Development of Real-time Simulation Models

Integration with Enterprise Information Systems

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***Abstract*—The paper discusses the integration method of simulation models used within the enterprise information system. The integration problem is presented on one sample class of models – the real-time models that are used in control, diagnostics and decision making processes. The suggested method is based on multi-agent approach with distributed knowledgeable agents. The dynamic model consists in the multi-agent resource conversion process model that supports multi-approach modeling, including discrete-event, agent-based, queuing systems. To substantiate suggested technical decision of the integration module existing message brokers were analyzed. The subject area ontology is presented. It is used for semantic data integration that is required for simulation modeling of technological processes, business processes and logistical processes. In order to achieve a cross-platform system, the Java language is used for development**.

Keywords-model integration; resource conversion process.

I. Introduction

Currently, multi-agent approach is among the perspective directions of enterprise management systems [1][2]. The paper deals with the representation of distributed corporate information systems of a metallurgical enterprise in form of a multi-agent system. Such systems consist of multiple interacting agents that solve the goals, set by analysts [3].

Development of state-of-the-art technologies allows large industrial enterprises to obtain and store vast data volumes that define technological, logistical and commercial problems of an enterprise. These data may be used for simulation modeling of various aspects of its activity. Simulation results may be used for quality control of manufactured products, defect prevention, optimization of logistical and commercial schemes. Integration of these models into the enterprise control circuit by interaction with the corporate information system and development of unified software is a pressing task.

After the introduction in section 2 we start from the state of the art overview for the area of simulation modeling tools with real-time capabilities. We identify the richest systems from the functionality point of view. In part 3 we present the architecture of suggested system, describing role of the agents. We move on to application of the system to metallurgical production. Here we present and discuss the ontology of the metallurgical enterprise. We get to the role of each agent within the system and discuss their interaction. In part 4 we present our research on how the developed models interact with each other. In part 5 we describe the integrating data model. Part 6 presents the mechanisms for semantic integration of data sources. In part 7 we compare our approach to similar implementations in other simulation systems in terms of performance. Finally in part 8 we present the conclusions from our research.

II. Current State Of Tools

The development trend of enterprise information systems focuses on wide application of Internet technologies. Currently the commercial simulation systems available on the market, including AnyLogic [4], ARIS [5], G2 [6], are all desktop applications. Additional requirements for simulation modeling tools for team development of comprehensive simulation models include support for multi-user environment, availability of model access on the Internet and running simulation experiments on the Internet.

A comparison of systems [7] showed that the most part of the functionality is included in AnyLogic [4] and BPsim [8] products. Only G2 is developed focusing on the direction of service oriented architecture [7]. At the moment the SaaS (software-as-a-service) technology [9] is the most convenient in use, optimal in performance and client software requirements. The end user in this case is the analyst or decision making person. Thus, the pressing problem is development of the model integration software for simulation modeling servers, using service oriented approach.

III. System Architecture

A multi-agent system architecture will further be discussed based on a sample integration system of automated system models of metallurgical production. It contains the following software agents:

- Data exchange agent. It is used for actualization of model parameters and data transfer (including experiment results) into corporate information system,
- Modeling agent. It is used to solve process control tasks in real-time on the basis of real-time models,
- Message exchange agents. It provides interaction between data exchange and modeling agents. This

agent decides when to activate real-time model, based on occurring events and activation rules, and also transfers messages into the corporate information system, e.g., into a MES-system or to a corresponding analyst's (specialist, technologist) workstation.

The method of design, development and operation of real-time models is based on the methodology of business process analysis and development of information systems. It includes integration of structural and object-oriented approaches, simulation and multi-agent modeling [10] and consists of the following stages:

- Design of simulation model in the model definition module,
- Running experiments for model verification and adequacy checks in simulation module. BPsim.MAS system is used for this task at the stage of schematic design [10]-[11],
- Design of real-time model for its further use in model integration module and interaction with other sub-systems of the corporate information system. BPsim.SD tool [12] is used for this task at the stage of schematic design. It implements the following design stages:
    - Design of architecture for the model integration modules by dataflow diagrams, use-case diagrams and sequence diagrams of unified modeling language,
    - Subject area ontology representation in form of class diagram,
    - User interface modeling,
    - Testing and debugging the real-time model in corporate information system,
    - Operation.

Use of real-time models means that modeling time must be less or equal to a set value, and modeling must be completed before the next portion of data is received from the corporate information system. Thus, the following features need to be considered during the models integration:

- Performance. Architecture of automated system for metallurgical production must be oriented towards maximum use of server resources,
- Scalability. Models must be able to run simultaneously on multiple computers, as well as effectively use multi-core and multi-CPU computers.

