Impact of History of Customer Demand Information in Supply Chain Performance

T. Chinna Pamulety
National Institute of Technology Calicut
Research Scholar
Department of Mechanical Engineering

V. Madhusudanan Pillai
National Institute of Technology Calicut
Associate Professor
Department of Mechanical Engineering

ABSTRACT
Supply chain is a network of organizations that are directly or indirectly involved in fulfilling the customer requirements. Bullwhip effect in a supply chain is having negative impact on the performance of the supply chain. One of the reasons for its occurrence in supply chain is lack of customer demand information at all stages and lead time. So, the objective of the present study is to know the impact of sharing history of Customer Demand Information (CDI) on bullwhip effect in a four stage serial supply chain and to evaluate its performance by conducting experiments similar to beer distribution game with one week lead time. History of CDI can be shared easily because of advancements in information technology. Various performance measures used for the evaluation are fill rate, variance of orders, total inventory at each stage and Total Holding Cost of the Supply chain (THCS). Results show that sharing history of CDI improves the performance of the supply chain.

General Terms
Information sharing, Bullwhip effect, Performance of supply chain

Keywords
Supply chain, Bullwhip effect, Customer demand information sharing

1. INTRODUCTION
Supply chain is a network of organizations that are directly or indirectly involved in fulfilling the customer requirements. Various functions performed in it are procurement of raw materials, converting the same into semi finished and finished products, and distributing them to the end customers. Increase in the demand variability as we move from downstream to upstream stage in a supply chain is called bullwhip effect. Forrester was the first person who noticed this phenomenon [1]. In some industries this effect is also known as whiplash or whipsaw effect. Downstream represents the direction towards the end customer and upstream is the direction towards the end supplier. Its presence creates excessive inventory investments, poor customer service level, ineffective transportation, unstable production plans and lost revenues. So, it is harmful and reduces the performance of the supply chain. The causes of the bullwhip effect are: lack of customer demand information [2], demand forecast updating, order batching, variation in prices, rationing and shortage gaming [3], replenishment rule [4] and lead time [5 – 7]. Procter & Gamble (P&G) observed this phenomenon in one of their best selling products called pampers where as Hewlett – Packard (HP) observed it in their printer product [3, 8]. They tried to reduce it and could see the increase in their profit. Reduction in bullwhip effect has the significant impact on the profitability of the whole supply chain [9]. Elimination or reduction of bullwhip effect can increase the profit of a firm [5].

Bullwhip effect can be tamed by following various ways such as: avoid forecasting at all stages, reduce the size of orders to be placed, stabilize the prices, supplying goods to the customer based on his past sales record than actual orders during supply shortages [3], reduce the lead time, adapt some strategic partnerships like Vendor Managed Inventory (VMI), etc. In VMI, vendor track the sales data at retailer and take necessary actions to supply the products. Vendor may take decisions like when and how much to supply so that the inventory and shortages at retailer may be minimized or reduced. So by VMI, the causes explained in Lee et al. [3] can be eliminated and the bullwhip effect can be reduced [10].

Another way of reducing the bullwhip effect is by sharing the customer demand information (CDI) among all stages in the supply chain [2]. Different forms of sharing CDI are customer demand distribution, Point of Sale (POS) data, history of customer demand and their combinations. In the present study, the performance of a four-stage serial supply chain is evaluated under with and without history of CDI sharing by conducting experiments similar to beer distribution game. Lead time considered is smaller (1 week) than the existing literature (4 weeks) [2, 11, 12] because it is the overriding cause of the bullwhip effect [5]. Various performance measures used for the evaluation are variance of orders placed by each stage, fill rate, total inventory at each stage and total holding cost of the supply chain. The experimental results are tested for statistical significance and the results of the statistical tests shows that the bullwhip effect in a supply chain cannot be eliminated completely but can be reduced by sharing the history of CDI sharing.

The paper is organized as follows: literature survey and experimentation are described in Section 2 and 3 respectively. Performance measures used are explained in Section 4. Statistical tests conducted are explained in Section 5. Discussion and conclusions are given in Section 6.

