THEORY AND PRACTICE OF INFORMATION FUSION MODELS' QUALITY ESTIMATION AND MODELS' QUALITY CONTROL

Boris Sokolov[a], Stanislav Micony[b], Alevtina Ziuban[c], Vadim Burakov[d], Iliya Pimanov[e], Dmitri Ivanov[f]

[a],[b] [c],[d],[e]SPIIRAS— St. Petersburg Institute of Informatics and Automation, Russian Academy of Sciences,
14th line 39, St. Petersburg, 199178, Russia
[a]ITMO University— St. Petersburg National Research University of Information Technologies, Mechanics and Optics,
13 Gdanovskaya str., St. Petersburg, 197198, Russia
[f]Department of Business Administration, Berlin School of Economics and Law,
Badensche Str. 50–51, 10825 Berlin, Germany

[a]sokolov_boris@, [b]smikoni@mail.ru, [c]alvz@yandex.ru, [d]burakov@eureca.ru, [e]burakov@eureca.ru,
[f]dmitri.ivanov@mail.ru

ABSTRACT
At the moment, the theory, methods and techniques concerning the application of mathematical models are wide-used. Nevertheless such problems as a problem of multi-criteria models' quality estimation, a problem of analysis and arrangement of models' classes, a problem of justified selection of applied task-oriented models are not well investigated yet. The importance of the considered problem increases when the object of research is described not via a single model, but via a multiple-model complex, consisting of models related to different classes or combined models (for example, analytical-imitating, logical-algebraic, etc). Aforementioned problems are the primary objects of the theory of mathematical models' and multiple-model complexes' quality control. We proposed to implement this theory in the Information Fusion applied area. In the paper software prototype for Information Fusion quality estimation and models' quality control in the sphere of operational river flood forecasting is proposed.

Keywords: information fusion procedures, multi-criteria models' quality estimation, models' quality control, decision support system

1. INTRODUCTION
At the moment, Information Fusion (IF) modeling plays a role of universal instrumentality of knowledge, research and design in different areas of applications. According to JDL ("Joint Directors of Laboratories") model of multi-level information fusion is considered as multi-level process with the following hierarchy (Steinburg, Alan N., Bowman, Christopher L., 1998) : Level 0: Sensor fusion for sub-object assessment, Level 1: Data fusion for object assessment, Level 2: Information fusion for situation assessment, Level 3: Information fusion for impact assessment including for situation prediction, Level 4: Process refinement (In particular, it supposes actionable decision making for resource management), Level 5: Human assessment followed by dynamic re-planning of resources in context of top-level intent and respective requirements in order to manage resources, situation, objects and sensor-level strategy.
Now, the theory, methods and techniques concerning the application of IF mathematical models are wide-used. Nevertheless, such problems as a problem of IF multi-criteria models' quality estimation, a problem of analysis and arrangement of models' classes, a problem of justified selection of applied task-oriented models are not well investigated yet. The importance of the considered problem increases when the object of research is described not via a single model, but via a multiple-model complex, consisting of models related to different classes or combined models (f. e. analytical-imitating, logical-algebraic, etc). Aforementioned problems are the primary objects of the theory of mathematical models' and multiple-model complexes' quality control. The goal of this paper to present some elements of this theory (Okhtilev, M.Y., Sokolov, B.V., Yusupov, R.M., 2006.,).

2. THE RESULTS OF INFORMATION FUSION INVESTIGATION
Within *the first line of investigations* the following scientific and practical results have been obtained by now.
It was established that the change from an automated processing of measuring information to a computer-aided analysis of received materials involves semantic aspects of data representation in place of syntactic ones. Thus, the information about control objects should rather be regarded as a set of interrelated parameters jointly characterizing objects' technical state than a simple collection of measurements. This provided for a conclusion that the metric-space concepts, typically used in simple monitoring problems, are weak and not suitable for our purposes, hence more general constructions should be used.

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It was proved that the parameters of objects' technical states can be described via a system of open sets forming a base of topology. It was assumed that the set of parameters has a topological structure. Thus a system of neighborhoods (meeting the axioms of topological spaces) was established for each element. The notion of a technical state was worked out. By the technical state we meant an abstract collection of data including whole information both about object's current attributes and the state of computations within the monitoring process. This view lets optimize computations in order to receive monitoring results in real time.

The following basic statements were proved: the whole set of technical-state parameters constructed trough the proposed model of knowledge representation is a lattice or a lattice ordered set; if the set of technical states have the greatest element and the least element (defining the initial data and the results correspondingly), then a complete lattice (an algebra over the set) can be formed via a construction of additive and multiplicative lattices; necessary and sufficient conditions for topology base existence were obtained for the set of technical parameters. The last result is very important, as the constructed topology is used for whole description of possible technical states and for planning of states analysis (for construction of computational scheme).

