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Information sharing as a remedy to demand amplification in supply chains

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Abstract-- ***Demand amplification, also known as bullwhip effect, is the amplification of demand variability as it progresses up a supply chain. Bullwhip effect has determinental effects on the performance of supply chains. Objective of this paper is to quantify the impact of information sharing on bullwhip effect in a model of inventory and order based multi-echelon supply chain. System dynamics simulation, with the help of iThink software package, has been applied. It has been found through simulation experiments that information sharing can be a very effective strategy to control bullwhip effect across supply chains. Increasing the percentage of information sharing results in bullwhip reduction. In a model of four tiers supply chains, information sharing can reduce bullwhip effect from 20:1 to 8:1. This shows that supply chains manager can effectively reduce cost, improve customer service level and increase efficiency of their supply chains by sharing information across whole supply chains.***

Keywords: Demand amplification, Bullwhip effect, information sharing and supply chain.

1. Introduction

A supply chain is a network of facilities that together produce raw materials and transform them into intermediate goods and then final products that are delivered to end customers. A supply chain incorporates procurement, manufacturing, and distribution functions, with activities covering local, regional, and increasingly global levels. A supply chain can be composed of many functional levels called echelons or tiers as shown in Figure 1. Each echelon can have numerous facilities. The number of echelons, the different operational policies at different echelons, the material and information flows between these echelons and supply chain uncertainties (demand fluctuations, lead time variations) all contribute to the complexity of a supply chain.

Figure 1. Multi-echelon supply chain

One of the most devastating phenomena in a supply chain is the bullwhip effect, i.e. the amplification of demand variability as it progresses up a supply chain. The bullwhip effect was first observed in industry by Jay Forrester [1]. Forrester did not use the term "*bullwhip effect*" but named the effect "*Demand Amplification*". In some industries it is also known as the "Whiplash

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Effect". The term, "bullwhip effect" was first used by Proctor & Gamble and later made popular by [2]. Executives of *Proctor and Gamble* observed that even though the demand for nappies was fairly stable over time, the retailers' orders were highly variable. In turn, production orders were even more variable. Figure 2 shows phenomenon of bullwhip effect across four tier supply chain.

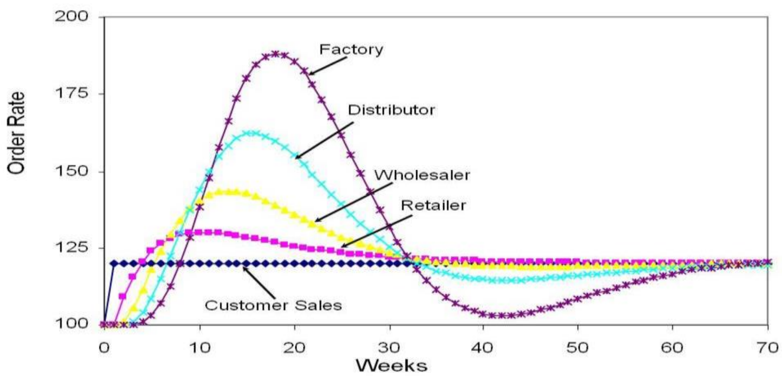

Figure 2. Bullwhip Effect in Multi-Echelon Supply Chain

Lee et al. [2] found that demand amplification or the bullwhip effect was due to demand signal processing, order batching, price variations and rationing and gaming and can be reduced through information sharing. Slack and Lewis [3] give an introduction to its causes and remedies. Its effects include inaccurate forecasting leading to periods of low capacity utilisation alternating with periods of not having enough capacity, i.e. periods of excessive inventory caused by over production alternating with periods of stock-out caused by under production. This leads to inadequate customer service and high inventory costs. Since the bullwhip effect is costly to upstream echelons of the supply chain, there is a real cost benefit associated with its reduction. Since the bullwhip effect is costly to upstream echelons of the supply chain, there is a real cost benefit associated with its reduction.

