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Modeling and analysis of cash-flow bullwhip in supply chain

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ABSTRACT

The bullwhip effect that occurs in supply chain inventory can distort demand forecasts and lead to inefficiencies such as excessive inventory, stock-outs, and backorders. In this paper we theorize that inventory bullwhip also leads to cash-flow bullwhip (*CFB*). Specifically, this paper focuses on studying *CFB* by developing mathematical and simulation models to analyze the relationship between inventory and cash-flow bullwhip by using Cash Conversion Cycle (*CCC*) as a metric. The mathematical models for inventory bullwhip are developed for two-stage and generic multi-stage supply chains, and then by extending these inventory models, the *CFB* models are developed for two-stage. *CFB* predicted by the proposed mathematical models approximately differ 14% from detailed simulation models. We find that increasing variability increases inventory and cash-flow bullwhip along with lead time, whereas increasing the demand observation period has the opposite effect. The average marginal impact of the bullwhip effect on the *CFB* is approximately 20%. Additionally, the *CFB* is also an increasing function of an expected value of inventory and a decreasing function of an expected value of demand.

1. Introduction

Most supply chains suffer from the effects of demand uncertainty, demand amplification, and information distortion from their immediate downstream order placement known as the “Bullwhip Effect” or “Whiplash” or “Whipsaw” effect (Lee et al., 1997; Jones and Towill, 2000). The bullwhip effect has been recognized in many companies. For example, Procter & Gamble and 3M found that the orders placed by the distributors had large fluctuation and the phenomenon was more severe in the upstream members while the customer demand was quite stable. The explanation of the bullwhip effect that is universally accepted is described by Lee et al. (1997). Such phenomenon arises when a downstream member in the supply chain place orders containing large variance compared to its actual sales (demand distortion), and this demand distortion propagates to its upstream member causing the demand amplification (Lee et al., 2004; Kahn, 1987; Metters, 1997; Baganha and Cohen, 1998). The bullwhip effect is illustrated in Fig. 1.

The graphs in Fig. 1 show the order quantity of each supply chain member over time. Customer demand (the rightmost graph) has little variation of the order quantity and then it becomes larger and larger when demand distortion propagates to the upstream member (the leftmost graph). The further upstream member in the supply chain the company is, the worse the bullwhip effect will be. We postulate that the bullwhip phenomenon in material flow may similarly happen to the cash flow across supply chain. The term “Cash Flow Bullwhip (*CFB*)” is introduced here in order to capture the bullwhip effect of the cash flow. The *CFB* is a similar phenomenon to the bullwhip effect of material except that it happens to the cash flow. Our motivation stemmed from the importance of cash as a crucial asset for operating a business, especially during the economic recession.

In this study, we develop the *CFB* from the Cash Conversion Cycle (*CCC*), which can be explained as follows.

$$CCC = \frac{Average\ Inventory}{COGS/365} + \frac{Average\ Account\ Receivable}{Revenue/365} - \frac{Average\ Account\ Payable}{COGS/365} \quad (1)$$

where *COGS* is a cost of goods sold.

The Cash Conversion Cycle (*CCC*) is the average days required to convert a dollar invested in raw material into a dollar collected from a customer (Stewart, 1995). It is one of the critical factors for a company to be successful in running business by representing how well the company manages its liquidity. A low *CCC* indicates that the company has lower financial cost to fund its business operation. A good example is Dell Computer Corporation which manages its *CCC* to be negative. In other words, Dell uses other people's money to operate its business (Farris and Hutchison, 2002). The *CCC* can be lowered by one or more of the followings; lower days-in-inventory outstanding, lower account receivable days, and higher accounts payable days. The smaller number of

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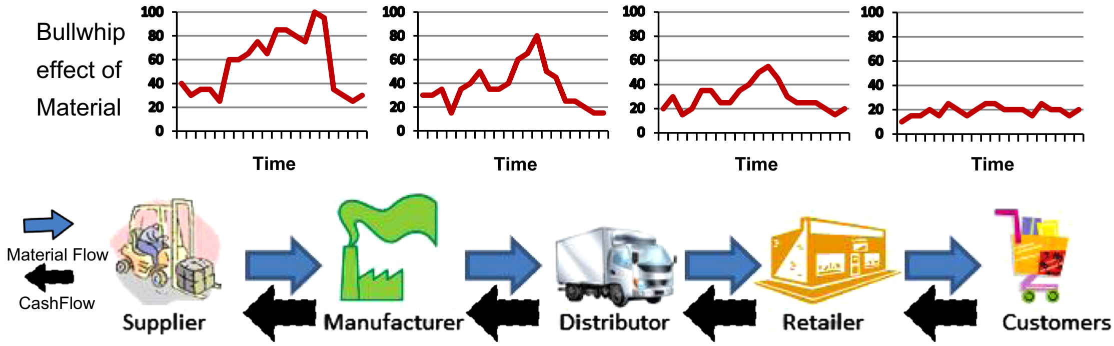

