Development of systems modeling technology in strategic decision support systems

Natalia Lychkina[1]

[1]HSE University, Moscow, Russia, Pokrovsky boulevard 11, 109028 Moscow, Russian Federation

Abstract

The article deals with the general principles of construction and architecture of modern cognitive centres to support strategic decision-making on socio-economic development and its basic components based on a generalised simulation model of the socio-economic system, complemented by modern knowledge-oriented cognitive technologies, as well as data analysis and scenario analysis techniques.

Approaches to the construction of multi-paradigm simulation models based on the principles of a composite combination of system dynamics and agent-based simulation modeling are proposed, which allow describing the processes of development and self-organization in socio-economic systems.

The promising directions for the development of systems modeling technology and the construction of multi-model complexes in strategic development projects based on the principles of stratification, ontological modeling, scenario planning are outlined.

Keywords

Socio-economic systems, Simulation modeling, System dynamics, Agent-based modeling, Stratification Ontological models

1. Introduction

The need to improve the tools of strategic scenario computer modelling of socio-economic systems is determined by several challenges of modern digital economy, as well as establishing a framework for strategic management in public administration (state programmes) and application of program-targeted management methods at all levels of state administration for socio-economic development of the country. Countries, regions and cities all around the world, that are developing successfully, have long had think tanks dedicated to strategic planning and social design.

In the ideal case, the strategic plans of the major socio-economic entities of the Russian Federation should be coordinated and synchronised in accordance with the overall development strategy of the country. However, a critical analysis of the state of strategic development in Russia demonstrates the practice of drafting static and formal strategic documents, without serious analysis and a holistic systemic approach in the complete absence of a scenario planning and proper coordination of these scenarios by all stakeholders.

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nlychkina@hse.ru (N. Lychkina)
https://www.hse.ru/org/persons/24114982 (N. Lychkina)
0000-0002-7576-9362 (N. Lychkina)

From the perspective of the systemic paradigm development strategy is a development in time of a complex socio-economic system, the coherent development of its subsystems, the trajectory of the development of the management object under conditions of dynamic and uncertain changes occurring in the external environment. The development of effective strategies is carried out through the generation and analysis of different scenarios to achieve the goals, analysing possible trajectories of development in order to find the most effective one that contributes to the achievement of the set targets. Strategic planning based on the scenario approach and system modelling can act as a tool for reconciling the interests of different socio-economic actors (population, different social groups and society, businesses, territories, state).

The main stages of the strategic management decision-making procedure include:

1. Evaluation of the current situation, analysis of trends in the external environment;
2. Goal formulation and modelling;
3. Generation of possible development scenarios;
4. Dynamic computer scenario analysis of the consequences of strategic decisions;
5. Alignment and selection of a successful strategy based on a balance of interests model.

The central step in this procedure is dynamic computer scenario analysis, which is based on a scenario approach with a generalised simulation model of the controlled object.

Uncertainty in forming the goals of strategic development, in making fore-casts in a complex environment impedes social planning and development of scenarios of the future, even in case of massive expertise and foresight technologies. Of course, we can increase the amount of experts' responsibility but their capabilities are limited. It is necessary to help experts, to provide them with computer tools, some kind of "computer foreteller" that could help them evaluate and compare development alternatives, evaluate long-term consequences of the decisions being made. The modern theoretical and methodological basis of system modeling and high-tech solutions of simulation modeling can solve this task which is overwhelming for the expert community, and can also help create consolidated (for different expert groups, ensuring the conciliation of the interests in the triad: civil society, state, business) scenarios of movement to the desired future. The main thing is to include the expert and analytical community, the persons responsible for developing managerial decisions and all the interested parties (civil society, business) in the interactive process of social modeling of the future.

Strategic problem solving requires the use of vision (goal modelling) and knowledge (domain ontologies, expertise), multi-dimensional information, solution architecture (scenario generation and selection). The process of making strategic decisions requires the combination of knowledge, data, scenario analysis of many possible management decision options based on the simulation modeling of the managed object. Thus, a strategic development project combines data, knowledge and scenarios.The systemic element of the strategic decision-making procedure is a generalised simulation model of the managed object, which represents system-wide knowledge of the problem,over which the strategic decision-making process is organised.

