Proceedings of GLOGIFT 08
June 14-16, 2008
Stevens Institute of Technology
Hoboken, NJ, pp. 490-505

SUPPLY CHAIN AND BEER GAME: STATISTICAL ANALYSIS USING SIMULATED DATA

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ABSTRACT

Supply Chain Management plays a vital role in improving competitiveness of organizations. Bullwhip effect is an important phenomenon in distribution channels. Bullwhip is undesirable and makes the supply chain non-productive, ultimately making the product expensive.

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. This paper has been developed to understand the effect of information sharing, order batching and lead time on bullwhip effect.

With the help of a well designed beer game simulation of a four member supply chain, we have collected some data of a fast moving consumer good under different controlled conditions. Beer Game simulation has been found appropriate to model bullwhip effect and to understand effect of different factors stated above on bullwhip effect. These simulated situations have been further analyzed for statistical validity with the help of SPSS software, which has helped in quantifying the major factors that affect "bullwhip effect". From the correlation analysis, it was found that correlation among the demand decreases as we move farther from one member and sometimes it becomes insignificant.

It has been found that information sharing at any level is beneficial in reducing bullwhip effect, and that complete information sharing is the best proposed solution to reduce the bull whip effect, as compared to upstream information sharing and downstream information sharing. It has been indicated that small order batch size and lesser lead time help supply chain managers to reduce bullwhip effect. The study indicates that human behavior is also one of the major factors affecting bullwhip effect, but its effect can be reduced by appropriate training and learning.

Keywords: *bullwhip effect, effective information sharing, information sharing, lead time, order batching, supply chain management.*

1. Introduction

Today, supply chain management is all about managing the flow of information, goods/services and funds effectively and efficiently to gain competitiveness over other supply chains. Demand

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information plays a vital role in positioning inventory and other resources. Information distortion leads to a problem called the bullwhip effect (Whiplash effect), often found in supply chains, which is an observed phenomenon where the variance of demand is amplified moving upstream in a supply chain. The bullwhip effect is unwarranted and harmful for the supply chain, because, it increases cost and decreases productivity of the supply chain; therefore, it becomes essential to control the overall cost and thereby increase the efficiency of the supply chain. (Kumar and Haleem, 2006, Kumar and Haleem, 2008) In India it is difficult to study an actual FMCG products supply chain due to unavailable actual data for all supply chain members and an organized retail industry, which is new and growing very fast. Thus, we have simulated a supply chain using the beer distribution model and have tried to find the effect of information sharing, order batching, and lead time on the bullwhip effect under different controlled conditions. A structured methodology has been adopted to stimulate and analyze the bullwhip effect. With the help of a well designed beer game, that is a type of simulation of supply chain, we have collected some data of a fast moving consumer good under different controlled conditions. These simulated situations have been further analyzed for statistical validity with the help of SPSS software, which has helped in quantifying the major factors that affect "bullwhip effect." The findings may help the managers of supply chain 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 Figure1.

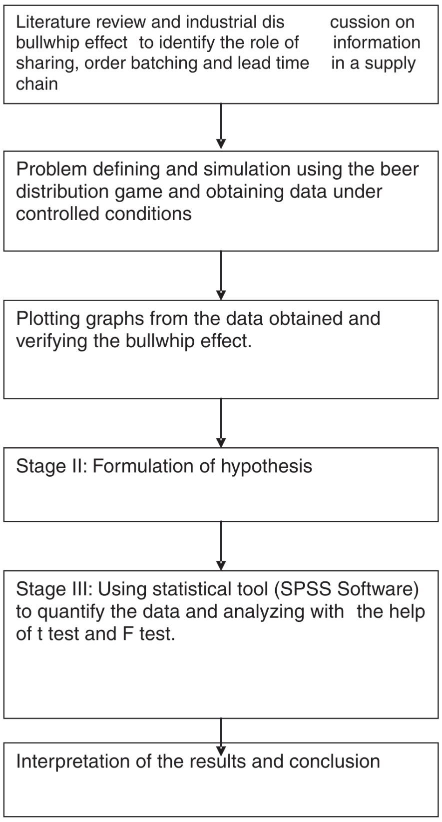

Figure1: Flow chart of the research methodology adopted in the paper to understand the effect of information sharing, order batching and lead time on bullwhip effect

