

# AGENT-BASED SIMULATION APPLICATION IN OPERATIONS MANAGEMENT

**Nelson Sakurada (POLI - USP)**

nsakurada@uol.com.br

**Dario Ikuo Miyake (POLI - USP)**

dariomiy@usp.br



*This work analyzes articles on the application of agent based simulation that have more recently arisen in the study of Operations Management. An exploratory study was conducted based on a literature review. In addition to this, this work delineates some theoretical gaps related to methodological aspects that should be worked out in order to facilitate the effective exploitation of the potential of agents in Operations Management. The cases were examined so as to develop a general understanding of the structure, elements and relations that comprise the operations system taken as subject model.*

*Palavras-chaves: Agent, Simulation, Modeling, Operations Management*

## 1. Introduction

The potential of agents usage has been increasingly explored in many knowledge areas (MACAL & NORTH, 2007). The application of simulation based on agents' properties is also highlighted as a promising tool to support complex system decision, where entities play a more significant role in the overall system.

Due to the rapid development of the technologies that support the application of the concept of agents in modeling and simulation, the volume of studies that exploit them has increased strikingly. A search using the keywords Agent, Operations Management, Simulation, and Modeling, within the Elsevier's Science Direct content, retrieved more than 400 publications published since 2000 to date (March 2010) in relevant related scientific journals, such as European Journal of Operational Research, International Journal of Production Economics, and Decision Support Systems. As exhibited in Figure, 1 there is an exponential increase of works related to the considered subjects. It is noteworthy that in the retrieved sample, the number of already published and indexed articles in the first quarter of 2010 equals the volume of articles counted in 2008.

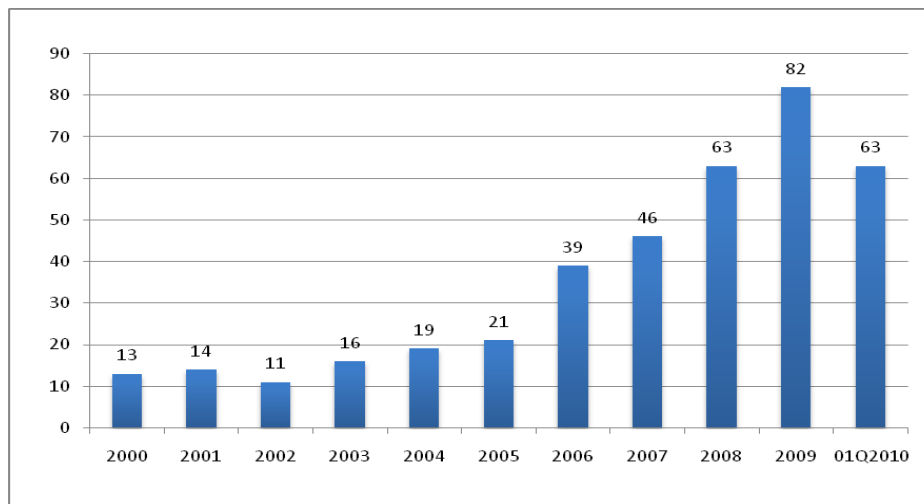


Figure 1. Number of publications related to the application of the concept of agents in OM

This work analyzes articles on the application of agent based simulation (ABS) that have more recently arisen in the study of Operations Management (OM) issues. In its earlier stage of development, the approach of considering the concept of agents in building simulation models has found broader adoption in areas such as computer networks/systems, agriculture/ecosystems/environment/ecological modeling, biology, system automation, social systems and life sciences. The increasing interest by this approach in OM research community is thus a quite recent phenomenon. This work is an explorative study that considers this trend aiming at to identify the most relevant issues discussed in the initiatives either to apply or to promote ABS in the OM area.

## 2. Research Methodology

This work is an exploratory study based on a literature review that covered publications about application of ABS within peer-reviewed literature in recent years. In addition to this, this work aims at to delineate some theoretical gaps related to methodological aspects that should be worked out in order to facilitate the effective exploitation of the potential of ABS in OM area as most of researchers in this area are not familiar with this new paradigm for modeling and simulation of operations systems.

Hence for the purpose of this study, the initial sample of articles retrieved from the more general search was further filtered and a more focused sample of 17 articles related to the application of ABS in OM was identified. The cases of ABS application described and discussed in these articles were then examined so as to develop a general understanding of the structure, elements and relations that comprise the operations system taken as subject model. An important point considered in this investigation was the manner how agents were defined and used to represent actual elements in the operations system under analysis.

