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The replenishment policy of agri-products with stochastic demand in integrated agricultural supply chains

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ABSTRACT

Market demand of agri-products is influenced by uncertain factors, such as weather, temperature, and customer preferences. In integrated agricultural supply chains, traditional inventory models are useless because of the stochastic demand and deteriorative characteristic of agri-products. This paper provides a method to determine the optimal replenishment policy of integrated agricultural supply chains with stochastic demand. In these EOQ/EPQ models, shortages are allowed and are backlogged if market demand is stochastic. The objective function is to minimize the total cost of the supply chain in the planning horizon. The total cost includes the ordering cost, the holding cost, the shortage cost and the purchasing cost. Thinking of the nonlinear relationship and dynamic forces in models, a system dynamic (SD) simulation model is constructed to find the optimal lot size and replenishment interval. Finally, an example is given to make a sensitivity analysis of the simulation model. Compared to traditional methods (such as equalize stochastic demand), the total cost decreases by 16.27% if the supply chains adopt the new replenishment policy. The results illustrated that the new replenishment policy (with intelligent method) is beneficial to help supply chain make decision scientifically. Moreover, the intelligent method can simulate stochastic demand perfectly, and it is effectively for solving the complicated and mathematically intractable replenishment problem.

1. Introduction

The fluctuation of agri-product demand can be affected by several uncertain factors, such as weather, temperature, and customer preferences. Because the occurrence of these uncertain factors is unpredictable, the agricultural supply chain (with traditional replenishment policy) may encounter vast decision-making mistakes and significant cost waste (Chen & Li, 2008). Moreover, stochastic demand makes the previous assumption that demand obeys a known distribution unreasonable to several types of agri-products (Cobb, Rumi, & Salmeron, 2013). The unreasonable assumption will make the previous economic order quantity (EOQ) and economic production quantity (EPQ) models with deteriorative items useless. In integrated supply chains, stochastic demand makes a replenishment policy with larger errors because of the joint inventory strategy between different players. In China, traditional agriculture supply chains are decentralized and complex systems. The joint inventory strategy is seldom used. However, with the development of order farming, players should make a replenishment policy together to achieve global optimality. The facility agriculture supply chain (FASC) is the main form of order farming in eastern China. It is studied in this paper as a type of integrated supply chain. In FASC, supermarkets order at a facility agriculture enterprise (FAE) based on market demand, and FAE makes a production plan based on the replenish requirement. Supermarket participates in the whole process of agri-products production, processing and circulation. It also provides services such as delivery, information consulting and sales for FAE (eg. Fangxinhengfeng Agricultural Co., Ltd in Hubei, China). Because of long product lead times and the deteriorative characteristics of agri-products, the production plan of FAE must depend greatly on supermarkets' orders in advance. Therefore, the replenishment policy of FASC should be formulated by considering stochastic demand. Additionally, in this integrated two-echelon supply chain, the demand of the supermarket is continuous, whereas FAE's demand is discrete. Previous studies have some flaws in determining the optimal joint solution as well. From the above analysis, EOQ and EPQ models of FASC are proposed, considering the certainty or randomness of the market demand in this paper. The deteriorative characteristic of agri-products, supply chain integration and other realistic factors are included. The values of EOQ and EPQ are calculated by minimizing the total cost of FASC. The total cost includes the order cost, shortage cost, holding cost and purchasing cost. Among them, purchasing cost can be divided into deterioration cost and sales cost.

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In the paper of Matthew, David and Carl (2011) and Sphicas (2014), EOQ/EPQ models that only considered backorders were proposed. These models were all based on the assumption that market demand was constant. The new EOQ/EPQ models formulated in this paper are a combination of backorders and stochastic market demand. Compared to Sicilia, M., and Febles-Acosta (2014) who considered a single-stage supply chain, this paper proposes the optimal replenishment policy of an integrated two-stage supply chain by uniting the EOQ and EPQ models. Because of the daily necessity character, shortages are allowed unless the stochastic demand dictates otherwise. Simulation appeared as the most effective tool to outline the actual relationships when the environment is plagued by variance. Cigolini, Pero, Rossi and Sianesi (2014) developed EOQ models based on forecast results by means of ARENA™ software tool. Jalali and Nieuwenhuyse (2015) focused on academic articles published between 1998 and 2013, aiming to unveil the extent to which simulation optimization had been used for solving practical inventory problems. They made a conclusion that the stochastic constraint in most of articles was related to customer service (and especially expected fill rate). However, the dynamic and stochastic demand, the perishable agri-products are less considered. Based on this, an intelligent system (system dynamic (SD) model) has been set up to find the optimal lot size and replenishment interval for agricultural supply chains. Meanwhile, there is a classical simulation model of the inventory cost in the system dynamic. This means that the SD can describe FASC perfectly with a certain extension.