The impact of information sharing on the bullwhip effect has been discussed by many authors and they have revealed the value of information sharing, see for example [4,5,6,7] Some authors, such as [8] and [9], argue that the value of information sharing depends on the particular parameter values used within the supply chain model. It is argued that information sharing has no value for the supply chain. This study fulfils this gap and simulates the impact of information sharing across multi-echelon supply chains.

The remainder of this paper is organized as follows. In section 2, the methodology is introduced and then the supply chain simulation model is presented in section 3. After that, the impact of the batching on bullwhip effect under step and stochastic demand process has been explored, value of information sharing with respect to batch size has been discussed, and sensitivity analysis has been carried out in section 5. Section 6 concludes.

2. Methodology

System dynamics is an approach to understanding complex systems, using modeling and simulation techniques capable of modeling feedback loops explicitly and evaluating the dynamics of complex processes and systems. The particular system dynamics software used in this research is *iThink*®. This has been developed more for the business community rather than for control engineers, so it should be suitable for supply chain managers and designers [4]. Models are built in *iThink*® using *flows* (e.g. of products from a factory to an inventory), *stocks* to model simple inventories or process delays such as a factory between flows, *connectors* to provide information flows (e.g. feedback of actual inventory levels for comparison with desired levels) and *converters* to apply gain factors or other formulae to variables – see Figure 3

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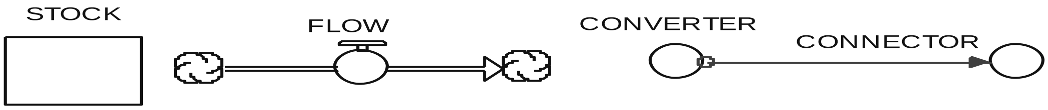

Figure 3: Building blocks of iThink software.

When the four-echelon supply chain is simulated, it is the 4th echelon that experiences the greatest demand amplification as it is farthest from the end-customer. As the dynamics of the inventory and order rate at the fourth echelon present the 'worst-case' scenario, the bullwhip effect experienced at this echelon is studied here. As the APIOBPCS design parameter values are varied, the same values are applied at all echelons in the supply chain as in previous studies, e.g. [10,11].

3. Multi-Echelon Supply Chain Model

Figure 4 presents the simulation model of the 4-echelon supply chain produced in *iThink*®. At the material flow level, each echelon consists of one inventory and one time delay, i.e. factory or other facility. Each echelon operates independently based on demand from downstream (towards the end-customer). At echelon-n, the input to the factory or other facility at time period *t* is the order rate ($ORATE^n_t$), which is determined by feeding forward the exponentially smoothed sales ($SSALES^n_t$), i.e. the demand forecast, and the actual end-customer demand, i.e. the smoothed sales from the retailer ($SSALES^1_t$), and feeding back the error in the inventory and the work-in-progress, with the aim of keeping the inventory at the desired level. The error in the inventory ($EINV^n_t$) is the difference between the desired inventory level ($DINV^n$) and the actual inventory level ($AINV^n_t$). Here, $DINV^n$ is fixed and equal to original demand. The work-in-progress (WIP^n_t) is the accumulation of orders that have been placed on the echelon but not yet completed and the desired WIP is $DWIP^n_t$. The error in the WIP ($EWIP^n_t$) is the difference between the desired $DWIP^n_t$ and the actual WIP^n_t . Ti is a divisor applied to the inventory deficit to control the rate of recovery and *Tw* similarly controls the WIP replenishment rate.

The retailer shares its end-customer demand with the other tiers, which then base their production rates ($ORATE^n_t$) on the weighted sum of this end-customer demand and incoming orders from their previous tier, i.e. their immediate customer in the supply chain. With full information enrichment (*IEP*=100%) a tier bases its $ORATE^n_t$ solely on end-customer demand, whilst with no information enrichment (*IEP*=0%) production is based solely on the incoming orders from the previous tier. $ORATE^n_t$ can be based on a combination using *IEP*% of end-customer demand plus (100 – *IEP*) % of the incoming orders from the previous tier; in the *iThink*® model these percentages are referred to as IEP1 and IEP2 respectively.

