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Design of a replenishment system for a stochastic dynamic production/forecast lot-sizing problem under bullwhip effect

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Abstract

Inventory has the function of balancing production and demand. To shorten lead time, businesses adopt the make-to-stock approach that satisfies customer's demand by inventory through forecast. This approach highlights the two contradictory objectives: to lower stock cost and to satisfy customer's demand. Moreover, forecasting is one of the main causes of the bullwhip effect. Therefore, it is the policymaker's concern to have good production planning and replenishment control through effective inventory management under such a circumstance. This paper studies a stochastic dynamic lost-sizing problem under the bullwhip effect. To solve this problem, this paper proposes a solution of two-stage ant colony optimization (TACO) and adds a mutation operation in the second-stage ACO. The experiment is mainly composed of two parts, with the first part analyzing the solution quality of the TACO, and the second part discussing the relationships between the bullwhip effect, replenishment (forecast) cycle, and the cost.

Keywords: Ant colony optimization; Bullwhip effect; Stochastic; Lot-sizing problem; Replenishment system

1. Introduction

To survive fierce competition, businesses generally change their operation modes from individual operation to join the supply chain. Offering products timely has long been the goal of the supply chain members. To achieve this goal, when there is non-deterministic demand from the customer, businesses make demand forecasts on the basis of previous data, according to which the production plan is decided. This is the make-to-stock (MTS) approach. In this approach, the products are made in accordance with the forecasted demand. When the customer places an order, the demand is satisfied by the inventory. However, demand information is influenced by forecast when being passed upward in the supply chain and is thus increasingly distorted. The upper the member is, the more obvious the demand amplification will be. This is a key factor that causes the bullwhip effect (Lee, Padmanabhan, & Whang, 1997a, 1997b). This paper proposes a production planning and replenishment control method in the push-based supply chain in the MTS environment.

Replenishment management and production planning are critical research areas in the supply chain. The former focuses on replenishment control, while the latter emphasizes production schedules (i.e. lot-sizing problems). The bullwhip effect restraining is the issue of importance in replenishment control. Sterman (1989) simulated the beer distribution game using the system dynamics to present the bullwhip effect in the supply chain. The simulation result shows that the demand variability increases apparently when going upstream, thus revealing the existence of the bullwhip effect. Order-up-to policy is often employed to study the issues of the bullwhip effect. Chen, Drezner, Ryan, and Simchi-Levi (2000) studied how customer's demand information influences the order variability of each supply chain member by quantifying the bullwhip

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effect under the order-up-to policy and the moving average forecasting method. The result indicated that centralizing customer's demand information helps decrease the bullwhip effect. Dejonckheere, Disney, Lambrecht, and Towill (2004) also mentioned that information sharing is critical for reducing the bullwhip effect. Dejonckheere, Disney, Lambrecht, and Towill (2003), in response to the bullwhip effect, proposed a replenishment rule developed from the order-up-to policy through the control theory. Disney and Towill (2003) studied what benefits vendor-managed inventory brought to the bullwhip effect using the two-stage supply chain model under the order-to-stock policy. The studies mentioned above are not about the optimization of production planning. In optimizing the stochastic lot-sizing problem, Dellaert and Melo (1996) studied a stochastic lot-sizing problem for a single item in the make-to-order environment. Tarim and Kingsman (2004) discussed a single-item stochastic lot-sizing problem with stochastic demands and service-level constraint, with the purpose of determining replenishment quantity without considering the lead time. Other studies regarding stochastic lot-sizing problems include those of Haugen, Løkketangen, and Woodruff (2001), Martel, Diaby, and Boctor (1995), and Dellaert and Melo (2003). In these researches, the universal decision variable for minimizing the expected cost is the replenishment quantity, while this paper considers a stochastic dynamic lot-sizing problem in which the bullwhip effect is taken into consideration.

In view of the development of artificial intelligence technology and its extensive applications, this paper proposes a system framework of two-stage ant colony optimization (TACO), which adds a mutation operation to the problem being solved when implementing the algorithm, to determine the replenishment policy. What is to be decided is a stochastic dynamic production/forecast lot-sizing problem (SDPFLSP), in which the impact of the bullwhip effect is taken into consideration. The organization of this paper is as follows. Section 2 formulates the SDPFLSP model, in which the supply chain members adopt order-up-to policy in the MTS environment. Section 3 constructs the methodology and the simulation design. Section 4 is to test through the simulation experiment the solution quality of the modified ACO (M-ACO) and to study the impact of the bullwhip effect on the results. Section 5 summarizes the findings of this paper.

2. Formulation for the problem

In this paper, SDPFLSP is a lot-sizing problem considering forecast and production planning. This paper assumes that the products are counted by integers and the simple exponential smoothing method is used for demand forecast. The assumption of Dejonckheere et al. (2003) is used in the forecast model for demand information. That is, the demand information for period t can be used as the forecast of this period because the order is placed at the end of the period.

2.1. Notations and definitions

Let T denote the length of the planning horizon. For $t = 1, 2, \ldots, T$, the notations are defined as follows:

- K_{1t} the fixed cost of a production at the manufacturer in period t
- K_{2t} the fixed cost of a replenishment at the wholesaler in period t
- p_{1t} the unit production cost at the manufacturer in period t
- $\tilde{p}_{1t}$ the unit overtime cost at the manufacturer in period t
- p_{2t} the unit replenishment cost at the wholesaler in period t
- c_t the original capacity at the manufacturer in period t
- O the quantity of expanded production capacity at the manufacturer
- h_{1t} the unit holding cost at the manufacturer in period t
- h_{2t} the unit holding cost at the wholesaler in period t
- w_{1t} the unit shortage cost at the manufacturer in period t
- w_{2t} the unit shortage cost at the wholesaler in period t
- S_{1t} the order-up-to level used at the manufacturer in period t
- S_{2t} the order-up-to level used at the wholesaler in period t
- α_1 the smoothing constant at the manufacturer
- α_2 the smoothing constant at the wholesaler
- $\hat{y}_t$ forecast demand at the manufacturer at the end of period t
- $\hat{d}_t$ forecast demand at the wholesaler at the end of period t
- D_t final customer demand at the wholesaler in period t
- k_1 the variable for extra order quantity at the manufacturer
- k_2 the variable for extra order quantity at the wholesaler
- $\tilde{x}_t$ the ordering decision make at the manufacturer at the end of period t
- $\tilde{y}_t$ the ordering decision make at the wholesaler at the end of period t
- x_t the production quantity at the manufacturer in period t
- y_t the replenishment quantity at the wholesaler in period t
- I_{1t} the inventory level at the manufacturer at the end of period t
- I_{2t} the inventory level at the wholesaler at the end of period t
- T_0 the length of the replenishment cycle
- q_t the decision variables for expand production capacity at period t
- $\mathbb{Z}_0^+$ a non-negative integer