The Multi-agent Resource Conversion Processes Model Design and Implementation

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***Abstract*—Most simulation models have an idea preceding their design. An idea to improve the effectiveness of a certain solution or to estimate the consequences of some activity. For the most part simulation software helps us, especially when we have a complex, but a predefined scenario for the process development. But in the case when we have multiple decision making persons interacting with each other, having conflicts when using common resources or trying to achieve a common goal but using different methods, we need to simulate this behavior as well. The paper focuses on the software apparatus used in distributed multi-agent resource conversion processes based tool BPsim.MAS, pointing out its advantages and describing used technologies, which have been introduced recently and relate to the support for the agent coalitions. This consideration allows the simulation of complex scenarios with multiple interacting agents. In the final part of the paper we present the model of a gas station network, implemented with the presented apparatus and compare it with the model, based on the nets of the requirements and capabilities.**

Keywords—agent-directed simulation; agent interaction; coalition; resource conversion process

I. INTRODUCTION

NOWADAYS enterprises face a high level of competitiveness at the rapidly changing markets. Simulation modeling is among the most effective tools for cushioning of risks and estimation of the alternatives.

Simulation modeling together with the related technologies is the most widely applied in Germany and the United States. A number of practical applications use distributed simulation modeling. To name a few problem domains of this kind, we may think of the following:

1. Logistical chains with the separate models representing different legal entities, e.g. Customer-Factory-Supplier.
2. Production chains with the models representing production units, business departments, divisions, branches, etc.
3. Analysis and planning military operations.

In the case of distributed simulation modeling, the simulators and their corresponding models may be used both to solve the problems of a certain legal entity of for the complex tasks of the whole logistical chain. In the first case a legal entity may represent an enterprise, participating in the supply chain, or even one of its departments. In the second general case we simulate a set of interacting activities, and all distributed simulators get involved. Such complex problems bring the technical challenges of simulation time synchronization and data exchange, as well as maintenance and software version control between the nodes of the distributed simulation modeling network. There are standards, including the Distributed Interactive Simulation (DIS) [1] and High Level Architecture (HLA) [2], focusing on these technical difficulties. These are supported in the simulation modeling system AnyLogic [3]. The agent-oriented distributed simulation modeling application experience with the business language for supply chains is presented in [4].

Conventional simulation modeling assumes that the model is used within a single application. In such a case, when simulation covers multiple companies, the model becomes more complicated and wraps multiple simple sub-models that represent the parts of the whole business process. In this scenario, a single modification of a single business components of the model can result in changes to the application, which carries a threat for the modifications in other elements of the business components and the model logic [4].

According to Jennings [5], the business process consists of multiple functional activities (operations) between the supplier and the customer with the tasks that need to be implemented in accordance with the specified control model, corresponding to the order graph.

An alternative approach in the development of open systems for simulation is the cloud-based computing [6]. An example of the system, developed for the major enterprises within the Ural Federal University together with the I-Teco, CJSC, is the automated system for metallurgical production [7-8]. In this system various simulation models may obtain the initial data from the external information systems in real-time through the data exchange module, which is built in accordance with the principles of the enterprise bus. Data exchange in the automated system for metallurgical production (SMP) is bi-directional, hence the models may be used for the control tasks and process analysis in real-time.

DIS, HLA and SMP all assume application in form of the control systems in real-time. Application of the data storages that contain the live information from the external information systems in the SMP and BPsim.DSS allows us to all these systems the open systems of simulation modeling. Use of the model-oriented approach allows the SMP and BPsim.DSS

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modifying, when necessary, only the business logic of the model, without affecting the source code of the applications themselves.

When we speak about the problem domain of supplies for the gas stations network, the external information systems, related to BPsim.DSS, include the geo-information systems for transportation monitoring, processing the GLONASS/GPS tracking data, city traffic analysis systems, systems for monitoring the fuel residues at the gas stations and the petroleum-storage depots.

Despite the active use of conceptual modeling tools, based on UML, in the area of information systems development, the application of such tools in simulation modeling engineering is limited [9]. Among the advantages of the approach of conceptual and simulation modeling integration, we may name a capability of the rapid transition from the conceptual models to the engineering and application models (software implementation) [9]. Ontologies and knowledge representation models may be used for the transition from the conceptual to the simulation models. BPsim.DSS system uses in its bases the multi-agent resource conversion process model [10].