Demand needs to be forecast at each tier before applying it in scheduling and there are potentially many methods to do this. Simple exponential smoothing is used in the APIOBPCS model used here. This is justified as it is the basis of much industrial practice and the approach used in other published models, e.g. [10,11,12] . In *iThink*® the built-in function SMTH1 calculates the first-order exponentially-smoothed value, with the smoothing constant (*Ta*) representing the time to average sales and the average age of data in the forecast. The value of *Ta* determines the degree of smoothing applied to the demand and is subject to $0 \leq 1/Ta \leq 1$.

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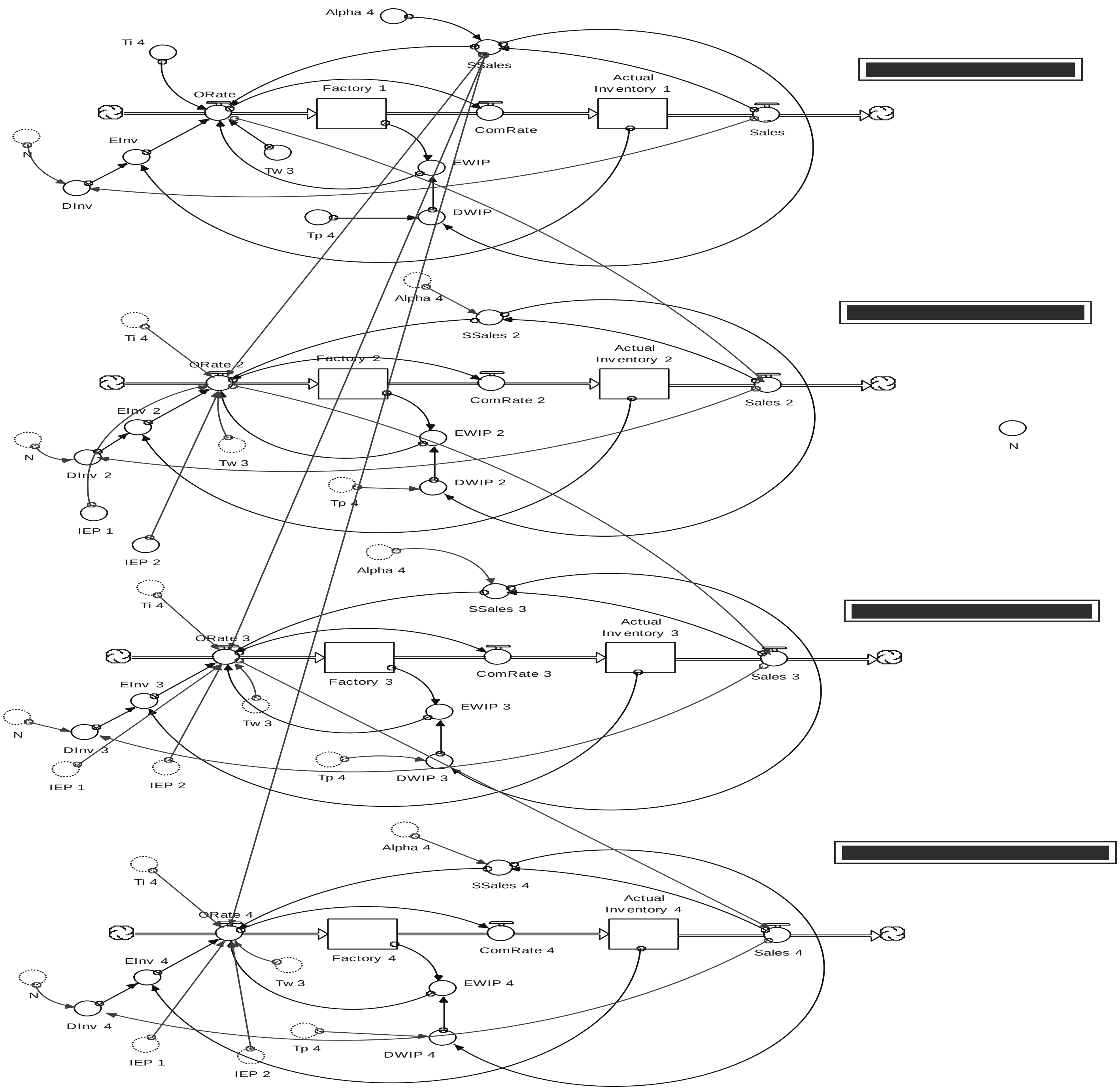

