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MODELING BULLWHIP EFFECT AND UNDERSTANDING THE ROLE OF INFORMATION SHARING

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ABSTRACT

Bullwhip effect is an important phenomenon in distribution channels. It is undesirable and brings down the efficiency of the supply chain ultimately making the product expensive. This paper has been written to understand the effect of information sharing on bullwhip effect. A four-member supply chain has been simulated using beer distribution game.

A literature review has indicated towards seven major sources of bullwhip effect: demand forecast updating, order batching, price fluctuation, rationing and shortage gaming, misperception of feedback, local optimization without global vision and company processes. Beer game simulation of four-member supply chain has been done with complete information sharing at all levels and without information sharing at all levels. Lead-time and customer demand variance have been taken constant in the experimental set up. SPSS software has been used to test the hypothesis and factors are analyzed for information sharing.

Keywords: Supply chain management, effective information sharing, bullwhip effect.

Introduction

This paper deals with studying supply chain management, bullwhip effect and analysis of a consequent beer distribution game. The objective is to understand role of information sharing. We have tried to study the bullwhip effect and effects of information sharing on bullwhip effect. For this, we have simulated a four-member supply chain (retailer, wholesaler, distributor and manufacturer) and obtained data under various controlled conditions.

The bullwhip effect (or whiplash effect) is an observed phenomenon in forecast-driven distribution channels. Customer demand is rarely perfectly stable; therefore businesses must forecast demand in order to properly position inventory and other resources. Forecasts are based on statistics, and they are rarely perfectly accurate. Because forecast errors are inherent, companies often carry an inventory buffer called safety stock. Moving up the supply chain (SC) from end-consumer to raw materials supplier, each supply chain participant has greater observed variation in demand and thus greater need for safety stock. In periods of rising demand, down-stream participants will increase their orders. In periods of falling demand, orders will fall or stop in order to reduce inventory. The effect is that variations are amplified the farther you get from the end-consumer.

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Need of the Paper

The bullwhip effect is an unwarranted and harmful effect for the supply chain. It results in increased cost and losses to the supply chain therefore it becomes essential to control the overall cost and thereby increase the efficiency of the supply chain. So we have simulated a supply chain using the beer distribution model and tried to find the effect of information sharing on the bullwhip effect under controlled conditions.

Objective of the Paper

The objective of our paper is to study the supply chain and bullwhip effect and to determine effect of information sharing on the bullwhip effect. We have simulated a supply chain using a beer distribution game, obtained data and used statistical tools to analyze the data obtained.

Paper Methodology

A very simple methodology has been adopted in this paper. With the help of a well designed beer game, which is a type of simulation of a supply chain, we have collected some data of a consumer good under different controlled conditions. These simulated situations have been further analyzed for their statistical validity with the help of SPSS software. This has helped us in quantifying the major factors that affect the bullwhip effect. This research-based paper may help managers of supply chain to be better prepared and consequently assist them in reducing the overall cost of the supply chain thus improving the competitiveness of the supply chain. The flow chart of methodology used to accomplish this paper is shown in the figure 1.

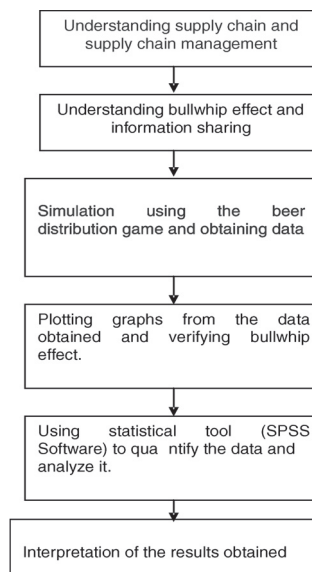


Figure 1: Flow chart of paper methodology

Scope of the Paper

Scope of this paper is that its findings are applicable to consumer goods and are restricted to a single echelon four-member supply chain. However, further extrapolation with some assumptions can be done to use these findings for other SC. There are certain initial assumptions in the simulation model, which have had an effect on our data. We have tried to

keep the variance of the demand of the customer constant which hardly exist in real situation.

