A methodological framework for the analysis of agent-based supply chain planning simulations

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Abstract

Agent-based simulation is considered a promising approach for supply chain (SC) planning, configuration and design. Although there have been many important advances on how to specify, design, and implement agent-based simulation, the concerned literature does not properly addresses the analysis phase. In this early phase, SC stakeholders decide what kind of simulation experiments should be performed and their requirements, which considerably influence the whole development process and the resulting simulation environment. This work proposes an agent-based simulation framework for modeling SC systems in the analysis phase. In addition, it proposes a formal method for converting the analysis model into specification and design models. The proposed framework is being validated by means of an agent-based simulation platform developed in the context of the lumber industry.

1. INTRODUCTION

Supply chain management can be seen as a business approach based on integration, synchronization and cooperation to improve shareholder and customer value by optimizing the flow of products, services and related information from early source of raw material to the final customer. In this context, SC planning (SCP) activities are very important, since they aim to balance supply and demand, from supplier to customer, in order to deliver high margin goods and services through the optimization of the SC assets.

Recent advances in SC management appeared in the area of agent-technology. This technology is able to capture the distributed nature of the SC entities (e.g., customers, manufacturers, logistic operators etc.) to mimic their business behaviours (e.g., making advanced production decisions and negotiating with other supply chain members) and to support the collaborative planning process of the SC entities. Because of these abilities, among several others described in the literature [6], agent-based SC systems have great potential for simulating complex and realistic scenarios.

Although several attempts have been made to take advantage of agent technology to specify, design and implement SC simulation tools, the related literature does not address the analysis phase in details [9]. The analysis is the first development phase, where functionalities of the system and non-functional constraints have to be described [5]. This phase is of crucial relevance because it helps defining the requirements of the simulation experiments the system has to perform. These phases are explained in more details in section 3.

This works aims at proposing a methodological framework for the analysis phase of developing agent-based SCP simulations. SCP is seen here as decisions functions from strategic to operational time frames. Besides, this work provides an approach to covert the analysis model into specification and design models. The proposed methodological framework is being validated by the FORAC research consortium. In order to do so, we are implementing the proposed framework in a multi-agent based simulation environment developed for the forest products industry. A case study in the lumber industry is used for validation purposes.

The paper is organized into the following sections: section 2 provides a literature review and explains in more details what is the research gap approached here. Next, section 3 presents the proposed methodological framework. Section 4 discussed how this framework is currently being validated. Finally, section 4 states some final remarks.

2. LITERATURE REVIEW

In the field of agent-based SC simulation, two types of modeling approaches can be identified in the literature. The first type proposes generic approaches for modeling agent-based SC systems in general terms, while the second type proposes modeling framework that specifically takes into consideration the use of optimization procedures or finite capacity planning models when performing supply chain planning. This second type of modeling approach provides more realistic models of SC, especially when Advanced

Planning and Scheduling systems ([11]) are used to support planning decisions.

In the first type of approach, examples of relevant contribution include Labarthe et al. [6], van der Zee, and van der Vorst [13], MaMA-S [37]. For example, one of the most recent and complete work in the domain is Labarthe et al. [6]. They propose an approach for modeling customer-centric supply chain in the context of mass customization. They define a conceptual model for supply chain modeling and show how the multi-agent system can be implemented using predefined agent platforms.

In terms of the group that explicitly takes into consideration optimization approaches, some important examples are Egri et al. [2], Lendermann & McGinnis [7] and Swaminathan et al. [12]. For example, one of the most recent approaches is Egri et al. [2], which is Gaia-based approach for modeling advanced distributed supply chain planning for mass customization. They develop a model for representing roles and interactions of agents based on SCOR model.

These simulation and modeling approaches have greatly contributed to the domain. Although these advances, one relevant gap in this field is related to the initial developing step of such simulation systems, the analysis phase. Most of the researched works in the literature suggests some approaches for the specification and design, and some for implementation. But the analysis phase is not explicitly treated. Most of the works suppose that the analysis phase provides the necessary information and concentrate their discussions in further phases, mainly specification and design.

Thus, this paper aims to contribute to this area by proposing a methodological framework for the analysis phase of agent-based SCP simulations.

3. METHODOLOGICAL FRAMEWORK

In order to explain the methodological framework, we provide in Figure 1 a schema that position our research.