Figure 4: iThink Model of Multi-Echelon

Supply chain

$COMRATE^n_t$ is the completion (output) rate of the factory or facility at echelon-n. As a simple time delay (*Tp*) is used to model the lead time, $COMRATE^n_t$ is simply equal to $ORATE^n_{t-Tp}$. The actual inventory $AINV^n_t$ is the accumulation of stock determined by $COMRATE^n_t$ minus $SALES^n_t$

In summary, at echelon n:

for n=1: $SALES^1_t$ = the actual end-customer demand data (1)

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for n>1: $SALES^n_t = ORATE^{n-1}_t$ (2)

$SSALES^n_t = SSALES^n_{t-1} + (SALES^n_t - SSALES^n_{t-1})/Ta^n$ (3)

for n>1: $ORATE^n_t = IEP^n \times SSALES^1_t + (100\% - IEP^n) \times SSALES^n_t + EINV^n_t / Ti^n + EWIP^n_t / Tw^n$

(4)

for n=1: $ORATE^1_t = SSALES^1_t + EINV^1_t / Ti^1 + EWIP^1_t / Tw^1$ (5)

$COMRATE^n_t = ORATE^n_{t-Tp}$ (6)

$AINV^n_t = AINV^n_{t-1} + COMRATE^n_t - SALES^n_t$ (7)

$DINV^n = SALES^n_0$ (8)

$EINV^n_t = DINV^n - AINV^n_t$ (9)

$DWIP^n_t = Tp^n \times SSALES^n_t$ (10)

$EWIP^n_t = DWIP^n_t - WIP^n_t$ (11)

To verify the *iThink*® model, the difference equations (1) to (13) were also implemented in a spreadsheet model. This produced results that agreed with the *iThink*® results.

3.1 Measuring the bullwhip effect

Like ([13,14,16], Bullwhip Effect is measured as follows;

$$\text{Bullwhip} = \sigma_{ORATE}^2 / \sigma_{SALES}^2 \quad (12)$$

σ_{ORATE}^2 is the unconditional variance of *ORATE* at the tier of the supply chain being measured. σ_{SALES}^2 variance of *SALES* at respective tiers .

4. Analysis and Discussion

In the model used here there are five control or design parameters at each echelon: Information enrichment percentage (IEP); Time to adjust inventory (Ti); Time to adjust WIP (Tw); Production (or pipeline) delay (Tp); Time to average sales (Ta)- Exponential smoothing. [11] found that for a four tier supply chain, the best setting of the design parameters should be Tp = Ti = Tw = 2Ta and this setting has also been used by [7,11,15]. Hence, in this study Tp = Ti = Tw = 6 and Tp = 2Ta setting of the design parameter is applied across four tiers and impact of information sharing has been explored.