Bullwhip Effect: A Brief Review

The bullwhip effect has been the focus of theoretical work on and off during the last few decades. However, papers reporting research findings in a more systematic fashion have been published just few years back. The effect was first identified in the 1980's through the simulation experiment, The beer game, which demonstrated the effects of distorted information in the supply chain (which is one of the causes of the bullwhip effect). (Christer Carlsson, and Robert Full'er, 2001)

The problem with the bullwhip effect is not only its essence itself, i.e., demand becomes more variable along the supply chain, but also the fact that it makes demand less predictable. Both increased variability and unpredictability causes substantial financial costs due to higher inventory levels and agility reduction. The bullwhip effect can be undesirable for the supplier because more volatile orders from the downstream stage can be very costly to the supplier. It can make it more difficult for the supplier to forecast demand, leading to higher inventory and shortage costs for the supplier. In addition, it can lead to large fluctuations in supplier production levels from period to period. (Julia Miyaoka, & Warren Hausman, 2004)

Source of Bullwhip Effect

Lee et al. (1997) identified four operational causes of the problem, including errors in demand signal processing, inventory rationing, order batching, and price variations, and recommended a number of operational strategies for dampening the effect. The second category focuses on the behavioral causes of the effect. Behavioral causes are usually studied in the laboratory because it provides ways to eliminate operational causes, which is impossible to do in this field. The existence of the behavioral causes of the bullwhip effect has been demonstrated in a variety of laboratory settings and by many different researchers, (Croson and Donohue K., 2003) and Croson et al. 2005). There is a large and growing literature on the bullwhip effect and its impact on supply chain performance. The magnification in demand is usually measured in terms of a change in the variance of orders placed at each supply chain level.

Demand Forecast Updating

Demand forecasts appear to be a major source of the bullwhip effect. The parties of the supply chain build their forecasts on historical demand patterns of their immediate customers. In this way, only the retailers build on the actual demand patterns of the customers, the other parties adjust to (unmotivated) fluctuations in the ordering policies of those preceding them in the supply chain. Companies base their orders on forecasts, which are themselves based on their incoming orders while such forecasts are not perfectly accurate. Therefore, companies order more or less than what they really require to fulfill their demand. In other words, forecasting errors amplify the variability of orders. A solution proposed to this cause is information sharing: each client provides more complete information to its supplier in order to allow the supplier to improve its forecasting. Information sharing is already a part of industry practices, such as VMI (Vendor-Managed Inventory), CRP (Continuous Replenishment Program), etc. (Thierry Moyaux, Brahim Chaib-draa, & Sophie D'Amours. 2006)

Order Batching

Order batching refers to a company ordering a large quantity of a product in one week and not ordering anything for many weeks. The main reason for a company ordering in batches is that it may prove to be less costly because of transportation costs or the company will receive

a discount if a large quantity is ordered in one period. (T.O'Donnell, L. Maguire, R. Mcivor and P. Humphreys, 2006)

Price Fluctuation

The producers initiate and control the price fluctuations for various reasons. Customers are driven to buy in larger quantities by attractive offers on quantity discounts, price discounts, coupons or rebates. Their behavior is quite rational. The problem introduced by this behavior is that buying patterns will not reflect consumption patterns anymore, customers buy in quantities which do not reflect their needs. This will amplify the bullwhip effect. The consequences are that producers (rightfully) suffer: manufacturing is on overtime during campaigns, premium transportation rates are paid during peak seasons and products suffer damages in overflowing storage spaces.

Rationing and Shortage Gaming

The rationing and shortage gaming occurs when demand exceeds supply. If the manufacturers once have met shortages with a rationing of customer deliveries, the customers will start to exaggerate their real needs when there is a fear that supply will not cover demand. The bullwhip effect will amplify even further if customers are allowed to cancel orders when their real demand is satisfied. The gaming leaves little information on real demand and will confuse the demand patterns of customers. Also rationing schemes that allocate limited production in proportion to the orders placed by retailers leads to a magnification of the Bullwhip effect (Chopra and Meindl 2004). Rationing and short gaming can cause major problems, as when the demand is not as high, the orders will stop, and cancellations will begin to arise. (T.O'Donnell, L. Maguire, R. Mcivor and P. Humphreys, 2006)

Misperception of Feedback

Sterman (1989) has noted that players in the beer game place orders in a non-optimal way because they do not understand the whole dynamics in their supply chain. For example, they do not correctly interpret their incoming orders, and in consequence, smooth their orders when they should order more, because they do not understand that market consumption has increased.

Local Optimization without Global Vision

Several authors [Kahn, 1987, Naish, 1994] have noted that companies maximize their own profit without taking into account the effect of their decisions on the rest of the supply chain. It has been formally proven that some of these policies induce the Bullwhip effect [Chen et al., 2000].