II. ANALYSIS OF THE EXISTING APPROACHES

We have analyzed three approaches and models of the multi-agent systems and business processes:

1. The multi-agent resource conversion process model [6, 10, 12];
2. The nets of requirements (RC-nets) by V. Wittich and P. Skobelev [11] that are used for development of the intelligent multi-agent systems in logistics;
3. The active and passive convertors (APC) model by I. Moskalyov and B. Klebanov [13].

The analysis results are presented in Table 1.

Two models meet the most requirements for the logistical model and support the corresponding problems: the multi-agent resource conversion process model and the RC-net. The software implementation of the RC-net in form of the Magenta technology was used for development of the multi-agent system for taxi management for the Addison Lee company (UK). The following results had been achieved in the first three months after deployment [14]:

1. Processed orders growth by 7% with the same fleet;
2. Lost orders decrease from 3.5% to 2%;
3. Empty run decrease by 22.5%;
4. Use of resources improvement: average growth of orders by two per car per week during the same time with the same fuel consumption.

The last two achievements are not only related to the economic effect, but also to the ecologic one. This generally supports the idea that the adequate planning leads to the more effective use of resources, decrease in empty runs and decrease in polluting emissions. This presents another evidence for the effectiveness of the development and use of the intelligent systems in logistics, in particular, based on multi-agent approach and simulation modeling.

TABLE I. ANALYSIS OF THE APPROACHES AND DYNAMIC SITUATION MODELS

Feature	MRCP	RC-net	APC
Various resource types	☑	☑	☑
Tracking timing data	☑	☑	☑
Collisions due to common resources and tools	☑	☑	☑
Discrete operations	☑	☑	☑
Complex resources (transacts), transact queue	☑	☑	☑
Analysis of situations and decision search	☑	☑	☐
Communications between agents	☑	☑	☐
Use of geo-data	☑	☑	☐
Building transportation routes	☑	☑	☐
Order distribution between transportation options	☑	☑	☐
Development of problem domain ontologies	☑	☑	☑
Subject otology for logistical problems	☑	☑	☐
Software engineering (using UML)	☑	☐	☐
Support for the distributed computational environments	☑	☑	☐
Simulation modeling	☑	☐	☑

Software implementation of the coalition model in the decision support suite BPsim

The decision support systems BPsim.MAS and BPsim.DSS [6, 10, 12] together form the software suite, implementing the coalition model of the multi-agent resource conversion processes.

Coalition may be defined in three different ways.

1. Using the object-oriented approach and defining a dynamic coalition class. The coalition forming method is triggered by the positive decision of the agents, participating in the coalition as a result of the message exchange between them.
2. Extending the agents knowledge base or their behavior models with the rules/actions for use/control/consumption of the common resources, tools, transacts and the internal conflict resolution system, specific to a given coalition.
3. Developing a coalition agent using the conventional features of BPsim.MAS. In this case the coalition agent must consider both the behavior models of the separate agents and the common rules for the distribution of resources, tools and transacts.

Communication between the different kinds of agents of the multi-agent resource conversion process is currently implemented in two ways.

1. Agents within the dynamic model of the multi-agent resource conversion process model may be reactive and hybrid, with the intelligent features. They exchange messages with the aid of the built-in dynamic message process, introduction of commands and command syntax for the active problem domain, together with the message processing rules in the models of the agents.
2. The message exchange between then dynamic model of the multi-agent RCP and the intelligent agents of the

frame-based expert system is performed via the message exchange buffer. It contains the common variables that are used in the modules of dynamic simulation system BPsim.MAS and business engineering system BPsim.DSS.

III. COALITION-BASED MULTI-AGENT RESOURCE CONVERSION PROCESS MODEL

The main concepts of the resource conversion processes (RCP) include the following.

A *resource*, is a quantitative measure of the capability of performing a certain activity. A resource is something that may be used and spent or the available duration of the machine operation.

A *transact* is a special class of the resources. A transact is a resource with a defined set of its attributes. It is the analog of the transact in the GPSS system. Transacts allow distinguishing of separate instances of the resources.

A resource conversion process is the continuous or discrete operation of converting the input, represented by the resource, required for process execution, into the output, or the products, the results of process operation. Conversion is performed with or without the aid of the tools.

The agents control the objects of the conversion process on the basis of the knowledge base. Agents correspond to the elements of the control system and the models of decision making people.

A coalition is a union of several agents into a community, with the aim of implementing the common goal. Agents that participate in the coalition isolate the resources and tools for the common use. Processes of forming and breaching the coalition lead to the structural and parametric changes of the resource conversion process model, as well as the changes in the behavior models and the knowledge bases of the agents. Forming and breaching the coalition takes certain time and is not done instantaneously. Coalition activities reflect the interaction of enterprise subjects that participate in the common process in the real world, that use common resources and focus on achieving one or several common goals.

