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Designing of an intelligent self-adaptive model for supply chain ordering management system

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ABSTRACT

One of the challenging issues in supply chain management is the coordination of ordering processes, especially in dynamic situations. In recent years, reinforcement learning algorithms are considered to be efficient techniques for solving such problems. In this paper, an agent-based simulation technique has been integrated with a reinforcement learning algorithm and has been applied to model a four-echelon supply chain that faces non-stationary customer demands. This approach leads to the development of a novel and intelligent simulation-based optimization framework, which includes a detailed simulation modeling of supply chain behavior. Finally statistical methods, including the Var technique, are used for the risk evaluation and sensitivity analysis have been provided to support the decision making process under uncertainty.

1. Introduction

The literature on supply chain management entails decision making processes in several areas such as procurement, production, inventory control, distribution, and so on. Also the decision making process in a supply chain is performed under three perspectives of operational, tactical and strategic decisions, so the nature of a supply chain management system (SCMS) makes it as a complex problem which has attracted the attention of several researchers.

In a SCMS, inventory control is one of the most important problems which cover nearly 50% of the total costs of the supply chain (Lancioni, 2000). One of the most important decisions about inventory control is the supply chain ordering management (SCOM), which is the main focus of this research. In fact, SCOM is an integrated approach to determine the ordering policy of each supply chain actors. In such a problem, the purpose of the decision maker is to minimize inventory costs and satisfying customers demand with a high service level, simultaneously.

A supply chain consists of independent and interacting actors with non-linear behaviors which have the ability of decision making. Also, there are several uncertainties such as uncertainty in demand, lead time etc. which cause a supply chain to be an instance of a complex adaptive system (CAS). Thus, an agent based modeling (ABM) technique can be considered to be a powerful bottom up technique for modeling a supply chain (Macal and Michael, 2009), especially in SCOM problems (Chaharsooghi et al., 2008). The ABM technique has the ability to model the detailed dynamic behaviors of complex systems, and there are several successful reports of using ABM techniques in industrial societies. For instance, the Boeing Company applied ABM for automating of its service supply chain in the case of perishable products Brintrup et al., 2009). In another project Honeywell laboratories employed ABM in its dynamic distribution SCM (Wagner et al., 2003).

For a real supply chain faced with complex and stochastic demand patterns, which leads to a time-varying state that evolves over time; so the mathematical and ordinary optimization techniques are unable to solve such problems. An artificial intelligence method may be helpful here to model a learning mechanism and providing the self-adapting agents. In this research, the main effort is dedicated to embedding a reinforcement learning (RL) algorithm (Sutton and Barto, 1998) in an agent based simulation model to develop an intelligent learning model in order to solve a SCOM as a Markov decision process (MDP).

The paper is organized as follows. Section 2 provides the related literature review. Section 3 describes the problem and the modeling process, while Section 4 is dedicated to implementation of the reinforcement learning algorithm. Section 5 is about performance analysis of the problem. Finally, conclusions and suggestions for future studies are discussed in Section 6.

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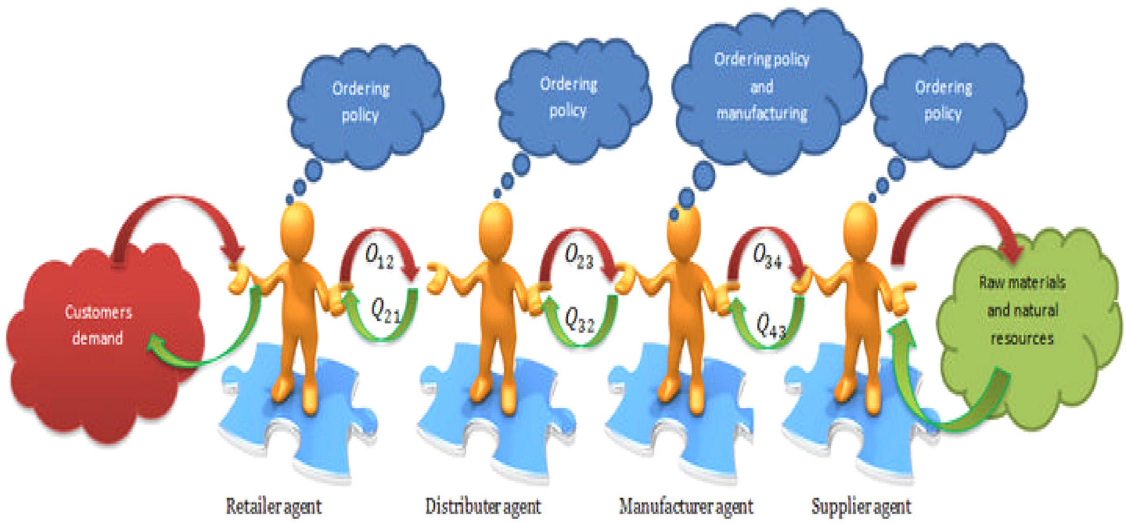

Fig. 1. Structure of agent based supply chain.