Moreover within the first line of investigations we have been obtained the following the results (Okhtilev M. Yu., Vasiliev I. Ye. 2004, Okhtilev M.Yu. 2001., Okhtilev, M.Y., Sokolov, B.V., Yusupov, R.M., 2006.): formal description of all possible kinds of controlled states (assessed situation) accounting for their adequacy to actual actions and processes on controlled object caused by application of different mathematical apparatus for various functional objects. Multi-model formalization intends for describe actions and processes on the controlled object; new integrated methods of program synthesis for automatic analysis (AA) of measuring information (MI) about complex technical object (CTO) states were worked out. These methods, as distinct from known ones, give an opportunity of, firstly, interactive intellectual processing of data and knowledge about CTO states for different physical properties (for example, functional parameters, range parameters, signal and code parameters, and integrated parameters) and for different forms of states description without reference to their physical features and, secondly, automatic generation of alternative program schemes for MI analysis according to the objectives of CTO control under the presence of changing environment; new algorithms of automatic synthesis of AA MI programs were proposed for poly-model description of monitoring processes via attribute grammars, discrete dynamic systems, and modified Petri nets. Applying of polytypic models resulted in adequate adaptation of the algorithms to different classes of CTO. Another distinguishing feature of the algorithms lied in application of underdetermined calculation and constraint-driven programming and provided that CTO states could be estimated rather adequately even if some parameters were omitted and the measuring information was incorrect and inaccurate; a general procedure of automatic (computer-aided) synthesis of CTO monitoring programs was developed. This procedure includes the following steps.

The 1st step. Description of conditions and constraints for the problem of AA MI programs synthesis via a special network model connecting input data with goals. An operator (he does not have to be a programmer) uses a special problem-oriented language to execute this step.

The 2nd step. Automatic existence analysis for a solution of AA MI problem that is defined via a formal attribute grammar.

The 3rd step. If the solution exists then the alternative schemes for AA MI programs are generated and implemented in a special operational environment (problem solver of the CTO monitoring system).

The main advantage and substance of the proposed procedure is simple modeling of MI sources (models generation) that can be performed by a non-programming operator in the shortest time and the real-time implementation of the intellectual methods and algorithms of MI processing and analysis for arbitrary structure of the measuring information.

The proposed methods of monitoring automation and modeling let switch from heuristic description of the telemetry analysis to a sequence of well-grounded stages of monitoring program construction and adaptation, from unique skills to unified technologies of software design. These methods are based on a conclusion that a functional description of monitoring process is much less complicated than detailed examination of software realizations. Consecutive specification of software functions is the ground of technologies to be used for creation of monitoring systems. The suggested technology of continuous design process includes such well-known phases as new proposal phase based on special operational environment.

Within the second line of investigations the following scientific and practical results have been obtained by now (Okhtilev, M.Y., Sokolov, B.V., Yusupov, R.M., 2006., Sokolov B.V. Yusupov R.M. 2002,2004.).

System analysis of the ways and means to formalize and solve the problem of the control over structure dynamics of monitoring system (MS) servicing CTO under changing environment was fulfilled. It was shown that the problems of structure-functional synthesis of monitoring systems and intellectual information technologies as applied to complex technical objects and the problems of CTO structure reconfiguration are a special case of structure-dynamics control problem. Other variants of structure-dynamics control processes in MS are: changing of MS objectives and means of operation; reallocation of functions, tasks, and control algorithms between MS levels; control of MS reserves; transposition of MS elements and subsystems.

The basic concepts and definitions for MS structure-dynamics control (SDC) were introduced. During our investigations the main phases and steps of a program-construction procedure for optimal structure-dynamics control in MS were proposed. At the first phase forming (generation) of allowable multi-structural macro-states is being performed. In other words, a structure-functional synthesis of a new MS make-up should be fulfilled in accordance with an actual or forecasted situation. Here the first-phase problems come to MS structure-functional synthesis.

At the second phase a single multi-structural macro-state is being selected, and adaptive plans (programs) of MS transition to the selected macro-state are constructed. These plans should specify transition programs, as well as programs of stable MS operation in intermediate multi-structural macro-states. The second phase of program construction is aimed at a solution of multi-level multi-stage optimization problems.

One of the main opportunities of the proposed method of MS SDC program construction is that besides the vector of program control we receive a preferable multi-structural macro-state of MS at final time. This is the state of MS reliable operation in the current (forecasted) situation. The combined methods and algorithms of optimal program construction for structure-dynamics control in centralized and non-centralized modes of MS operation were developed too.

