AGENT-BASED SIMULATION APPLIED IN OPERATIONS MANAGEMENT: A LITERATURE REVIEW

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This paper provides an overview of the modeling process for operations systems using the concept of agent-based simulation (ABS), whose dissemination is relatively recent in the field of Operations Management. The agents represent entities with individual characteristics and autonomy which allow them to interact with other entities and environment, enabling the model to better represent, for instance, the behavior of human resources. Additionally to the concept of agents and its properties, this article will also discuss the advantages of ABS and the main applications in the Operations Management's literature review.

Palavras-chaves: Agent, Simulation, Operations Management

1. Introduction

Manufacturing and service enterprises are facing more complex market demands due to the influence of a global economy, growing product customization and fluctuating operations environment. Some characteristics are considered essential to sustain competitiveness such as quick and real time response in satisfying customer requests and operations flexibility to adapt to the changing environment. In this context, simulation tools offer ways to assist managers and researchers during the conceptualization and evaluation of operations systems (HAO & SHEN, 2007).

According to Shannon (1975), simulation is "the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies for the operation of the system". Additionally, simulation studies are recommended when the complexity of the operations turns impracticable the application of any other analytical method.

The simulation modeling process requires a clear agreement of the study objective and the modeler's ability in codifying the reality by means of structured logic programming that mimic the system to be evaluated. Rivett (1980), Pidd (1996) and Carson II (2005) argue that the subjective nature in the modeling process requires a combination of science and art in the simulation studies.

This paper provides an overview of the modeling process for operations systems using the concept of **agent-based simulation** (ABS), whose dissemination is relatively recent in the field of Operations Management. The agents represent entities with individual characteristics and autonomy which allow them to interact with other entities and environment, enabling the model to better represent, for instance, the behavior of human resources. Additionally to the concept of agents and its properties, this article will also discuss the advantages of ABS and the main applications in the Operations Management's literature review.

2. Research Methodology

This paper introduces general concepts of ABS and illustrates the potential applications of this emergent scientific approach in the search of a better representation of operations systems that can be applied in their planning, design and analysis. The research is supported by an exploratory review of general simulation literature with a focus on traditional simulation techniques and ABS. Considering the vast field of simulation studies, the scope of this work is limited to a qualitative discussion of the main ABS characteristics. As the ABS application for Operations Management is relatively recent, a considerable amount of the referenced articles were extracted from scientific events in computational simulation, such as the *Winter Simulation Conference* and from the *Society for Modeling and Simulation International*. In order to discuss the application of the ABS and to draw attention to the new modeling properties offered by this simulation approach, a brief description of available ABS toolkits that have been applied in academic and business areas is presented.

3. System Simulation

Winston (1993) defines **system** as "a collection of entities that act and interact toward the accomplishment of some logical end". However, this definition depends on the objectives of the simulation study. In addition, a system can also be influenced by the environment, thus the main external factors that can affect the system should be considered when the modeler defines the scope of the model based on the purpose of the study.

Pidd (1996) describes a **model** as an explicit representation of part of the reality according to the modeler view, and is used to understand, change, manage and control part of that reality. Although a model is a simplified representation of a real system, it must offer enough details to be used as a valid representation (Banks *et al*., 1996).

Simulation can be defined as a technique of imitating the behavior of a system or process by means of a suitable analogous artificial system or process. In other words, it can be viewed as a method to analyze the behavior of real systems and the effect of exogenous interventions on such systems that modify them and/or their inputs.

The simulation study embraces a series of stages that allow the modeler to clearly understand the structure and dynamics of the real system to be simulated before translating the conceptual model into computational procedures using a simulation language or toolkits which will enable the experiment and analysis of the results. The main stages of the simulation study are presented in Figure 1, according to Shannon (1975), Winston (1993) and Banks *et al.* (1996).