Strategy is a product of intellectual activity. A large-scale strategic development project involves and interacts with subject matter experts and specialists who work with knowledge; public managers and other stakeholders who work with meanings, goals and scenarios; system's methodologists and analysts; computer simulation modelling specialists; IT specialists who are responsible for presenting relevant information on problems; specialists in cognitive analytics and knowledge engineering. All of them work with different perceptions of the system or the problem. The result of the procedure and joint activities is a system-wide understanding of the problem (problem structuring) and an overall concept for solving the problem. The problem is seen as a whole. Systemic solutions to the problem are seen in development. The overall concept and structuring of the issue, as a result of a joint activity, is formalised as a structured stratified view of the system or problem, with the aim of further detailing and modelling of it.

The technology for implementing such projects is available using system-wide principles and a modern information and analytical framework. The elaboration and justification of strategic development programmes for the country, regions, industries and businesses determines the relevance of establishing an infrastructure of modern strategic decision support systems and cognitive centres, whose capabilities enable problem-solving from a systems perspective:

1. Formulation of a long-term development strategy, alignment with short-term plans;
2. Analysis of possible trajectories and consequences of the implementation of the proposed development scenarios, analysis of the success of the strategy in achieving the goals set;
3. Analysis of the risk of not achieving the set goals, including the deadlines for implementation;
4. Coordination of development programmes at different levels (federal, regional, sectoral);
5. Finding a consolidated development scenario and balancing the interests of the state, enterprises and population.

However, the current state of situational and information-analytical centres at the federal and regional levels of government do not allow to solve tasks of such scale and complexity. As a rule, they adhere to the ability to monitor socio-economic processes and control key indicators, collect and analyse retrospective information to assess the current situation. They provide information and support for operational tasks. They lack sufficient analytical capabilities to carry out systemic and strategic modeling of complex socio-economic systems (SES) on the basis of Strategic (cognitive) centres in terms of conducting group expert analytical work based on modern tools of dynamic computer scenario analysis of socio-economic processes in order to form effective development scenarios.

The complexity of political and economic problems, the growing influence of civil society on responsible government decision-making process, the development of professional and expert communities, expert and analytical centres, a convergent approach to governance and management decision-making, the need to create interactive models of "alignment and balance of interests", the use of visual analytical technologies, methods of involving experts in the model analysis and management decision-making - all determine the need to combine expert-analytical activities on the basis of promising information and analytical technologies for the analysis of structured and weakly structured information, the intellectualization of DSS (model and knowledge management, application of image-cognitive models) and scenario analysis procedures using simulation models of socio-economic systems. The development of computer technologies for data analysis and knowledge management, artificial intelligence methods, cognitive analytics, simulation modelling technologies, and ontology modelling open up new perspectives in modelling complex socio-economic processes and solving weakly structured strategic planning tasks. This is a fundamentally new class of intelligent information systems, the cognitive component of which relies on massive expertise, network expert technology, big data analytics, and modern computer simulation modeling.

The article examines and elaborates on:

1. General architecture of modern cognitive centres and its components.
2. Principles of building multi-paradigm and composite simulation models of developing socio-economic systems.
3. Main directions of development of system modelling technology in strategic development projects.

2. Cognitive centres architecture

The level of development of modern digital technologies allows to construct an infrastructure of cognitive centres and strategic decision-making support systems (SDSS), where the simulation model is integrated with visual and mathematical models, ontologies, monitoring systems, dashboards, network expertise and other infrastructure components of decision-making procedures. The overall architecture of the SDSS is shown in Fig.1

Let us consider the basic components, architecture and infrastructure of the Information-Analytical Centre for Strategic Planning, providing information-analytical support of strategic management tasks; as well as the purpose of the simulation model as a backbone of strategic planning, the content and methods of the scenario approach, the balance of interests models as a tool of joint activity in the procedures of developing a collegial agreed scenario. The main functions of modern SDSS: Data Management; Knowledge Management; Model Management; Scenario Management.