The main combined method was based on joint use of the successive approximations method and the "branch and bounds" method. A theorem characterizing properties of the relaxed problem of MS SDC optimal program construction was proved for a theoretical approval of the proposed method. An example was used to illustrate the main aspects of realization of the proposed combined method.

Algorithms of parametric and structural adaptation for MS SDC models were proposed. The algorithms were based on the methods of fuzzy clusterization, on the methods of hierarchy analysis, and on the methods of a joint use of analytical and simulation models

The SDC application software for structure-dynamics control in complex technical systems was developed too.

Within the third line of investigations the following scientific and practical results have been obtained by now the pilot versions of computer-aided monitoring system (CMS) for CTO states supervision (in space systems and atomics) work in network of IBM/PC-compatible computers; it uses special operational environment (Kalinin, V.N. and Reznikov, B.A., 1987., Okhtilev M. Yu., Vasiliev I. Ye. 2004, Okhtilev M.Yu. 2001., Okhtilev, M.Y., Sokolov, B.V., Yusupov, R.M., 2006), real-time database management system, multi-window interface, and programming language C/C++.

The prototypes of CMS belong under the class MMI/CACSD/SCADA/MAIS (man-machine interface/ computer-aided control system design/supervisory control and data acquisition/ multi-agent intellectual system).

Our investigation have shown that today a great number of information fusion models, methods, algorithms, and techniques are used for modeling the aforementioned objects and processes in application to the specified types of tasks. This set corresponds to different levels of information fusion related to the considered area of application (levels 0 – 5 of Information Fusion). The most used classes of models are the following ones: deterministic models, stochastic models, uncertain analytical-imitating models and multiple-model complexes, logical-algebraic models, logical-linguistic models and multiple-model complexes, combined classes of models. Nowadays an information fusion models plays the important role of universal instrumentality of knowledge, research and design in different areas of applications. For example, there are many approaches to model describing of information a knowledge fusion in Rome Laboratory (USA): a Bayesian techniques, Knowledge Based approaches, Artificial Neural Systems (Neural Networks), Fuzzy Logic, and Genetic Algorithms. In this case very interesting and important to develop information fusion models' quality estimation and models' quality control theory (Kalinin, V.N. and Reznikov, B.A., 1987., Merkuryeva, G., Merkuryev, Y. and Vanmaele, H., 2011., Peschel M., 1981, 1978., Polyak, Yu.G., 1971., Samarskii, A.A. and Mikhailov, A.P., 2001Norenkov I.P. 1998., Okhtilev, M.Y., Sokolov, B.V., Yusupov, R.M., 2006., Steinburg, Alan N., Bowman, Christopher L., 1998.).

3. METHODOLOGICAL AND METHODICAL FUNDAMENTALS OF THE INFORMATION FUSION MODELS' QUALITY ESTIMATION AND MODELS' QUALITY CONTROL THEORY

In this theory, we investigate two main research tasks. They are: elaboration of the methodological and methodical fundamentals of information fusion models and multiple-model complexes' qualimetry; development of the computer software prototypes implementing meta-models, methods, and algorithms of multi-criteria quality estimation and control in information fusion models and multiple-model complexes used for information fusion.

From our opinion, the proposed research theory includes the following main directions of the work: elaboration of the basic definitions, principles, and approaches used in the information fusion models' and multiple-model complexes' qualimetry; development of the hierarchy of conceptual models of developing situations, when the participants are the objects, the subjects, and the models being elaborated (used); classification and systematization of information fusion models and multiple-model complexes, determination of the interconnections and mutual associations of different types and kinds of information fusion models; classification and selection of the system of the parameters estimate the quality of the information fusion models and multiple-model complexes;

elaboration of the combined methods for estimation of parameters of quality that are presented by digital and non-digital scales in the information fusion models and multiple-model complexes; elaboration of the methods and algorithms for solving the problem of multi-criteria analysis, arrangement and selection of information fusion models and multiple-model complexes, and quality control of information fusion models; development of object-oriented specification of the software tool according to the developed model of developing situations. Working out detailed object-oriented specifications for the case of formulating and resolving the direct and inverse problems of performance efficiency estimation for MO CS. (levels 2, 3 of Information Fusion); development of the computer software prototype for solving the problems of estimation and quality control of information fusion models and multiple-model complexes based on direct problem of performance efficiency estimation for different types of complex systems (CS) which have artificial and natural background (CS).

The primary goal of our investigation is the elaboration of the theory of information fusion models' quality estimation and quality control, qualimetry of information fusion models and multiple-model complexes of CS. The main objects of the investigation are the characteristics of information fusion models and multiple-model complexes of CS. The information fusion models are here considered as models, developed on the basis of natural and artificial languages. The latter ones include all formal languages. The elaboration of the theory should be started from setting up the appropriate terminology and system of definitions that will be the basis for the further argumentations and conclusions. The basic definitions used in the theory are as follows: developing situations, gnoseological and ontological models' adequacy, certainty, completeness, accuracy, essential correctness, model's utility.