Company Processes

Taylor and his colleagues [Taylor, 1999] propose two causes of the bullwhip effect: variability in machine reliability and output, and variability in process capability and subsequent product quality. These two causes are summarized as Company Processes.

It is a fact that these causes of the bullwhip effect may be hard to monitor, and even harder to control in the industry. We should also be aware of the fact that these causes may interact, and act in concert, and the resulting combined effects are not clearly understood, neither in theory nor in practice. It is probably the case that the causes depend on the supply chain's infrastructure and the strategies used by the various actors.

Effects of Bullwhip Effect

The effect is costly because it causes excessive inventories, unsatisfactory customer service, and uncertain production planning. Christer Carlsson and Robert Fuller found that the bullwhip effect will have a number of negative effects in the paper products industry, that will cause significant inefficiencies:

1. Excessive inventory investments throughout the supply chain.
2. Poor customer service as some part of the supply chain runs out of products due to the variability and insufficient means for coping with the variations.
3. Lost revenues due to shortages, which have been caused by the variations.
4. The productivity of invested capital in operations becomes substandard, as revenues are lost.
5. Increased capacity plans to meet peak demands.
6. Sub-optimal transportation schemes due to variation in demand.
7. Missed production schedules due to demand fluctuations. (Christer Carlsson, and Robert Fuller, 2001)

Information sharing in Supply Chain: an Attempt to Counteract Bullwhip Effect

A huge amount of information is being interchanged between manufacturers and retailers, between retailers and consumers, between companies and investors, and also among the parties in the same level of a vertical chain. Advances in information system technology have had a huge impact on the evolution of supply chain management. As a result of such technological advances, supply chain partners can now work in tight coordination to optimize the chain-wide performance, and the realized return may be shared among the partners. A basic enabler for tight coordination is information sharing, which has been greatly facilitated by the advances in information technology. (Lee H.L. and Whang S., 2004)

In general, vertical information sharing, e.g., transmission of point-of-sales data between a retailer and a manufacturer, has two effects, the “direct effect” on the payoffs between the parties engaged in information sharing, and the “indirect effect” of information sharing on other competing firms. For example, knowing that the manufacturer receives some information from a retailer, other retailers may respond to the fact by changing their strategies, and such a reaction may cause additional gains or losses to the parties directly engaged in information sharing.

Johnson (1998) pointed out the ways to eliminate bullwhip effect: sharing information in the form of point-of-sale data, trying to develop channel alignment by exchanging decision rights, reducing lead time, and eliminating forecast updating. Chen et al. demonstrated that the bullwhip effect could be reduced partially by centralizing demand information. Information sharing, particularly sharing information on inventory levels, has been cited as a possible countermeasure to the bullwhip effect. From an operational perspective, inventory information can be used to update demand forecasts and lessen the impact of demand-signaling errors and delays. In fact, such information may even be helpful in supply chains where the demand distribution is known to all supply chain members and each member makes ordering decisions based on an order-up-to policy. From a behavioral perspective, inventory information can also provide a means to affect behavior and, as a result, increase trust (or at least understanding) throughout the supply chain. In an experimental setting based on the popular beer distribution game, Croson and Donohue (2003) showed that human decision makers in a four-member, serial

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supply chain continued to exhibit bullwhip behavior in their ordering patterns even when all the operational causes of the bullwhip were removed. They further found that sharing everyone's inventory information throughout the entire supply chain significantly dampened order oscillations, although it did not eliminate the effect completely (Croson, R. and Donohue, K., 2005). It has been suggested that the value of information sharing could be more significant in situations where there is much uncertainty concerning future demand, such as product introductions or promotions (Cachon and Fisher, 2000). (Lehtonen, Smaros & Holmström, 2004) The bullwhip effect increases with longer lead times. The degree of volatility amplification in components supply chains is driven primarily by the inventory lead-time. (Anderson jr. E. G., Fine C. H. & Parker G. G.. 2000) With a little simplification there appears to be three possible approaches to counteract the bullwhip effect:

- Find some means to share information from downstream of the supply chain with all the preceding actors.
- Build channel alignment with the help of some coordination of pricing, transportation, inventory planning and ownership - when this is not made illegal by an anti-trust legislation.
- Improve operational efficiency by reducing cost and by improving on lead times.