*Data Management.*Management of structured and unstructured information about the object of analysis and the external environment – is a prerequisite for strategic analysis and assessment of the current state of the management object, identification of systematic patterns based on data and features of the functioning of the object.Key methods and technologies: Big Data, indicative analysis, content analytics, intelligent analysis of structured and unstructured information and machine learning.Assessment and visualisation of the current state (or of a certain preceding period of time), interpretation of the dynamics of the object and its environment on the basis of retrospective data - information base for conducting strategic work.The results of the information work on the identification of regularities between the various factors can be applied in strategic analysis, and can also form the basis for analysing issues and constructing (hypotheses, dependencies) a simulation model of system.

*Knowledge Management.*A great deal of information (knowledge) comes from experts: concepts of the subject area, poorly formalised information about the control object, its management (possible scenarios), the specifics of its behaviour (development), futurological perceptions of the expert about the possible future behaviour of the object and possible changes in the external environment.The decision-making process in complex management situations, requires the involvement of the decision makers in the management decision-making process at all stages (from analysis of the current situation to the generation of scenarios and analysis results of

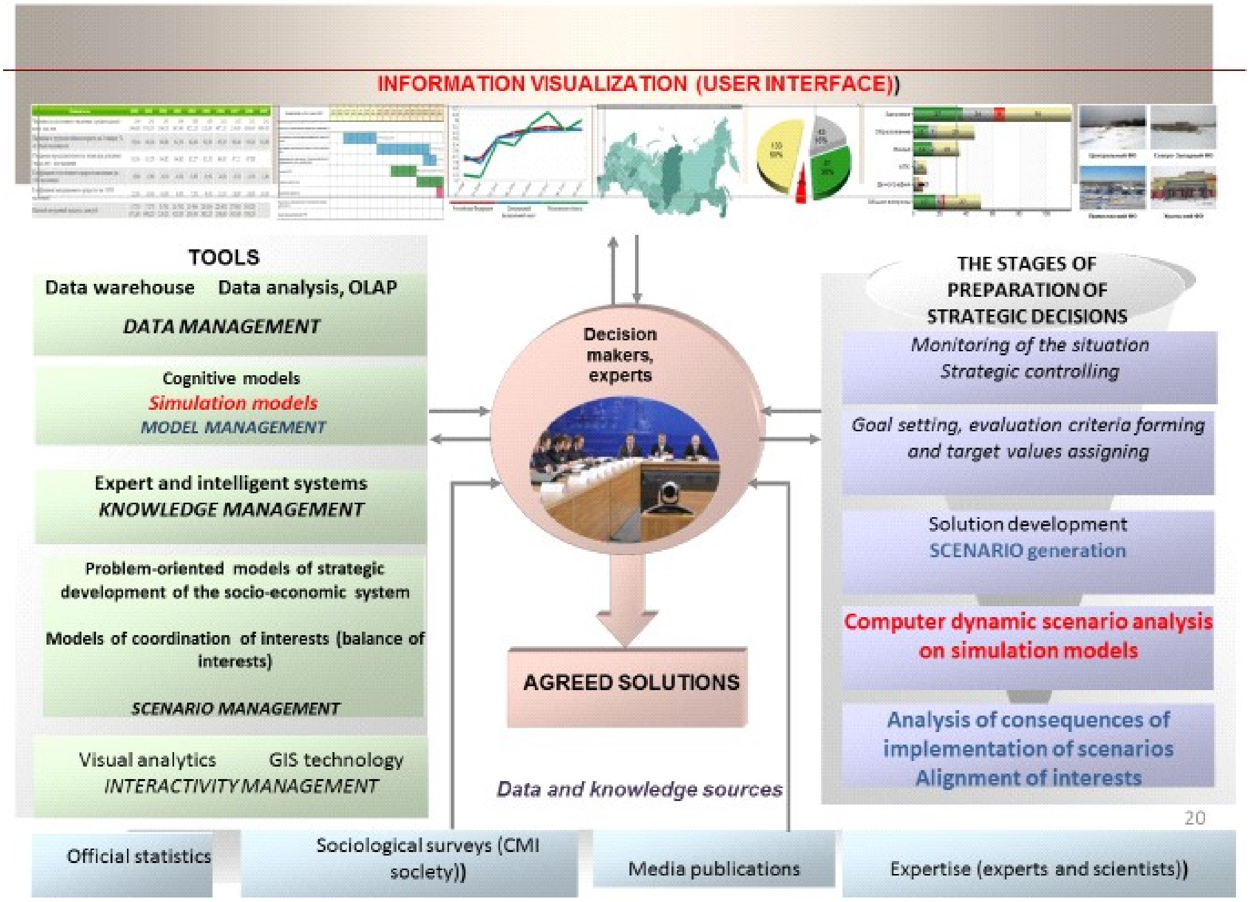

Figure 1: The infrastructure of information and analytical activities in strategic decision support systems.

