic" and "Infoanalytic" computer platforms in the form of a network of intellectual workplaces and stations (IWS) for various professional purposes [8-13].

Currently, there are 28 different types of IWS (licensed and patented software packages), that can be configured in accordance with the purpose of the task, almost any professional management network can be organized. These are "IWS-Director", "IWS-Financial Director", "IWS-Energy", "IWS-quality", "IWS-personnel", "IWS-Ecologist", "IWS-territory", "IWS-fish farm", "IWS-Forestry", "IWS-water Farm", "IWS-Governor", "IWS-Housing" and others.

It is obvious, that in accordance with the above directions of digitalization of the economy, these types of IWS can be used to create methodological and technological bases for solving practical problems of the digital economy in its real sectors.

5. Methodology of BIM and software package to measure the integral indicators

The tasks of system synthesis are to obtain integral parameter estimates, models of complex systems, estimates and models of situations, scenarios of events, and other complex solutions. In General, system synthesis, as a process of information processing, is the inverse task of restoring some integral characteristics or images of real objects from the available information. In this way, you can define system synthesis as the process of creating an image of a real object based on available information.

In conditions of a sufficient full volume of information, that is, in conditions of certainty, the task of system synthesis is reduced to determining the parameters of some systems, for example, by solving a system of equations.

Under conditions of uncertainty, that is, incomplete, fuzzy, inaccurate information, solutions are unstable and inadequate for real objects.

To formalize the solution of system synthesis problems under uncertainty, the following concept is proposed.

A specific feature of the task of system synthesis in conditions of uncertainty is the involvement of additional knowledge, indirect information, and non-formalized knowledge of subjects, such as experts, fashion designers, and decision-makers, in the process of obtaining solutions. Taking this property into account in methods for solving problems of system synthesis gives them a cognitive character.

Based on this thesis, a generalized dynamic model of a real system G(o)t of system synthesis can be written as follows:

$$G(o)t = G(mo)t * G(so)t, \quad (3)$$

where G(mo)t is a model of a real system obtained from available and incoming information (direct and indirect), G(so)t is a complementary model of a real system obtained from subjective information; the symbol * denotes a convolution of model spaces (compacts), in which they are defined.

The process of forming a model can be represented as a sequence of stages of collecting and processing information obtained from a network of information sources. Such a network can be represented as a network of information sources-agents, which include information sources in the form of technical devices and subjects. In algorithmic terms, these are two actively interacting networks that must be developed during the operation of the algorithm for solving the system synthesis problem.

In order for the solutions of system synthesis problems to be stable, it is necessary to regularize the solutions in the space of some compact containing them.

The Regularizing Bayesian approach (RBA) is one of the effective approaches to analytical processing of information under uncertainty that can provide regularization of solutions. Using methods and technologies based on it, you can develop the concept of system synthesis to the level of algorithmic solutions.

Then details a model object, with the knowledge obtained from the subject about values or estimates of property values and the environment, both in numerical and linguistic form. This process is associated with the creation of various scales by the subject corresponding to the properties of the object and the environment, which together form a hypercube of the dynamic compact of solutions according to equation (1).

All these tools allow you to extract the subject's knowledge.

The subject's skills are reflected in the form of technologies or algorithms for solving a problem or subtasks. To extract the subject's skills, special computational modules of the “Infoanalytic” platform are used: a Calculator for calculating Regularized Bayesian estimates (RBE), a library of Bayesian mathematical statistics (BMS), and a block for generating recommendations

The Bayesian mathematical statistics library is used for processing samples (primarily small samples) of statistical data. It contains both classical mathematical statistics algorithms and Bayesian mathematical statistics algorithms that work under conditions of small samples and significant uncertainty. As data for BMS, there may be samples consisting not of probabilistic data, but of “possible” data, for which the probability of their occurrence is replaced by a possibility or a fiducial (subjective) probability. This makes it possible to process data series generated by the subject based on some of its assumptions.

In addition, the BMS allows the subject to create not only a sample of data, but also the process of processing it. To do this, it can extract individual algorithms from the BMS library and combine them into a technology, setting the necessary sequence of their implementation in the computing process. Statistical measurement algorithms are implemented using BMS. A very important and powerful tool for solving problems of system synthesis is the module for determining the distribution laws of indicators, properties, and States of real objects of system synthesis. Detailed information about this module is presented in [23].

The recommendation generation module allows the user to set some corrective actions to increase or decrease the influence of a factor in the system model, thereby creating a control effect in the measurement and analytical system.

Thus, it is possible to recommend the proposed concept, technologies, IWS, the platform of the “Infoanalytic” software complex and application systems, based on IWS for solving problems of system synthesis in conditions of uncertainty.

Integrated use of IRMS allows to build intelligent housing systems that implement the principle “from generation to payment for consumption”, the methodology and examples of which are given in [23]. Sustainable development of rural areas is associated with numerous aspects of various factors. However, it is possible to identify the fundamental factors that determine the main trends in the development of rural settlements. These include a system of factors that determine socio-humanitarian potentials. The system contains mostly non-qualitative indicators that are difficult or impossible to measure using classical measurement methods. To solve this problem, we used methods and tools of BIT and SM.