Methodological basic of the research consists of following items: concepts of system analysis and complex modeling; principles of program-aimed and situating control; principles of requisite variety; principles of exterior supplementation and embedding; subjective and objective, and integral approaches to the modeling of complex objects and processes.

The basics of the elaboration of conceptual meta-models of quality estimation and quality control of information fusion models' and multiple-model complexes are twofold (Aframchuk, E.F., et al., 1998., Mesarovich, M. and Takahara, I., 1978, 1975). The object of the modeling is not the actual (designed or abstract) object but the developing situation, that includes as participants the objects and the subjects of the modeling (persons responsible for the accepting the solutions (decision maker), persons responsible for the substantiation of the solution (decision), experts, and persons responsible for the execution of the solutions), and the designed or used models themselves. The specifics of the developing situation is that the space of conditions for all participants is time varying because of different objective, subjective, interior, exterior, and other factors. The process of modeling is here assumed as a control process of developing situation under uncertain conditions, caused by absence of information needed for forming the substantiated decisions. The aforementioned specifics of the conceptual representation of the investigated objects allow to apply for their formal description the mathematical structures being developed in the theory of control and knowledge engineering.

This step should be implemented via classification and systematization of information fusion models and multiple-model complexes. This step will be performed at the first stage of the research on the basis of theory of sets, mathematical structuring, and functor-category description. Particularly, in the case of functor-category descriptions the family of the models related to the same types are represented via a category consisting of the objects that conform to the models (Aframchuk, E.F., et al., 1998., Mesarovich, M. and Takahara, I., 1978, 1975, Okhtilev, M.Y., Sokolov, B.V., Yusupov, R.M., 2006). The interconnections between the models are characterized by category's morphisms. The interconnections between different families of the models (categories) are characterized by the functors. The main objective of these descriptions is the determination of interconnections and mutual associations between different types and kinds of information fusion models, detection of models' generalized specifics, and structuring of the investigated objects' space as well Figures 1–3 show different variants of classification of developing-situation models, methods, algorithms and technics of information fusion applied area. The analysis of these figures have shown that first focused item of the developing theory is the problem of multi-criteria estimation and quality control of information fusion models and multiple-model complexes. For this the classification of such models' parameters as adequateness, simplicity, accuracy, efficiency of the computer implementation, universality and scalability, multi-functionality and specificity, openness, cost, adaptability, flexibility, and intellectuality should be elaborated. Figure 3 presents as an example the basic elements of the theory of estimation and control of the quality of models developed recently, which are used in integration of data and knowledge (Information Fusion Models) (Okhtilev, Sokolov, Yusupov 2006; Kalinin and Reznikov 1987; Yusupov 1977; Ceany and Raiffa 1981). In our opinion, the development of qualimetry of models should be made in parallel in the main two lines of investigations that closely interact with each other. In the framework of the first line of investigations, the general problems based on the results obtained in solving applied problems of the theory of estimation and control of the model quality.

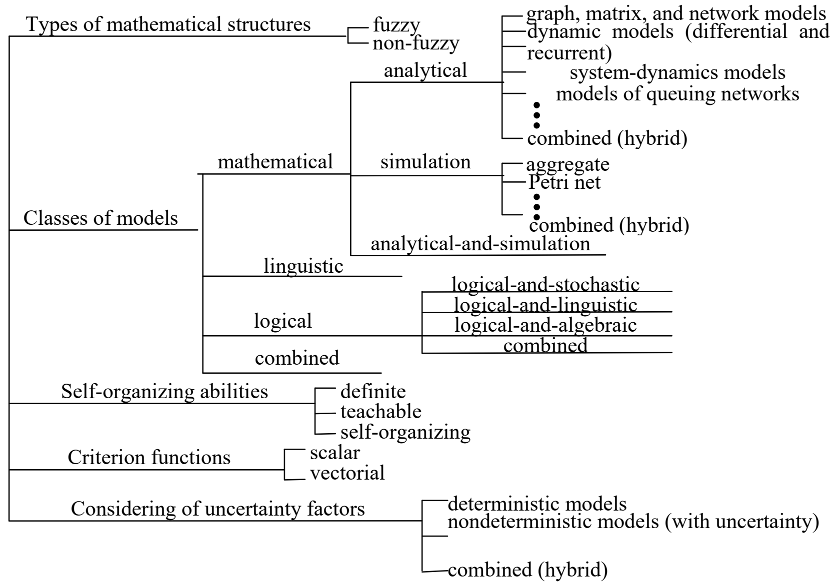

Figure 1: Classification of information fusion models for developing-situations analysis