2. LITERATURE SURVEY
Since the presence of bullwhip effect reduces the performance of a supply chain, many researchers tried to find the ways by which the bullwhip effect can be reduced or controlled. They used different tools like analytical methods, simulation, and

experimentation for the same. Experiments are conducted by using beer distribution game which was developed by MIT, USA. The beer distribution game is a simulation of a supply chain with four co-makers (retailer, wholesaler, distributor and factory). The details of the game can be seen in [2, 13]. Sterman [2] is the first person who used the beer distribution game for evaluating the performance of the supply chain experimentally. This experiment involves a supply chain with four players namely retailer, wholesaler, distributor and factory. Each player receives the orders from their immediate downstream member and takes decisions about the order quantity and shipment quantity independently without consulting the other players. They reported that the reason for larger variability in their orders is their inability to predict the pattern of customer demand. Impact of customer demand distribution, Point of Sale (POS) data and inventory information sharing are studied by Croson and Donohue [11, 12]. It is found that the bullwhip effect cannot be eliminated completely but can be reduced by sharing above type information. Lead time considered in these studies is 4 weeks which is one of the sources for bullwhip effect. In the present study, history of customer demand with small lead time (1 week) is shared and its impact is studied under no back order situations. Usually, the back orders also promote bullwhip as replenishment varies with the back order quantity. Various performance measures used in the present work are also different and were not measured in the above existing experimental studies. Steckel, et al. [14] also used beer distribution game to know the impact of POS and lead time in the performance of supply chain and found that reducing the lead time is the better option to improve the performance of the supply chain than sharing POS.

3. EXPERIMENTAL SET UP AND PROCEDURE

A supply chain role play game is developed and used for conducting the experiments. Its features and design details are available in Pamulety and Pillai [15]. It works similar to the beer distribution game. It facilitates to set a four-stage serial supply chain under different settings and evaluates the same. Different settings include with & without CDI sharing, and with & without backorders. It allows to enter custom generated customer demand manually which is required to compare the performance of supply chains. It also gives the flexibility in setting the lead time between the stages, holding and backordering cost of stages. It simulates the operational decisions taken at each stage in a four-stage serial supply chain and evaluates its performance in terms of variance of orders placed by each stage, customer service level (fill rate), total inventory at each stage and total holding cost of the supply chain. The decisions taken at each stage are shipment quantity and size of the order to be placed. These decisions are taken with the objective of maximizing the fill rate and minimizing the inventory.

There are 56 students from under graduate and graduate studies have participated in the experiments and most of them are from Industrial Engineering and Management background. Each student acts as a stage manager in a four-stage serial supply chain and formed 14 identical supply chains. The retailer places order to wholesaler, wholesaler to distributor to factory and the factory issues the production orders. Among them, 7 supply chains are tested under without any information sharing and remaining are tested under history of CDI sharing. A trial game for a period of 10-week is played before the actual experiment. The duration of the actual experiment was not revealed to the participants and was continued for 55 weeks. In those 55 weeks, first 6 periods are considered as trial period and the periods from 7 to 48 are considered for performance analysis purposes. This is considered to reduce the end game effect [14]. The performance of each supply chain under each setting is evaluated

4. PERFORMANCE MEASURES

The performance of all supply chains is analyzed by measuring order variance at each stage, fill rate, total inventory at each stage and total holding cost of the supply chain. They are explained below.

Notations used:

i – Stage index in the supply chain, i = 1, 2, ..., 4
t – Time period in weeks
h_i – Holding cost per unit per period at stage i
n – Number of time periods
THCS –Total Holding Cost of a Supply chain
SQ_t^i – Quantity shipped by stage i in period t
D_t – Customer demand in period t
O_t^i – Order quantity of stage i in period t
PO_t – Production order by factory in period t
I_t^i – Ending inventory of stage i in period t
σ_i^2 – Variance of orders placed by stage i
$I_0^i = 40, \ \forall i$
$SQ_0^i = 0, \ \forall i$
$O_0^i = 0, \ \forall i$ and
$PO_0 = 0$

4.1 Variance of Orders Placed By Each Stage

It is used to measure the bullwhip effect in a supply chain. If the variance of orders placed is in increasing order from downstream to upstream, then we can say that bullwhip effect is present in that supply chain.

Variance of orders placed by stage i is determined with the following formulae.

$$\sigma_i^2 = \frac{\sum_{t=7}^{48} \left(O_t^i - \overline{O}\right)^2}{n-1} \quad \ldots \quad (1)$$

Where, $\overline{O} = \frac{\sum_{t=7}^{48} O_t^i}{n}$, and $n = 42$

4.2 Fill rate

The fill rate is defined as the fraction of demand met from the shelf. This is an appropriate performance measure that determines the customer service level. Maximizing the customer service level is one of the objectives of supply chain management.

$$\text{Fill rate} = \frac{\sum_{t=7}^{48} SQ_t^{i=1}}{\sum_{t=7}^{48} D_t} \quad \ldots \quad (2)$$

The equation (2) gives the fill rate of the retailer and it is the supply chain fill rate.