To provide these features each model needs to be executed as a standalone process. Special mechanisms, included with the integration module should be used for the interaction of processes.

Integration is suggested to be performed at the data level. Each model performs analysis of data, received from the data storage. Modeling results are transferred either into the data storage or immediately into the corporate information system.

In general case, the following data integration levels may be distinguished [13]: physical, logical and semantic. A

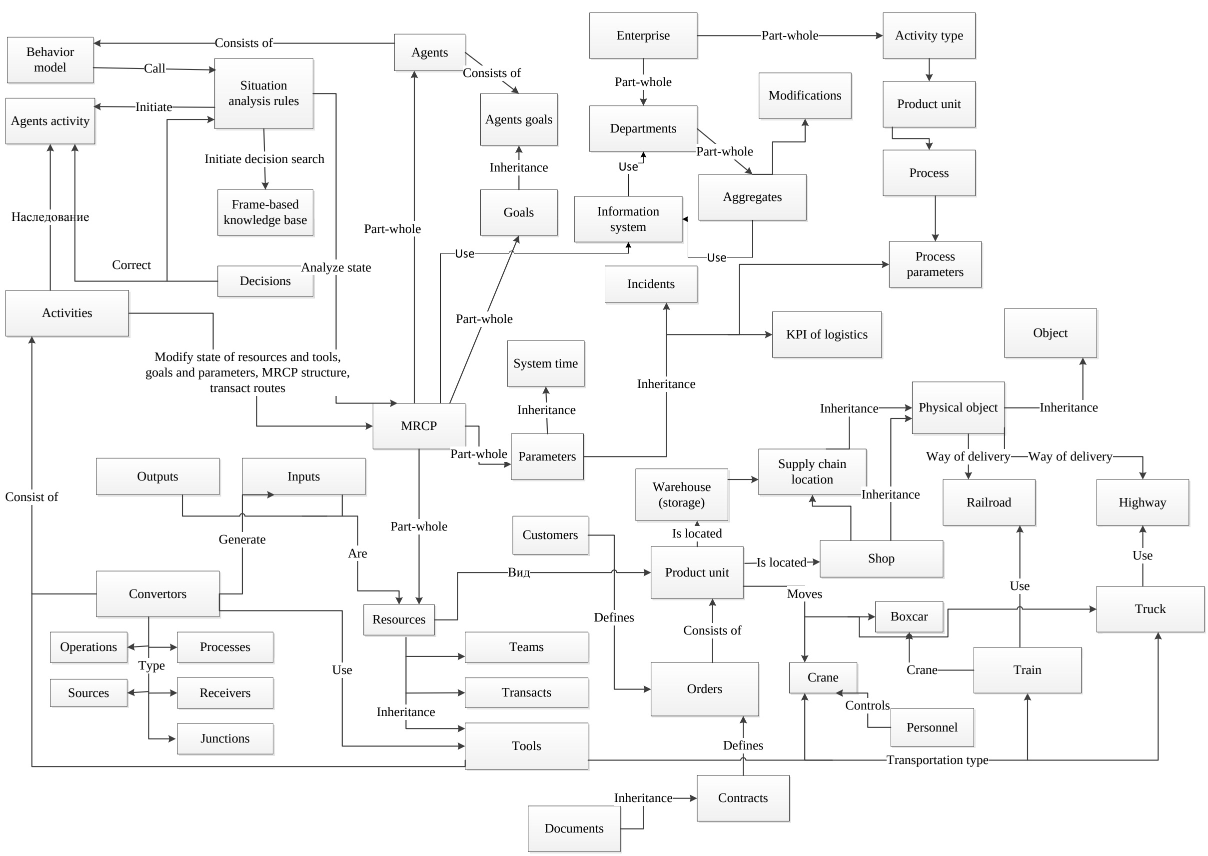

Figure 1. Subject area ontology

single ontology of subject area needs to be developed for consideration of semantic properties.

Ontologies are defined as a result on subject area analysis. In our case, the approach suggested by Girardi et al. [14] has been used. It is based on the Chen's model "entity-relation", since all data is suggested to be stored in relational database. The model has been extended in a way to be able to store other "entity-relation" models and related data.