modeling studies).The system-analytical toolkit for strategic decision-making is formed on the basis of a combination of analytical information processing and expert-cognitive methods in management decision-making procedures; expert-analytical and information-analytical processing of data, information and knowledge is carried out.Such "cognitive centres"offer comprehensive tool solutions, including methods and models of cognitive analytics, specialised analytics for processing multiple information flows, distributed network expertise and knowledge management technologies. Management tasks are characterised by high complexity, dynamism, uncertainty, multidimensionality, and overlapping flows of control actions in the generated scenarios.The structuring of data and tasks acts as the basis for expert analytical work on the problem, involving a large number of experts in different subject areas and their knowledge (expert panels and revisions), a reference model of the subject area is formed, a kind of knowledge base, including a metamodel of the subject area based on the ontology.In simulation and cognitive modelling, experts are involved in the process of semantic comprehension of the problematics, specifics of the subject area and mapping of real phenomena and processes occurring in socio-economic systems. It is their mental knowledge that forms the framework of simulation models of socio-economic systems.

Model Management. The SES simulation model acts as a central and backbone of the strategic decision-making procedure in the SDSS, along with the monitoring system, data analysis, scenario generation methods, scenario research and analysis techniques.Strategic management analytics based on SDSS in public authorities is built in the form of procedures and landscape for conducting dynamic computer scenario analysis based on a generalised simulation model of the management object, supplemented by methods for generating possible scenarios of SES development, expert analysis of scenario consequences, methods and models for coordinating the interests of participants in the social design process.

The developed SES simulation models rely on sound econometric estimates in the identification of socio-economic processes and the specification of social and economic agents.Analytical monitoring, sociological research and situation analysis form the information base for describing the current state of the system-dynamic model, parameterisation and specification of its elements (processes, agents).Expert revision procedures and expert cognitive analysis are used to stratify, ontologically model socio-economic systems, generate possible development scenarios played out on simulation models, and build "balance of interests" models.

The experts believe the model, which they understand and interpret, so decision-maker's oriented analytics applies here. Schematisation, diagrams, cognitive representation of the problem situation and visualisation of the dynamics of its development (system behaviour over time) provide the expert with the opportunity to understand and comprehend, to explain the patterns of system behaviour and to actively participate in the process of creating and revising such a model.

*Scenario Management.*The scenario approach allows experts to generate possible development scenarios or trajectories for the SES based on information about the state and structure of the SES and action programmes (plans), and to analyse them using a simulation model.An SES development scenario should provide an indication of possible future states and development trajectories of the system. The task of building a scenario for a developing system relies on studying the behaviour of a complex dynamic, controlled system, understanding the patterns of its development, in order to correctly select the points, place and time of application of management efforts consistent with the internal capabilities of the system itself, which is extremely important in scenario planning and the model experiment supporting it.The simulation model of the management object serves as a structural and informational basis for the construction of a scenario. The formation of a scenario model, the conduct of scenario (experimental) research to form qualitative alternatives for the future, and the synthesis of effective scenarios is an under-researched area of forecasting and analytical activities in development management. Intelligentisation, formal methods (morphological analysis and others) and computer-based scenario generation and analysis tools constitute the core content of modern computer scenario analysis based on a simulation model of the control object.

An important aspect in the formation of strategic decisions is the coordination and harmonisation of the interests of all participants in the process: government, business, and the population.The debate in the expert and analytical community, which is trying to propose many scenarios for this development, sets the stage for a consolidated development scenario or a long-term "balance of interests of all actors" based on the simulation model.A convergent approach to management and decision-making ensures accelerated convergence of the processes of reaching agreement (consensus) among decision makers on goals and courses of action, relying on network expertise, representation and knowledge management methods.Specific methods in a modelling research setting are: a regime of collective expert revisions of model structure and system solutions, organising procedures for developing agreed, multi-stakeholder solutions based on a "balance of interests" model and some others.