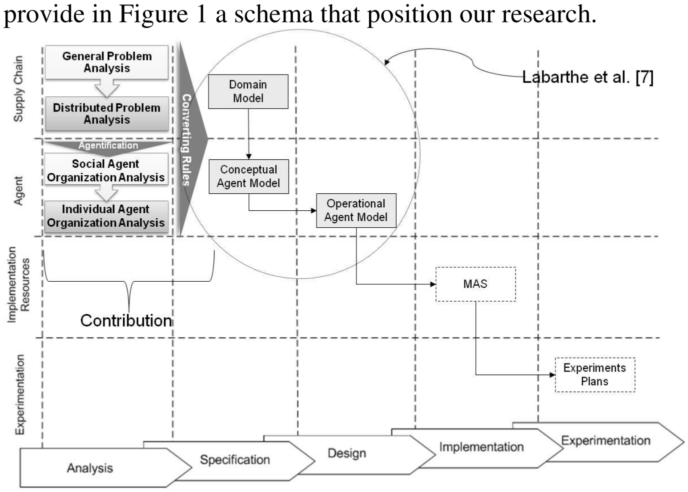

Figure 1. Overview of the methodological framework.

Figure 1 presents a meta-model of the framework where different concepts are organized in a logical way. It is organized according to two logical views [9]: the modeling organization view and the methodological phases view.

The modeling organization view consists of four aspects: i) supply chain: which basically refers to the SC problem; ii) agent: the supply chain domain problem is translated into an agent-based view; iii) implementation resources: it refers to a specific model to define how an agent system can be supported by computing resources (as software languages, toolkits and integrating infrastructure); iv) experimentation: refers to the practical utilization of the simulation environment, i.e., the design of experiments.

The methodological phases view comprehends: i) analysis: an abstract description of the modeled system containing the simulation requirements; ii) specification: the translation of the information derived from the analysis into a formal model; iii) design: definition of a structural organisation of agents, i.e., a data processing model; iv) implementation: translation of the model resulting from the design to a specific software platform; and v) experimentation: when users creates a set of experimental plans. This aspect is based on Galland et al. [5].

This work proposes four modeling approaches for the analysis phase, as one can see in Figure 1. Between the SC system level and the agent level, it is also proposed the agentification method for translating the SC requirements into some distributed agent-based requirements. Finally, some converting rules for translating the analysis model to specification and design models of Labarthe et al. [6] are proposed, i.e., the domain model, conceptual agent model (for specification) and operational agent model (for design). Our proposed modeling approaches are discussed next. The computing and experimentation systems are beyond the scope of this work. However, the proposal of Labarthe et al. [6] was included in the framework in order to provide to the reader a full methodology.

3.1. Analysis Modeling

The following paragraphs explain what are the modeling methods suggested:

- ***General Problem Analysis (GPA)***: based on Santa-Eulalia et al. [9], this step proposes that the simulation analysis have to take into consideration the following aspects: the simulation objective and scope, the object to be studied, its related environment and simulation hypothesis, the virtualization[1] approaches to be used, which SC sub-systems will be simulated, where are the object and environment in the SC sub-systems and anticipation approach to be employed. These elements refer to the general definition of the simulation problem one desire to study and will guide the whole development process. For

[1] In some situations, an element of the simulation can be part of the real system and others can be virtualized. The reader is referred to [9] for more details.

further details about these elements, the reader is referred to Santa-Eulalia et al. [9].

- ***Distributed Problem Analysis (DPA)***: using the main requirements identified during the previous phase, this phase analyzes how the simulation problems can be distributed into several modeling units that will be referred to as agent later on. The DPA is divided into two views, the static and the dynamic views. The static view is basically related to the system structure, i.e., what are the desired SC entities and what are their respective roles. These entities are related to the loosely coupled decision domains of the supply chain. We propose a modeling method where these entities can be created based on a three dimensional approach according to their business mission: (i) the interpemporal aspect (decision level at strategic, tactic, operational and execution levels), (ii) the functional aspect (functions based on procurement, manufacturing, distribution and sales) and (iii) the spatial aspect (based on the SC echelons, i.e., vendors, facilities, clients and consumers). These three dimensional model allows us to capture and differentiate between the various decision domains that together carry out the whole supply chain management function. These entities are then analyzed in terms of the dynamics of their environment. So, the dynamic view then discusses what can change in the system (i.e., the uncertainties) and what are the consequences of these changes in the studied object (which was obtained in the GPA). This dyad is then linked to the simulation hypotheses and the related key performance indicators.

