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The effect of vendor managed inventory (VMI) dynamics on the Bullwhip Effect in supply chains

S.M. Disney*, D.R. Towill

Logistics Systems Dynamics Group, Cardiff Business School, Cardiff University, Aberconway Building, Colum Drive, Cardiff CF10 3EU, UK

Abstract

The paper compares the expected performance of a vendor managed inventory (VMI) supply chain with a traditional "serially linked" supply chain. The emphasis of this investigation is the impact these two alternative structures have on the "Bullwhip Effect" generated in the supply chain. We pay particular attention to the manufacturer's production ordering activities via a simulation model based on difference equations. VMI is thereby shown to be significantly better at responding to volatile changes in demand such as those due to discounted ordering or price variations. Inventory recovery as measured by the integral of time × absolute error performance metric is also substantially improved via VMI. Noise bandwidth, that is a measure of capacity requirements, is then used to estimate the order rate variance in response to random customer demand. Finally, the paper simulates the VMI and traditional supply chain response to a representative retail sales pattern. The results are in accordance with "rich picture" performance predictions made from deterministic inputs.

Keywords: Bullwhip; Forrester Effect; VMI; Supply chains; Inventory control

1. Introduction

This paper is concerned with the comparison of a vendor managed inventory (VMI) supply chain to a traditional "serially linked" supply chain. The particular emphasis of this paper is the impact the two supply chain structures have on the "Bullwhip Effect" (Lee et al., 1997a, b) generated within the supply chain. The performance is investigated using difference equations forming a simulation model. Focusing on one supplier one customer relationship, special attention is given to the manufacturer's production scheduling activities. The latter is known to be one well-established source of bullwhip (which we term the Forrester Effect after the seminal work of Jay Forrester (1961)). A number of standard ways of reducing bullwhip have been examined by Wikner et al. (1992), van Ackere et al. (1993), and summarised by Towill (1997). Furthermore, these methods actually work in the real world, as demonstrated by Towill and McCullen (1999). They found that, for a global mechanical precision product supply chain, bullwhip was typically reduced via an appropriate BPR Programme by 50%, and simultaneously stock turn improvements of 2:1 were observed.

VMI is of particular interest in the bullwhip context. Potentially VMI offers two possible

*Corresponding author. Tel.: +44-2920-8760-83; fax: +44-29-2087-4301.
E-mail address: disneysm@cardiff.ac.uk (S.M. Disney).

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sources of bullwhip reduction. Firstly, there is the elimination of one layer of decision-making. Secondly, we have the elimination of some information flow time delays. Since removing both factors reduces distortion, they can be utilised to damp down bullwhip. Hence herein we provide an overview of both VMI and the traditional supply chain in which the latter is used as our performance benchmark. We also describe how bullwhip, and particularly the Forrester Effect, can arise in the real world. The difference equations used to model the VMI and the traditional supply chains are described in detail. Optimum parameter settings from previous analytic and field research are also reviewed as possible starting points for the simulation studies.

The "rich picture" resulting from using step response tests are conclusive in indicating bullwhip reduction via VMI. As we have shown previously (Mason-Jones et al., 1997) this "rich picture" gives considerable insight into system response under a wide range of conditions. This includes the well-known supply chain phenomenon of rogue ordering. For example, a large positive spike of advance orders may appear, only to be followed by an equally large drop some time in the future, i.e. a net change of zero. Simulating the unit step input is also very useful as it is a very simple non-stationary input, from which many qualitative and quantitative performance aspects may be inferred. Many of these insights are difficult to achieve in an analytical approach only where stationary characteristics are typically studied. Such a waveform also emulates price discounting, as illustrated by Fisher et al. (1997). Inventory recovery is assessed via the use of the integral of time × absolute error (ITAE) performance metric. VMI is shown to be substantially better in reducing ITAE following a step demand by the customer. A step response is simply the integral of the impulse (or the spike induced by rogue ordering due to promotions). Thus, in a linear system the impulse response is directly related to the step. However, the step input has the advantage that it is accumulative and slight differences that off-set responses may be readily identified. It is thus our demand signal of choice. Order rate variance is conveniently estimated via the calculation of noise bandwidth. It is shown that the performance benefits predicted from the "rich picture" and order rate variance analysis are confirmed via simulation of the supply chain responses to a typical retail sales pattern.

2. Overview of a traditional supply chain

A supply chain is a system consisting of material suppliers, production facilities, distribution services, and customers who are all linked together via the downstream feed-forward flow of materials (deliveries) and the upstream feedback flow of information (orders), as shown in Fig. 1 (Stevens, 1989). In a traditional supply chain each "player" is responsible for his own inventory control and production or distribution ordering activities. One fundamental characteristic and problem that all players in a traditional supply chain (such as retailers, distributors, manufacturers, raw material suppliers) must solve is "just how much to order the production system to make (or the suppliers to supply) to enable a supply chain echelon to satisfy its customers' demands". This is the classic production/inventory control problem.

According to Axsäter (1985), "the purpose of a production/inventory control system (the method used to control inventory levels and production rates) is to transform incomplete information about the market place into co-ordinated plans for production and replenishment of raw materials". Practitioners tackle the production/inventory control problem by inspecting data relating to demands, inventory levels and orders in the

Fig. 1. Schematic of a traditional supply chain.