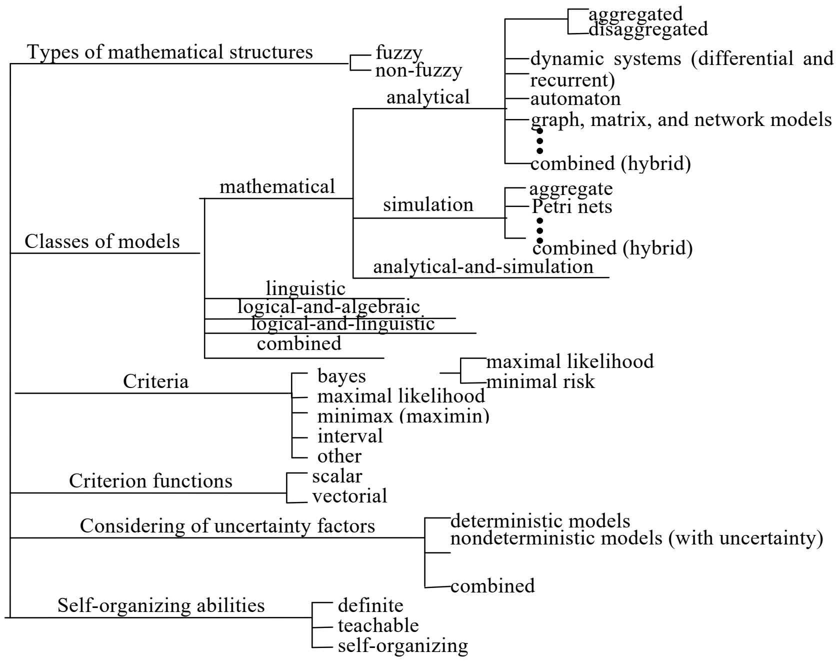

Figure 2: Classification of information fusion models for evaluation of states in developing situations