The scale and complexity of strategic problems and challenges and the counter-intuitive nature of complex SES require changes in approaches to system modelling of developing SES and support for strategic decision-making based on dynamic multi-component simulation models. The implementation of such strategic development projects and their information and analytical support, in which system analysts, problem experts and public administration specialists cooperate, requires improvement of system modelling technology in the tasks of system conceptualisation of large-scale strategic problems and complex SES, construction of multi-model complexes based on stratification principles, improvement of methods and tools of scenario planning, information and analytical support for strategic decision-making procedures based on dynamic computer scenario analysis.

3. Multi-paradigm simulation models of developing socio-economic systems

In the author's works, the principles of constructing multi-paradigm simulation models describing the processes of development and self-organization in socio-economic systems were developed [1].The methods of combining composite system-dynamic and agent-based models of developing socio-economics systems are proposed.

System dynamics (SD [2]) is a method of describing nonlinear dynamic systems with inverse relations which is based on flow stratification or representation of the system being modeled as an aggregate of interacting flows of different character. This method was offered by the American scientist J.Forrester [2]. According to the fundamental concepts of system dynamics, the key element in describing the system dynamics is its structure represented as interacting flows, and also the interaction of inverse relation contours in its structure. The language of system flow charts and the specialized graphic technique for structuring the dynamic objects being modeled make this approach a very expressive and efficient tool for system analysis procedures – decomposition and subsequent composition (synthesis) of a complex dynamic system on the basis of cause-effect analysis and the principles of inverse information relations.

Agent-based modeling and simulation (ABMS[3]) emerged not so long ago as a kind of a specific branch in a broad specter of sciences dedicated to artificial intelligence and computer technologies. Presently it draws its conceptual view and existence philosophy in social sciences, behavioral economics, management, cognitive psychology etc. [3]. Agent-based models represent the real world as separately specified active elements which are called agents; these elements interact between themselves and with their environment. The activity of the agents is expressed in their capability to form individual behavior. The behavior of a complex system emerges as the result of interaction of agents in which they perform their behavior; this allows us to observe and study the patterns and features characteristic for the system in general.

Modeling of a complex SES has a problem of stratification of SES structural layers and interpretation of interaction between the layers. Different layers of a complex system are characterized by different degrees of organization and the character of dynamic processes in different strata of such a system. We can conventionally determine particular strata in SES description and examine the cyclical transitions between socio-economic configurations:

the micro level – the main focus of research is the individual solutions of economic and social agents;

the meso level – the collective organizational forms (and social groups in the society system);

the macro level – the processes of SES evolution and development.

Internal dynamics and the processes occurring at the micro level and meso level of SES have a significant impact on the behavior of the entire system and determine the path (trajectory) of further development of the system. At the macro level new system characteristics of society emerge. On the contrary, the processes at the macro level form the environment for the lives of many individuals at the micro level, where they implement their decisions depending on the current socio-economic situation. Approaches to SES stratification based on structural approaches need to be supplemented with interpretations of interactions between downward and upward strata of the socio-economic system that describe the cause-effect relations and dynamic manifestations of the interpenetration of phenomena occurring in different strata of the socio-economic system. Consistency in the consideration of the societal system and socioeconomic system is enhanced by the cyclical character of descending and ascending interaction between the main strata of the simulated system, highlighting aspects of such interaction in systems of various types.

Let us consider the general approach to the creation of simulation models which describe such phenomena in socio-economic systems. The simulated model of a society system should connect the micro level at which individuals make decisions and take actions, and the macro level which describes the state, the basic structure and the development of such a system. All the model variables are constantly changing during the long-term period under the impact of external and internal factors, in the environment of transforming system structures and socio-economic system characteristics.

In the process of creation of a generalized simulation model of a socio-economic object, system dynamics models and methods are used. At the macro level model designs are produced by means of the aggregated system-dynamic models describing the main elements and processes of development of a society system: population, economy, production and social infrastructure, environment and other factors of social life.