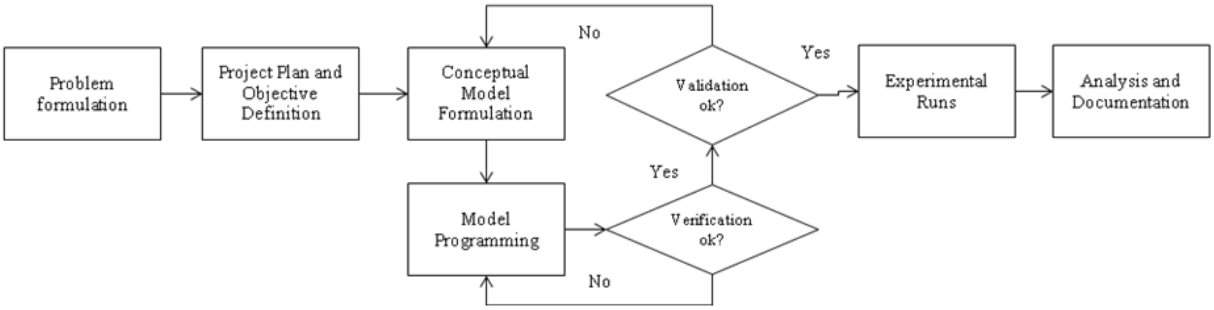

Figure 1 - Study of simulation

4. Discrete Event Simulation

The DES definition consider the study of simulation models whose state variables change instantaneously in specific points of time, in contrast to continuous models, whose state variables change continuously over the time. In practice, however, only few systems are completely discrete or continuous type. It is usual to consider the predominant characteristic of events occurrence in the system during the simulation modeling process (GORDON, 1978; LAW & KELTON, 1991).

The usage of DES employs the concepts of entities, resources, dynamic variables, random numbers generation, calendar and block diagrams to describe the entities behavior and flow in a system. This simulation approach started to draw public attention in the early 1960 when Geoffrey Gordon developed the programming language called GPSS (*General Purpose System Simulator*).

In this context, **entities** can represent objects as people, materials, documents, tasks, messages, vehicles, etc. which enter the system flow and are subject to different process steps modeled using stochastic distribution times. Entities can be attached to **resources**, queued or be transformed into new objects. The typical range of applications using DES varies significantly and can be found in areas such as manufacturing, services, logistic, military and businesses for instance. Borshchev & Filippov (2004) argue that the model developed using DES considers a global understanding of the system behavior and the entities are passive objects whose rules that drive the system are centralized in the flowchart blocks.

Pidd (2008) points out an explosive growth in DES toolkits during the last 20 years. It is incontestable that the simulation tools are much more user friendly and with a higher performance than its previous generations. Some improvements were due to the advances in computer hardware and also because of user requirements. However, although the continuous developments of faster and better simulation tools did not reach its end, a critical point remains unchanged: the need of development of coherent models. These models need to fulfill the simulation primary objectives by supporting the system behavior analysis and its improvement. It also means that the models must be developed in an appropriate period of time and be able to provide direct and fast analysis results.

5. Agent-based Simulation

5.1 Definition

Macal & North (2005); Smith *et al*. (2007) define that ABS comprises of multiple, interacting and autonomous agents situated within a model or simulation environment. ABS has connections to many fields including operations research, artificial intelligence, social sciences in general and traditional modeling and simulation disciplines. The main idea of this simulation approach is to expand the traditional theory to include entities whose behavior can be modified throughout the time, depending on the circumstances of the environment.

Samuelson (2005) found that many researchers credit ABS origins to Santa Fe Institute with essentially starting the field in its current form, in the late 1980s and 1990s, by developing **Swarm**, the first widely available computer package designed for ABS, followed by **Repast** (University of Michigan and the University of Chicago). These and other packages offer the ability to specify entities - agents - within the system, program them with rules to govern their behavior and interaction, and then analyze the simulated results.

In this paper the acronym ABS is used, nevertheless various alternative terms (and their acronyms) can be found in the literature, such as Agent-Based Computational Modeling (ABCM), Agent-Based Social Simulation (ABSS), Agent Based Computation Simulation (ABCS), Agent-Based Modeling and Simulation (ABMS) and Individual-Based Modeling (IBM) (SMITH ET AL., 2007; MACAL & NORTH, 2005).

According to Gentile *et al*. (2005), the interest in ABS has grown steadily; the first international workshop on ABS was promoted by the International Conference on Multi Agent Systems in Paris in 1998, and the first conference on ABS of the Society for Modeling and Simulation (SCS) dates to 2000. However, the usage of ABS should not be seen as an original simulation paradigm because it is influenced by and partially builds upon some existing paradigms, such as parallel and distributed DES, object-oriented modeling and dynamic micro simulation (Davidsson, 2000). In fact, as long as agents can be considered an extension of objects, an ABS model can in principle be viewed as a further step away from object-oriented modeling, which defines a system as a collection of active and autonomous entities.