The development of this study is divided in two parts. Initially it organizes an overview of emerging ABS applications in OM, through an analysis of the sampled articles considering five dimensions which characterize the nature and reasons for the application of the Agent approach as well as the manner how this was implemented. The set of dimensions considered are given below:

- a) **Application Area:** characterizes the nature and scope of the investigation (e.g. a department, a sector, an entire supply chain)
- b) **Problem/Objective:** delineates the nature of the problem that motivated the study and the main objective addressed by means of the agent approach
- c) **Metrics monitored:** indicate the nature of the managerial interest in the study and the underlying evaluation and control criteria
- d) **Reason(s) to apply Agent approach:** justify the adoption of Agent approach
- e) **Entities Representation:** which elements in the actual system were selected to be modeled as agents

Though simulation approaches such as discrete event and system dynamics have already a long tradition of application in OM, the diffusion of ABS is still in an early stage in this area. Thus, modeling strategies or methods that are best fit to ensure effective exploitation of ABS in OM area should be carefully sought. To contribute in this direction, in the second part of the study, the sampled articles are further investigated with a focus on the model building process undertaken.

### 3. Literature Review: Agent based simulation

The Agent definition is not a consensus among researchers depending on the field of application. In this study, an agent is defined as an entity in the system that demonstrate proactive and reactive behavior, which interact and communicate with the environment and other agents within the system simulated. It has goals and objectives as well as abilities to adapt and to learn through its experiences (MACAL & NORTH, 2005; SAMUELSON & MACAL, 2006; ZHANG & ZHANG, 2007). An agent can be defined as a theoretical, virtual or physical entity capable to act on itself and on the environment in which it evolves. The behavior of an agent is the consequence of its observations, knowledge and interactions with other agents.

Agents can be characterized by their characteristic functional properties. Wooldridge and Jennings (1995) point out the following set of properties that distinguish an agent:

- a) **Autonomy:** an agent operates without human being or other direct intervention, and neither the actions it realizes nor its internal state are submitted to any control.
- b) **Reactivity:** an agent perceives its environment and reacts in an appropriate way to environmental changes.
- c) **Pro-activity:** an agent is able to show behaviors directed by internal goals, taking initiatives.
- d) **Sociability:** agents interact with each other using communication languages and common sociability rules.

Swain (2007) surveyed the simulation literature and pointed that real systems like military and industrial operations rarely operate in a homogeneous way, but rather in a more unpredictable form due to the improvisation among interacting players. Even entities that represent workers typically operate by rules that are not similar to those of the machines. For instance, in a typical manufacturing simulation, products may be pushed through the system using a schedule of orders to be processed. Few models represent workers with meaningful autonomy to make decisions, to learn from their environment or to cooperate with each other when problems arise.

#### 4. Operations Management and Agent application

A diversity of studies or projects that rely on the application of modeling techniques and software tools based on traditional simulation approaches have been developed in the OM area by professionals and academics. The selection and application of a specific category of simulation method and associated programming tool is a planning decision that must be taken rationally taking into account the characteristics of the operations systems under analysis and the functionalities that required in this study or project. Depending on factors like the complexity of the subject system and the nature of the results sought, the adoption of a conventional approach like discrete event simulation may suffice. For instance, this may occur in the modeling of simpler systems conceived under a reductionist or mechanistic perspective upon which a low complexity configuration is deliberately pursued.

This brings to point the need to clarify the reasons that justify the adoption of the concept of Agents for the purpose of modeling and simulating operations systems in manufacturing, service and transportation organizations. Marik & McFarlane (2005) recommend the usage of agent properties in OM situations when some specific aspects of the operations system under study must be considered, such as:

- Real-time manufacturing operations
- Physically highly distributed systems
- Transportation and material handling
- Frequently disrupted operations
- Organizations with conflicting goals
- Frequently reconfigured and automated environments

Each of these aspects involves complex programming issues that are quite difficult to deal with in detail by means of software language and tools more commonly used in the

context of OM studies. The simultaneous consideration of multiple aspects similar to these would involve an even more challenging model building and programming process, thus is often seen as a daunting subject.