The findings of this paper may be limited to only consumer goods and is restricted to a single echelon four-member supply chain. However, further extrapolation with some assumptions can be done to use these findings for other types of supply chains. There are certain initial assumptions in the simulation model that have some bearing on the results. We have also tried to keep the variance of the demand of the customer constant, which hardly exists in real life situation. We made interactions with the supply chain practitioners and found that one of the highest issues with variation at corporate level is demand forecasting.

2. 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 that can demonstrate the bullwhip effect by simulating a make-to-stock supply chain with four tiers. Participants of the beer distribution game which was developed by Sloan's system dynamics group in the early 1960s as part of Jay Forrester's research on industrial dynamics, take the role of the retailer, the wholesaler, the distributor, or the factory. The players' objective is to minimize total team costs. (Nienhaus, Ziegenbein and 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 following three forms:

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. The peak order rate at the factory is on average more than double the peak order rate at retail.

c. Phase lag: The order rate tends to peak later as one move from the retailer to the factory.

Beer games were played to identify effect of information sharing (analysis and results discussed in section 3.1), order batching (analysis and results discussed in section 3.2) and lead time (analysis and results discussed in section 3.3) on bullwhip effect.

3. Analysis and Results

***3.1 Effective Information Sharing for Reducing Bullwhip Effect*:** In a supply chain, a huge amount of information is being interchanged among its members containing the bullwhip effect using effective information sharing. 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 reaction may cause additional gains or losses to the parties directly engaged in information sharing.

Johnson (1998) pointed out that there are four ways to eliminate bullwhip effect: 1) sharing information in the form of point-of-sale data, 2) trying to develop channel alignment by exchanging decision rights, 3) reducing lead time, and 4) eliminating forecast updating. Additionally, Chen et al. (2000) demonstrated that the bullwhip effect could be reduced partially by centralizing demand information. Finally, 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 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, and Donohue, 2005). Effective information sharing to reduce bullwhip effect is relevant to the Indian FMCG sector also (Kumar and Haleem, 2007a; Kumar and Haleem, 2007b). 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, and Holmström, 2004)

Advances in information system technology have significantly impacted the evolution of supply chain management; allowing supply chain partners to 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 the coordination among members of the supply chain is information sharing, which has been greatly facilitated by the advances in information technology (Lee, Padmanabhan, and Whang, 2004) However, information sharing among the members may pose a threat to the confidentiality of the data.

Supply Chain Games: The key factors affecting the bullwhip effect — namely lead-time, order batching and information sharing — have already been identified. We considered information sharing as a variable to identify its effects. Different types of games were played, three times each, to validate the results obtained from each game. The different types of games are:

- Normal game without information sharing at all (NG)
- Normal game with upstream information sharing (UIS)
- Normal game with downstream information sharing (DIS)
- Normal game with complete information sharing (CIS)

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

Data from the Beer Distribution Game

Game Type: Normal game without information sharing at all, no constraints, lead time 1 week, and random demand pattern.

