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Architecture of the multi-agent resource conversion processes extended with agent coalitions

Konstantin Aksyonov[a], Eugene Bykov[a], Olga Aksyonova[a],
Alena Nevolina[a], and Natalia Goncharova[a],*

[a]*Ural Federal University, Mira st. 19, Ekaterinburg, 620000, Russia*

Abstract

Pretty often there is a process visualization in one's mind before the process is implemented in form of a simulation model. The main purpose of this visualization is the certain improvement of an imperfect or ineffective process, or the estimation of the influence of various impacts. Most of the time the simulation systems provide a certain benefit for us, especially when the process develops in a predefined way, no matter how complex it is. But sometimes there are situations when the decision making persons have to interact between each other and make a decision with consideration of the other person's opinion. Moreover, that may have conflicts in case they use the same resources or they are focused on a common goal by using different approaches (and again, same resources). Anyway, this sort of behavior has to be modelled as well. In this work we are presenting the apparatus of the resource conversion processes for the distributed simulation system BPsim.MAS. We will present the advantages of the software, the technologies lying under the hood and some recent additions that were implemented for the definition of agent coalitions. This is something which helps us create the simulation models of the complex systems and behavior scenarios, when multiple agents interact with each other. At the end of the work we suggest a sample implementation of the system on the basis of a network of petrol stations, that relies on presented apparatus. We also compare our results with the ones achieved with the simulation model, based on the networks of requirements and capabilities.

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Keywords: Agent-directed simulation; agent interaction; coalition; resource conversion process

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* Corresponding author. Tel.: +7-905-801-2406; fax: +7-343-283-0219.
E-mail address: e.a.bykov@urfu.ru

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1. Main text

Nowadays we observe a constantly growing rate of competitiveness between the enterprises, especially in the markets that change fast. One of the most effective approaches to estimate the alternative options and to balance the risks is to make use of simulation modeling.

Mostly it is used in the two parts of the world, that utilize the state of the art technologies, namely in the USA and in Europe. Several applied systems find use of distributed simulation modeling as well. We can easily name some problem domains that will surely benefit from the distributed systems.

1. The logistical chains, which have a model for every enterprise, acting as a whole entity, for example, a chain from the Supplier to the Customer.
2. The production chain, where there are simulation models for the production departments, shops, divisions, and more.
3. Military planning and operation analysis.

When we turn to distributed simulation, we may find out that here the simulation models may be designed to achieve the two goals. One is detecting the problems of a particular entity, and two is the task, related to the full model of the logistical chain as a whole. In the first option an entity may be a company, or one of the enterprise's departments that participates in the supply chain. In the second option we have multiple activities, interacting with each other, and this is when we bring all distributed simulation engines into action. We have to keep in mind that these may be located randomly, thus there are technical challenges we have to face, including the problem of the time sync and the problem of the rapid data update and exchange. We need to make sure of the adequate maintenance of software at the endpoints of the simulation network and worry of the version control. Several standards have been developed to make sure these problems are addressed. The first is DIS [1], which is the standard for Distributed Interactive Simulation. Another one is HLA [2], standing for the High-level architecture. AnyLogic system [3] supports both these standards. Working with the distributed agent-based simulation system for supply chains is defined in [4].

Traditional simulation relies on the model being encapsulated within one application. Thus, when we are trying to simulate the activity of multiple companies, we encounter challenges in locating all within one standalone system. As the system complexity grows, the model starts wrapping more and more sub-models as the parts of the whole simulation process. A single change of one unit may lead to modifications of the whole system, bringing the consequences that will be too expensive to deal with. This is a threat for the adequacy of the model, because there are cases when we are unable to implement a change in the model, which is important for process behavior [4].

As stated by Jennings in [5], multiple functional operations between the supplier and the customer, constitute the business process. The tasks have to be defined according to a particular control model, which corresponds to the order graph.

Alternatively, when focusing on the development of the open simulation systems, we may start looking at the cloud simulation [6]. The Ural Federal University has partnered with the software development company iTeco in order to develop an information system for metallurgical production [7-8], with a goal to provide the major companies with a higher level of automation. Obtaining data is a major problem. In order to solve it we suggest using a data exchange module. It is implemented for the automated system for metallurgical production, further referenced as SMP, and is based on the principles of the enterprise bus. It can deliver information from the external information system and present it to all simulation models that are connected to it in real-time. The data exchange in the SMP is bi-directional. Thus, the simulation models of the system may be set up to control the activity in real-time and analyze the data, immediately available in the data exchange module.