Swain (2007) surveyed the simulation literature and pointed that military and industrial operations rarely operate in a homogeneous way, but rather in a more unpredictable form due to the improvisation among interacting players. A limitation of the traditional simulation has been the limits on autonomy provided in the modeling constructs. 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. Workers tend to individual or groups of machines according to well-defined rules, priorities and characteristics of the work. Few models provide any meaningful autonomy to make decisions, to learn from their environment or to cooperate with each other when problems arise.

5.2 Concept of Agent

Zhang & Zhang (2007) and Smith *et al*. (2007) noted the concept of **agent** is highly abstract and there is not an agreement of its definition in the literature of simulation modeling. In general, any simulation entity that contains the following attributes can be considered an agent:

- Independent behavior (pro-active and reactive);
- Individual characteristics;
- Interaction and Communication;
- Spatial mobility.

Macal & North (2005) present the following common characteristics to the agent:

- It is an identifiable individual and presents a set of rules that govern its behavior and capacity of decision making;
- It is positioned in the system and capable to interact with other agents. It has protocols of interaction (e.g. communication protocols) and the capacity to react to the environment;
- It has goals and objectives;
- It presents the ability to learn and to adapt throughout its experiences;
- Its rules can be modified.

Samuelson & Macal (2006); Zhang & Zhang (2007) describe that in the ABS approach, the system behavior results from the interactions of many individual agents. Some authors characterize this approach as a bottom up technique. Additionally, the ABS can be classified as decentralized (individual focus), in contrast to the usual modeling approach of macro level systems.

Table 1 summarizes the main characteristics of agent considered in this paper.

Agent properties	Authors
Autonomy and self-direction: An agent controls its own actions; operates without a central control influence.	Macal & North (2005); Ito (1999); Zhang & Zhang (2007); Smith *et al.*(2007); Hübner (2003); Davidsson (2000).
Objective oriented: An agent has defined goals and not only can react to external factors.	Macal e North (2005); Ito (1999).
Interaction protocols that enable communication and ability to respond to the environment; can interact with other agents and cooperate to achieve its objectives.	Macal & North (2005); Ito (1999); Zhang & Zhang (2007); Smith *et al.*(2007); Davidsson (2000).
Adaptation/Learning: Agents can be designed to alter (limited to a given threshold if required) their states depending on their current states, permitting agents to adapt with a form of memory or learning.	Macal & North (2005); Ito (1999); Smith *et al.*(2007); Davidsson (2000).
Mobility: Agents can roam the space in which they are situated within a model.	Zhang & Zhang (2007); Smith *et al.*(2007); Davidsson (2000).
Identifiable: can plan and negotiate with other agents; presents bounded rationality.	Macal & North (2005); Ito (1999); Zhang & Zhang (2007); Smith *et al.*(2007); Hübner (2003).

Pro-active/goal-directed: Agents are often deemed goal-directed, having goals to achieve with respect to their behaviors. **Reactive**/Perceptive: Agents can be designed to have an awareness, or sense of their surroundings.	Macal & North (2005); Smith *et al*.(2007); Hübner (2003); Davidsson (2000).
Heterogeneity: Agents permit the development of autonomous individuals. Groups of agents can exist, but they are generated from the bottom-up.	Smith *et al*.(2007).

Table 1 – Main agent properties

5.3 ABS toolkits

One of the main factors that allowed the growth of ABS applications was the development of computational packages more user-friendly and equipped with support modeling tools. Smith *et al*. (2007) suggested that an ABS can be programmed completely from scratch using a low-level programming language if a modeler has sufficient programming knowledge and experience. Nevertheless, nowadays simulation toolkits provide a conceptual framework for organizing and support the designing of agent-based models. They provide appropriate libraries of software functionality that include pre-defined routines/functions specifically designed for ABS.

The development of ABS can be greatly facilitated by the utilization of simulation toolkits. They provide reliable templates for the design, implementation and visualization of agent-based models, allowing modelers to focus on research (i.e. building models), rather than building the fundamental tools necessary to run a computer simulation. A review of all toolkits currently available is beyond the scope of this paper. However, below are discussed a selection 3 noteworthy toolkits according to Samuelson & Macal (2006).

5.3.1 Swarm

Swarm was designed to study biological systems, and attempts to replicate mechanisms observable in biological phenomena. In addition to modeling biological systems, Swarm has been used to develop models for anthropological, computer science, ecological, economic, geographical, and political science purposes. It was developed in 1996 by Chris Langton in the Santa Fe Institute and is an open source simulation toolkit, maintained currently by *Swarm Development Group* (SDG). Thanks to the public research and academic support, Swarm offers many resources for ABS, such as:

- Calendars;
- Interaction mechanisms;
- Capabilities to store agent’s states;
- Wide scale development support.