The first approach can probably be focused on finding some good information technology to accomplish the information sharing, as this can be shown to be beneficial for all the actors operating in the supply chain. We should probably implement some internet-based support technology for intelligent sharing of validated demand data.

The second approach can first be focused on some non controversial element, such as the co-ordination of transportation or inventory planning, and then the alignment can be widened to explore possible interactions with other elements.

The third approach is probably straightforward: find operational inefficiencies, then find ways to reduce costs and to improve on lead times, and thus explore if these solutions can be generalized for more actors in the supply chain.

The most effective - and the most challenging effort will be to find ways to combine elements of all three approaches and to find synergistic programs to eliminate the bullwhip effect, which will have the added benefit of being very resource-effective.

(Carlsson Christer, and Fuller Robert, 2001)

Beer Game Simulation of Supply Chain

The beer game is one of a number of management flight simulators developed at MIT's Sloan school of management demonstrates the bullwhip effect by simulating a make-to-stock supply chain with four tiers. Participants of the beer distribution game take up the role of the retailer, the wholesaler, the distributor or the factory. The game was developed by Sloan's system dynamics group in the early 1960s as part of Jay Forrester's research on industrial dynamics. The game is played on a board that portrays the production and distribution of beer. At each stage there are shipping delays and order processing delays. The players' objective is to minimize total team costs. (Joerg Nienhaus, Arne Ziegenbein & Christoph Duijts, 2003). The result from the graph plotted from the demands of the retailer, wholesaler, distributor and the manufacturer clearly showed the bullwhip effect in the form of: (a) Oscillation: Orders and inventories are dominated by large amplitude fluctuations, with an average period of about 20 weeks. (b) Amplification: The amplitude and variance of orders increases steadily from customer to retailer to factory. (c) Phase lag: The order rate tends to peak later as one move from the

retailer to the factory.

Supply Chain Simulation Results

The key factors affecting the bullwhip effect namely lead-time, order batching, information sharing have already been identified. We considered information sharing as a variable to identify its effects. The different types of games which were played are:

- Normal game without information sharing at all (NG)
- Game with complete information sharing (CIS)

The demand data obtained from these games were then plotted in the forms of graphs and these graphs were then interpreted to show the presence of bullwhip effect and verify the effects of information sharing on bullwhip effect.

Data from the Beer Distribution Game

Normal game without information sharing at all, no constraints, lead-time 1 week, random demand pattern.

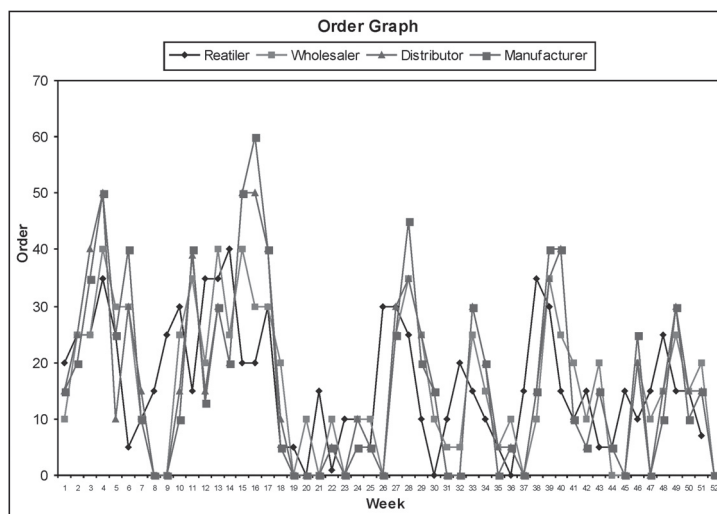


Figure 2: Ordering curve for normal game

It is quite evident from the figure 2 that the bullwhip effect is present in the supply chain. The three indicators of bullwhip effect i.e. oscillation, amplification, phase lag can easily be seen in the ordering curve. The demand posed by the downstream member to the immediate upstream member is not the actual demand of the customer. Hence it results in the amplification of demand. We should consider the fact that only the customer is consuming the product and so the increased demand further results in increased inventory level which increases the cost of the supply chain and for that particular member also in the form of material holding cost. The possible reason for the oscillation in demand could be due to lack of information sharing. Since only the retailer knows the exact demand of the customer, all the other members have to forecast the demand and also depend upon the decision taken by the previous member.