The information that can be shared includes inventory levels, sales data, demand forecasts, the status of orders, product planning, logistics and production schedules and can be grouped into three types: product information; customer demand information; inventory information. In this paper the sharing of customer demand information is first studied by comparing the performance of a supply chain with and without such information sharing. The basic, non-information-sharing supply chain is the four echelons, beer game model without information sharing and is constructed by joining together four APIOBPCSs. The retailer observes end-customer demand and upstream tiers take as their demand the incoming orders from their previous tier as shown in the *iThink* model diagram in Figure 3. In the information enriched version of the supply chain model, the retailer shares end-customer demand (perhaps EPOS data) with the upstream tiers so that they base their order rate on the end-customer demand and the incoming orders from their previous tier as shown in *iThink* model in Figure 4. In order to lessen the impacts of spikes in customer demand and to avoid ramping production up and down, which offers no benefits, customer demand is smoothed before sharing.

To combine the end-customer demand and the incoming orders from the previous tier in the

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supply chain, a simple weighted sum is used here. The weights must add to 100% (when expressed as a percentage) so that they do not distort the underlying demand value. The percentage applied to the end-customer demand is called the *Information Enrichment Percentage* (IEP). With full information enrichment (IEP = 100 %) a tier bases production on the end-customer demand, whilst no information enrichment (IEP = 0 %) means production is based on the incoming orders from the previous tier. Production can be based on a combination with IEP% of end-customer demand plus (100 – IEP) % of incoming orders from the previous tier; in the *iThink* model these percentages are referred to as IEP1 and IEP2 respectively. Five levels of information enrichment (IEP = 0 %, 25 %, 50 %, 75 %, and 100 %) are simulated. The tier that is furthest from the end-customer demand faces the worst impact of demand amplification. Hence, the impacts of information sharing on the dynamic response of the inventory and the order rate of the factory at the 4th tier are studied here.

Figure 5 shows the extremely beneficial impact of information enrichment on the dynamic response of the order rate of the factory after a 20% pure step increase (100-120) in demand. Results are observed on the order rate and inventory level of the factory (Tier 4). Information sharing yields a smaller initial overshoot and much dampened oscillatory behavior. The order rate of the 100% enriched factory begins to rise in week 2 while the order rate of 0% enriched factory does not start to rise until week 4; showing that information sharing speeds you the response as there is no delay due to having to propagate the signal through the supply chain. The additional 2 week delay equates to the 2 intervening echelons of the supply chain and with more layers this delay would grow.

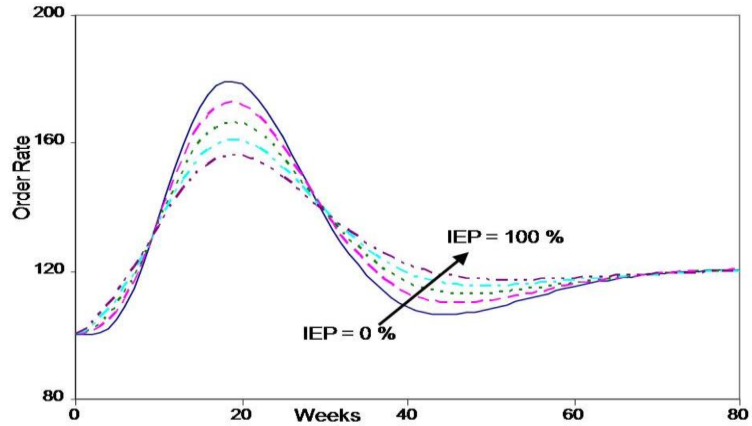

Figure 5. Impact of Information Sharing on Order Rate

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In the beer game model, the end-customer demand is distorted by each successive tier in the chain. However, in an information enriched supply chain each tier can base its forecast on the true end-customer demand. The sharing of real customer demand directly removes the problem of distortion and amplification which in turn improves the dynamic performance of the whole supply chain. In the example in Figure 5, 100% enrichment results in a 55% reduction in the overshoot of the order rate at the factory. This effect on the order rate would be extremely beneficial to a manufacturing business as very large fluctuations in order rate are met by costly over-capacity, buffer stocks or reduced service levels. However, even with information sharing, there is still much room for improving the dynamic performance by tuning the design parameters of the control system, especially Ta and/or Ti.