The information technologies for supporting management decisions, based on the BIM and SM methodology are designed for a wide range of practical tasks in managing territorial development. The use of these technologies makes the management process efficient and increases the possibilities of successfully solving new complex applied problems, including digitalization problems.

6. Conclusion

Currently, district and regional administrations are faced with the task of developing investment programs and programs for sustainable rural development, digitalization of the municipal economy, and training civil servants to work actively with digital technologies. The proposed methodology, technologies, and tools in the form of intelligent measurement systems, monitoring, decision support, and intelligent work station can be successfully used to solve these problems.

7. References

[1] S. Prokopchina, Methodological foundations of the theory of soft measurements. In the book. “Soft measurements and calculations”, Moscow, Publishing House “Scientific Library”, 1 (2017).

[2] S. Prokopchina, Methods and tools for modeling the distribution law under uncertainty, Moscow, Publishing House “Scientific library”, 2018.

[3] S. Prokopchina, The concept of Bayesian measurement intellectualization in complex object monitoring tasks, Artificial intelligence news, 3 (1997) 7-56.

[4] Fundamentals of the digital economy, Eds. M. I. Stolbov, E. A. Brendeleva, Moscow, Publishing House “Scientific Library”, 2018.

[5] S. Prokopchina, Methodological aspects of the theory of soft measurements, Proc. of the Int. Conf. “SCM-2005”, St. Petersburg, 2005, 49-63.

[6] S. Prokopchina, G. Shcherbakov, Yu. Efimov, Modeling of socio-economic systems under uncertainty, Moscow, Publishing House “Scientific Library”, 2018.

[7] Experience in solving socio-economic problems based on Bayesian intellectual technologiesm, Ed. by S. Prokopchina, Moscow, 2014.

[8] D. Nedosekin, S. Prokopchina, E. Chernyavsky, Information technologies of measurement process intellectualization, St. Petersburg, Energoatomizdat, 1995.

[9] A. Lukyanets, S. Prokopchina, Methodology of decision support in the management of energy supply organizations based on the regularized Bayesian approach, Tomsk. Non-profit Foundation for regional energy development, 2006.

[10] Intellectual Workplace of a quality specialist (Rospatent certificate of official registration of the computer program no. 2004610246, 19.02.2004).

[11] Intellectual Workplace of the financial Director (Certificate of the Federal service for intellectual property, patents and trademarks on official registration of the computer program no. 2005611423, 08.08.2005).

[12] Infoanalyst (Certificate of the Federal service for intellectual property, patents and cake marks on the official registration of the computer program no. 2004611741, 12.08.2004).

[13] Intellectual Training Complex for specialists of the enterprise (Rospatent certificate of official registration of the computer program no. 2006610210, 21.03.2006).

[14] Intellectual Workplace of a territory management specialist (Certificate of the Federal service for intellectual property, patents and trademarks on official registration of the computer program no. 20066102)

[15] S. Prokopchina, Cognitive measurements on the basis of Bayesian intelligent technologies, Proc. of the Int. Conf. “SCM-2010”, St. Petersburg, 1 (2010).

[16] S. Prokopchina, The approach to measuring socio-humanitarian potentials using Bayesian intellectual technologies, “State audit, Law, Economy”, 3 (2013) 73-82.

[17] S. Prokopchina, Principles of creating a single information space based on BIT, Collection of reports of the international conference on soft computing and measurement, St. Petersburg, Publishing house GETU, 2003, 64-70.

[18] S. Prokopchina, System measurements and modeling of economic systems under uncertainty based on the regularizing Bayesian approach (RBA), Economics and management Problems and solutions, Moscow, 7 (2014).

[19] S. Prokopchina, Systematization of methods of generalized measurement theory for solving socio-economic problems, Economics and management. Problems and solutions, 5 (2018) 214-221.

[20] S. Prokopchina, Cognitive Bayesian measurement networks based on the regularizing Bayesian approach, Soft measurements and calculations, 2 (2018) 56-64.
[21] S. Prokopchina, Principles and methodological aspects of constructing a scale with dynamic constraints for measurement under uncertainty, Soft measurements and calculations, 3 (2018) 4-15.
[22] S. Prokopchina, Intelligent housing and utilities networks based on the regularizing Bayesian approach in the digital economy, Soft measurements and calculations, 5 (2018).
[23] S. Prokopchina, Methods and tools for modeling the distribution law under uncertainty, Moscow, Publishing house "Scientific library", 2018.
[24] V. Tarassov, Cognitive Measurements: a New Paradigm of Measurement Science, Proceedings of the 5th International Conference on Sensors and Electronic Instrumentation Advances (Canary Islands. Tenerife, Spain, Adeje, September 25-27, 2019). – Barcelona: IFSA Publishing S.L., 2019, 286-291.
S. Kovalev, V. Tarassov, M. Koroleva et al., Towards Intelligent Measurement in Railcar On-Line Diagnostics: From Measurement Ontologies to Hybrid Information Granulation System, Proceedings of the 2nd International Scientific Conference "Intelligent Information Technologies for Industry" (IITI'17, Varna, September 14-16, 2017), Eds. by A. Abraham, S. Kovalev, V. Tarassov et al. Advances in Intelligent Systems and Computing. Cham, Switzerland: Springer International Publishing, 679 (2018) 169-181.