4.3 Total inventory at each stage

The performance of the supply chain can be increased by managing the inventory at each stage.

Total inventory at stage *i* in period *t* is given below.

$$I_t^i = I_{t-1}^i + SQ_{t-1}^{i+1} - D_t \quad \text{for } i = 1 \quad \ldots \quad (3)$$

$$I_t^i = I_{t-1}^i + SQ_{t-1}^{i+1} - O_{t-1}^{i-1} \quad \text{for } i = 2,3 \quad \ldots \quad (4)$$

$$I_t^i = I_{t-1}^i + PO_{t-1} - O_{t-1}^{i-1} \quad \text{for } i = 4 \quad \ldots \quad (5)$$

$$\text{Total inventory at stage } i, I^i = \sum_{t=7}^{48} I_t^i \quad \ldots \quad (6)$$

4.4 Total Holding Cost of the Supply Chain

It is the holding cost of all stages in the supply chain and is given below.

$$THCS = \sum_{i=1}^{4} \sum_{t=7}^{48} h_i I_t^i \quad \ldots \quad (7)$$

The above performance measures are calculated for each supply chain in the experimentation. The average value of each performance measure is calculated by considering seven supply chains under history of customer demand sharing and remaining seven without information sharing and is tabulated in Table.1. Variance of orders placed by each stage under no information sharing and with history of CDI sharing is shown in Figures 1 and 2 respectively.

5. RESULTS

The performance measures are calculated for each supply chain in the experimentation. The average value of each performance measure is calculated by considering seven supply chains under history of customer demand sharing and remaining seven without information sharing and is tabulated in Table.1. Variance of orders placed by each stage under no information sharing and with history of CDI sharing is shown in Figures 1 and 2 respectively.

Table 1. Average values of performance measures

Performance measures	Stage Name			
	Retailer	**Wholesaler**	**Distributor**	**Factory**
	Supply chain under no information sharing			
Variance of orders	31.74	94.85	217.97	205.62
Fill rate	0.931			
Total end period inventory	388.14	581.85	786.85	1034.71
THCS in $	1395.82			
	Supply chain under history of CDI sharing			
Variance of orders	27.24	69.52	87.94	101.76
Fill rate	0.973			
Total end period inventory	587.42	693.57	863.85	433.28
THCS in $	1289.07			

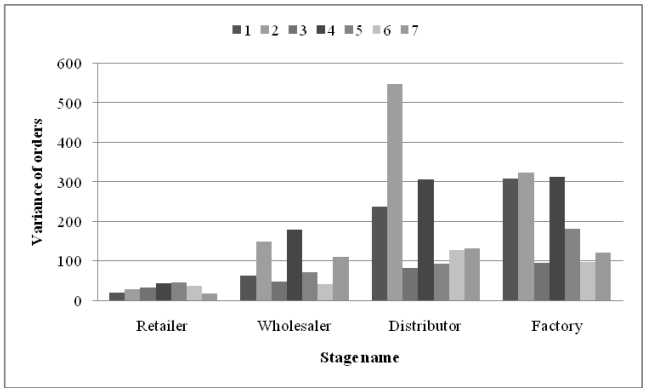

Fig 1: Variance of orders placed by each stage under no information sharing

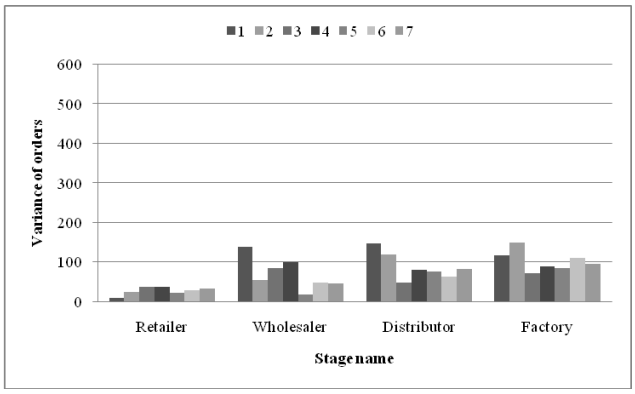

Fig 2: Variance of orders placed by each stage under history of CDI

6. STATISTICAL TESTS CONDUCTED

Variance of orders placed by each stage under no information sharing and with history of CDI sharing is shown in Figures 1 and 2 respectively. Sign test and Wilcoxon-Mann-Whitney non-parametric tests are conducted to draw conclusions from the experimental results. The tests are explained below and are evaluated at 5% significance level.