The method has been extended with such features as availability to process cause-and-effect relations and knowledge of decision making people. Semantic model of the multi-agent resource conversion processes [11] was used for this. It was further extended with the elements of logistical projects ontology, presented by Kowalski et al. [15], and adapted to specific features of logistical problems, related to metallurgical production. Also, the ontology included elements of technological and business process. The designed ontology is presented on Figure 1.

Model integration method focuses on several problems [13]. They are briefly discussed further.

The automated system for monitoring, control, modeling, analysis, and optimization of the full production cycle of metallurgical production, due to specific requirements of the automation object, consists of a large number of various modules, each of which performs a specific task. Together they monitor state of the industrial objects, check parameter validity, model consistency, analyze and prepare recommendations for optimization of the full production cycle of metallurgical production. These recommendations are based on integration of mathematical models of technological, logistical, and business processes of an enterprise. Thus, the automated system for metallurgical production may be considered a distributed multi-agent system. Separate modules are represented with software agents with complex behavior and communicative capabilities.

Automated system for metallurgical production is an open multi-agent system. This consists in bi-directional interaction with multiple information systems of a metallurgical enterprise, related to such classes of information systems as ERP (Enterprise Resource Planning) [16], MES (Manufacturing Execution System) [17], automated technological process control systems, technologists' automated workstations.

An automated system for metallurgical production consists of the following modules (or main agent types):

1. Enterprise automated systems data exchange. Technically this corresponds to the enterprise services bus
2. Data preparation
3. Enterprise processes optimization
4. Models integration – allows use of models in decision making tasks in real-time.

Certain problems make use of data storage, query constructor, and model design modules that are also included in the automated system of metallurgical production.

Architecture of the automated system is implemented in the way that load ration of specific agents may result in copying of these agents in order to distribute and balance load.

One of the applied directions of multi-agent technologies is planning. The concept of an agent corresponds to hardware or software implemented entity, which is capable of acting for the benefit of goal achievement set by the owner or user. Agents possess certain intelligent capabilities [18][19].

A sample application of the multi-agent system for planning operation of a flexible production system is discussed in [18]. We may name the following advantages of the multi-agent system:

1. Formalization of decision making points in form of the agents. The points include specific situation processing scenarios. Technically this process is a part of knowledge formalization stage.
2. Planner is dynamically embedded by means of interaction of specific element of the multi-agent system and thus is ready to modify the plan in case of delays or unexpected (unintended) situations. The planner works in real-time.
3. Agent network, interconnected with relations, self-coordinates its activity.

An additional benefit of multi-agent planning is the capability of automated information sharing between process individuals about changes of controlled object, which introduces control transparency. Subject area knowledge is being formalized during development and deployment of the planning multi-agent system, the decision making process is automated. Thus we ease activity, related to decision making.

Agents may be separated into three following types: reactive, intelligent and hybrid [18][19]. Reactive agents make decisions on the basis of "Situation-Response" rules. Intelligent agents solve the set tasks according to its goals, using common limited resources and knowledge of external world. Hybrid agents have features of both classes.

Agents of the automated system for metallurgical production, that are immediately operating in control and decision making tasks, may have goals presented on Figure 2. Intersection of their goals may be present. Thus, agents have to co-operate. In order to achieve a common goal, agents use messaging.

Interaction of agents of the metallurgical enterprise corporate system introduces problems, related to identifiers of the very same objects and parameters in different data storages. In addition, there is a dis-synchronization of single object-related processes in time.

In order to fix such problems, the data exchange agent is capable of transforming its internal identifiers into identifiers of other agents and vice-versa. Apart from this, the messages are dispatched, which help other agents to fix the problems, related to process arrangement in time.

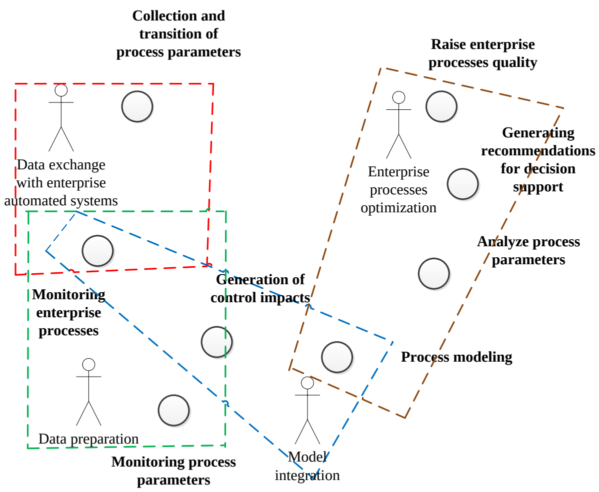

Figure 2. Agent goals

The development of the automated system for metallurgical production is based on decision support method for information system development. This method, in turn, is based on multi-agent approach. The method is supported by the products of BPsim family [11][12], which allows definition of hybrid agents on production and frame-based knowledge bases.