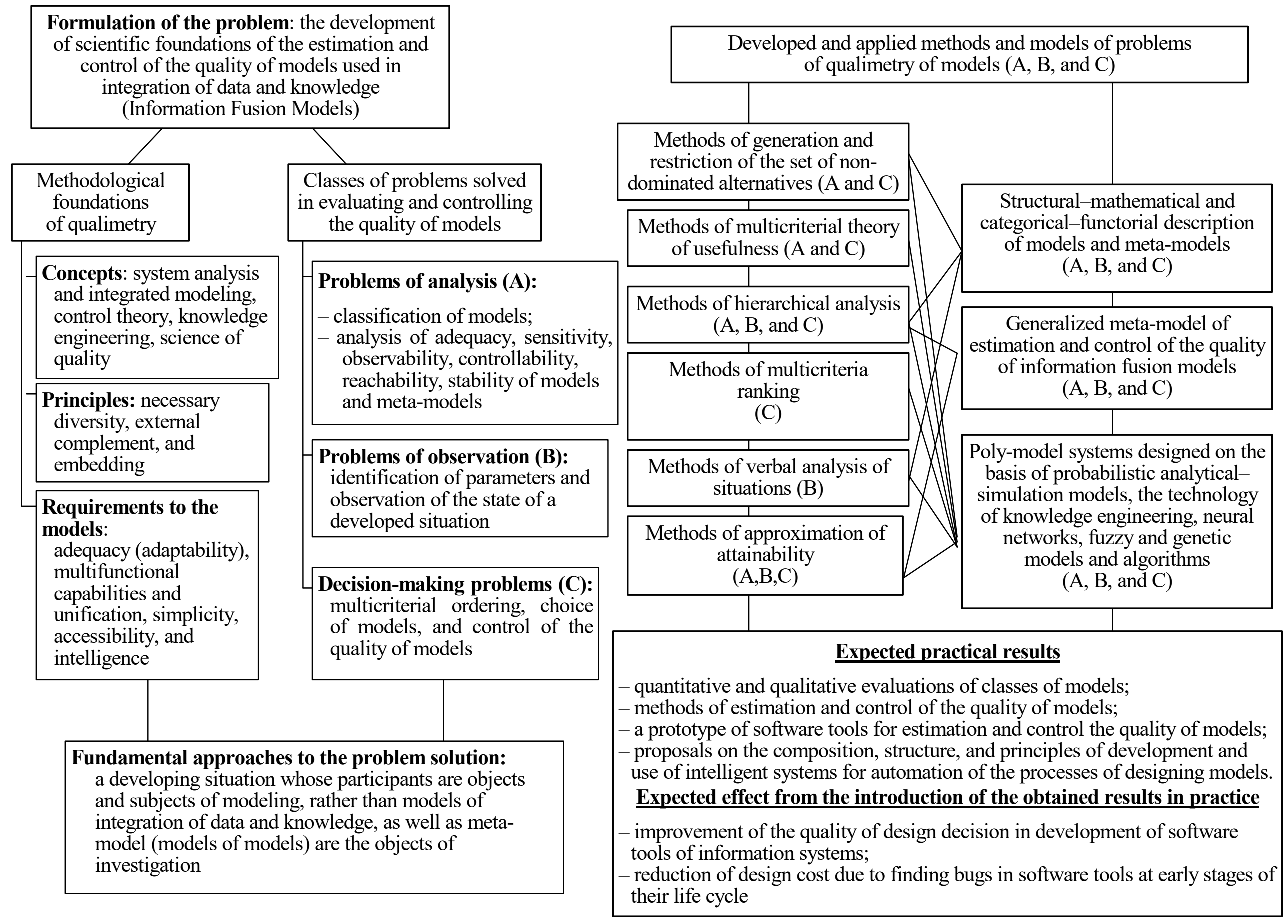

Figure 3: Classification of information fusion models for developing-situations analysis

The second item is the development of combined methods of multi-criteria estimation, analysis, arrangement, and selection of information fusion models. These methods are based on the methods of forming and reduction of set of non-dominated alternatives (Pareto sets), methods of Multi-Attribute Utility Theory, methods of Analytical Hierarchy Processes, methods of arranging of multi-criteria alternatives ELECTRE, methods of verbal analysis of situations (ZAPROS), methods of forming and approximation of domains of accessibility for dynamic systems (Aframchuk, E.F., et al., 1998. Larichev, O.I., 2000, Kalinin, V.N. and Reznikov, B.A., 1987., Val'kman, Yu.R., 1996., Ceany, R.L. and Raiffa, H., 1981)

Formulation and solving of the problem of information fusion models' quality control are performed based on their graph description. This description uses the dynamic alternative system graph that generalizes the known classes of structure models and causal-consequential models. After the additional parameters and structures are added to the information fusion models and multiple-model complexes according to the proposed techniques, the quality control allows to provide the desired (maximal) likelihood of the original object and its model. Moreover, in this case it is possible to adjust the model for the specific applied task The scientific and practical results of the research could be widely used for solving problems in different areas of applications. Developed techniques of multi-criteria information fusion models' quality estimation and control allow performing the well-substantiated and well-analyzed selection and design of the models of developing situations.

4. EXAMPLE OF PROPOSED THEORY IMPLEMENTATION

The design of operational flood forecasting automated systems implies, as was noted above, that no universal model exists to describe flood development processes at river sections that are different in length and configuration. When choosing hydrodynamic models to solve flood forecasting problems, it is advisable to implement the multiple-model approach: depending on the length of the monitored section and the presence of initial information, it is possible to choose between one-dimensional hydrodynamic models for river valley sections of 100–1000 km long and two dimensional models for sections shorter than 100 km with wide beds and floodplains, complex configurations, and various structures located in them.

Combined (hybrid, complex, multiscale) computing by one-dimensional and two-dimensional models can yield a significant effect in effort and fund economy when investigating and monitoring lengthy river areas. Therefore, a principal issue in designing information systems for flood forecasting is to form a mechanism of choosing the most adequate hydrological model for specific conditions.

Within the theory of model qualimetry and polymodel complexes, which the authors of this article are developing (Okhtilev, M.Y., Sokolov, B.V., Yusupov, R.M., 2006), several technologies of their structural–parametric adaptation have been designed. One of them, applicable to operational flood forecasting, is given in Fig. 4.

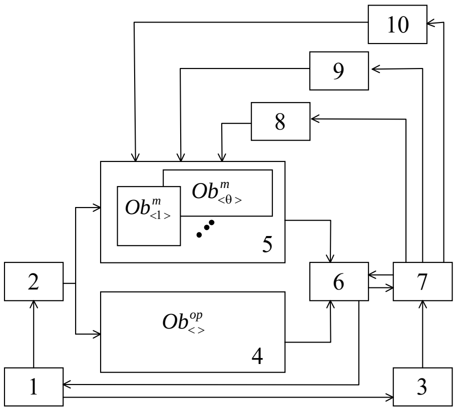

Figure 4: The generalized technique of estimation and control of the quality of models of the first class

In this figure, we take the following notation: 1, for forming the goals of functioning of $Ob^{op}_{<>}$; 2, for determination of input actions; 3, for setting goals of modeling; 4, for the modeled system (objects $Ob^{op}_{<>}$) of the first class; 5, for the model ($Ob^{m}_{<\theta>}$) of the investigated system $Ob^{op}_{<>}$; 6, for the estimation of the quality of a model (poly-model system); 7, for controlling the quality of models; 8, for controlling the parameters of models; 9, for controlling the structures of models; and 10, for changing the concept of model description. This technology was implemented in software prototype for information fusion quality estimation and models' quality control in the sphere of operational river flood forecasting. We are going to speak about it in the next subsection of our paper.