### 5. An analysis of Agent approach application in OM studies

This section presents an analysis of the modeling strategy undertaken in each case comprised by the sample of 17 articles examined in this study which were considered under the perspective of the dimensions enumerated in Section 2 that guided the investigation of ‘How’ and ‘Why’ the ABS approach was chosen and implemented. Table 1 summarizes the main aspects and elements that describe the manner the Agent approach was applied in each article. The contents observed in these articles support some of the characteristics mentioned by Marik & McFarlane (2005).

Authors	Year	Journal	Application Area	Objectives	Metrics	Why agents?	Agent representation
Labarthe et al.	2007	Simulation Modelling Practice and Theory	Supply Chain	- Mass customization impacts - Modeling methodology	- Demand modeling accuracy	- Distributed nature of Supply Chain - Interactions between systems elements - Autonomy and responsibilities - Dynamic environment	- Distributor - Suppliers - Manufacturers - Activities - Customers - Support agents
Wang & Tadisina	2007	Decision Support Systems	Supply Chain	- Scenarios comparison using different IT systems - Lead time impact - Costs impact	- Project lead time - Cost reduction	- Autonomous projects - Rules, decision and judgement of system components	- Customer - Project team - Engineering dept - Accounting dept - Manufacture dept - Communication agent - Transport agent
Pan et al.	2009	Expert Systems with Applications	Supply Chain	- Replenishment point evaluation in order to minimize inventory costs	- Total Supply Chain costs	- Agent supports decision making process when facing unpredictable environment changes	- Vendor - Supplier - Planner - Transport - Inventory manager - Forwarding agent
Turowski	2002	Int. J. Production Economics	Supply Chain	- Scenarios comparison using different IT systems	- Total costs	- Agents support inter organizational communication - Negotiation and communication required	- Manager - Information converter - Negotiator
Mele et al.	2007	Computers and Chemical Engineering	Supply Chain	- Supply chain evaluation considering demand uncertainty	- Manufacturing costs - Transportation costs - Warehouse costs - Sales	- Decentralized Supply Chain - Cooperation and tasks division between elements within the system	- External customer - Manufacturing sites - External supplier - Sub agent - Transport - Procurement - Production
Wang et al.	2008	Engineering Applications of Artificial Intelligence	Manufacturing	- Line sequence evaluation	- Tasks delay	- Decentralized and dynamic sequence - Work cells with autonomy to negotiate activities	- SOA (System Optimal Agent) - CCA (Cell Coordinated Agent)
Lara	2003	European Simulation Multiconference ESM'2003	Evacuation / People flow	- People flow and safety level evaluation	- Evacuation time	- Sensor usage to allow people orientation	- Runner

**Table 1: Overview of articles on the application of the concept of agents in the simulation of operations systems (cont.)**

Authors	Year	Journal	Application Area	Objectives	Metrics	Why agents?	Agent representation
Guizzardi et al.	2002	Simpósio Brasileiro de Informática na Educação – SBIE	Learning Systems	- P2P system evaluation to support collaborative learning	- System efficiency/adherence	- There is not a central server to manage the system	- Student - Professor - SIG member - SIG assistant - Facilitator - Manager - Server
Azevedo et al.	2004	Journal of Computer Science & Technology	Learning Systems	- Improvement of learning support system	- System efficiency/adherence	- Process complexity - Assynchronous computation - Distributed information	- Portfolio agent - Librarian - Support agent - Appraiser - Negotiator - Counter
Shibghatullah et al.	2006	Winter Simulation Conference	Service Systems	- Line sequence interruption modeling	- Operational costs - Operations lead time	- Different rules for each element - Unpredictable events	- User - Supervisor - Staff - Manager
Hao & Shen	2007	Robotics and Computer-Integrated Manufacturing	Manufacturing	- Kanban system simulation	- Waiting time - Process time - Equipment occupancy	- System adaptability due to the dynamic environment - Negotiation model between transport and programmer	- Kanban planner - Transport vehicle
Siebers et al.	2007	Winter Simulation Conference	Service Systems	- Management scenarios impact on service productivity	- Employee utilization - Average process time - Customer satisfaction level	- Human behavior characteristics - Customer and Staff interaction	- Customer - Staff - Manager
Macal & North	2007	Winter Simulation Conference	Service Systems	- Evaluation of customer flow dynamics within a department store	- Average itens found by customer - Queue average time - Return index - Customer satisfaction level	- Customer interaction (customer + customer and customer + staff) - Memory to register past experiences	- Customer
Anosike & Zhang	2006	Int. J. Production Economics	Manufacturing	- Cost reduction based on the linkage of Planning and Manufacturing reconfiguration	- Operational costs - Number of possible systems configurations	- Dynamic environment - Line reconfiguration decision process	- Planner - Manager - Tasks facilitator - Resources

