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A Fuzzy agent-based model for reduction of bullwhip effect in supply chain systems

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Abstract

This paper addresses the bullwhip effect in a multi-stage supply chain, where all demands, lead times, and ordering quantities are fuzzy. To simulate the bullwhip effect, a modified Hong Fuzzy Time Series is presented by adding a Genetic Algorithm (GA) module for gaining of a window basis. Next, a back propagation neural network is used for defuzzification. The model can forecast the trends in fuzzy data. Then, an agent-based system is developed to minimize the total cost and to reduce the bullwhip effect in supply chains. The system can suggest the reasonable ordering policies. The results show that the propose system is superior than the previous analytical methods in terms of discovering the best available ordering policies.

Keywords: Supply chain management; Agent-based; Fuzzy time series; Bullwhip effect; Simulation

1. Introduction

Since the introduction of the term supply chain management (SCM) in 1982, it has received ever-growing interest both in the literature and industrial practice. The main reason for this interest is that it has so many facets. The tasks of accomplishing the aims of the SCM are so demanding that it is more an ongoing endeavor than a single short term project. This broad scope of the SCM faces the difficulty of finding a suitable definition and description of the term (Stadtler, 2005).

One of the most fruitful research sub-areas in the studying of supply chain management is bullwhip effect or whiplash effect. The bullwhip effect occurs when the demand order variations in the supply chain are amplified as they move up the supply chain. Five possible sources for bullwhip effect are recognized in the literature (Lee, Padmanabhan, & Whang, 1997a, 1997b). They include: demand forecast updating, prize fluctuation, rationing and shortage gaming, order batching and none-zero lead time. The first formal description of the bullwhip effect can be traced back to the work of Forrester (1961). Sterman (1989) further demonstrates and discusses this phenomenon in the popular beer game. According to (Sterman, 1989), the bullwhip effect originates from the non-optimal solutions adopted by a supply chain participant while does not consider the system as a whole. In the recent works, Cachon and Lariviere (1999) study the shortage gaming; Kelle and Milne (1999) and Cachon (1999) study the order batching and Drezner, Ryan, and Simchi-Levi (2000), Baganha and Cohen (1998), Graves (1999), Chen, Drezner, Ryan, and Simchi-Levi (2000) and Li, Wang, Yan, and Yu (2005) study the demand updating and information sharing issues. Li et al. (2005) use the term information transformation to describe the phenomenon where for each of the stages

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considered outgoing orders from a lower to the higher stage of a supply chain have a different variance from incoming orders that each stage receives.

However, there is only one work (Carlsson & Fuller, 2001a) that applied fuzzy logic related concepts to bullwhip effect. Based on an optimal crisp ordering policy that drives the bullwhip effect, they presented a policy in which orders are imprecise. In an environment where orders can be intervals, they allow the actors in the supply chain to make their orders more precise as the time point of delivery gets closer. They show that if the member of the supply chain share information with intelligent support technology, and agree on better and better fuzzy estimates on future sales for the upcoming periods the bullwhip effect can be significantly reduced. However, they did not consider the uncertainty in the demands and lead times in their proposed model.

As a matter of fact, for analyzing the Bullwhip Effect in the real world, one should consider it in an uncertain environment. In this research, Fuzzy Logic is utilized as a means to represent and interpret the uncertainty in the real world supply chains. Thus, we propose to study the effect of fuzziness, i.e., information uncertainty, on the bullwhip effect. Here, it is assumed that all demands, lead times and order quantities have fuzzy values, i.e., they are imprecise. Then, the bullwhip effect is simulated in such an environment. To simulate the bullwhip effect in a fuzzy environment, we need to apply a fuzzy time series model. Among the available fuzzy time series approach, the Hong method (Hong, 2005) is selected and a GA module is added to obtain the value of window basis. In addition, a back propagation Neural Network module is added to defuzzify the output of Hong's model. After simulating the bullwhip effect in such an environment, an Agent-Based model is developed to reduce the bullwhip effect in the above mentioned situation. Geary, Disney, and Towill (2005) categorized all previous approaches for reducing the bullwhip effect into five categories: OR Theory, Filter Theory, Control Theory, Adhocacy, and What-if simulation procedure. The proposed solution is a combination of OR Theory and What-if simulation approaches.