The main purpose of this paper is to establish the EOQ and EPQ models for FASC with two scenarios. One scenario is certain market demand, and the other scenario is stochastic market demand. With the characteristics of these models, an SD simulation model has been built. Compared to previous studies (such as Sun, Li and Fang (2013), and Zhang and Zhang (2008)), the total cost decreases by 16.27% if the supply chains adopt the new replenishment policy. The organization of this paper is as follows. In Section 2, a review of several optimization approaches in inventory theory is presented. In Section 3, the mathematical models with certain demand are derived to minimize the total cost of FASC. In Section 4, uncertain demand is considered in the EOQ and EPQ models. In Section 5, an SD simulation model is proposed to find the values of the EOQ and EPQ is established. It can also determine the optimal replenishment interval. A case is provided in Section 6 to demonstrate the applicability of the proposed models. The contrastive analysis between the optimal solution and traditional method is performed in this section. Finally, the conclusions and possible future work are discussed in Section 7.

2. Literature review

Because of the asynchronism between order and production, players in the supply chain have to order well in advance. However, because of the high uncertainty in demand forecasting, it is difficult to formulate the optimal replenish quantity and frequency for players. Therefore, to decrease the operating cost, many studies regarding ordering and production opportunities are discussed as follows.

For a single period inventory, Lau and Lau (1997) developed a newsboy model with mid-period replenishment. In his model, the buyer negotiated a smaller initial lot at the selling season and then replenished sometime later to cope with the resource constraint in the season. Later, Lau and Lau (1998) introduced a model with two ordering opportunities as an extension. They analyzed the second-order time and order quantity. To research the harmonization of the two-order strategy with return policy, Lin and Hui (2008) established an optimization function aimed at maximizing the total expected profit. In the model, the manufacturer and retailer shared information such as price, cost and demand. Meanwhile, Linh and Hong (2009) developed a two-period newsboy model. The model shared the revenue contract, and the second ordering was performed at the end of the selling season. To receive a win-win outcome, authors discussed the methods to determine the revenue sharing ration and wholesale prices. Currently, more and more studies have adopted the revenue sharing mechanism (Pan, Lai, Leung, & Xiao, 2010; Van der Rhee et al., 2010). Unlike other studies, Kalpana and Kaur (2011) proposed not only the retailer's revenues to the manufacturer but also a DP model. The model considered both the possibilities of unsatisfied demand and unsold units at the end of the first ordering instance. They considered the whole supply chain rather than a single entity. With Dada, Petruzzi and Schwarz (2007) extending the classical one-period, stochastic-demand newsboy model to consider the situation that multiple suppliers produced random supply based on the quantities ordered, many researchers paid attention to the problem of multiple suppliers with uncertain supply. Ross, Rong and Snyder (2008) introduced an uncertain supply EOQ model, which could be solved in closed form. However, if an inventory system faces not only yield uncertainty but also the risk of supply disruptions, the single-period time truncation may distort the optimal order quantity. So, Schmitt and Snyder (2012) considered a multi-period setting to take advantage of inventory as both a proactive tool and a reactive tool. They demonstrated the importance of analyzing a sufficiently long time horizon, when modeling inventory systems were subjected to supply distribution. In addition to EOQ models, other researchers paid attention to EPQ. Pasandideh and Niaki (2008) optimized a multi-product EPQ model with discrete delivery orders and constrained space by using a genetic algorithm approach. Wee and Wang (2012) provided more flexibility for decision makers to vary the backordering rate via the two EPQ models. Moreover, Wee, Huang, Wang and Cheng (2014) proposed an EPQ model with partial backorders, considering linear and fixed backordering costs. Their approach determined whether the shortage period should be scheduled. In the complex algorithm part, Pasandideh, Niaki and Sharafzadeh (2013) developed a bi-objective multi-product EPQ model in which the number of orders was limited and imperfect items were produced. To calculate the value, the non-dominated sorting genetic algorithm (NSGA-II) and multi-objective particle swarm optimization (MOPSO) algorithm are proposed.

Classical inventory models about industrial products have been proposed in many literatures. However, significant works need to be done for determining the optimal ordering policy for the perishable inventory (Padmanabhan & Vrat, 1995). With the easily loss characteristic, the inventory models about perishable goods were more complex. Since Aggarwal and Jaggi (1995) extended Goyal's model into deteriorating items, the researches about perishable goods became more and more popular. In Jamal, Sarker, & Wang, 1997 generalized a model to allow for shortages and deterioration. However, they just had indicated that the total relevant cost might be convex by several simulations. Lately, Chang and Dye (2001) extended the model of Jamal et al.. Their model not only considered a varying deterioration rate but also requiring the backlogging rate. These models all ignored the difference between unit price and unit cost. Meanwhile, for commodities with short life cycle, the backlogging rate decreased with the consumers' waiting time. Sana (2011) considered the influence of selling price. In his EOQ model, the objective is to find the optimal ordering quantity and optimal sales prices that maximizes the vendor's total profit. Recently, Taleizadeh, Mohammadi and Cardenas-Barron (2013) observed the influence of temporary discount to purchasers' special order quantity, and Mishra and Singh (2013) presented an EOQ model for deteriorating items with power demand and shortage partially backordered. To optimal production, Mahata (2012) built an EPQ-based inventory model for exponentially deteriorating items. In the paper, retailer maintained a powerful decision-making right and could obtain the full trade credit was assumed. Meanwhile, an EPQ model for deteriorating items had been constructed under crisp and fuzzy environment in the paper of Pal, Mahapatra and Samanta (2014).