When building operational flood forecasting systems, this technology is implemented through the creation of an intelligent interface, which unites heterogeneous ground and space-based data and expert knowledge to be used later for forecasting. The intelligent interface's main purpose is to choose and to adapt a specific model to simulate water propagation and flood depths on the basis of contextual information (initial data accuracy, flood dynamics, operational result efficiency, etc.). The methods and algorithms that are currently being developed intensively within the theory of evolutionary modeling have been chosen as the scientific basis for the adaptation of hydrological models (http://litsam.ru).

Overall, the creation of an intelligent interface ensures a synergetic effect from the joint processing and use of heterogeneous ground–space data and the implementation of a model complex to assess possible flood areas.

The proposed architecture of intelligent information systems (IIS) is shown on fig. 5. It follows from the above described IIS composition that the IIS architecture should ensure flexible interaction of many components, including the existing and potential software modules based on hydrological models, input data processing modules, forecast result visualization modules, control modules, etc. In this respect, it is desirable to build IISs based on service oriented architecture (SOA). In this case, the proposed IIS should have three components: a control application, a service bus, and an intelligent interface. The control application is designed to implement the logic of the system's operation, which depends on the interrelationship of data acquisition, processing, publishing, and visualization operations. The service bus in this case is a software core that stores information about services available in the system. By services, we understand separate weakly interrelated software modules that realize technological operations, for example, data acquisition from external sensors, processing space images, and publishing a vector map on the geoserver.

The above described operational flood forecasting system was practically tested in several regions of Russia and abroad. The most demonstrative are the results obtained during the 2013 flood of the Daugava River (Latvia) near Daugavpils. In terms of estimating and forecasting flood areas and operational warning of the population and organizations, the best results were obtained for the 12–24 h forecasting interval. The St. Petersburg Institute for Informatics and Automation, RAS (SPIIRAS), and Riga Technical University jointly carried out this experiment within the ESTLATRUS cross border cooperation project [31]. Figure 6 shows the overall structure of this experiment.

5. CONCLUSION

In the present conditions, the development of methodological and methodical fundamentals of models' quality estimation and models' quality control, in other words the development of models' qualimetry theory is highly urgent. This theory belongs to the branch of science, known as quality control, and, in its turn, can be decomposed into many applied theories for estimation of models in different data domains. Thus, Fig. 4 shows main elements of the qualimetry theory for integration of data and knowledge (Information Fusion Models) (Okhtilev M.Yu. 2001, Okhtilev, M.Y., Sokolov, B.V., Yusupov, R.M).

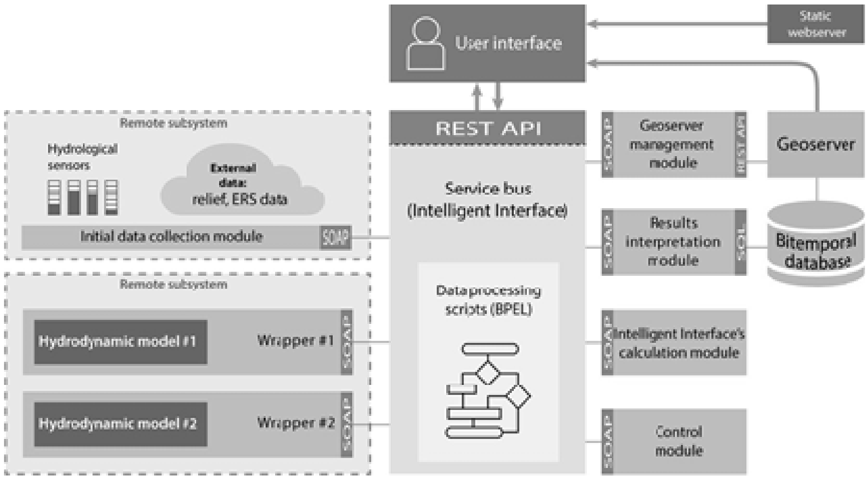

Figure 5: The generalized technique of estimation and control of the quality of models of the first class

It can be seen that the central problems of qualimetry, as applied to Information Fusion Models are, firstly, forming of qualitative and quantitative measures for estimation of models' characteristics, and, secondly, development of combined methods for multi-criterion estimation, analysis, classification, and selection of semiotic models (Steinburg, Alan N., Bowman, Christopher L., 1998, Kalinin, V.N. and Reznikov, B.A., 1987, Okhtilev, M.Y., Sokolov, B.V., Yusupov, R.M., 2006.). Figure 3 shows, as an example, methods and meta-models to be applied to estimation of the considered models.