The coalition model of the multi-agent resource conversion processes is based on the authors' hybrid model, built as a result of integration of the simulation, expert, situational and multi-agent modeling [10]. To implement the coalitions and communications, the multi-agent RCP model has been extended with several elements. They include the coalition (C), coalition knowledge base (KB_C), coalition goal (G_C), coalition activity model (D_K), agent lifecycle and the coalition lifecycle. The model received additional procedures for forming and breaching the coalitions, negotiating the decisions and holding of the auctions. The main objects of the coalitional model of the multi-agent resource conversion processes are presented on Figure 1, with additional objects, namely SPC, representing the coalition behavior scenario, SPA for the agent behavior scenario, U for the control command and Msg for the message.

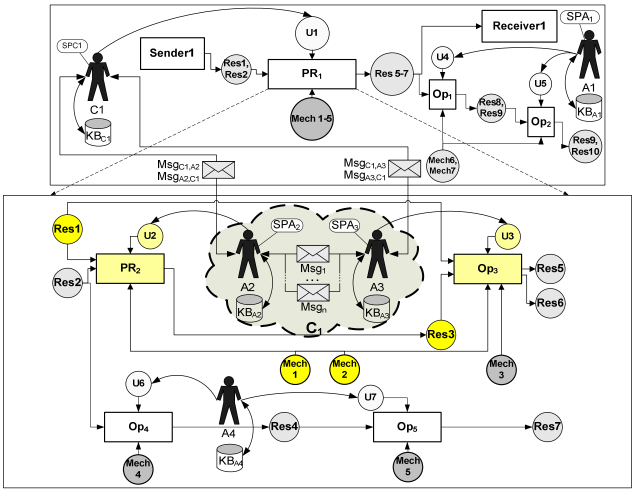

Fig. 1. Objects of the coalitional model of the multi-agent resource conversion processes

In the case of logistical problems forming and breaching the coalitions are equivalent to the matching procedures of Skobelev and Wittich's nets of the requirements and capabilities (the RC-nets) [11]. For the subject of supplies for the gas station network forming and breaching the coalitions include the following decision making processes.

1. Assigning a petroleum-storage depot for the gas station supply request,
2. Assigning a fuel tanker to the request,
3. Assigning the gas stations for the remaining sections of the fuel tanker to the same gas station or to the nearby stations.

If we turn back to Fig. 1, the agents A2 and A3 are both members of the coalition. They may be supervised by the coalition C1 itself. The multi-agent simulation model of the resource conversion process that supports forming and breaching the coalitions must allow several additional structural and parametric changes at the moments of forming/breaching the coalition. These include linking/unlinking agent's operations and processes; switching on/off separate model nodes and agent rules; separation/unification of resources and tools; modification of the state of resources, tools, transact; dynamic modification of operations and agent rules priorities for consumption/use of resources and tools. These changes must be supported during simulation experiment runtime.

Introduction of coalitions and communications into the multi-agent resource conversion process model extends the capabilities for modeling of the conflicts that emerge on the common resources and tools. The conflicts may be settled using communication (using message exchange or holding of the auctions) or coalitions (conflict settlement rules may be defined within the coalition agent). The processes, presented on Fig. 2 function within the coalition-based multi-agent resource conversion process model.