**Table 1: Overview of articles on the application of the concept of agents in the simulation of operations systems**

The application case presented by each article was examined under the dimensions considered and classified into some major categories and the frequencies of cases classified in these categories were computed. For example, concerning the metrics used, it was observed how frequently the articles adopted variables like ‘Cost’ and ‘Time’ to monitor and evaluate the model performance. The figures found are discussed in the following.

As shown in Figure 2 the application area of the selected articles is highly diversified. Roughly, half of the considered articles are concentrated in Supply Chain and Service Systems. This observation corroborates that one of the main reasons that motivates the selection of the Agent approach during the modeling process: the distributed and autonomous nature of these systems, which are not tightly ruled by a central command, but rather by independent entities oriented to specific goals.



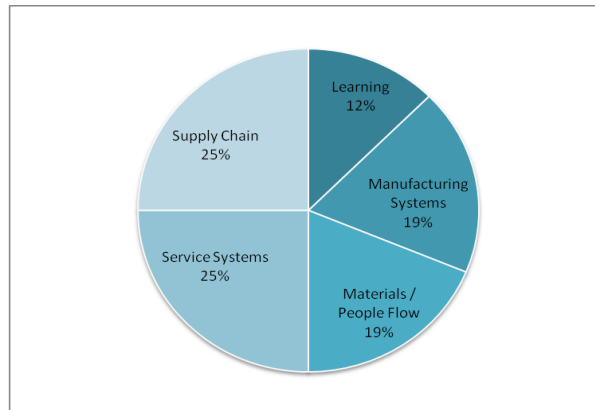


Figure 2. Distribution of articles by application area

With regard to the nature of the objective sought in these articles, as Figure 3 exhibits, the most common metrics that were monitored in the simulation studies were Costs, Lead Time and Utilization (related to resources efficiency), which are typical metrics evaluated in OM problems.

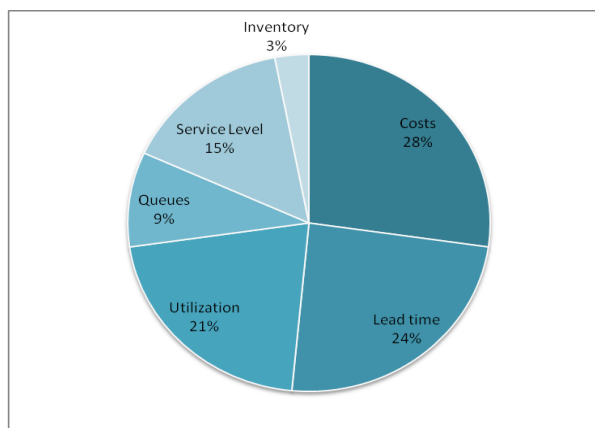


Figure 3. Distribution of articles by the nature of the objective considered

As for the motives of the study, Figure 4 summarizes the main reasons pointed out in the sampled articles to explain the adoption the agent approach. Characteristics such as ‘Communication’ and ‘Distributed Nature’ of the agents in the system are the most cited, followed by ‘Autonomy’ and ‘Ability to adapt in a Dynamic Environment’ and ‘Decentralized Systems’. The reasons observed are clearly related to the main properties of agent, which explain the natural choice of this simulation approach. The simulation of entities that incorporate such features is very challenging from the perspective of model programming, thus in ordinary cases of model building for investigation of OM issues, the consideration of these aspects is greatly simplified or neglected.