5.3.2 Repast

Originally developed at the University of Chicago, the Recursive Porous Agent Simulation Toolkit (Repast) is currently maintained by Argonne National Laboratory and managed by the Repast Organization for Architecture and Development (ROAD). The ROAD is led by members of the American government, academics and industries. Repast is one of the most popular open source toolkits and can be accessed via <http://repast.sourceforge.net/> with similar applications in social sciences field (SALLACH & MACAL, 2001).

Repast is available in Java language and its application is based on components libraries that can be incorporated to the model using a visual form, thus trying to reduce the modeler requirements of advanced programming skills.

5.3.3 AnyLogic

AnyLogic is one of the commercial packages developed by XJ Technologies (Russia) that offers support functionality for development of agent-based models and other simulation approaches such as DES and System Dynamics (SD). It also uses Java language and its applications varies from social sciences, manufacturing planning and process flow, ecosystem dynamics, and disease propagation, to name a few.

In Table 1 the main functionalities of the simulation packages are compared that use agents as basic concept for modeling.

	AnyLogic	Swarm	Repast
Developers	XJ Technologies	Santa Fe Institute / SDG (SWARM Development Group)	University of Chicago (Dep. Computational Research of Social Sciences)
Origin (Country)	Russia	USA	USA
License of use	Commercial software	Open source	Open source
Date of development	Not available	1996	2000
Website	http://www.xjtek.com	http://www.swarm.org	http://repast.sourceforge.net
Implementation language	Java	Java	Java/Python/Microsoft.Net
Operational system	Windows, UNIX, Linux, Mac OSX	Windows, UNIX, Linux, Mac OSX	Windows, UNIX, Linux, Mac OSX
Required programming experience?	Yes. Moderate	Yes. Strong	Yes. Strong
Integrated graphs , diagrams and statistics?	Yes	Yes	Yes
Availability of demonstration models?	Yes	Yes	Yes
Source code of demonstration models?	Not available	Yes	Yes
Guide and Tutorial?	Yes	Yes	Yes
Typical applications	Planning, process analysis, logistic, manufacturing, military, social sciences	Biological systems, ecology, social sciences, geographic information (GIS)	Biological systems, ecology, social sciences, geographic information (GIS)

Source: Adapted from Smith *et al.* (2007); Swain (2007)

Table 2 – Comparison between SBA toolkits

6. ABS literature review applied in Operations Management

The specific differences between ABS and conventional simulation models are summarized by the following points:

- Part of the system entities is associated with agents;

- The system model is intrinsically distributed because agents behave autonomously;
- A new flexibility is allowed for the system evolution because agents can be created and destroyed dynamically;

The agents are entities with some defined behavior and the interaction among them may originate in a complex system evolution. Thus, according to Gentile *et al*. (2005), the decision in choosing the ABS approach depends on whether the system can be suitably modeled in terms of entities and behaviors.

As mentioned earlier in this paper, the literature review was based on articles extracted from scientific events related to modeling and simulation, such as the *Winter Simulation Conference*, the *Society for Modeling and Simulation International* and journals such as *Robotics and Computer-Integrated Manufacturing*, *Mathematical and Computer Modelling*, *Computers in Industry* and *Decision Support Systems*. Thus 15 articles were selected based on the potential applications in Operations Management using the concept of agents to represent the analyzed system or just part of it.

Yang & Yasser (2008) used the ABS approach to model different resources allocation in construction processes where entities share and compete for limited resources dynamically. A similar approach is proposed by Shibghatullah *et al.* (2006) in order to optimize the scheduling of bus crew considering resources restrictions and an unpredictable traffic. Scheduling problems in a changing demand environment with limited resources are also addressed in manufacturing studies using the agent concept (ANOSIKE & ZHANG, 2006; MES *ET AL*., 2008).

Another application for ABS considering resources representation can be found in modeling the interaction between resources in a collaborative environment. Zhang & Hammad (2007) suggested the agent approach to model cranes for construction operations that work cooperatively when performing a complex task. Moreover, team's collaborative work modeling is suggested by Rojas & Giachetti (2007) in order to determine the best configuration design to perform a particular job.

The human behavior is also a frequent topic studied using ABS modeling approach. In service operations designed to have a close customer interface with the system's resources, it is useful to model customers and the staff as agents to simulate behavior and entities interaction/communication process within the system. Macal & North (2007) and Siebers *et al*. (2007) suggested the usage of agents enables the modeler to represent the system variations due to the human interference in a more realistic way.