- ***Agentification***: the distributed entities of the DPA are the basis of the agents' creation process. Generally speaking, each entity can be converted into an agent. But, other situations can arise. For example, SC entities can be modeled as a single agent or several agents depending on criteria, such as the specialization of the agents, the efficiency of the system, or the implementation requirements. Besides, additional agents can be created to support the whole distributed planning process, as mediators, brokers and other supporting agents. Thus, a discussion on the agentification process is necessary at this level. One can use pre-specified rules or logic to create agents. For example, Bussmann et al. [1] provide some standard rules for clustering decision units and creating agents. Alternatively, one can use an ad hoc approach, which is probably the most common way of creating agents. In our framework we do not provide formal rules, instead we suggest some guidelines for performing the agentification process. Based on this analysis step, a list of agents is provided.

- ***Social Agent Organization Analysis (SAOA)***: having decided what are the main agents of the SCP system, one can add human capabilities to the agents identified. An agent can be simple and reactive, or can be complex and intelligent. One of this human ability concerns its social behaviour. It is relevant in the SC domain, as discussed before. At the SAOA stage, one have to decide what are the general agent organization and what are the possible agent connections. The former stands for the general system architecture, which defines the pattern of relationship between the agents. For example, Shen et al. [10] affirm that agents organization can take several forms from full control to full collaboration architectures. In between, we can find several intermediary architectures, as hierarchical, federated or autonomous ones. Based on the general agent organization, one can after define the possible agents' interactions, characterizing the communication and the interactions protocols. Theses protocols are of fundamental importance, since the behaviour and the performance of the distributed SCP system depends highly on the coordination, cooperation and negotiation mechanisms. Here, one can use an ad hoc method to define agents' connections. Alternatively, one can first define agents' dependencies and match them against some standardized library, as for example a FIPA-IPL (Interaction Protocol Library) and customize it.

- Individual Agent Organization Analysis (IAOA): complementarily to the SAOA, this step also adds human capabilities to the agents identified before. In the IAOA internal agents behaviours are identified, i.e., the agents' internal architecture. Based on the [8] idea, we suggest that three elements are important here: local knowledge, local planning and local behaviour. The local knowledge refers to all information possessed by agents to perform their activities. The local planning capability stands for the planning optimization abilities of each agent, i.e., each agent can encapsulate one or more planning tools and use then in different situations. These planning tools are central in SCP systems. Finally, the local behaviour refers to how one agent can react to a certain stimuli from the environment [3]. For example, when a new order arrives, an agent can simply provide its available-to-promise information or start a complete planning process.

- ***Converting Rules***: the four analysis methods are the basis for the specification phase. If a standard specification method is to be used, the analysts have to think how to convert the analysis models into the specification models in question. In out framework we propose some converting rules to the Labarthe's approach [6], which we consider relevant for this domain. We translate them do the three models, i.e., the domain model, the conceptual agent model and the operational agent model (Figure 1).

Next sub-section explains how our modeling approaches are articulated during the requirement analysis.

3.2. Results of the analysis phase

During requirement analysis two activities are jointly performed, the requirement determination and the requirement structuring. The modeling approaches discussed in the last sub-section first guides the requirements determination. This activity identifies what are the main requirements of the SC and agent levels. As a result, a list of requirements is produced. As the requirements list can be quite complex, the requirement structuring then organizes all requirements in a set of use case-based diagrams and tables.

4. VALIDATION

Our framework is being validated using two methodological techniques [14]: a proof-of-concept approach and a validation with analysts.

In the first case, we demonstrate the usefulness of our framework by employing it in a real situation. We are currently instantiating it in the lumber industry and implementing the resulting models in a multi-agent based simulation platform. In order to do so, we developed a case study inspired by real data obtained from our industrial partners. Based on this case study, we modeled a set of simulation experiments based on our framework and translated them to specification and design models. The experiments are then being implemented in the platform. As a result, one can evaluate if the framework contribute in creating an agent-based SC simulation.

Future work will aim to validate the framework with analysts. We intend to run a case study with two groups of SC analysts. The first group will know the proposed framework, while the second group will not know it. We will ask both groups to model a set of simulation experiments for the case study. The first group will employ the framework and the second uses an ad hoc approach. Next, the results of both groups will be compared and specific aspects related to the perceived ease-of-use will be measured.

