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Modeling and analysis of the causes of bullwhip effect in centralized and decentralized supply chain using response surface method

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ABSTRACT

The "bullwhip" effect is a major cause of supply chain deficiencies. This phenomenon refers to grow the amplification of demand or inventory variability as it moves up the supply chain. Supply chain managers experience this variance amplification in both inventory levels and orders. Other side, dampening variance in orders may have a negative impact on customer service due to the increase in the inventory variance. This paper with simulating a three stage supply chains consisting of a single retailer, single wholesaler and single manufacturer under both centralized and decentralized chains. In this paper, it is intended to analysis the causes of bullwhip effect from two dimensions of order and inventory variance using the response surface methodology. The results show that in both supply chains, rationing factor is considered as the least important cause of bullwhip effect. While the wholesaler's order batching and the chain's order batching are considered as the main causes for the bullwhip effect in the decentralized and centralized chains, respectively.

1. Introduction

There is ample anecdotal evidence that many companies experience significant extra costs owing to supply chain problems. Konicki [1] showed that the company faced sharp falls in demand for products and sales merchandise was often out of stock when customers arrived in the store. Furthermore, bloated stocks of other goods were kept alongside these empty racks and display shelves, but they were not any guarantee for the high customers' service level. Therefore, inventory managers must consider two primary factors when making replenishment. First, a replenishment rule has an impact on order variability (as measured by the bullwhip effect, i.e., the ratio of the variance of orders over the variance of demand) shown to the supplier. Second, the replenishment rule has an impact on the variance of the net stock (as measured by the net stock amplification, i.e., the ratio of net stock variance over the variance of demand). This is the key trade-off faced by members of a supply chain. Indeed, the bullwhip effect is driving costs at the upstream stage (e.g. the manufacturer or supplier) and consequently, the downstream stage (e.g. the retailer) may not worry about it. Other side, dampening the bullwhip effect may have a negative impact on the customer service [2].

Forrester was one of the first researchers who pointed out to this phenomenon in 1961. He named this phenomenon as strengthening the demand [3]. Procter and Gamble named this phenomenon as the bullwhip effect to explain the observed behavior between customers and suppliers [4]. There are a lot of evidences resulted by this phenomenon in the industry for instance: the commercial operations of Campbell's Soup [5], HP and Procter & Gamble [4], a clothing supply chain [6], etc.

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This enlargement generates a large volume of inefficiencies such as increasing stock and generating stock outs while it is moving to a greater number of units than its necessary, [4,7,8]. Lee et al. defined this phenomenon as increase the variability of the order when the orders move up thorough the supply chain [4,9]. Hence, customers demand patterns convert to the highly irregular produce patterns for their supplier. They identified five main causes of the bullwhip effect i.e. lead time, demand signal processing, order batching, price fluctuations, and rationing and shortage gaming. Disney and Towill [6] considered a particular importance for the lead time and demand signal processing. Potter and Disney [10] have shown that setting the batch size such that a multiple of the batch quantity matches the average demand can result in the bullwhip measure reduction. Yao and Dong-Qing indicated that demand forecasting and ordering policies are two key methods of controlling the bullwhip effect [11]. Beside, Paik [12] based on an experimental design, identified the demand forecasting and lead time in purchasing as the most important variables for bullwhip control. Geary et al. [13] analyzed the different causes of bullwhip, highlighted the importance of synchronization and information sharing to be able to eliminate part of the uncertainty. Ton Hien Duc et al. [14] considered the forecasting technique as the most important cause because the inventory system of the supply chain is directly affected by the forecasting method. Adenso-Díaz et al. [8] summarized the different causes of bullwhip effect that has been identified in the literature as associated with the bullwhip phenomenon in the forward chain. Zotteri [15] investigated the causes and the effects of the bullwhip by analyzing the empirical demand data for fast moving consumer goods in a personal care sector.

In terms of engineering science techniques, control engineering attitude and statistical attitude are two common methods for quantifying the bullwhip effect. For instance, Lee et al. [9]; Chen et al. [16,17] used the statistical attitudes for quantifying the bullwhip effect and defined the bullwhip effect as a lower bound. They focused on quantifying the impacts of demand forecasting techniques [16,17] and demand processes [9] on the bullwhip effect for a simple and two-stage supply chain.

The usage of control engineering for controlling the production and inventory through the Laplace Conversion was firstly suggested by Simon [18]. The control engineering approach goes back to the work of Vassian [19]; Adelson [20]; Forrester and Technology [21] and Towill [22,23]. This methodology enables us to obtain the important insights in the dynamic behavior of replenishment rules. Likewise, there are other strategies discussed by Disney et al. [24], Ouyang and Daganzo [25], Sucky [26] and Ouyang and Li [27] for quantifying or mitigating the bullwhip effect.

The statistical method of response surface methodology (RSM) has been proposed to include the influences of individual factors as well as their interactive influences [28,29]. It is an empirical statistical modeling technique employed for multiple regression analysis. RSM uses the quantitative data obtained from properly designed experiments to solve multivariable equations and evaluate the relative significance of several affective factors even in presence of complex interaction, simultaneously. This paper is constructed based on a replenishment model similar to the one used by Disney et al. [24]. Based on this research, we consider the bullwhip effect and the net stock amplification named by Coppini et al. [30] as the inventory oscillations by generalized policy (s, S) used by each of chain members. In this paper, it is tried to study the impacts of causes of the bullwhip effect using RSM as well as their interactions on the demand and net stock amplification, concurrently.

This paper is organized as follows: in Section 2, modeling of the problem is explained in a three stage supply chains. Section 3 investigates the results and discussion. Section 4 presents the results of two supply chains. Finally, Section 5 summarizes our findings and conclusion.

2. Supply chain model

For modeling the problem, firstly, the parameters of the problem are defined. Then, the replenishment rule and response surface methodology are presented. Afterwards, the experiments with their detailed information such as the factors selection, levels determination and their response variable are presented. The experiments are considered in a single-product three-stage supply chain that each member has an unconstrained capacity. In this supply chain, a production–distribution serial system under both centralized and decentralized scenario is managed through the unidirectional flow of material.

2.1. Problem formulation

Let us introduce the following notations:

Parameters	Description
ANS	adjustment of net stock
AWIP	adjustment of work in progress
$\bar{D}$	the constant of demand
$\hat{D}_t$	demand forecast at period t
$\hat{D}^{TP+R}$	demand forecast over $T_p + R$ periods
i.i.d	independent and identically distribution normal distribution
K	the normal variant used to determine the safety stock in the order-up-to model
$T_p = L^*_{(i)}$	the physical production/distribution lead-time