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A simulation of vendor managed inventory dynamics using fuzzy arithmetic operations with genetic algorithms

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ABSTRACT

This paper develops a new simulation method for vendor managed inventory (VMI) model based on fuzzy arithmetic in the supply chain (SC). The traditional VMI model has been successfully used to reduce the "Bullwhip Effect" in the SC. Thus, in real industry the VMI model can be observed that some variables/parameters may belong to the uncertain factors. Therefore, the traditional VMI model may need to be extended to treat the vague variables or parameters. This study develops a fuzzy system dynamic to simulate vendor managed inventory, automatic pipeline, inventory and order based production control system (VMI-APIOBPCS) model based on fuzzy difference equations, and these operators of difference equations adopt the weakest *t*-norm (T_W) operators. Based on the weakest *t*-norm operators we can get the approximate result using sup-min convolution for simulating fuzzy VMI model, and the fuzzy VMI model can be easier simulated under uncertain environment Moreover, the results of fuzzy VMI-APIOBPCS model can provide the whole extended information regarding the system behavior uncertainties for the decision-makers with fuzzy interval. Furthermore, the study uses genetic algorithms (GA) to search optimal parameters of fuzzy VMI-APIOBPCS model. The performance of Bullwhip measures shows that fuzzy VMI-APIOBPCS model also can reduce the "Bullwhip Effect" as crisp VMI model which can be evidenced by analysis of variance (ANOVA), and the performance of integral of time × absolute error (ITAE) shows that the fuzzy VMI model outperforms previous method with fixing customer service level.

1. Introduction

A traditional supply chain is a system consisting of material suppliers, production facilities, distribution service, and customers who are all linked together via the delivers and orders (see Fig. 1, Stevens, 1989). In traditional SC model each player is responsible for his inventory control, production or distribution ordering activities, and each echelon only has information their immediate customers. This lack of visibility of real demand causes a number of problems in traditional SC. Among the "Bullwhip Effect" is a common phenomenon/problem in traditional supply chain. Lee, Padmanabhan, and Whang (1997a, 1997b) refers to the scenario where the orders to the supplier tend to have larger fluctuations than sales to the buyer and the distortion propagates upstream in an amplified form. Therefore, many industries were required to improve supply chain operations by sharing inventory or demand information for supplier and customer. Different markets sectors have developed alternative terms based on the same idea of vendor managed inventory. The VMI can increase cooperative relations between supplier and customer, controlling inventory, increasing cash flow and operating flexibility. Hence, VMI has been widely applied to various industries. For example, one survey found that in hospital materials management, VMI achieved higher penetration than just-in-time and stockless methods (Gerber, 1991). Another survey of the VMI is discussed in some detail with a case illustration to examine the practical implementations of the system in the Taiwanese grocery industry (Tyan & Wee, 2003). VMI is a unique supply chain control strategy as advocated by Christopher (1992), Holmström (1998), Waller, Johnson, and Davis (1999). Rusdiansyah and Tsao (2005) used the ideas essential to VMI to solve procedures of the Inventory Routing Problem (IRP) encountered in vending machine supply chains working.

Moreover treating uncertainty is also an important issue in supply chain modeling and analysis of supply chain behavior and performance. Different sources of uncertainty in the supply chain model can exist, encompassing suppliers, production/manufacturing processes and customers. These uncertainties may be different in nature, caused by random events, imprecision in judgment, lack of evidence availablility or lack of certainty in evidence. There are

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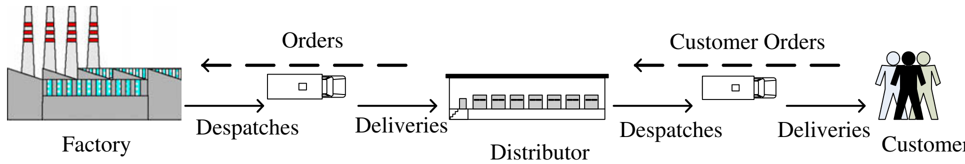

Fig. 1. An illustration of a traditional supply chain.

many important contributions to treat the randomness in SC systems by fuzzy set successfully (Petrovic, Roy, & Petrovic, 1998; Petrovic, Roy, & Petrovic, 1999; Petrovic, 2001). Wang and Shu (2005) develops a fuzzy decision methodology that provides an alternative framework to handle SC uncertainties and to determine SC inventory strategies, while there is lack of certainty in data or even lack of available historical data. Aliev, Fazlollahi, Guirimov, and Aliev (2007) point out that we are usually faced with uncertain market demands and capacities in production environment, imprecise process times, and other factors introducing inherent uncertainty to the solution. Their research developed a fuzzy production–distribution aggregate planning problem in SC. The model is formulated in terms of fuzzy programming and the solution is provided by genetic optimization. Alex (2007) provides a novel approach to model the uncertainties involved in the supply chain management using the fuzzy point estimation. Selim, Araz, and Ozkarahan (2008) adopted different fuzzy programming approaches for the collaborative production–distribution planning problems in different SC structure. Thus, from previous research we can observe that the VMI model has not been investigated in an uncertain environment. Most researches of fuzzy SC focus on discussing traditional SC model, and previous research can not provided whole extended information. Hence, this research develops a fuzzy system dynamic to simulate VMI-APIOBPCS model, and in fuzzy VMI-APIOBPCS model these operators of difference equations adopt the weakest t-norm (T_W) operators.