Game with Complete Information Sharing with Lead-time One Week

Due to the presence of complete information sharing it can be seen from figure 3 that there is almost insignificant amplification and phase lag in the demand pattern since every member of

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the supply chain is aware of the inventory level of other members. The presence of oscillation is due to the oscillation of the demand pattern of the customer. There is presence of a phase lag, which may be attributed to the lead time of one week.

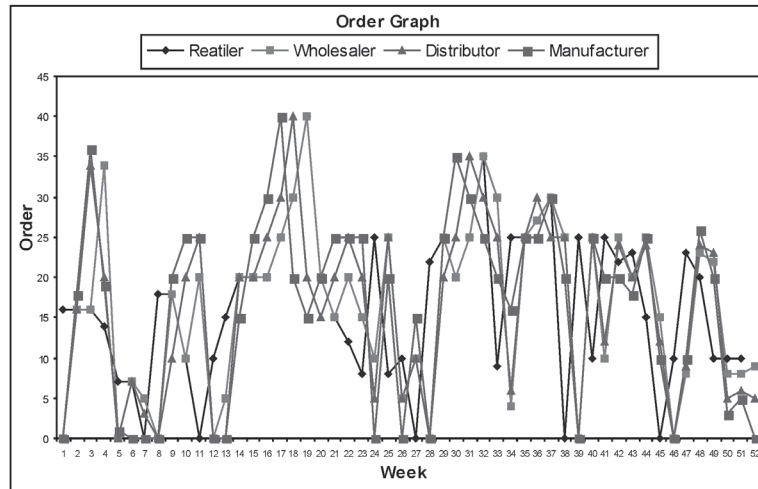


Figure 3: Ordering Curve for complete info sharing game

Data Quantification and Analysis

Comparison on the basis of information sharing has been carried out in three stages as given below:

Stage I – In this stage the correlation between the demand and ordering pattern of all the members within a game is determined.

Stage II – Formulation of hypothesis.

Stage III – Comparison of means and variances both within and between the games using t-test and F-test respectively.

Stage I: Calculations of correlation coefficients

From every correlation table (table 1 and 2 given in annexure 1) it can be seen that the demand and ordering pattern between every successive level is correlated, however as the distance between two members increases the demand becomes less correlated and sometimes becomes insignificant. It is also seen that as the level of information sharing increases the correlation between the demands and ordering pattern also increases. It is further seen that the demand and ordering pattern is highly correlated in the complete information sharing game as compared to the other game.

Stage II: Formulation of hypothesis.

Hypothesis: Information sharing within the supply chain will decrease the level of amplification of variance of orders throughout the supply chain related to the mean order value.

Stage III: Comparison between means and Comparison between variances.

The comparison consists of two parts:

- a. Comparison within a game.
- b. Comparison between games.

Comparison within a game

- **Comparison between means (t-test)**

The t-value at 95% level of confidence as seen from the table comes out to be 2.01. It can be clearly seen from table 3 and 4 given in annexure 1, that the t-values from the games are less than the t-significant value. Hence it can be said that the difference in the means of demand and order pattern of the members within a game is insignificant which proves that the data is valid for performing the F-test within a game.

- **Comparison between variances (F-test)**

The F-value at 95% level of confidence as seen from the table comes out to be 1.23. It can be clearly seen from table 5 and table 6 given in annexure 1 that most of the F-values are greater than the significant F-value. This provides the evidence of presence of bullwhip effect within a game.

Comparison between games

- **Comparison between means (t-test)**

The t-values at 95% level of confidence come out to be insignificant as seen from the table 7 given in annexure 1. This proves that the mean value of the order pattern of all the members in all games is similar. Therefore they can now be tested for bullwhip effect using F-test.

- **Comparison between variances (F-test)**

Considering only the diagonal elements from the table 8 given in the annexure 1, the F-values of retailer, wholesaler distributor and manufacturer when compared with F-significant value at 95% level of confidence come out to be significant. The table provides the evidence of presence of reduction of order amplification when information sharing is introduced in the supply chain, which proves our hypothesis.

Scope for Future Work

This work can further be improved and extended. The factors affecting the bullwhip effect can be prioritized and the most significant factor can also be determined and controlled so as to reduce the bullwhip effect to a greater extent. This can be undertaken in different conditions.