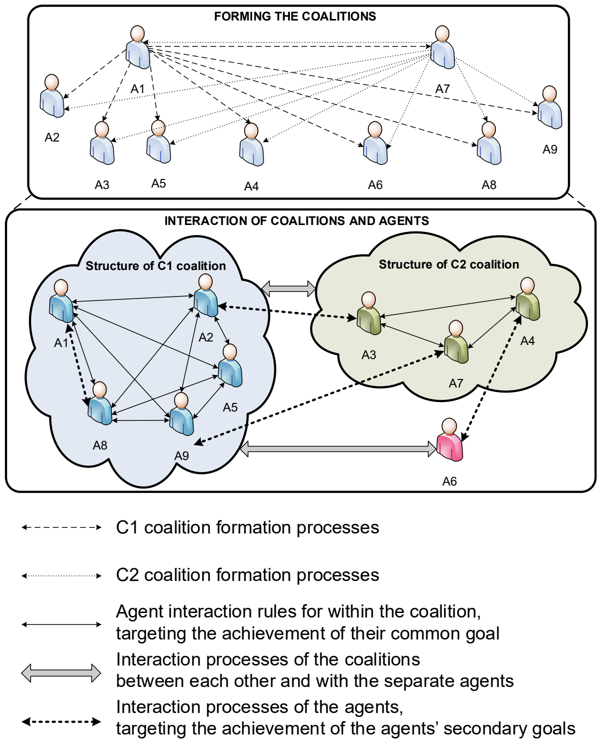

Fig. 2. Processes within the coalition model of the multi-agent RCP

The algorithm of modeling for the coalition model of the multi-agent resource conversion process consists of the following main stages: defining the current moment of time; diagnosis of arisen situations, generation of control commands, generation of conversion rules queue; execution of the conversion rules, modification of the work memory state, namely the resource and tool load data. The algorithm was extended by the two additional stages: forming/breaching the coalitions; structural and parametric modifications of the dynamic multi-agent RCP model.

IV. PRACTICAL IMPLEMENTATION OF THE MODEL

The operation of a network of the gas stations was simulated within the BPsim software. There are five gas stations in the network, a garage with three gas tankers and a bulk plant. All stations provide regular and premium gas, two of them also provide diesel. The tankers have two bays, 4600 liters each.

Initially the tankers are located at the garage. When a request for the fuel appears at one or several gas stations, the dispatchers assigns these requests to the tanker. When the tanker gets the first request assigned, it does not immediately head to the bulk plant, but awaits a second request for the predefined time, so that there is no half-empty run with no fuel in the second bay. Further the tanker heads to the bulk plant.

The bays get filled, after which the tankers heads to the assigned gas station. When the tanker arrives to the gas station, its operation is suspended for the duration of the fuel drain. When the tanker finishes processing all assigned transacts, it waits for the new requests at the last processed gas station for the specified time period. If those arise, the tanker heads to the bulk plant, if not – to the garage, where it is further waiting for the requests.

To compare the MRCP approach with the RC-nets we simulated the similar situations for the two models, and estimated the following parameters after execution of the two models.

1. Total simulation time;
2. Average tanker load;
3. Total number of tanker runs;
4. Total volume of the delivered fuel.

Two situations were simulated.

Experiment 1. Fuel requests arrive uniformly over the period of 3 days of gas station operation;

Experiment 2. Order requests arrive incrementally, like an avalanche, over the period of 3 days of gas station operation.

Experiment results are presented in Table 2.

TABLE II. EXPERIMENT RESULTS FOR THE MRCP AND THE RC-NET MODELS

Parameters / Experiments	Exp. 1, MRCP	Exp. 1, RC-net	Exp. 2, MRCP	Exp. 2, RC-net
Simulation time, min	30	99	41	147
Average tanker 1 load, %	62,78	63,96	63,04	48.79
Average tanker 2 load, %	56,41	30,36	51,92	37,94
Average tanker 3 load, %	31,02	25,38	38,72	37,22
Total number of runs	35	27	30	22
Total fuel volume, ltr	224.200	207.000	225.400	183.000

The experiments with the MRCP model take significantly less time for the equivalent model compared to the RC-net model. This is explained by the lower number of agent rules, required for request-to-tanker assignment, and the overall lower number of the agents within the MRCP model. Simulation time in many cases is the important criterion. With the increasing model complexity, the simulation time is growing geometrically, with the most important factor being the number of communication actions within a tick of modeling time.

Average tanker load is mostly similar over all simulation configurations. The RC-net model shows a lower number and respectively lower volume of supplied fuel (7.7 to 19% lower), rather than the MRCP model. The reason for this is the repeating re-scheduling with the goal to search for the more efficient delivery routes, from the point of view of the current tanker, and cancellation of the assigned requests in favor of the optimal. Thus, the communications and the matching procedure result in the negative effect of system nervousness. The practical application of the Magenta technology, implementing the RC-nets for taxi services and cargo transportation, showed that matching in real time negatively affect the drivers.

Finally, the design of the MRCP model requires significantly less time than the RC-net model.

V. CONCLUSION

The paper presented the stages of development of the coalition-based multi-agent resource conversion process model. We have defined the main concepts of the coalition model of the resource conversion process. We developed the algorithm of multi-agent modeling responding to forming and breaching the coalitions within the model and allowing structural and parametric modifications for the dynamic resource conversion process model. Finally, we presented the possible implementation of he applied multi-agent models with the coalitions in the BPsim software in the context of the gas station network supply problem.

ACKNOWLEDGMENT

The work was supported by Act 211 Government of the Russian Federation, contract № 02.A03.21.0006.

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