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Integrating System Dynamics and Agent-Based Modeling

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Abstract

This paper presents an approach to integrate the system dynamics and the agent-based modeling techniques. After reviewing the fundamental principles of the two modeling approaches, an agent-based supply chain simulation model is developed. The model consists of two levels of aggregation; on the macro level a discrete agent-based modeling approach is applied, on the micro, the agent level system dynamics is used to model the agents' internal cognitive structure. The paper concludes with first preliminary simulation results and aspects of future research.

Extended Abstract

Coming from the field of complexity science, the agent-based modeling approach gains growing popularity. At the core of this perspective is the assumption that complexity arises from the interaction of individuals (Phelan, 2001). The behavior of these individuals, also called agents, is dictated by their schemata. According to Anderson, a schema is "a cognitive structure that determines what action the agent takes at time *t*, given its perception of the environment" (Anderson, 1999). An agent's schema can evolve over time what allows it to adapt to its environment. From a modeling perspective, this adaptation can be achieved by the use of feedback and learning algorithms (Phelan, 2001). In agent-based modeling schemata are mostly modeled as sets of simple generative rules.

The above mention of structure and feedback already points at the use of system dynamics for modeling an agent's schema. To evaluate the feasibility of this approach, the agent-based and the system dynamics modeling techniques have to be compared. Some of the basic differences between the two approaches are summarized in Table 1.

Principle	System Dynamics	Agent-Based Modeling
Building block	Feedback loop connecting behavioral variables	Individual agents connected by feedback loop
Object of interest	Structure of the system	Agents' rules
Research approach	Deductive: infer from structure to behavior	Inductive: infer from individual agents' behavior to system behavior
Development of object of interest over time	Structure is fixed	Agents' rules can be adaptive
Handling of time	Continuous simulation	Discrete or continuous simulation

Table 1: Differences between system dynamics and agent-based modeling

Despite these differences both modeling approaches share a common aim: the understanding of the behavior of dynamic systems and the underlying principles. While system dynamics looks for these principles in system structure, agent-based modeling seeks them in agents' rules.

This paper integrates the two modeling approaches applied to the field of supply networks. In system dynamics, supply chain modeling is almost as old as the discipline itself. As early as 1958 Forrester modeled a four-level downstream supply chain (Forrester, 1958). With the help of this model he already described, analyzed, and explained many issues currently of interest in supply chain management research (Angerhofer and Angelides, 2000).

Recently the field of complexity science gained growing interest in the modeling of supply networks (Parunak et al., 1998, Pol and Akkermans, 2000). The underlying reason is that a supply chain, by its nature, consists of a set of autonomous or semi-autonomous agents and therefore it seems to be obvious to model it as such.

The drawback of the system dynamics approach in modeling supply networks is the fixed structure of a system dynamics model: the levels, rates, and the equations linking them have to be determined before starting the simulation. To overcome this drawback, the model developed here consists of two levels of aggregation as shown in Figure 1.

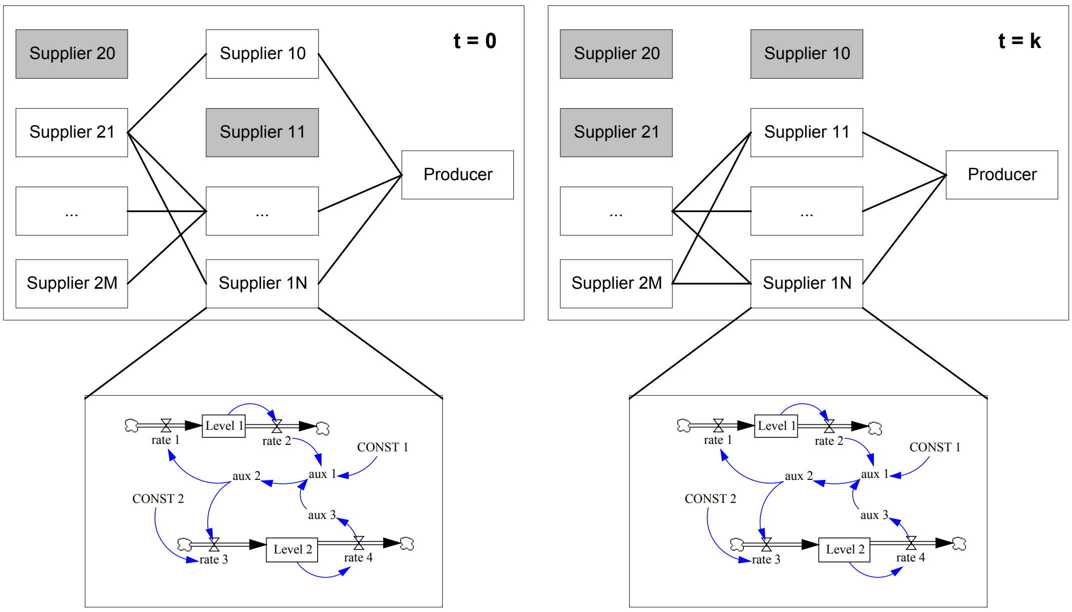

Figure 1: Supply network at time t=0 and t=k

On the macro level a discrete agent-based modeling approach is applied, meaning every company represents an agent interacting with other agents. The supply network is modeled as an emerging system, where the participants of the network can exit or new agents can enter (Choi et al., 2001). Therefore the network structure is flexible. The interactions between agents are a result of the decisions made by agents. These again result from the agents' schemata which are implemented on the second, the micro level. The modeling approach used here is system dynamics. Therefore an agent's schema is not as much seen as a set of rules, but as this agent's mental model or, with Anderson's words, its "cognitive structure" (Anderson, 1999). For making a decision, the agent evaluates the information available to it according to its preferences.

From an implementation perspective the model consists of a master program, the macro level model, and several modules, the internal structures of the different agents. Whenever one agent is chosen to take part in an exchange process, the master program calls the system dynamics model of this particular agent. The output of the simulation run is then passed to the master program and a function is called to take action according to this output. An example for the output could be the preference of one agent to buy from a specific supplier, the amount of goods to be bought or the expected delivery date.

The outline of the paper is as follows. Firstly, the two approaches, system dynamics and agent-based modeling are compared. Secondly, a method of integrating the two approaches is presented and applied to the field of supply networks. First preliminary simulation results are then presented. The paper concludes with aspects of future research needed.

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