The rest of this paper is organized as follows: In Section 2, first a review of the fuzzy time series models is presented; then a modified Hong approach (Hong, 2005) is proposed. Next, based on the new fuzzy time series model, the bullwhip effect is simulated. In Section 3, we discuss Agent-Based supply chain management. Then, an agent-based model for reduction of the bullwhip effect is developed. Finally, the conclusions and some guidelines for future research are presented in Section 4.

2. Model and algorithm of simulation

In this section, we first review fuzzy time series models and then propose a new approach that is developed by modifying Hong (2005) method. Finally, our approach is defined and simulated.

2.1. Fuzzy time series models

In the literature, there exist several forecasting models. The main drawback of traditional forecasting methods is that they are unable to deal with forecasting problems in which the historical data have linguistic values. In order to overcome this drawback, Song and Chissom (1993a) proposed the concept of fuzzy time series. Song and Chissom (1993b, 1994) presented two fuzzy time series models to solve enrollment forecasting problems of the University of Alabama and obtained good forecasting results. In the following, we briefly review the concept of fuzzy time series from (Song & Chissom, 1993a).

Definition 1 (Song and Chissom, 1993a). Assume that the universe of discourse, $Y(t)$ $(t = \ldots, 0, 1, 2, \ldots)$ is a subset of real numbers and $\mu_i(t)$ $(i = 1, 2, \ldots)$ are fuzzy sets defined on $Y(t)$. Let $F(t)$ be a collection of $\mu_i(t)s$ $(i = 1, 2, \ldots)$. Then $F(t)$ is called a fuzzy time series of $Y(t)$ $(t = \ldots, 0, 1, 2, \ldots)$.

It can be observed that $F(t)$ is a function of time t, and $\mu_i(t)s$ are linguistic values of $F(t)$, where $\mu_i(t)$ $(i = 1, 2, \ldots)$ is represented by a fuzzy set. Song and Chissom (1993a) divided the fuzzy time series into two categories: the time-invariant and the time-variant fuzzy time series.

Definition 2 (Song and Chissom, 1993a). If $F(t)$ is caused by $F(t-1)$ denoted by $F(t) \to F(t-1)$, then this relationship can be represented by

$$F(t) = F(t-1) \circ R(t, t-1) \qquad (1)$$

where, $R(t, t-1)$ is a fuzzy relationship between $F(t)$ and $F(t-1)$ and is called the first-order model of $F(t)$, and "$\circ$" is the max–min composition of $F(t-1)$ and $R(t, t-1)$.

Definition 3 (Song and Chissom, 1993a). Assume that $F(t)$ is a fuzzy time series, and $R(t, t-1)$ is a first-order model of $F(t)$. If $R(t, t-1) = R(t-1, t-2)$ for any time t, then $F(t)$ is called the time-invariant fuzzy time series. If $R(t, t-1)$ is dependent on the time t, i.e., $R(t, t-1)$ may be different from $R(t-1, t-2)$ for any t, then $F(t)$ is called the time variant fuzzy time series.

Similar to the traditional time series, in fuzzy time series models the historical data is used to set up a relationship among values of interest at different times. However, the relationship in fuzzy time series is different from that of traditional time series. These relationships are models. In fuzzy time series, the knowledge of the past experience is applied into a model and the knowledge has the form of "IF … THEN …" rules. So, the main characteristic of modeling fuzzy time series is to identify the historical law in "IF … THEN …" forms (Song & Chissom, 1993b).

Wang et al. (1996) proposed a new method of fuzzification to revise Song and Chissom's method. They used a different triangular fuzzification method to fuzzify crisp values, and involve determining an interval of extension from both sides of crisp value in triangular membership functions to get a variant degree of membership. Wang