Both standards, the distributed interactive simulation and the high-level architecture, as well as the SMP, all assume the simulation model to be the real-time control system. We may use the data storage with up-to-date and constantly live updated information from the other systems (external in our case). Use of SMP with BPsim allows to use the open systems in simulation. We may use the model-oriented approach. In such case we have the formal access to the business logic of the model. Thus we may modify it without touching the sources of the application. So, we separate the programming logic of the simulation system operation and the simulation logic of the model definition.

If we turn to the problem, which is presented at the end of this work, namely the fuel delivery problem for the network of petrol stations, we have to gain access to the geo-information systems, to provide monitoring of transportation. We also need to process the satellite data from the GPS trackers, traffic analysis systems, and petrol-specific systems, like those that monitor the remaining petrol at the petrol station tanks and petroleum storage depots.

Currently many conceptual modeling tools, based on the unified modeling language, are widely popular for the development of automated systems. Despite this, their application in the area of simulation modeling is limited [9]. One of the greatest benefits that we get from the integration of simulation modeling with conceptual modeling, is a quick transition from the conceptual model to the software implementation in form of the application model and the engineering model [9]. In order to achieve this transition, we use the knowledge representation models with the ontologies. The multi-agent resource conversion process model is the basis for the BPsim.DSS system [10].

2. Existing approaches analysis

The table further presents the comparison of the three models and their basic approaches to multi-agent simulation:

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

The analysis results are shown in Table 1.

The first two models meet the most requirements for the logistical model. They also support the corresponding problems. The networks of requirements and capabilities are implemented as the Magenta technology. It was used for the development of multi-agent system for the Addison Lee company in the United Kingdom for taxi service management operations. Only a few months after its deployment the system showed the following results [14]:

1. Number of orders has been increased by 7% using the same number of vehicles;
2. Almost a double decrease from 3.5% to 2% of the missed orders;
3. Empty vehicle runs decreased by almost a quarter (23%);
4. Improved use of resources: average weekly growth of orders by two per vehicle with the same amount of consumed petrol.

This generally supports the idea that the adequate planning results in the effective use of resources and the decrease in empty runs. This, intelligent systems in logistics, that are based on the multi-agent simulation modeling, are really effective and are worth developing.

Table 1. Analysis of different approaches and models for the simulation of dynamic situations

Feature	MRCP	RC-net	APC
Different types of resources	☑	☑	☑
Logging temporal data	☑	☑	☑
Conflicts due to the same resources and mechanisms	☑	☑	☑
Discrete processes and operations	☑	☑	☑
Complex resources (orders or transacts), queue of orders	☑	☑	☑
Situational analysis and decision search	☑	☑	☐
Agent communication	☑	☑	☐
Use of geolocation data	☑	☑	☐
Calculation of transportation routes	☑	☑	☐
Order distribution between multiple transportation options	☑	☑	☐
Development of ontologies for the subject area	☑	☑	☑
Subject otology for logistical problems	☑	☑	☐
Software engineering (using unified modeling language)	☑	☐	☐
Support for the distributed computational environments	☑	☑	☐
Support for simulation	☑	☐	☑

3. 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 are the parts of a bigger software suite. It implements the agent coalition model of the multi-agent resource conversion processes.

There are three different ways of defining a coalition.

1. Using the object-oriented approach and defining a dynamic coalition class. The coalition formation method is started by the positive decision of the agents, that take part in the coalition as a result of the message exchange between those.
2. Extending the knowledge base or their behavior models of the agents with the rules and actions for use, control and 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 traditional 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 by using the built-in dynamic message process, using the commands and command syntax for the active subject area, as well as the rules for the message processing in the agent models.
2. The message exchange between the model of the multi-agent resource conversion process and the intelligent agents of the frame-based expert system is performed through the message exchange buffer. It contains the common variables that are being written and read in the modules of the simulation system BPsim.MAS and business modeling system BPsim.DSS.

4. Coalition-based multi-agent resource conversion process model

The main concepts of the resource conversion processes include the following.

A *resource*, is a quantitative measure of the capability of engaging in some activity. A resource is a material entity that may be used and spent for the available duration of the mechanism activity.

An *order* or a *transact* is a more complex class of the resources. A transact is a resource with a set of attributes. It is the analog of the transact in the GPSS system. Transacts allow defferentiation of the separate instances of the resources.

A resource conversion process is the continuous or discrete operation of transforming the input, represented by the resource, which is necessary for process execution, into the output, or the products, representing the result of process operation. This operation may be processed with or without the help of the mechanisms.

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 individuals.

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.

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].

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.

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.

5. 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.