Fig. 1. Bullwhip effect of material flow in the supply chain.

days-in-inventory outstanding, the lower the *CCC*. However, Tsai (2008), who investigated the cash flow risks of a simple supply chain using an auto regression model, showed that some common practices used to lower the *CCC* can lead to higher cash flow risks (Tsai, 2008). Some other existing literatures relating the *CCC* to the supply chain, such as the work of Banomyong (2005), measured the *CCC* of the international supply chain. On the other hand, high *CCC* can lead to an opposite scenario. As shown in Eq. (1), the *CCC* can be increased by an increment of an average inventory, assuming that the other terms do not change. Disney and Towill (2003) found that the inventory variance increases when the production lead-time increases. Associated with the work of Chen et al. (2000), the increase of the lead-time results in the increase in the bullwhip effect.

Most of the existing literatures regarding the bullwhip effect emphasize the existence of the bullwhip effect, the reasons of its occurrence, and possible ways to lower it. For example, Sterman (1989) provided evidence of the bullwhip effect via the study of the 'Beer distribution game'. Similarly, Burbidge (1989) studied the bullwhip effect, prescribed reasons for its existence, and then concluded that demand amplification occurring across supply chains is a system induced phenomena influenced by information and material delays in the supply chain. Later on, four major causes of the bullwhip effect, which are (1) demand forecast updating, (2) order batching, (3) price fluctuation, and (4) rationing and shortage gaming, were identified (Lee et al., 1997). Jones and Towill (2000) studied the influence of the bullwhip effect to supply chain uncertainties known as the Uncertainty Circle, which is (1) supply side, (2) manufacturing process, (3) process controls, and (4) demand side. Additionally, they found that forecasting error can lead to shortage of supply which not only results in a loss of sale but also a loss of consumer confidence, which may impact future sales (Jones and Towill, 2000). The bullwhip effect or the demand amplification may also result in numerous negative effects: excessive inventory level, stock-outs and backorders, expensive production capacity swings, uncertain production planning, ineffective transportation, expensive cost for correction, distorted demand forecasting, and so forth (Lee et al., 1997; Chen et al., 1999). Lee et al. (2004) studied the flow of demand information across the supply chain and made observations regarding the distortion in demand information as it propagates up the supply chain as orders (Lee et al. (2004)). A number of studies dedicated to quantify the bullwhip effect as follows. Chen et al. (2000) formulated a model to quantify the bullwhip effect for a simple supply chain. Later on, Kim et al. (2006) developed a model for a stochastic lead time as well as Fiorolli and Fogliatto (2008) developed a model for a stochastic demand and lead time.

All the works surveyed in this literature review, however, mainly focus on analyzing and mitigating adverse effects of the bullwhip effect, or studying the effect of this phenomenon on inventory and ordering policies. On the other hand, the focus of this paper lies in modeling and analyzing the *CFB* as well as understanding its causes and managerial implications. The important contribution that our work seeks to make in comparison to previous research is to analyze its impact on the cash flow, particularly, the Cash Conversion Cycle (*CCC*). We postulate that the bullwhip effect may also impact the cash flow in the same way as it does to the material flow. Consequently, when the bullwhip effect of the material occurs, the *CFB* is anticipated to take place in a supply chain. We will explain and present how to model the *CFB* in Section 2.

The rest of the paper is organized as follows. The next section provides the analytical model to determine the *CFB* which is derived from the variability of inventory and the *CCC* for a simple supply chain and multi-stages supply chain. Section 3 gives an overview of the simulation model used for experimentation. Section 4 presents the results and discusses the impact of the bullwhip effect on the variability of inventory and *CFB*. Lastly, in Section 5 the conclusion and direction for future work are discussed.

2. Analytical model for *CFB*

In this section, we develop the analytical models for inventory bullwhip effect in a simple supply chain, and then extends the model for a multi-stages supply chain. The model shows how the bullwhip effect impacts the inventory. Then, we extend the inventory bullwhip effect model to the *CFB* model, which is derived from the Cash Conversion Cycle (*CCC*).

2.1. Impact on inventory in simple supply chain

Consider a simple supply chain which contains a single retailer and a single manufacturer. The retailer observes his inventory level at time t, I_t. By the end of period t, the retailer places an order q_t to the manufacturer. Assume the lead time L is fixed, thus, the order will be received at the start of period t+L. After the order is received, the retailer fills the customer demand D_t and backlogs any excessive demands. Kahn (1987) provides the demand model that the retailer faces in the form of

$$D_t = d + \rho D_{t-1} + \mu_t \tag{2}$$

where d is a nonnegative constant, ρ is a correlation parameter satisfying $|\rho| < 1$, and μ_t is an independent and identically normally distributed random variable with zero mean and variance σ^2. The demand model of this form has been used by many authors to analyze the bullwhip effect (Chen et al., 2000).

The approach in Chen et al. (2000) is used in this research as a starting point in the development of the proposed Cash Flow Bullwhip model. The order quantity (q_t) can be written relative to