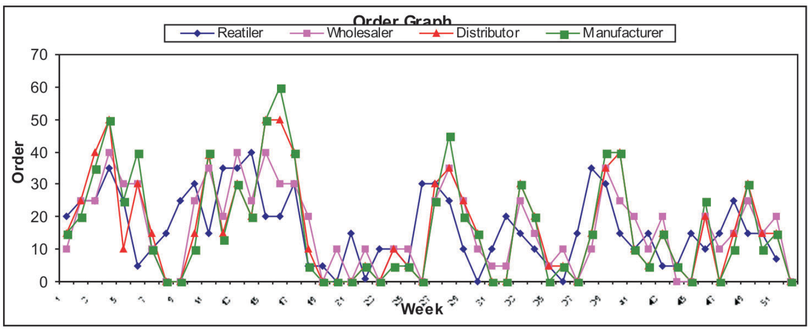

Figure 2: Ordering Curve for Normal Game

It is quite evident from Figure 2 that the bullwhip effect is present in the supply chain. The three indicators of bullwhip effect — i.e. oscillation, amplification, and phase lag — can easily be seen in the ordering curve.

Game Type: *downstream information sharing with lead time of one week:* From Figure 3, it is evident that there is presence of bullwhip effect. Furthermore, there is reduced amplification, since the upstream member has an idea about the demand of the immediate downstream member of the supply chain. However, there is still the presence of oscillation, phase lag and amplification of the demand patterns in the upstream members.

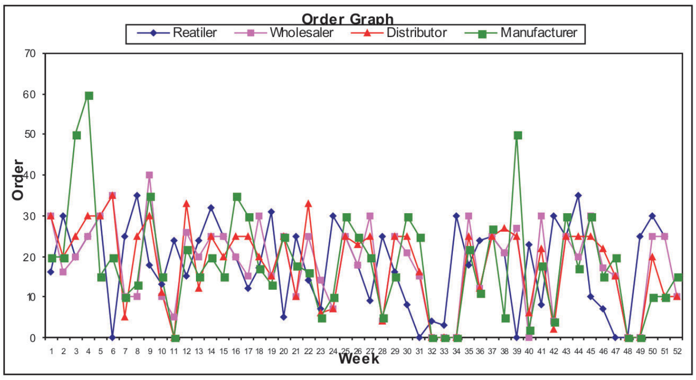

Figure 3: Ordering Curve for downstream info sharing game

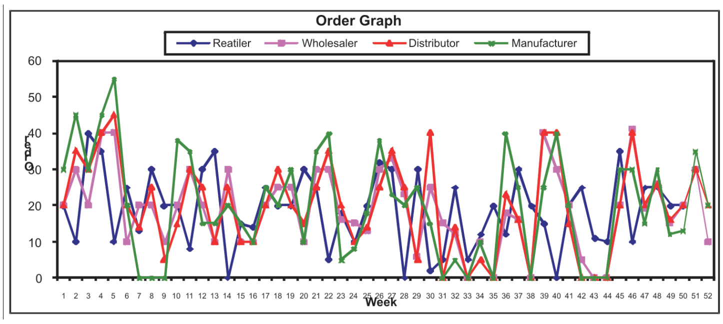

Figure 4. Ordering Curve for upstream info sharing game

Game Type: *Upstream information sharing with lead time of one week:* From Figure 4, it is evident that there is presence of bullwhip effect. There is also a reduction in the amplification, since the downstream member is aware about the inventory levels of the upstream member and places the order accordingly to reduce the overall cost of the supply chain, which is only possible when there is coordination in the supply chain. However, there is still the presence of oscillation, amplification, and phase lag of the demand patterns in the upstream members.

Game Type: *Complete information sharing with lead time of one week:* Due to the presence of complete information sharing (Figure 5) there is almost insignificant amplification in the demand pattern, since every member of 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. Phase lag is also present, which may be attributed to the lead time of one week due to the stabilization of demand.