2. Literature review

As the main contributions of this paper are twofold, i.e. modeling of supply chain as a multi-agent system and developing of a RL algorithm for solving of SCOM as a Markov decision problem, we have categorized the relevant literature in two subsections including the agent based modeling of a supply chain and then, the application of reinforcement learning methods in the inventory optimization problems.

2.1. Agent based modeling of supply chain

ABM is a well-known architecture for modeling of distributed systems. In this paradigm, components of system are modeled as agents with the ability of decision making and communication. Such agents are autonomous and self-organizing with specific rules to make decisions. Thus, the ABM technique is suitable for modeling of complex systems with non-linear behavior.

To the best of our knowledge, there are two main areas in SCM in which ABM technique is applicable. The first area is scheduling and production systems (Leitão, 2009; Aissani et al., 2012; Trentesaux, 2009; Tehrani Nik Nejad et al., 2010) and the second area, which forms our focus in this paper, is the ordering policy. One of the first research works in agent based modeling and simulation of supply chain is presented by Swaminathan et al. (1998). In this research, ABM is employed for designing of a decision support system with the aim of reengineering of the supply chain. Agents represent the supply chain entities, i.e. the retailer, the distribution center, etc. while several inventory control policies are considered. Strader et al. (1998) applied ABM to simulate of an assembly supply chain which is associated with computer and electronics industries. They investigated the impact of information sharing on orders fulfillment. Later Fox et al. (2001) used ABM to develop two different supply chain architectures with the aim of supply chain coordination and managing of perturbation. In the other research, Pathak et al. (2004) used a simulation framework based on the ABM method for simulation of growth dynamic in an adaptive SCM.

In later research works, there are various models of supply chains supported by ABM technology. In some of these research works, financial decisions are investigated by the ABM approach. For instance, Sun et al. (2012) used agent based simulation for mitigating of a bankruptcy propagation through the supply chain by considering operational parameters in financial decision making, While Li et al. (2010) used agent based simulation for analyzing the dominant players' behavior of supply chains. The latter research showed that the profit stability is feasible in spite of decreasing the sales price.

Table 1
Mean of customers demand in 12 week period.

Week	1	2	3	4	5	6	7	8	9	10	11	12
Mean of daily demand	1	2	4	5	6	7	7	6	5	4	2	1

In recent years, many researchers have reported works in the area of inventory control. Wang et al. (2008) used agent based simulation to analyze the impact of radio frequency identification (RFID) technology on the improvement of an inventory system of LCD supply chain in Taiwan. Wang et al. (2011) developed a multi-agent model of supply chain to investigate (RFID) impact on inventory system based on total inventory cost, inventory turnover and the bullwhip effect.

Considering of highly dynamic customer demands, supply chain coordination, especially, ordering management, is important for optimum performance of supply chain. On the other hand, simulation can be considered to be an efficient tool for decision making and risk evaluation of supply chains under uncertainty (Galasso and Thierry, 2009). In this area, some researchers used simulation optimization techniques, including agent based simulation and meta-heuristic algorithms. For instance, Pan et al. (2009) used simulation optimization based on agent based simulation and genetic algorithm for obtaining the optimal reordering strategy in apparel supply chains which experience dynamic customer demands. In another work, Sinha et al. (2011) applied agent based simulation, assisted by the co-evolutionary particle swarm optimization (PSO) algorithm to coordinate a petroleum supply chains, while Brintrup (2010) employed NSGAII with a bi-objective function to optimize a supply chain using the ABS. In this research, maximization of supply chain revenue and minimization of lead time are considered to be objective functions while manufacturing policy and supplier selection are decision variables.

Although meta-heuristic algorithms are well known techniques for simulation optimization, there are several potentially suitable techniques in this area. Among other methods, RL is one of the most efficient techniques to solve dynamic optimization problems. Furthermore, RL is based on multi-agent modeling paradigms and hence it can be potentially advantageous for optimization of agent based simulation models. But using RL for agent based simulation optimization, is relatively rare in related literature, which is hence a major contribution of this paper.