The rest of this paper is organized as follows: in the following, Section 2 introduces the weakest t-norm operations of fuzzy number system, and Section 3 introduces the principle of system dynamic with fuzzy arithmetic. This fuzzy system dynamics method can model complex and dynamic systems in general with fuzzy variables and operations. Section 4 depicts the VMI-APIOBPCS model with fuzzy arithmetic and Section 4.1 shows procedure of GA algorithms for parameter selection of VMI-APIOBPCS model. Section 4.2 shows general dynamic comparison of crisp and fuzzy VMI-APIOBPCS with GAs. Finally, the research draws conclusions and makes suggestions for further research in Section 5.

2. The weakest *t*-norm operations of fuzzy number

The fuzzy arithmetic, following the Zadeh's extension principle (Zadeh, 1965) for the fuzzy set theory, was investigated first by Dubois and Prade (1980), Mizumoto and Tanaka (1976), amongst others. The importance of t-norm has been shown in Ling (1965), Hong (2001a, 2001b), and also the references therein. For fuzzy sets or fuzzy numbers on the real line $\Re$, the following definitions and the fuzzy arithmetic may be introduced.

Fuzzy numbers – Let $\widetilde{A}$ be a fuzzy set or a fuzzy number (FN) on $\Re$ and can be written as (a_1, a_2, a_3), where a_2 thus denotes the *mode* and a_1 and a_3 denote the *left and right bounds*, respectively of $\widetilde{A}$, with the *membership function* $\widetilde{A}(x)$ that defines the membership grades of elements $x \in \Re$ to $\widetilde{A}$:

$$\widetilde{A}(x) = \begin{cases} 0, & x < a_1, \\ L((x-a_1)/(a_2-a_1)), & a_1 \leqslant x \leqslant a_2, \\ R((a_3-x)/(a_3-a_2)), & a_2 \leqslant x \leqslant a_3, \\ 0, & x > a_3, \end{cases}$$

where L and R, respectively denote the *left and right shape functions* of $\widetilde{A}(x)$, and L and R are necessary satisfying below conditions:

(1) $L(0) = R(0) = 1$ and $L(1) = R(1) = 0$ and for $x \in (0,1), L(x) \in (0,1), R(x) \in (0,1)$.
(2) L and R are non-increasing and continuous functions from $[0,1]$ to $[0,1]$.

In particular, the fuzzy numbers with triangular membership functions or called triangular fuzzy numbers (TFNs) may be shown as

$$\widetilde{A}(x) = \begin{cases} 0, & x < a_1, \\ (x-a_1)/(a_2-a_1), & a_1 \leqslant x \leqslant a_2, \\ (a_3-x)/(a_3-a_2), & a_2 \leqslant x \leqslant a_3, \\ 0, & x > a_3, \end{cases}$$

In the Zadeh's extension principle Zadeh (1965), if generalized by using a general norm T that replaces the original 'min', and the binary T norm on the interval $[0,1]$ is said to be a triangular norm (or called t-norm) iff it is associative, commutative, and monotonous in $[0,1]$ and $T(x,1) = x$ for every $x \in [0,1]$. Therefore, four basic arithmetic operations of t-norm can be written as

(1) Addition:

$$(\widetilde{A} + \widetilde{B})(z) = \sup_{x+y=z} T(\widetilde{A}(x), \widetilde{B}(y)).$$

(2) Subtraction:

$$(\widetilde{A} - \widetilde{B})(z) = \sup_{x-y=z} T(\widetilde{A}(x), \widetilde{B}(y)).$$

(3) Multiplication:

$$(\widetilde{A} \times \widetilde{B})(z) = \sup_{x \times y=z} T(\widetilde{A}(x), \widetilde{B}(y)).$$

(4) Division:

$$(\widetilde{A} / \widetilde{B})(z) = \sup_{x/y=z} T(\widetilde{A}(x), \widetilde{B}(y)).$$

where the binary T norm on the interval $[0,1]$ is said to be a triangular norm (or called t-norm) iff it is associative, commutative, and monotonous in $[0,1]$ and $T(x,1) = x$ for every $x \in [0,1]$. Moreover, each t-norm may be shown that satisfies the following inequalities

$$T_W(a_2,b_2) \leqslant T(a_2,b_2) \leqslant T_M(a_2,b_2) = \min(a_2,b_2),$$

where

$$T_W(a_2,b_2) = \begin{cases} a_2, & \text{if } b_2 = 1, \\ b_2, & \text{if } a_2 = 1, \\ 0, & \text{otherwise}, \end{cases}$$

T_W is the weakest t-norm. The importance of t-norms, e.g., $\min(a_2,b_2), a_2 \cdot b_2, \max(0, a_2+b_2-1), T_W(a_2,b_2)$, has been shown in Dubois and Prade (1980), Hong and Do (1997). It is well known that the addition/subtraction of fuzzy numbers by T_M and T_W preserves the original shape of the fuzzy numbers. With the T_M in