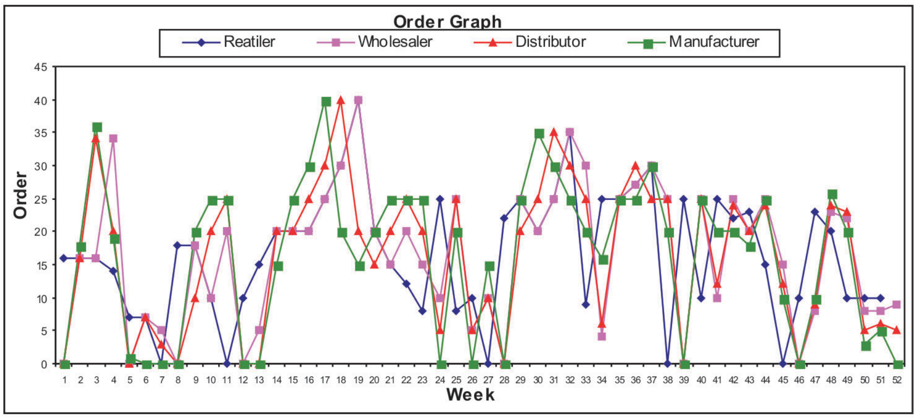

Figure 5: Ordering Curve for complete info sharing game

3.1.1 Data Quantification and Statistical Analysis

Comparison and analysis of the same on the basis of information sharing has been carried out in three stages as

- 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.

The games considered in this case are:

- Normal game (N.G)
- Upstream information sharing (U.I.S)
- Downstream information sharing (D.I.S)
- Complete information sharing (C.I.S)

Stage I: Calculations of correlation coefficients

From Correlation analysis (Table 1) it is observed 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 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 other games.

Table 1: Correlation Coefficients for N.G.

	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

Stage II: Formulation of hypothesis.

Hypothesis I: Information sharing within the supply chain will decrease the level of order amplifications throughout the supply chain.

Hypothesis II: Complete information sharing will lead to greater reduction in order amplification, as compared to downstream information sharing and upstream information sharing.

Stage III: Comparison between means and Comparison between variances.

Null hypothesis: We assume the means and variances of the data are the same and check for its significance. If the value is insignificant, the hypothesis is accepted else rejected. The comparison consists of two parts:

a) Comparison within a game.

b) Comparison between games.

3.1.1 a. Comparison within a game

- Comparison between means (t-test)

The t-value (Table 2) at 95% level of confidence is insignificant. Hence, it can be said that the difference in the means of demand and order pattern of the members within a game is insignificant, proving the data is valid for performing the F-test within a game.

Table 2: Paired Samples Test for N.G.

	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

- Comparison between variances (F-test)

The F-value at a 95% level of confidence in most of the cases is significant. This provides evidence of the bullwhip effect within a game.

3.1.1 b. Comparison between games

- Comparison between means (t-test)

The t-values at a 95% level of confidence are insignificant, proving that the mean value of the order pattern of all members, in all the 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 Table 3 to Table 8, the F-values of retailer, wholesaler, distributor, and manufacturer, when compared with F-significant value at a 95% level of confidence, are significant. Table 3, 4, and 5 provide evidence of the presence of reduction of order amplification when information sharing is introduced in the supply chain, proving our first hypothesis. Further Table 6, 7, and 8 provide evidence of reduction in order amplification with the increase in the level of information sharing from upstream to downstream to complete information sharing, proving our second hypothesis.

Table 3 : F-value for N.G. & U.I.S.

Normal Vs Upstream info sharing F-Value				
N.G. / U.I.S.	Retailer	Wholesaler	Distributor	Manufacturer
Retailer	**1.0829**	1.4444	2.2116	2.5866
Wholesaler	0.9459	**1.2618**	1.9319	2.2594
Distributor	0.7259	0.9683	**1.4827**	1.7340
Manufacturer	0.5343	0.7126	1.0911	**1.2763**

Table 4: F-value for N.G. & D.I.S.

Normal Vs Downstream info sharing F-Value				
N.G. / D.I.S.	Retailer	Wholesaler	Distributor	Manufacturer
Retailer	**1.0869**	1.4477	2.2102	2.5924
Wholesaler	0.9627	**1.2987**	1.9661	2.2995
Distributor	0.7940	1.0590	**1.6217**	1.8965
Manufacturer	0.6642	0.8860	1.3566	**1.5857**

Table 5 : F-value for N.G. & C.I.S.