6.1 Sign Test

Since the variable under consideration (variance) has continuous distribution, sign test can be used to test the presence of bullwhip effect [9, 14, 16]. This non-parametric test is used to know whether the bullwhip effect is present or not in a supply chain under sharing the history of customer demand with small lead time of 1 week. The experimental results of variance of orders placed by each stage under history of customer demand are shown in Figure 2.

Hypothesis: The bullwhip effect will not occur under sharing the history of customer demand in a supply chain with small lead time and no backorders.

The procedure of the sign test is as follows. For each supply chain, we code an increase in the variance of orders placed between stages as a success and a decrease as a failure. If the variance of orders between stages is same, we code it as zero and is not considered for analysis. The sum of the successes and failures forms sample size (N). The probability of success or failure is 0.5. Success is represented by a plus (+) sign and a failure with minus (-) sign. If X represents the number of plus signs, then the probability of getting X or more plus signs is calculated from the Binomial distribution. If this probability is less than the significance level (α = 0.05) fixed, the null hypothesis must be rejected. The details of the sign test can be found in [17, 18]. For the problem described here, N = 21 and we got X as 17 and hence the P($X \geq 17$) is 0.0036 which is less than the significance level set for the present problem. So the above hypothesis must be rejected and we conclude that bullwhip effect is present under history of CDI sharing with a small lead time and no backorders. Similarly, it is possible to establish the presence of bullwhip effect with no information sharing case also.

6.2 Wilcoxon-Mann-Whitney Test

This test can be used [9, 14, 16] to know the impact of history of customer demand sharing on variance of orders. The hypothesis is given below.

Hypothesis: There is no difference in variance of orders placed by stages in the supply chain with no information and with history of CDI sharing.

The variance of orders placed by all stages with no information sharing and with history of CDI sharing can be considered as group x and y respectively. Let, k and l be the number of observations in the group x and y respectively. In this test, we have to combine the observations of both groups and assign ranks from 1 to ($k + l$) by arranging them in ascending order. The parameters of the test such as W_x, W_y, z and p need to be calculated. W_x and W_y are the sum of the ranks belong to group x and y respectively. The value z is estimated based on the following equations.

$$z = \frac{W_x \pm 0.5 - \mu_{W_x}}{\sigma_{W_x}} \quad \ldots \quad (8)$$

where, $\mu_{W_x} = \frac{k(k+l+1)}{2}$ and

$$\sigma^2_{W_x} = \frac{kl(k+l+1)}{12}$$

The details of this test can be seen in Siegel and Castellan [17]. The result shows that the impact of history of CDI sharing is significant (k = 28, l = 28, z = 1.94 and p = 0.0262) and we conclude that the information sharing has reduced the magnitude of variance of orders.

7. DISCUSSION AND CONCLUSIONS

The performance of a four-stage serial supply chain is evaluated under with and without history of CDI sharing. Various performance measures used are variance of orders placed by each stage, fill rate, total inventory at each stage and total holding cost of the supply chain. In a traditional supply chain, only order information is shared between the stages and the members at upstream stages decides the size of orders to be placed by using this information. This way of ordering leads to bullwhip effect. If the customer demand information is shared with the members especially, the members at upstream stages can be benefited and helps to take better decisions which reduce the bullwhip effect [11]. The results obtained in this study show the same conclusion. However, in the present study some of the factors contributing to bullwhip effect are removed or reduced to the lowest level. Even then bullwhip effect is present and this may be due to the behavioral aspect of the decision makers.

The results of Wilcoxon statistical test show that the magnitude of the variance of orders placed under information sharing is less than the other and is the effect of sharing history of CDI. Information can be shared easily at less cost because of the advancements in information technology and it reduces the lead time also. We can conclude that bullwhip is a phenomenon which is present in all supply chains and the human behavior contributes considerably to this effect. Customer demand Information sharing generally reduces its severity.

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