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The distribution processing and replenishment policy of the supply chain under asymmetric information and deterioration: Insight into the information value

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ABSTRACT

This paper proposes a dynamic lot-sizing problem for the supply chain, based on the fuzzy theory. Past studies on inventory problems of asymmetric information typically focus on suppliers providing incentive contracts to attract buyers to cooperate with the replenishment policy, and the uncertain environment is constructed by statistics and probability methods. However, random variables are difficult to calculate during the analysis process. This paper focuses on analyzing how asymmetric information will affect cost deviation. The analytical result can be an important basis for decision makers when deciding budget for gaining insight into the information. This proposed problem considers the fact products deteriorate before distribution processing. In this problem, asymmetric information is constructed, using fuzzy theory. Suppliers may be responsible for monitoring the cost, to gain insight into the information. However, if the investment budget is larger than the cost deviation caused by the asymmetric information, it is not worthwhile. Decision makers must understand the degree of cost deviation caused by asymmetric information. This paper proposes some properties and theorems of the proposed problem. This paper applies those proposed properties to reduce the solution space for the algorithm to search. An ant colony optimization is constructed to solve this problem, based on the theorem of this paper. Numerical analysis shows variables related to asymmetric information affect cost deviation.

1. Introduction

Asymmetric information means buyers or sellers possess more information than the other party in market transactions. When buyers and sellers achieve information transparency with information sharing, this is called *full information*. Non-transparent information in the supply chain is categorized as asymmetric cost information and asymmetric demand information. Asymmetric demand information causes transmission distortions in demand information between members. Upstream members' information distortion is more significant. This will cause upstream members' larger demand variance than downstream members'. This phenomenon is known as the bullwhip effect. Such effects cause supply chain inefficiency, excessive inventory, and higher costs (Dejonckheere, Disney, Lambrecht, & Towill, 2003). In the cost structure of asymmetric information, decision makers' optimum planning may yield deviation. Mishra, Heide, Jan, and Cort (1998) stated asymmetric information widely exists between consumers and retailers, and between manufacturers and retailers. The asymmetric information between manufacturers and retailers may be corrected with incentive contracts and monitoring. Suppliers may seek an information intermediary for information transparency (i.e., insight into the information). The information intermediary plays the role of information gathering and analysis. The information intermediary profits by providing required information to buyers or sellers, and does not own any actual product (Grover & Teng, 2001). This paper proposed a dynamic lot-sizing problem considering asymmetric information.

Since a one-stage dynamic lot-sizing problem was solved by Wagner and Whitin (1958), dynamic lot-sizing has been the most discussed topic. Studies for multistage dynamic lot-sizing problems include: Jaruphongsa, Cetinkaya, and Lee (2004), Gencer, Erol, and Erol (1999) and Özdamar and Birbil (1998). In practice, a serviceable quantity of deteriorating product will decrease with time variations. Smith (1975) proposed a one-stage dynamic lot-sizing problem, which states products deteriorate after some periods. The goal of this problem is to maximize revenues by determining a replenishment schedule and sales pricing. Friedman and Hoch (1978) proposed a one-stage dynamic lot-sizing problem, considering a non-increasing deterioration rate. Other works include: Hsu (2000, 2003). In these works, their dynamic lot-sizing problem assumes the supply quantity is unlimited. Due to resource constraints and seasonal effects, the supply of semi-finished products is limited and uncontrollable. Also, the deterioration rate of product is greatly reduced after distribution processing and packaging. This paper proposes a dynamic lot-sizing problem without

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deterioration after distribution processing. The proposed problem also considers asymmetric information.

This paper proposes a dynamic lot-sizing problem with deterioration and asymmetric information (DLSPDAI). Most previous studies construct asymmetric information model with random variables. However, probability and statistic methods possess some limitation and are not easy to implement. This paper utilizes the fuzzy theory to construct an asymmetric information model. To solve DLSPDAI, this paper proposes several theorems, and develops a modified ant colony optimization. The organization of this paper is as follows: Section 2 introduces related literatures considering the inventory problem of asymmetric information. Section 3 formulates DLSPDAI and constructs an algorithm. Section 4 analyzes how asymmetric information parameters affect cost deviation. Section 5 summarizes the experiment results and suggests further research.

2. Literature review

Past literatures considered inventory problems with asymmetric information and incentives contract, and most adopted statistics and probability approaches. Corbett and de Groote (2000) proposed a joint economic lot-sizing problem considering asymmetric information. The objective function minimizes expected cost. In their problems, suppliers used price discounts as incentives, and the time-varying approach in the problem was continuous. Corbett, Zhou, and Tang (2004) further categorized the test environment into three incentive types: (1) simple wholesale pricing schemes, (2) two-part linear schemes of fixed wholesale price and side payment and (3) two-part nonlinear schemes. They reviewed the performances under both full and asymmetric information. The objective function was to maximize expected profit.