Normal Vs Complete info sharing F-Value				
N.G. / U.I.S.	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**

Table 6 : F-value for U.I.S. & D.I.S.

Downstream Vs Upstream info sharing F-Value				
U.I.S / D.I.S.	Retailer	Wholesaler	Distributor	Manufacturer
Retailer	**1.002**	1.1473	1.4950	2.0314
Wholesaler	0.8890	**1.017**	1.3260	1.8019
Distributor	0.7330	0.8393	**1.093**	1.4860
Manufacturer	0.6134	0.7022	0.9149	**1.243**

Table 7: F-value for D.I.S. & C.I.S.

Downstream Vs Complete info sharing F-Value				
D.I.S / C.I.S	Retailer	Wholesaler	Distributor	Manufacturer
Retailer	**1.1719**	1.3212	1.6020	1.9149
Wholesaler	0.9400	**1.059**	1.2850	1.5360
Distributor	0.8945	0.9746	**1.1818**	1.4126
Manufacturer	0.7835	0.8833	1.0710	**1.282**

Table 8 : F-value for U.I.S. & C.I.S.

Upstream Vs Complete info sharing F-Value				
C.I.S. \ U.I.S.	Retailer	Wholesaler	Distributor	Manufacturer
Retailer	**1.1746**	1.3446	1.7521	2.3807
Wholesaler	0.9421	**1.078**	1.4053	1.9096
Distributor	0.8664	0.9919	**1.2933**	1.7562
Manufacturer	0.7852	0.8989	1.1713	**1.5918**

3.1.2 Findings: The simulation of a four member supply chain under different controlled conditions, followed by quantification and analysis of data so obtained, have helped us arrive at the following major findings:

- The ordering curves plotted indicate towards reduced amplification in the case of information sharing (UIS, DIS and CIS), as compared to normal game without information sharing. Presence of oscillation and phase lag formed are still evident in all the cases.
- Information sharing increases the correlation between the demands and ordering pattern, most significantly in complete information sharing case.
- The difference in means within a game and between games is insignificant for all the games with the help of t-test, but valid for F tests.
- The F tests performed within the game indicated a significant difference in variances of demands for all the games, which means presence of bullwhip effect in all types of games.
- Further F test performed between different types of games to test for significant difference in variances of demands indicated towards significant reduction of order amplification with information sharing, as compared to normal game without information sharing. Complete information sharing has been formed, the best followed by downstream information sharing and upstream information sharing.

Developing an understanding of effect of information sharing on bullwhip effect, in next subsection 3.2 we will discuss importance of order batching in a supply chain.

3.2 Importance of Order Batching

This section deals with studying supply chain management, bullwhip effect and consequent beer distribution game. We have simulated a four member supply chain (retailer, wholesaler, distributor, and manufacturer) using the beer distribution game and obtained data under various controlled condition.

Supply Chain Games: Nine different types of games were played, three times each, to validate the results obtained from each game. The different types of games played are:

- Normal game with cost consideration
- Normal game with cost consideration and order batching

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

Data from the Beer Distribution Game:

Game Type: Normal beer game with no constraints but shortage, holding, ordering, and material costs to be considered.

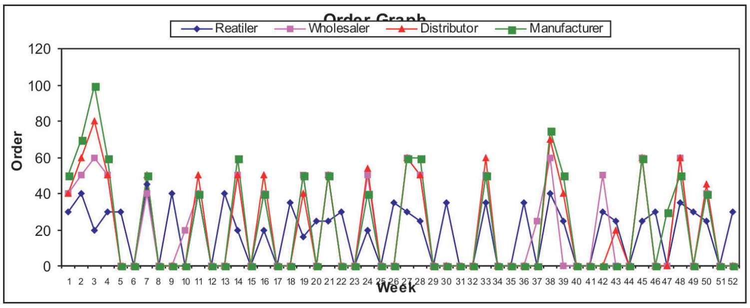

Figure 6: Ordering Curve for Normal Game (With Cost)

Game Type: Beer game with Order Batching with shortage, holding, ordering and material costs to be considered.