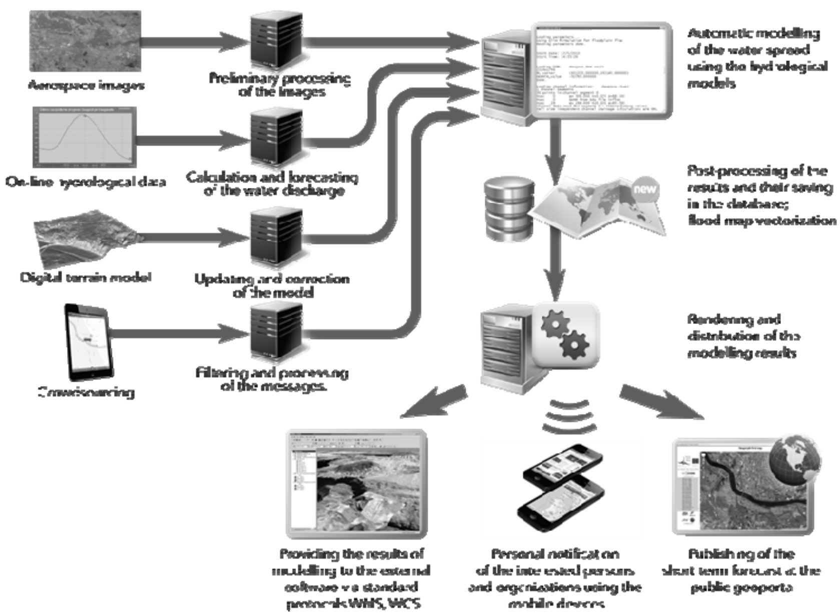

Figure 6: Scheme of the experiment for testing the operational flood forecasting system

From our point of view, models' qualimetry should be developed in two main mutually enriching directions. The first direction includes general matters of qualimetry and is based on the results of the second direction, that is the development of applied qualimetry theories for models' estimation and quality control in different data domains.

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AUTHORS BIOGRAPHY

BORIS SOKOLOV is a deputy director at the Russian Academy of Science, Saint Petersburg Institute of Informatics and Automation. Professor Sokolov is the author of a new scientific lead: optimal control theory for structure dynamics of complex systems. Re-search interests: basic and applied research in mathematical modelling and mathematical methods in scientific research, optimal control theory, mathematical models and methods of support and decision making in complex organization-technical systems under uncertainties and multicriteria. He is the author and co-author of 9 books on systems and control theory and of more than 450 scientific papers. Professor B. Sokolov supervised more over 90 research and engineering projects. Web-page can be found at http://litsam.ru.

MIKONI STANISLAV — Ph.D., Dr. Sci., professor, professor of mathematics and modeling department, Petersburg State Transport University, leading researcher of information technologies in the system analysis and modeling laboratory, St. Petersburg Institute for Informatics and Automation of the Russian Academy of Sciences (SPIIRAS. Research interests: system analyses, decision making, intellect technologies. He is the (co)-author of more than 254.

ZUBAN ALEVTINA — PhD, associate professor; senior researcher of St. Petersburg Institute for Informatics and Automation of the Russian Academy of Sciences (SPIIRAS). Research interests: innovations, computer networks, information technologies, database management systems. He is the (co)-author of more than 40.

BURAKOV VADIM — Ph.D., Dr. Sci., associate professor, leading researcher of information technologies in system analysis and modeling laboratory, St. Petersburg Institute for Informatics and Automation of the Russian Academy of Sciences (SPIIRAS). Research interests: technology of quality management software tools, software engineering, evaluation, and quality improvement programs. He is the (co)-author of more than 160.

ILIYA PIMANOV — Post graduate student, St. Petersburg Institute for Informatics and Automation of the Russian Academy of Sciences (SPIIRAS). Research interests: geoinformatics and geographical cartography, applied research in mathematical modelling, optimal control theory. Author of 15 publication.

DMITRY IVANOV — Prof. Dr. habil. Dr., professor for Supply Chain Management at Berlin School of Economics and Law (BSELЭ) His *research* explores supply chain structure dynamics and control, with an emphasis on global supply chain design with disruption consideration,distribution planning, and dynamic (re)-scheduling. He is (co)-author of structure dynamics control method for supply chain management. He applies mathematical programming, simulation and control theoretic methods. He is the (co)-author of more than 250 publications