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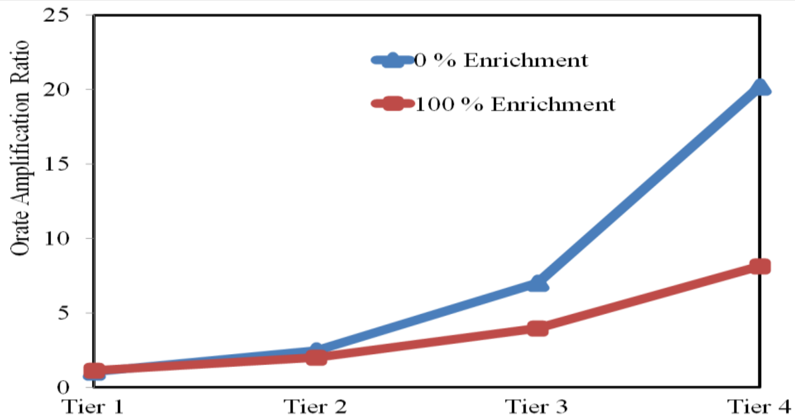

Figure 6. Impact of information sharing on bullwhip effect

4.1. Impact of information sharing on bullwhip effect

To simulate a stochastic customer demand, SALES follows a normally distributed, stationary stochastic I.I.D. process with a known mean, μ, and variance σ2. it is assumed that σ is significantly smaller than μ,, so that the probability of negative demand is negligible [2, 16]. A normally distributed stochastic demand pattern with a known mean of 100/week and standard deviation of 20 is simulated and the results are the average of 50 runs of the model, each of 500 weeks length.). Bullwhip effect is calculated by computing the variance ratios (variance of order at Tier n/ variance of end customer demand). The phenomenon of demand amplification can be seen clearly in Figure 6, which shows the variance amplification of the stochastic response for Tier 1 and Tier 4 with 0% and 100% IEP. It can be seen from Figure 6 that the bullwhip effect (the ratio of the variance of the order rates at concerned echelon in relation to the variance of end customer demand) gets extremely large at the farthest Tiers of supply chain. There is still bullwhip effect at all Tiers of supply chain in 100 % information enriched scenario, however the increase in variance amplification is much than it is in 0% information enriched supply chains. The increase in amplification ratio of the order seems linear at upstream tiers in information enriched supply chain, whereas it seems to be geometrical when there is no information sharing. In the literature, a typical amplification ratio observed between two echelons is 2:1 [17] and between four echelons is 20:1 [18]. In Figure 6, an amplification ratio of the order of 20:1 is indeed seen between Tier 4 with IEP=0% (no information sharing) and Tier 1. The amplification ratio can be reduced to the order of 8:1 through full information sharing, i.e. IEP=100% and this agrees with the findings of [13].

For the Warehouse (Tier 2), whilst the amplification ratio is less, making demand amplification arguably a less significant problem for two Tier supply chains, the use of information sharing can almost eliminate any significant demand amplification. There is a dilemma here because information sharing will have a cost associated with its implementation, and whilst it may deal with the problem of demand amplification very well, the problem is primarily caused at Tier 1. In contrast, information sharing is clearly of great value when supply chain got more than two Tiers. So, with the increasing of Tiers, there is an increasing justification for adopting and investing in information sharing.

4. Conclusion

This paper explores the impact of information sharing on bullwhip across four tiers supply chain. It is vital that the sharing of point of sales data among the supply chain partners minimizes the demand amplification. Information sharing has a direct impact on the production scheduling, inventory control, and delivery plans of supply chain members. Through information sharing the upstream members of the supply chain can have more accurate and timely customer demand information. For the Warehouse (Tier 2), whilst the amplification ratio of order rate is less, making demand amplification arguably a less significant problem for two Tier supply chains, the

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This study paves the way for a more detailed study into controlling the bullwhip effect and to extending the supply chain model to incorporate capacity constraints and order batching, as these are known to be further sources of demand amplification

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