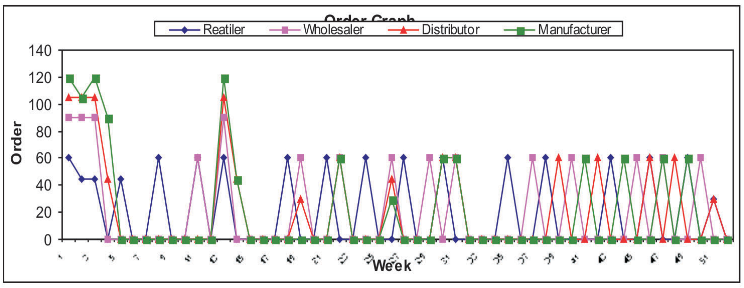

Figure 7: Ordering Curve for 1st Batch Game with Cost (Batch Size 15)

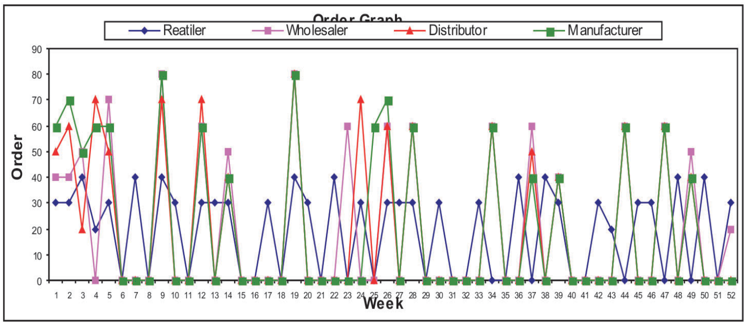

Figure 8: Ordering Curve for 2nd Batch Game with Cost (Batch Size 10)

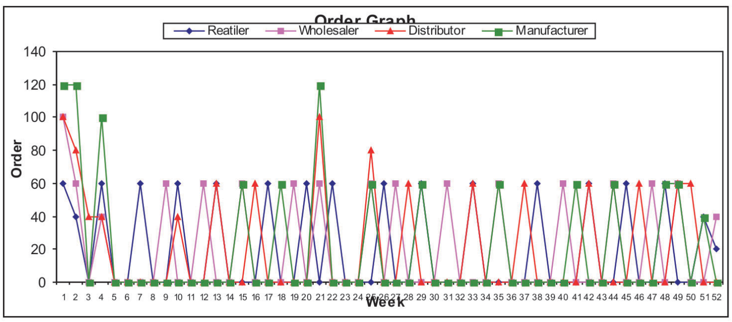

Figure 9: Ordering Curve for 3rd Batch Game with Cost (Batch Size 20)

It can be seen (Figures 6 to 9) that very large oscillations are present in the demand pattern, therefore, the members of the Supply Chain place a very high order for one week, which is followed by no orders in the subsequent weeks, as compared to ordering weekly to reduce the cost of the respective member. It is clearly seen from the Figures that there is presence of phase lag which may be attributed to order batching.

3.2.1 Data Quantification and Analysis: The analysis was carried out in three stages 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.

The games considered in this case are:

- Normal Game with cost considerations (N.W.C.)
- Order Batching (Batch size 10) with cost considerations. (B10.W.C.)
- Order Batching (Batch size 15) with cost considerations. (B15.W.C.)

Stage I: Correlation between order and demand patterns.

From the correlation analysis, 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 batch size increases, the demand and the ordering pattern becomes less correlated.

Stage II: Formulation of hypothesis.