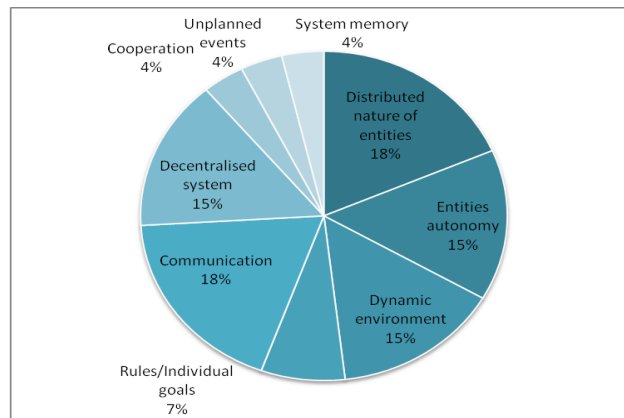


Figure 4. Distribution of articles by reasons for adoption of Agent approach

Regarding the system representation using ABS, Figure 5 shows a broad range of agent applications according to the objective and problem scope. The entity taken as an agent can represent from a single employee/customer to an entire Industry, and it can represent tangibles elements like machines installed within an area or intangible element such as communication systems. In addition, due to the complexity that is intrinsic to the human elements and their behavior, the application of the agent approach may be an appropriate decision when emphasis should be given to the examination of their dynamics in the system under evaluation.

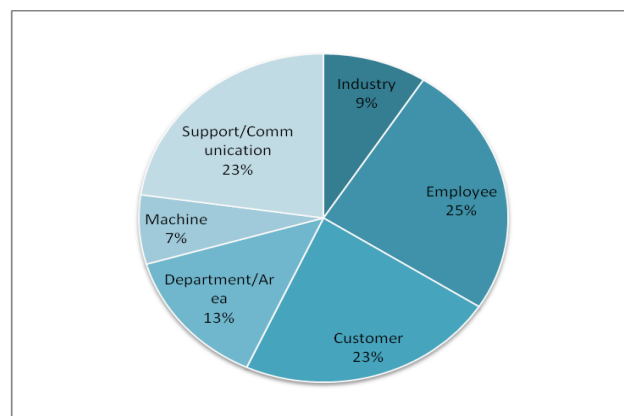


Figure 5. Distribution of articles by the system entity represented by Agent

Despite the fact the articles analyzed in this work were limited to those that applied ABS within OM field, it is noticeable the wide range of possible applications provided by this approach. Seemingly, these diverse forms of application have been accomplished in the development of each project/study through a peculiar method of model systematization undertaken by individual authors.

The next section will cover a brief discussion of the manner by means of which the modeling processes are being developed in order to facilitate documentation, communication, and most importantly, to capture the essentials of the real system behavior under evaluation and to incorporate them in the target model.

## 6. Process Modeling using Agent



A detailed examination of the simulation modeling approach applied in the sampled articles revealed that there is not yet a prevailing method of agent model development in OM area. The ABS models analyzed suggest that the modeling and programming activities in their development were undertaken on a rather ad-hoc basis, with each modeler articulating a particular set of representation means and tools to capture and describe relevant aspects of the system under analysis. Despite of the miscellaneous methods identified, some similar patterns of modeling and representation were found and should be highlighted.

Labarthe et al. (2006) recommend that the deployment of ABS (as a software product) be relied on the implementation of classical Software Engineering approaches which guide the development process and ensure its quality, its robustness, its sustainability and its adaptability.

Some modeling methods are based on adaptations and extensions of Object Oriented methodologies such as Unified Modeling Language (UML), Object Modeling Technology (OMT) or Knowledge Oriented methodologies (LABARTHE et al., 2006). The use of a methodology is then guided by the study purpose and the level of information needed to represent the agent in the system modeled.

A standard procedure to represent the model plays an important role in agent-based deployments. Among the several standardization initiatives in the multi-agent domain, the Foundation for Intelligent Physical Agents ([www.fipa.org](http://www.fipa.org)) is the most active and influential. FIPA has provided numerous standards for organizing communication and negotiation, as well as for creating and maintaining those definitions.

The examination of the modeling process undertaken in the articles comprised by the selected sample, revealed that some UML representation features were applied. The UML unifies and formalizes the methods of many approaches to the object-oriented software lifecycle (BAUER, 2001). According to Rumbaugh et al. (1999), the UML is a general-purpose visual modeling language that is used to specify, visualize, construct, and document the artifacts of a software system. It supports the capturing of decisions and understanding about systems that must be constructed. It provides concepts and tools that support the understanding, design, browsing, configuration, maintenance, and control of information about such systems. It is intended for use with all development methods, lifecycle stages, application domains, and media.