Conclusion

Beer games played under different conditions have been complied and their statistical significance has been tested using appropriate techniques. In this paper quantification and analysis of the data collected has also been undertaken using correlation, t-test and F-test. It was found that complete information sharing is the best-proposed solution to reduce order amplification and ultimately the bull whip effect.

The bullwhip effect is unwarranted and makes the supply chain uncompetitive. This results in increased cost and losses to the organizations and sometimes lost customers as well. Reduction of the bullwhip effect is possible but its complete removal in the supply chain seems to be impossible. Through this paper, we have been able to identify major factors affecting bullwhip effect. These factors are: order batching, lead-time, information sharing, and price fluctuation.

Modeling Bullwhip Effect and Understanding the Role of Information Sharing

The quantification and analysis of the data collected was done using SPSS software. Correlation, t-test and F-test were conducted on the data collected. Correlation reveals that the order data are correlated or not. The t-test and F-test were done to compare the means and the variances respectively and to check whether the variation was significant or not. All the three tests were performed to check variation within a game, however for between the game variations only the t-test and the F-test were performed. This paper was divided in three main stages which were, firstly to collect and study the relevant literature in the field of bullwhip effect, secondly to collect the data by simulating a supply chain by using the beer distribution game and lastly to analyze the data using statistical techniques (SPSS Software) so as the significance of various factors is determined.

From the correlation analysis it has been found that the demand and ordering pattern are correlated when the distance between two members is less. The level of information sharing increases the correlation between demands of two members. Hypothesis has also been formulated regarding information sharing effect on level of amplification. Comparison between means and variances has also been done by employing requisite statistical tests. SPSS software has been used to explore the significance of various factors on bullwhip effect. It was found that information sharing leads to reduction in bullwhip effect.

References

1. Anderson Jr. E. G., Fine, C. H. & Parker, G. G., "Upstream Volatility in the Supply chain: The Machine Tool Industry as A Case Study", Copyright © 2000, *Production and Operations Management Society* Pg 239-261.
2. Cachon, G. and Fisher, M. (2000) Supply chain inventory management and the value of shared information, *Management Science*, Vol. 46, No. 8, p. 1032 - 1048.
3. Carlsson, C. and Full'er, R., "Reducing the Bullwhip effect by means of intelligent, soft computing methods", *PP Proceedings of the 34th Hawaii International Conference on System Sciences*, 2001.
4. Chen, F., Drezner, Z., Ryan, J. K., and Simchi-Levi, D. (2000). Quantifying the Bullwhip effect in a simple Supply chain: The impact of forecasting, lead times, and information. *Management Science*, 46(3): 436-443.
5. Chopra, S. and Meindl, P., *Supply chain Management: Strategy, Planning and Operation* 2nd ed., 2004 (Prentice-Hall: Englewood Cliffs, NJ).
6. Croson, Rachel and Donohue, Karen. "Upstream versus downstream information and its impact on the bullwhip effect", *PP System Dynamics Review* Volume 21 Number 3 Fall 2005, Pg 249-260.
7. Croson R & Donohue K. (2003). The impact of POS data sharing on Supply chain management: an experimental study. *Production and Operations Management* 12: 1-11.
8. Johnson, M.E. (1998) Giving 'me what they want. *Manage Rev* 87(10): 62-67
9. Kahn, J. A. (1987). Inventories and the volatility of production. *The American Economic Review*, 77(4): 667-679.
10. Lee, H.L., Padmanabhan, V., and Whang, S., "The Bullwhip Effect in Supply Chain," *Sloan Management Review*, spring, 1997, Pg. 93-102.
11. Lee, H., Padmanabhan, V., and Whang, S., "Comments on "Information Distortion in a Supply chain: The Bullwhip effect", *PP Management Science* 50(12S), pg. 1887-1893, ©2004 INFORMS
12. Lehtonen, Johanna Småros & Jan Holmström. "The Effect of Demand Visibility in Product Introductions", *PP 16th Annual NOFOMA Conference*, June 7-8, 2004, Linköping, Sweden
13. Miyaoka, Julia & Hausman, Warren. "How a Base Stock Policy Provides Supply chain Benefits Manufacturing & Service Operations Management 6(2), pp. 149-162, ©2004 INFORMS
14. Moyaux, T., Chaib-draa, B., D'Amours, S. "Information Sharing as a Coordination Mechanism for Reducing the Bullwhip effect in a Supply chain", 2006.
15. Naish, H. F. (1994). Production smoothing in the linear quadratic inventory model. *The Economic Journal*, 104(425): 864-875.