At the level of micro processes description, aggregated system-dynamic models of SES are supplemented with agent-based models and also with models describing the interaction of a multitude of social groups. The human factor in both its individual and collective manifestations is essential in the study of socio-economic processes. The active elements of the economic and social system are people, individuals. They are a rather complex system as well. The behavior of such a person, representative of the society, individual choice and his communications in society and economic life can be described using multi-agent simulation. Algorithmic constructions of such models can reproduce the individual behavior of such active agents at the micro level of the societal system. Characteristics of an agent change with time. He alters his decisions under the influence of changes in his environment. He interacts, exchanges information with other participants of a socio-economic system. Groups and structural formations are set up. Changes in the organization of the socio-economic group itself arise. They influence the socio-economic environment in which the agent lives and makes his choice. It is at the micro level where the processes of self-organization and self-reproduction are started. These processes determine stability and other dynamic manifestations in particular elements of a socio-economic system. It is possible to define a meso level at which we describe how people behave and interact; and where social groups forming as a result of such interaction are determined. Social behavior emerging at the micro level can lead to global changes in the societal system. The properties of a complex economic system at the macro level are formed as a result of agents' interaction at the micro level where their behavior is carried out. This allows us to observe and study patterns, properties and dynamics characteristic for the system in general. The agent-based model allows us to investigate the individual behavior of different groups of agents, the specificity of their adaptation to the changing environment, and the way the processes of self-organization influence the evolution and development of the socio-economic system as a whole.

Thus, effective model designs of developing SES are created upon the principles of composite combination of system-dynamic simulation models and agent-based simulation models. Composite dynamic models of SES function on the basis of a united model and information frame which allows organizing the processes of information exchange and the mechanisms of interaction between the macro level and the micro level of the SES being modeled. SES at the macro level is an external environment in which social and economic agents carry out their individual behavior, and which to a large extent predetermines the rules of decision-making, experience and knowledge of the agents. In turn, the emerging social behavior starts the processes of self-organization, development or stagnation that define functioning and control of the SES in whole. Such an approach to creation of multi-model complexes on the basis of composite system-dynamic and agent-based simulation models allows us to study the dynamics and development of socioeconomic processes through the cyclical interconnection between micro level and macro level in a particular SES.

The author endorses the proven approaches to the construction of model complexes used across the social sphere ([7], [6], [5]), regional (area-specific) systems [4] collaborative specialized projects [8]. Such approaches streamline extensive transdisciplinary research in economics, sociology, and management of organizational systems.

4. Development of systems modeling technology

The SES model complex is implemented in line with the principles of stratification, using multi-paradigm S&M environments (such as software by AnyLogic) underpinned by a single model frame with extensive information and implicit links between models across various layers and ontological levels. The principles of designing the multi-paradigm models and technologies for building up the multi-model SES complexes need further elaboration and should be refined to be applied in actual nationwide and regional administrative projects and strategic development roadmaps, as well as for information and cognitive centers.

Let us review the mainstream trends in the development of system modeling technology and methods of the multi-model complex formation based on system principles. The major challenge is to devise a unified technology enabling assembly of model layers within the system and the formation of an ontologically complete domain model. The conceptual representation and scalable nature of the generalized SES simulation model requires decomposition of multiple submodels, descriptions of structure, dynamic representations, and other constituents.

Such strategic development projects and design of system-dynamic models cannot be delivered without involving extensive transdisciplinary communications (subject experts, IT professionals) with comprehensive expert audits. Even the expressive language of SD diagrams may be insufficient in multi-model environments. SD and ABMS employ different specifications. Models should be clear to the experts engaged in the conceptualization process. Simulation models are conceptualized and structured on the basis of a stratified description of the problem and the system. *Stratification and methods of a stratified description for a problem and a system* (as a conceptualization technology) enable devising large-scale and interconnected models, combined into a single model complex, while preserving implicit relations between the models of the model complex across various strata and levels of generalization (aggregation). As a general principle of system-wide S&M, stratification reflects structured knowledge about the system, while providing a necessary tool to build up an S&M complex for sophisticated SES, to work out the system phenomenon logic and to maintain implicit links between various models comprising the set of models. The stratified description of the modeled SES may be used for discussing and generalizing a systemic problem, harmonizing diverse views on the problem, supporting versatile representations (through notation) of conceptual layouts. The author of this work proposes approaches to stratification of a multi-model complex, including various ways to represent conceptual descriptions of a complex SES: cognitive, flowing, structurally functional, informational, as well as other helpful visual graphic techniques ([9],[10]). This facilitates the models construction at the conceptual modeling phase, contributes to the audit procedures and streamlines transdisciplinary interaction among subject experts.