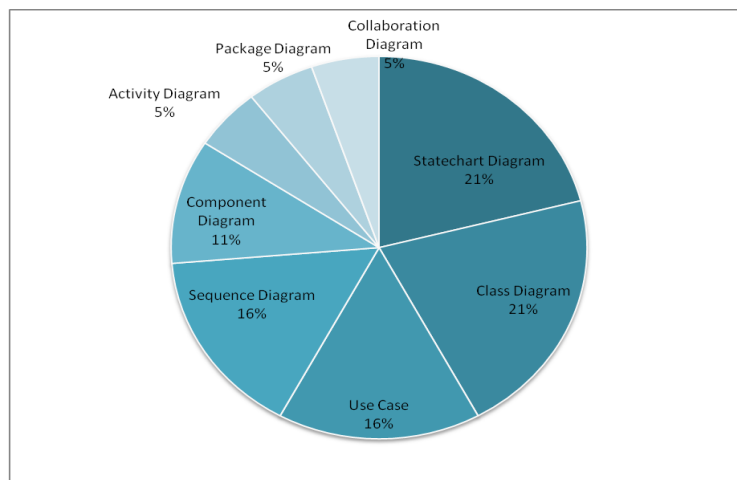
An overview of the set of diagrams used in UML with some basic concepts about them are summarized in Table 2:

Diagram	Main concepts
Class Diagram	A graphic presentation of the static view that shows a collection of declarative (static) model elements, such as classes, types, and their contents and relationships
Use Case	The use case view models the functionality of the system as perceived by outside users, called actors. A use case is a coherent unit of functionality expressed as a transaction among actors and the system
Sequence Diagram	A diagram that shows object interactions arranged in time sequence. In particular, it shows the objects participating in an interaction and the sequence of messages exchanged

Collaboration Diagram	A diagram that shows interactions organized around roles—that is, slots for instances and their links within collaboration. Unlike a sequence diagram, a collaboration diagram explicitly shows the relationships among the roles. On the other hand, a collaboration diagram does not show time as a separate dimension,
State Chart Diagram	A state machine models the possible life histories of an object of a class. A state machine contains states connected by transitions. Each state models a period of time during the life of an object during which it satisfies certain conditions
Activity Diagram	An activity graph shows a procedure or a workflow. An activity graph describes both sequential and concurrent groups of activities
Component Diagram	A diagram that shows the organizations and dependencies among component types. A component diagram shows the dependencies among software components, including source code components
Package Diagram	The view of the model itself. It comprises a set of packages that hold model elements, such as classes, state machines, and use cases. A general-purpose mechanism for organizing elements into groups. A system may correspond to a single high-level package, with everything else in the model contained in it recursively

**Table 2: Basic concepts of UML diagrams. Based on Rumbaugh et al. (1999)**

Figure 6 exhibits the UML diagrams that were most frequently used in the articles to conceptualize the model and the agent characteristics.



**Figure 6: Visual tools to support modeling process and model documentation**

The tools that were most frequently applied in the articles analyzed are the Statechart Diagrams and Class Diagrams. These diagrams can capture the entity history and also the particular characteristics of the entity (individuality). Thus, they seem to be suitable tools to represent some important agent features in the system. Next, the use of Sequence Diagrams and Use Cases were also observed with relatively higher frequency. These tools depict the relationship between the system elements, which is also an important characteristic for agent properties (communication and relationships). Although UML was not developed for specific agent modeling purposes, it has provided useful support for modelers to represent complexities brought by the adoption of Agent approach.

However, Marik & McFarlane (2005) argue that Object Oriented methodologies are sometimes unsuitable to capture all the agent details, such as complex communication

protocols and interactions. Thus, agent-oriented methodologies suffer from high generality. Some extensions of UML such as AUML (Agent-UML) have been proposed in order to adapt the original concepts to better represent the agent particularities, making the model easier to be understood by modelers.

## 7. Conclusion

This study indicates that the research field regarding ABS applied in OM problems is rapidly growing. The range of application is vast and the new possibilities opened by this approach are promising. The need to ensure consistency and effectiveness in their exploitation, leads to issues regarding when and how to apply the agent concept. The implication is that the modeling representation are also specific for each model purpose, and although some tentative schemes of standardization through Object Oriented methodologies have been proposed, they are still incipient for most of the articles analyzed in this study. UML has provided some support tools to represent agents' properties and dynamics in the system, but it also reveals area for further investigation.

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