IV. Model Interaction

The most effective way of interaction of model integration system and automated information system of an enterprise consists in automated obtaining the data required for modeling directly from the automated information system (Figure 3). In order to implement this method, we suggest using the Messages queue system, which itself constitutes the architecture and intermediate level software, which collects, stores and distributes messages between subscribers.

Existing message brokers have been analyzed during research. All of them provided guaranteed message delivery between applications. Analysis results are presented in Table 1.

Since implementation, based on REDIS [20] and Socket.IO message exchange [21], is simpler, they were selected for data exchange between the automated information system and automated system of metallurgical production.

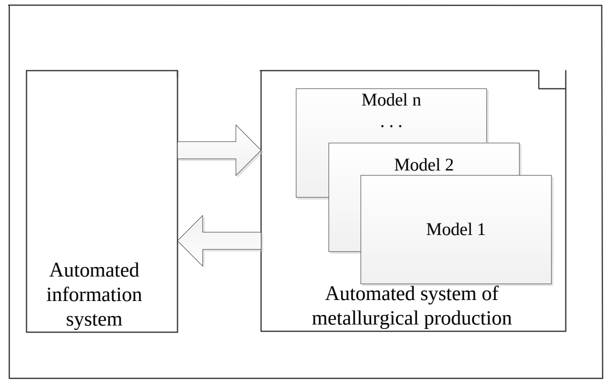

Figure 3. Interaction of integration module with the corporate information system

V. Design Of Integrating Data Model

Integrating data model represents the basis of the common user interface in the integration system. Since the web-interface is suggested for model integration system, a decision, based on JSON (JavaScript Object Notation) [22] and XML (eXtensible Markup Language) standards for the integration model seems reasonable.

The MVC (Model-View-Controller) [23] concept is suggested as the main concept of the model integration system development. The concept utilizes several design templates, which allows the application data model, user interface and user interaction are distributed between three specific components, when modification of just one component has minimum impact on other ones. Model integration system includes common classes that implement typical procedures for data obtaining from the automated information system, as well as presentation of modeling results (parameter values, graphs, etc.).

Since the integration module has the multi-agent structure, the agent elements need to correspond to certain elements of MVC. To make things easier, consider a reactive agent with a single rule: “if a>b, then a=a-b”. Figure 4 shows the dataflow diagram that presents operation of such agent. Data storages correspond to work memory, which is required to store the variable. Operations on the diagram are all If-Then rules. The agent formulae in software implementation that are stored in “If” and “Then” rules of an agent, are transferred into method definition of the corresponding class.

Thus, from the MVC point of view, work memory represents the *Model*, while the logical output machine together with agent rules form the *Controller*. When visualization of modeling results is required by the user, corresponding classes would represent the *View*.

TABLE I. COMPARISON OF QUEUING BROKERS

Criteria	**Redis**	**RabbitMQ**	**ActiveMQ**	**Socket.IO**
Performance	high	high	high	high
Scalability	high	high	high	high
Clustering	no	yes	yes	no
Java support	yes	yes	yes	yes
Ease of use	high	average	average	high