Ontological modeling is used as a toolkit for the information interaction and semantic consistency of conceptual models ([11], [12]) that make up a multi-model complex. Ontologies facilitate the construction and revision of models, aid the experts with navigation through different levels and strata of the system representation in the model complex, streamline the communication of experts on the problem, coin a unified and expressive language of users, while combining (through semantic and informational integration) various conceptual representations created by different users in different languages. Ontological engineering provides a unified environment for information interaction and keeps the models within array logically consistent, offers a unified language for the subject experts to collaborate and communicate, while maintaining conceptual clarity and common understanding, a view of the system as a whole, and facilitating the technological transition from domain-specific conceptual models to their computer models. Top-level ontologies build up system-wide knowledge, whereas applied ontologies bring the domain knowledge, experience in dealing with issues and solving problems both obtained in the course of experimental S&M research.

Research based on a computer-aided SES model leverages *dynamic computer scenario analysis* and special tools for the scenario approach, which requires the experts to be actively involved in the elaboration of scenarios and their reproduction in the simulation model in order to deploy scenarios temporally, and find the appropriate time and points of application of management decisions in line with the system's own capabilities and current conditions. Such methods need enhancements, and are based on a combination of a scenario-based approach and expertise, an experimental approach; methods of constructing models of the balance of interests of the participants.

A strategic development project amalgamates data, knowledge and domain models. The simulation model of the system is at the core of the strategic decision-making procedures, which determines the approaches to devising and parameterizing the models using heuristics, cognitive analytics methods, scenario analysis, convergence of S&M methods and technologies with data analysis. *Ensuring the strategic planning procedures in heterogeneous information and analytical environments* employing a wide range of analytical methods is an important component of strategic development projects. Ontological modeling facilitates the elaboration and execution of decision support procedures, interaction between simulation models, data, various analytical applications and IT services.

5. Conclusion

The current level of development of information technologies allows us to create the infrastructure of *cognitive centers and systems of support of strategic decision-making*, where a simulation model is integrated with visual and mathematic models, ontology, monitoring systems, display panels, network expertise and other infrastructural components of the decision-making procedures.

A simulation model of the socio-economic system acts as the core of the procedure of strategic decision making in the cognitive centers, along with the monitoring system, data analysis, methods of generating scenarios, the technology of the scenario studies and analyzing their results. Strategic management analytics on the basis of SDSS is set up in the form of procedures and landscape for conducting dynamic computer *scenario analysis on the basis of a generalized computer model* of the control object, supplemented with the methods of generation of possible SES development scenarios, expert analysis of the consequences of scenario implementation, methods and models of coordination of interests of the participants in the social planning process.

Created simulation models of SES are based on reliable econometric estimates in identification of socioeconomic processes and specification of social and economic agents.Analytical monitoring and situation analysis form an informational basis for describing the current state of a system-dynamic model, parameterization and specification of its elements (processes and agents).

The procedures of expert revisions and expert cognitive analysis are used for stratification, ontology engineering of the socio-economic systems being modeled, formation of possible development scenarios tested in simulation models, and creation of the "balancing of interests" models.

The scenario approach allows experts to form possible scenarios or trajectories of SES movement on the basis of the information about SES state and structure, and action programs (plans). They can analyze them with the help of a simulation model. An important aspect in forming strategic decisions is coordination and balancing of interests of all participants of this process: state, business, people. The discussions going on in the experts and analysts community, which is trying to offer a large number of scenarios of such development, create favorable conditions for forming a consolidated development scenario or a long-term “balancing of interests of all participants” on the basis of a simulation model.

Improvement of the technologies of system modeling and scenario planning on the basis of information and analytical centers in the framework of the tasks of strategic planning in public and corporative management requires improvement of *the methods of conceptualization of systems being modeled and stratification of modeling complexes on the basis of ontologies.*

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