Chu and Lee (2006) reviewed a newsboy inventory model containing asymmetric information in a supply chain. The supply chain members are comprised of a seller and a retailer, and the supply chain adopts vendor-managed inventories (VMI) as the collaboration model. Lau and Lau (2005) reviewed a scenario adopting the Stackelberg game to determine pricing and batch-size. The supply chain members include a manufacturer and a retailer. Lau, Lau, and Zhou (2007) extended the research of Lau and Lau (2005). They considered the model for dominant manufacturers' asymmetric information. The aforementioned literature discussed supply chain members' relationships toward pricing, batch-size and profit. Reyes (2005) researched a two-echelon newsboy model with asymmetric market information, and assumed retailers possess more demand information. His works mainly discuss how manufacturers gather market information to enhance supply chain efficiency. Yue, Mukhopadhyay, and Zhu (2006) adopted the Bertrand game to discuss the pricing for a complementary product. Three supply chain environments are implemented in their work: (1) there is asymmetric forecast information between members, (2) members adopt forecast information for sharing and (3) members form a strategic alliance. Sucky (2006) proposed an inventory model with an asymmetric model to optimize joint order and production policy. His works assumed buyers' cost structure is non-deterministic. Burnetas, Gilbert, and Smith (2007) reviewed a scenario where suppliers coordinate the asymmetric information by incentive contracts. Other works include: Cachon and Lariviere (2001), Sucky (2004), Taylor (2006) and Corbett (2001).

Past works show most asymmetric information inventory problems for a supply chain possess random variables, and they are often discussed in continuous-time model. These works coordinate pricing and lot-sizing with incentive contracts to maximize profits or minimize costs. This paper mainly analyzes how asymmetric parameters affect cost deviation, and utilizes fuzzy theory to construct the model for asymmetric information. The analytical result will be a basis for decision-makers' reference. The analytical result can be adopted by decision makers as a basis to determine budgets for insight into the information. This paper facilitates fuzzy theory to construct inventory problems of asymmetric information.

3. Problem and method establishment

Enterprises nowadays often adopt postponement strategy. They often postpone the final packaging or assembly operations until products are in the distribution centers, which are closer to final customers. The manufacturing process in the distribution center is known as *distribution processing*. This paper assumes the deterioration rate after distribution processing is negligible.

3.1. Fuzzy numbers

This paper demonstrates asymmetric information with the fuzzy theory. To construct uncertain scenarios, statistics and probability are common methods. It is easier to calculate fuzzy numbers than random variables. Therefore, the fuzzy theory's efficiency for calculation is higher than probability and statistics. The definition of a fuzzy number in this paper is based on the works of Kaufmann and Gupta (1985). The fuzzy number and calculation in this paper are shown as follows:

Definition 1. In a universe of discourse X, fuzzy number $\underset{\sim}{A}$ is a fuzzy set. This set is characterized as the degree of membership function μ_A associates with each element in X. μ_A is a function in the interval [0, 1]. The membership function can be defined as

$$\mu_{\underset{\sim}{A}} : X \to [0,1]. \tag{1}$$

Besides, u is an element of universe of discourse X, and $\mu_A(u)$ is a membership function for fuzzy number A. This function value represents the degree of u associated with $\underset{\sim}{A}$, as

$$\underset{\sim}{A} = \{(u, \mu_{\underset{\sim}{A}}(u)) | u \in X\}. \tag{2}$$

Definition 2. Discrete fuzzy set

When the universe of discourse X is a finite discrete set $\{u_1, u_2, \ldots, u_n\}$, fuzzy set $\underset{\sim}{A}$ can be shown as

$$\underset{\sim}{A} = \frac{\mu_{\underset{\sim}{A}}(u_1)}{u_1} + \frac{\mu_{\underset{\sim}{A}}(u_2)}{u_2} + \cdots + \frac{\mu_{\underset{\sim}{A}}(u_n)}{u_n} = \sum_{i=1}^{n} \frac{\mu_{\underset{\sim}{A}}(u_1)}{u_i}. \tag{3}$$

Eq. (3) represents discrete fuzzy number. $\mu_{\underset{\sim}{A}}(u_i)/u_i$ does not imply a fraction, and it implies a relationship between element u_i and the respective membership function value. Σ does not imply a sum, and a conjunction notation for each element and membership function value.

Definition 3. Fuzzy number sum

$A(+)B$ represents the sum of A and B. The membership function is defined as follows:

$$\mu_{A(+)B}(z) = \bigvee_{z=x+y} (\mu_A(x) \wedge \mu_B(y)) \tag{4}$$

where $\vee$ represents the notation for maximization; $\wedge$ represents the notation for minimization.

Definition 4. Fuzzy number multiplication

$A(\cdot)B$ represents the multiplication between A and B. The membership function is defined as follows:

$$\mu_{A(\cdot)B}(z) = z = \bigvee_{x \cdot y} (\mu_A(x) \wedge \mu_B(y)) \tag{5}$$