5. FINAL REMARKS

The proposed methodological framework is an innovation in the domain since most of the previous works suppose that the analysis phase provides the necessary information and concentrate their discussions in more advanced phases, mostly on specification and design. We believe that the framework can support SC analysts to streamline the development process, since it provides a solid base for further phases in the development process.

We are now finishing the first validation step and will soon start the second one. By using these two validation methods, we believe that, based on the technology acceptance theory, we will be able to evaluate the perceived usefulness and the perceived ease-of-use and also identify some improving points for the proposed framework.

References

[1] Bussmann, S., Jennings, N.R. and Wooldridge, M., 2004, "*Multiagent Systems for Manufacturing Control: A Design Methodology*", Springer, Berlin.

[2] Egri, P. and Vancza, J., 2005, "Cooperative Planning in the Supply Network – A Multiagent Organization Model", In Proceedings of CEEMAS 2005, pp. 346–356, 2005.

[3] Forget, P., D'Amours, S. and Frayret, J.-M., 2007, "Multi-Behavior Agent Model for Planning in Supply Chains: An Application to the Lumber Industry", Robotics and Computer-Integrated Manufacturing Journal.

[4] Frayret, J.-M., S. D'Amours, Rousseau, A. and Harvey, S., 2005, "Agent-based Supply Chain Planning in the forest products industry", Working Paper DT-2005-JMF-1, CIRRELT, Laval University, 2005. Available at URL www.cirrelt.ca, last visit on November 2007.

[5] Galland, S., Grimaud, F., Beaune, P. and Campagne, J.P., 2003, "MAMA-S: An introduction to a methodological approach for the simulation of distributed industrial systems", International Journal of Production Economics, No. 85: 11–31.

[6] Labarthe, O, Espinasse, B., Ferrarini, A., Montreuil, B., 2007, "Toward a methodological framework for agent-based modelling and simulation of supply chain in a mass customization context", Simulation Modelling Practice and Theory, 15, Issue 2: 113-136.

[7] Lendermann, P., and McGinnis, L.F., 2001, "Distributed simulation with incorporated APS procedures for high-fidelity supply chain optimization", in Proceedings of the 33nd Winter Simulation Conference, (December 09-12), Arlington, VI,.

[8] Parunak, H.V.D., 1998, "Practical and industrial applications of agent-based systems", *Industrial Technology Institute*, available at URL: http://agents.umbc.edu/.

[9] Santa-Eulalia, L.A.; D'Amours, S.; and Frayret, J.-M., 2007, "Essay on conceptual modeling, analysis and illustration of agent-based simulations for distributed supply chain planning", INFOR Information Systems and Operations Research Journal, Special Issue on Supply Chain Operations Analysis, Canada (submitted).

[10] Shen, W., Norrie, D.H. and Barthes, J.-P.A., 2001, "*Multi-agent system for concurrent intelligent design and manufacturing*", Taylor & Francis, London.

[11] Stadtler, H. and Kilger, C., 2004, "*Supply chain management and advanced planning: concepts, models, software and case studies*", Third Edition, Springer, Berlin.

[12] Swaminathan, J.M., Smith, S.F. and Sadeh, N.M., 1998, "Modeling supply chain dynamics: A multiagent approach", Decision Sciences, 29, No.3, 607-632.

[13] van der Zee, D.J. and van der Vorst J.G.A.J., 2005, "A Modeling Framework for Supply Chain Simulation: Opportunities for Improved Decision Making", Decision Sciences, February: 36, no.1: 65-95.
[14] Zelkowitz, M., Wallace, D.R, and Binkey, D.W., 2003, "Experimental validation of new software technology, in *Software engineering empirical validation*, Natalia Juristo and Ana Moreno eds., Molex.

Biography

Luis Antonio de Santa-Eulalia is currently a Ph.D. candidate in Industrial Engineering at the FOR@C Research Consortium, Université Laval, Canada and is a member of the CIRRELT as a doctoral student. He received his MSc. and BSc. in Industrial Engineering respectively from University of São Paulo and Federal University of São Carlos, both in Brazil. He has worked as a researcher and consultant in domains of information systems and business process reengineering for logistics. His current research interests are in the area of agent-based simulation and supply chain management.

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