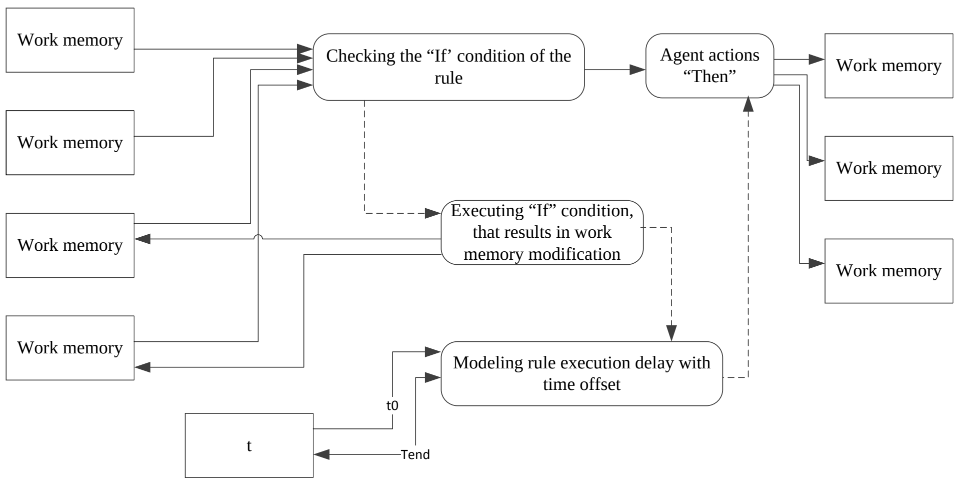

Figure 4. Sample DFD diagram for the reactive agent with one rule

VI. Development of Mechanisms for Semantic Integration of Data Sources

Object-relational mapping is used as a means of data sources semantic integration. This is a programming technology, which allows conversion of incompatible model types between relational data storage and programming objects. Such technology is implemented in ORM (Object-Relational Mapping) systems [24]. After analysis, two systems have been selected for further development, namely, Morphia [25] and Cayenne [26] due to the following factors:

- Their features fully satisfy the requirements of model integration system,
- Cayenne has a convenient feature of visual development of connection of software classes and entities in the database. This reduces the time required for development and debugging.

The prototype of model integration module for automated information system of metallurgical production has been developed after analysis. Since at this stage, some models of the system are yet to be implemented, testing and running the experiments used the emulated parameter inflow from the technological process. Data required for the simulation model integration module were forwarded to corresponding models for analysis and result output. Model results transfer into the corporate information system for further processing has also been emulated.

VII. Performance Comparison

An enterprise uses its own quality assurance software, which includes the enterprise process definition module for design of simulation models of processes under research, and process optimization module for experimenting with the models and searching for management decisions. These two modules are based on multi-agent modeling and the concept of big data. Authors compare the metallurgical manufacturing process model definition with the enterprise software and the popular simulation tools Plant Simulation [27], Simio [28], and AnyLogic [4]. The description of the model itself goes beyond the scope of this work, and only the comparison results are presented.

We assume that models are equivalent and produce averagely the same output. As an effectiveness criterion we use the duration of experiment on the same hardware with animation set to off (Figure 5).

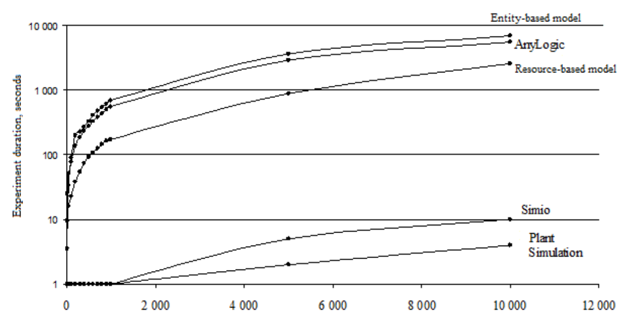

Figure 5. Experiment duration and number of processed product units

The analyzed simulation modeling tools may be separated into fast tools (Simio, PS) and slow tools (AnyLogic and enterprise process optimization module). Optimization module speed is related to detailed journaling of log tables and statistics on model variables and entity instances. No other simulation tool provides these statistics. Resource-based model works faster in the same simulation system. This fact is related to computational resources being spent on queues processing in the process optimization module. The slowest experiment duration was 2 hours and 13 minutes, which may be applicable in case of non-real-time decision making.

After analyzing simulation results we may conclude:

1. All models are adequate to logistical processes of a metallurgical enterprise,
2. Simulation speed is applicable for all simulation systems for various production volumes,

3. Simio and PS have an advantage in simulation speed for simulation of logistical processes of an enterprise,
4. CPU and RAM load are applicable for a short (under 10 minutes) simulation experiment without animation in all systems,
5. CPU and RAM load are applicable for a long non-animation experiment (over 1 hour) for all systems, except PS (due to hang up) and Simio (due to high RAM load),
6. Advantage of the enterprise optimization module from the RAM load point of view for “short” and “long” non-animated experiments.

VIII. CONCLUSION

Use of simulation modeling for analysis of technological, logistical and business problems of an enterprise is a perspective direction. The discussed method of simulation models integration has been implemented in practice and has successfully passed the tests.

The automated system for metallurgical production may assist in the following areas:

1. Collection and storage of information about enterprise products and processes,
2. Analysis of quality of products, diagnosis of production stages with most faulting operations, with full information of production cycle,
3. Application of models in decision making and control tasks. In case a model used in control process diagnoses a significant deviation from quality indicators for a product unit, it generates a signal and forwards in to a MES system, in order to reassign routes for further processing.

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