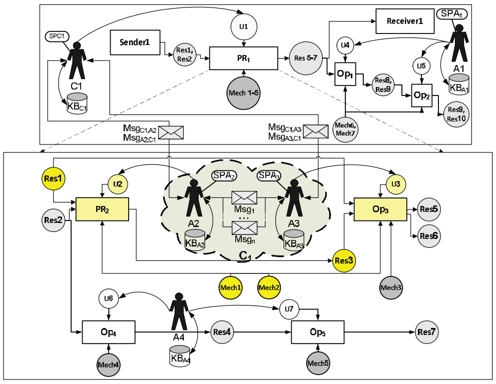

Fig. 1. Objects of the coalitional model of the multi-agent resource conversion processes

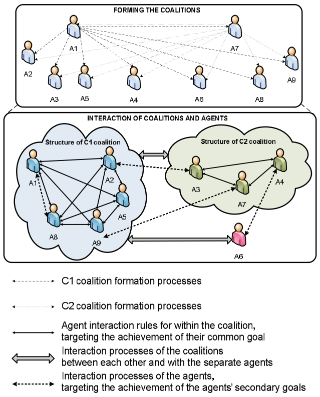

Fig. 2. Processes within the coalition model of the multi-agent RCP

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.

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.

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References

1. IEEE Std. 1996. "IEEE Standard for Distributed Interactive Simulation - Communication Services and Profiles." IEEE Std 1278.2-1995. doi:10.1109/IEEESTD.1996.80824.
2. IEEE Std. 2000. "IEEE Standard for Modeling and Simulation (M Amp;S) High Level Architecture (HLA) - Framework and Rules." IEEE Std 1516-2000. doi:10.1109/IEEESTD.2000.92296.
3. http://www.xjtek.ru/ - AnyLogic software official website
4. Carlos Braganca de Oliveira, Antonio Carvalho Brito. A business language for a distributed simulation framework // P.220-226.
5. Jennings N.R., Faratin P., Norman T.J., O'Brein P., Odgers B., Alty J.L. 2000. "Implementing a business process management system using ADEPT: A real-world case study." Applied Artificial Intelligence 14 (5) (June): 421-463. doi:10.1080/088395100403379.
6. Aksyonov K.A., Bykov E.A., Kamelsky V.D., Aksyonova O.P. Analysis of Business Process Dynamic Models for Development of Simulation Modeling Service // Proceedings of ESM'2012 (ESM - European Simulation and Modelling Conference) October 22-24, 2012, FOM University of Applied Sciences, Essen, Germany. P.227-230.
7. Aksyonov K., Bykov E., Aksyonova O. Real time simulation models integrated into the corporate information systems // 33rd Chinese Control Conference, CCC 2014; Nanjing; China; 28 July 2014 through 30 July 2014, Pages 6810-6813.
8. Aksyonov K., Bykov E., Aksyonova O., Goncharova N., Nevolina A. Simulation of the Real-time Simulation Systems and its Integration with the Automated Control System of an Enterprise // 2015 IEEE International Symposium on Robotics and Intelligent Sensors (IEEE IRIS2015) 18-20 October 2015 Berjaya Langkawi Resort, Malaysia pp. 241-246.
9. Giancarlo Guizzardi, Gerd Wagner Tutorial: Conceptual simulation modeling with Onto-UML [Text] // Proceedings of the 2012 Winter Simulation Conference, (WSC 2012), December 9-12, 2012, Berlin, Germany.
10. K. A. Aksyonov, E.A. Bykov, E.F. Smoliy, A.A. Khrenov Industrial Enterprises Business Processes Simulation with BPsim.MAS // Proceedings of the 2008 Winter Simulation Conference (WSC 2008), December 07-10, 2008, Miami, USA, Pages 1669- 1677.
11. V. A. Wittich, P. O. Skobelev, “Multi-agent interaction models for the design of the nets of requirements and capabilities in open systems”, Automatics and telemechanics, vol. 1, 2003. pp. 177-185.
12. K. Aksyonov, E. Bykov, E. Smoliy, E. Sufrygina, O. Aksyonova and Wang Kai Development and Application of Decision Support System BPsim.DSS // Proceedings of the IEEE 2010 Chinese Control and Decision Conference (CCDC 2010), 26-28 May 2010, Xuzhou, China, Pages 1207-1212.
13. I. M. Moskalyov, System for analysis and optimization of the resource conversion processes, PhD thesis work: 05.13.01, Ekaterinburg, 2006.
14. Skobelev P. O. Multi-agent technologies for the control of resources in real-time. Proceedings of the seminar “Mechanics, control and informatics”, track “Perspective computer systems: devices, methods and concepts”, Tarusa, 2-4 March 2011. http://www.iki.rssi.ru/seminar/2011030204/presentation/20110303_03.pdf (accessed: 14.09.2016).