Food Cold Chain Equilibrium Based on Collaborative Replenishment

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ABSTRACT
This article analyzes the food cold chain (FCC) equilibrium based on collaborative replenishment policy. The entirety of collaborative replenishment (ECR) includes one supplier, one retailer and one consumer. The two players join in the non-cooperative game. Both of them pursue their own ideal benefits and achieve the equilibrium in terms of food quantity and price. A new iterative algorithm based on the theory of fixed point is designed to improve the equilibrium model. A numeric example was set to identify the applicability of the model. The parameter sensitivity analysis shows that the overall profit of ECR will increase with consumers' demand, while the customer satisfaction will decrease to some extent when the food deterioration rate and shortage cost increase, the overall profit of ECR will decrease. We find that the former leads to decreasing of the customer satisfactory and the latter do the opposite. Appropriate strategies should be chosen based on the actual situation for each equilibrium subject.

Keywords: Food cold chain, game, equilibrium, collaborative replenishment, fixed point Method.

1. Introduction

The food cold chain (FCC) is a specific supply chain, and it keeps the products in stable temperature to maintain its quality (Lan, 2009) [1]. In order to improve the customer satisfaction and reduce the cost, the cooperative relationship between the companies in FCC must be built, which can also prevent the occurrence of the bullwhip effect. The purpose of collaborative replenishment between the supplier and retailer in FCC is to get more benefits through the collaboration and integrate the plans together. Supply chain equilibrium is a branch of the Equilibrium Theory. Consumers will have their own demands on quality, quantity and price in the FCC, which will feed back to affect the collaborative replenishment between supplier and retailer. It will further affect the overall benefits of ECR.

We propose a FCC equilibrium model based on the collaborative replenishment policy. In the dynamic supply chain system, a supplier and a retailer get the maximum benefits through the collaborative replenishment. Then they reach the equilibrium condition by coordinating its relationship with consumers and making the consumers achieve their best satisfaction. After that, an iterative algorithm was designed based on the theory of fixed point to solve the analytical model. The method can avoid the previous difficulties of function derivation when applying the variational inequality to solving the supply chain equilibrium model.

The organization of the paper is as follows. First, we review literature in FCC, equilibrium theory and collaborative replenishment policy in Section 2. Then we make the analysis of FCC equilibrium based on collaborative replenishment in Section 3. Future more, we describe the establishment and analysis of the proposed model and its iterative algorithm in Section 4. Section 5 illustrates a numerical example to demonstrate the applicability of the proposed model. Finally, concluding remarks are then summarized in Section 6.

2. Literature review

2.1 Food cold chain (FCC)

The early research is based on the conditions to discuss the character of the FCC. Jean-Pierre Hugot et al. (2003) [2] believe that the Cold chain can combine with the food in order to keep its quality. K. Likar et al. (2006) [3] studied present situation, problems and countermeasures about

the FCC. With respect to the FCC management, Liu (2007) [4] researched the issues about the FCC under circumstance of supply chain and pointed out that the FCC was a special supply chain which could be improved and perfected by supply chain theory. Panda et al. (2008) [5] analyzed the inventory model on perishable seasonal products. Kanchana and Anulark (2006) [6] established a cyclical model to solve the two-stage perishable product inventory--distribution system problems. We can find that most researches built their models based on the special conditions, such as the temperature system. Few of them pay attention to the relationship between food quality and the price.

2.2 Supply chain equilibrium

Nagurney (2002) [7] developed a supply chain network equilibrium model with the competitive factors. Nagurney (2003) [8] proposed a dynamic global supply chain super network model, which considered the exchange rate effect on the benefits got by manufactures and sellers. On the basis above, Dong（2004）[9] and Jose M. Cruz (2011) [10] established a random demand equilibrium model. Anna Nagurney et al. (2012) [11] summarized the multi-period effects of social relationship in the supply chain networks and made the model. Other related studies from different perspective were as follows: Wua and Mallik (2010) [12] considered a supply chain system with two manufacturers producing a single substitutable product from an equilibrium aspect. Morales and Vermeulen (2009) [13] researched the existence of equilibrium in a decentralized two-level supply chain. Leng and Parlar (2010) [14] analyzed both simultaneous-move and leader–follower games to determine the Nash and Stackelberg equilibrium respectively. Wenlong Chai and Hujun Sun (2013) [15] studied the price competition of a supply chain with demand disruption, which optimized the profits of chain partners. Ian Liu and Haiyan (2013) [16] analyzed different cases of the optimal pricing and ordering strategy in Bertrand-Nash game and Stackleberg game. M. Cedillo-Campos and C. Sánchez-Ramírez(2013) [17] proposed a dynamic self-assessment of performance on supply chains operating, which come to the conclusion that it is necessary to integrate the local actors of differentiated advantages which include suppliers, manufacturers, logistics providers, etc.We can find that few people make research in the supply chain equilibrium of FCC, so we expand the using branch of the equilibrium theory.

2.2 Collaborative replenishment policy

Effective collaborative replenishment policy should balance the benefits of single point in the supply chain and the whole benefits of supply chain.

Ju-Chia Kuo et al. (2009)[18] combined the temperature control with the replenishment policy and made the advanced Multi-Temperature Joint Distribution System for the FCC. Zhang et al. (2006) [19] studied the time-based VMI collaborative replenishment pattern. Zhao and Wang (2008) [20] constructed a collaborative replenishment policy model which better reflect the modern market competition under random demand by introducing the CPFR operational mechanisms. Chu and Leon (2008) [21] considered the collaborative replenishment between a single-retailer and multi-buyer. Lyu et al. (2010) [22] proposed three collaborative replenishment mechanism models in the collaborative supplier and store-level retailer environment.

Since the 60s of last century, replenishment problems for deteriorating items had been paid much attention by scholars. Ghare and Schrade (1963) [23] first study the optimal replenishment policy for deteriorating items. Assuming that the deterioration was carried out by exponential distribution and the demand was a fixed constant, they finally got an EOQ formula. Lin (2007) [24] considered the collaboration between a supplier and a buyer and took the deterioration property into consideration. Du et al. (2007) [25] studied the problem of VMI inventory replenishment and shipment scheduling for deteriorating items, and developed a mixed replenishment ship model based on VMI under Poisson demand process. Hernandez, S et al. (2012) [26] proposed a new method,Golden-section Algorithm, for the multi-item replenishment problem to solve inventory management problems, which can be more effective than traditional method.

Despite remarkable advances in FCC, supply chain equilibrium and collaborative replenishment was discussed the issue of the FCC supply chain