16. Nienhaus J. et al. al.: Trends in Supply chain Management – A survey among more than 200 European Companies, Centre for Enterprise Sciences (BWI), *Swiss Federal Institute of Technology (ETH) Zurich*, Switzerland, 2003.
17. O'Donnell, T., Maguire, L., Mcivor, R., and Humphreys, P. "Minimizing the Bullwhip effect in a Supply chain using genetic algorithms", *International Journal of Production Research*, Vol. 44, No. 8, 15 April 2006, Pg 1523–1543.
18. Serman, J. D. (1989). Modeling managerial behavior: Misperceptions of feedback in a dynamic decision making experiment. *Management Science*, 35(3): 321-339
19. Taylor, D. (1999). Measurement and analysis of demand amplification across the Supply chain. *The International Journal of Logistics Management*, 10(2): 55-70.

Annexure 1:

Table 1: Correlation Coefficients for NG

	CUST.D	RET.D	WHOL.D	DIST.D	MANUF.D
CUST.D	1.000	.585	.372	.181	.156
RET.D	.585	1.000	.887	.758	.755
WHOL.D	.372	.887	1.000	.885	.884
DIST.D	.181	.758	.885	1.000	.970
MANUF.D	.156	.755	.884	.970	1.000

Table 2: Correlation Coefficients for CIS

	CUST.D	RET.D	WHOL.D	DIST.D	MANUF.D
CUST.D	1.000	.730	.639	.633	.710
RET.D	.730	1.000	.846	.753	.693
WHOL.D	.639	.846	1.000	.857	.731
DIST.D	.633	.753	.857	1.000	.887
MANUF.D	.710	.693	.731	.887	1.000

Table 3: Paired Samples Test for NG

	Pair	t	df
Pair 1	CUST.D - RET.D	.207	51
Pair 2	CUST.D - WHOL.D	.136	51
Pair 3	CUST.D - DIST.D	.112	51
Pair 4	CUST.D - MANUF.D	.112	51
Pair 5	RET.D - WHOL.D	-.049	51
Pair 6	RET.D - DIST.D	-.014	51
Pair 7	RET.D - MANUF.D	.000	51
Pair 8	WHOL.D - DIST.D	.019	51
Pair 9	WHOL.D - MANUF.D	.035	51
Pair 10	DIST.D - MANUF.D	.034	51

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Table 4: Paired Samples Test for CIS

	Pair	t	df
Pair 1	CUST.D - RET.D	.018	51
Pair 2	CUST.D - WHOL.D	-.045	51
Pair 3	CUST.D - DIST.D	-.044	51
Pair 4	CUST.D - MANUF.D	-.080	51
Pair 5	RET.D - WHOL.D	-.098	51
Pair 6	RET.D - DIST.D	-.076	51
Pair 7	RET.D - MANUF.D	-.098	51
Pair 8	WHOL.D - DIST.D	.000	51
Pair 9	WHOL.D - MANUF.D	-.034	51
Pair 10	DIST.D - MANUF.D	-.052	51

Table 5: F-value for NG

Normal F-Value				
	Retailer	Wholesaler	Distributor	Manufacturer
Retailer	1	0.7497	0.4897	0.4188
Wholesaler	1.3338	1	0.6531	0.5587
Distributor	2.0420	1.5311	1	0.8554
Manufacturer	2.3880	1.7900	1.1690	1

Table 6: F-value for CIS

Complete Information Sharing F-Value				
	Retailer	Wholesaler	Distributor	Manufacturer
Retailer	1	0.8022	0.7380	0.6685
Wholesaler	1.2466	1	0.9197	0.8340
Distributor	1.3550	1.0873	1	0.9066
Manufacturer	1.4958	1.1990	1.1030	1

Table 7: Paired Samples Test for Complete Information sharing to normal information sharing

	t	df
Retailer	-.107	51
Wholesaler	-.080	51
Distributor	-.068	51
Manufacturer	-.042	51

Table 8: F-value for NG & CIS

Normal vs. Complete info sharing F-Value				
NG \ CIS	Retailer	Wholesaler	Distributor	Manufacturer
Retailer	1.27	1.6966	2.5978	3.0382
Wholesaler	1.0201	1.3609	2.0837	2.4370
Distributor	0.9383	1.2515	1.916	2.2412
Manufacturer	0.8503	1.1342	1.7367	2.0312