A special attention using ABS is given to material handling system's studies. Babiceanu & Chen (2005) proposed a comparison using centralized and decentralized scheduling approaches for allocation of material handling operations to the available resources in the system. Similarly, Hao & Shen (2008) used a combined simulation approach to model a kanban-based material handling system. Part of the kanban logic was modeled using agents in a DES environment in order to add a more realistic behavior in the simulated system. Kotak *et al*. (2003) and Mes *et al*. (2008) applied the ABS to model logistics control of AGV's and material transport system considering dynamic changes in layout, breakdowns and cooperative work aiming the lowest cost, time or distance.

The ABS seems to be an appropriate tool to analyze situations in which distributed entities with an autonomous behavior are present. This explains the increasing number of

ABS applications for the analysis of the business process along the manufacturing supply chain. In this scenario, various distinct entities must interact in a coordinate way to reach specific and shared objectives.

Table 3 summarizes the main ABS focus and applications in Operations Management.

Item	ABS application issue	Agent representation	Authors
1	Resource allocation problem and scheduling	Resources, transport units, AGV's	Yang & Yasser (2008); Shibghatullah *et al.* (2006); Anosike & Zhang (2006); Mes *et al.* (2008)
2	Customer behavior and interactions between system elements	Customers, atendents	Macal & North (2007); Siebers *et al.* (2007); Dubiel & Tsimhoni (2005)
3	Resources collaborative work	Cranes (equipment); teams (staff); AGV's	Zhang & Hammad (2007); Rojas & Giachetti (2007); Mes *et al.* (2008)
4	Decentralized/local decision making	Enterprises, resources	Macal & North (2006); Babiceanu & Chen (2005); Anosike & Zhang (2006)
5	Material handling system decision modeling	Resources, work pieces, AGV's	Babiceanu & Chen (2005); Hao & Shen (2008); Kotak et al. (2003); Mes *et al.* (2008)
6	Planning and control	Intermodal transport, assembly line, resources	Gambardella *et al.* (2002); Yaskawa & Sakata (2003); Anosike & Zhang (2006)

Table 3 – ABS literature review

It is also observed that some applications consider the combination of more than one simulation approach to model the operations systems. This reinforce the concept previously stated that the ABS is not a substitute for the conventional simulations techniques, whereas it may enhance the model building process representing the complexity of real systems in a more appropriate way.

Table 4 attempts to summarize the main issues modeled using ABS and their associating relevant properties that are recommended to take into consideration when modeling a system. The attributes may vary depending on the simulation objective and should be used only as a reference table based on the literature review presented in this paper.

Item	ABS application: ABS properties:	Autonomy	Objective oriented	Interaction	Adaptation/Learning	Mobility	Identifiable	Heterogeneity
1	Resource allocation problem and scheduling	X	X			X	X	X
2	Customer behavior and interactions between system elements	X	X	X	X	X		X
3	Resources collaborative work	X	X	X	X	X	X	
4	Descentralized/local decision making	X	X	X	X			
5	Material handling system decision modeling	X	X	X		X	X	X
6	Planning and control	X	X		X		X	

Table 4 – Suggestion of ABS properties application

7. Summary

The development and dissemination of ABS models are enabling new ways for applications in Operations Management field which could lead to a more representative modeling build according to the system behavior.

Based on the literature review and examples mentioned in this paper, the authors agreed that although the dissemination of the ABS approach is highly promising in terms of application range and model properties, this modeling technique does not seem to tend to substitute completely the usual DES approach. Firstly, the simulation modeling technique should be selected based on the main simulation objectives. This should be the most important driver when choosing the best technique to analyze any system. Secondly, the model building process should also be taken into consideration regarding time and programming skills necessaries to accomplish the simulation study. Currently some ABS toolkits demand moderate to strong programming skills to translate the conceptual model in terms of logic commands, in contrast to most DES toolkits commercially available nowadays.

Additionally, some ABS modeling properties discussed in this study seem to be an adequate tool to better represent human factors that confer unique behaviors difficult to simulate using the other simulation techniques. Thus, this technique should be taken into consideration when the human resources play a major role in the simulation model.

The applications of ABS in manufacturing seems more appropriate in cases in which production activities are affected by dynamic variations or involves complex decisions, and in instances in which the agents are adopted to make systems interoperate, playing a role of intelligent middleware components. Moreover, the literature review indicates there are still great potential of new applications in representing operations and complex system's behavior.

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