Hypothesis I: Order Batching within the Supply Chain will increase the level of order oscillations throughout the Supply Chain related to the mean order value.

Hypothesis II: As the batch size increases, the level of order oscillations throughout the Supply Chain related to the mean order value also increases.

Stage III: Comparison between means and Comparison between variances.

Null hypothesis: We assume the means and variances of the data are the same and check for its significance. If the value is insignificant, the hypothesis is accepted else rejected.

The comparison consists of two parts:

a) Comparison within a game.

b) Comparison between games.

3.2.1a Comparison within a game

- Comparison between means (t-test)

It is found that the difference in the means of demand and order pattern of the members within a game is insignificant, proving that the data is valid for performing the F-test within a game.

- Comparison between variances (F-test)

It is found that most of the F-values are greater than the significant F-value. This provides evidence of oscillation being present within a game.

3.2.1bComparison between games

- Comparison between means (t-test)

The t-values of Retailer, Wholesaler Distributor, and Manufacturer, when compared with t-significant value at a 95% level of confidence, are insignificant. This proves that the mean value of the order pattern of all the members in all the games is similar. Therefore, they can now be tested for oscillations using F-test.

- Comparison between variances (F-test)

Table 9: F-value for N.W.C. & B10.W.C.

Normal Vs Batching (10) with cost F-Value				
	Retailer	Wholesaler	Distributor	Manufacturer
Retailer	**1.106**	3.1649	3.2214	3.3810
Wholesaler	0.4582	**1.311**	1.3345	1.4006
Distributor	0.3861	1.1047	**1.124**	1.1801
Manufacturer	0.3433	0.9824	0.9999	**1.049**

Table 10: F-value for N.W.C. & B15.W.C.

Normal Vs Batching (15) with cost F-Value				
Batch (10) / Normal	Retailer	Wholesaler	Distributor	Manufacturer
Retailer	**3.005**	4.1169	4.4798	5.4833
Wholesaler	1.2449	**1.705**	1.8557	2.2714
Distributor	1.0489	1.4370	**1.563**	1.9139
Manufacturer	0.9328	1.2779	1.3905	**1.702**

Table 11: F-value for B10.W.C. & B15.W.C.

Batching (10) Vs Batching (15) with cost F-Value				
Batch (15) / Batch (10)	Retailer	Wholesaler	Distributor	Manufacturer
Retailer	**2.716**	3.7219	4.0499	4.9572
Wholesaler	0.9495	**1.3**	1.4154	1.7325
Distributor	0.9328	1.2780	**1.3906**	1.7021
Manufacturer	0.8888	1.2177	1.3250	**1.6218**

Considering only the diagonal elements from Table 9 to Table 11, the F-values of Retailer, Wholesaler Distributor, and Manufacturer, when compared with F-significant value at a 95% level of confidence, are significant. Table 9 and Table 10 provide evidence of the presence of oscillation amplification when order batching is introduced in the Supply Chain, proving our first hypothesis. Further, Table 11 provides evidence of increase in oscillation amplification with the increase in batch size, proving our second hypothesis.

3.2.2 Findings

The simulation of four member supply chain under different controlled conditions, followed by quantification and analysis of data so obtained, have helped us arrive at the following major findings:

- The ordering curves plotted indicate towards reduced amplification in the case of smaller order batch size.
- The difference in means within a game and between games is insignificant for all the game with the help of t-test, so valid for F tests.
- The F tests performed within the game indicated towards significant difference in variances of demands for all the games, which means the presence of bullwhip effect in all types of games.
- Further F test performed between different types of games to test for significant difference in variances of demands, indicated towards significant reduction of order amplification with a smaller order batch size.

After understanding the effect of information sharing and order batching on bullwhip effect, in next subsection 3.3 we will discuss importance of lead time in a supply chain.

3.3 Importance of Lead Time

Nine different types of games were played, each three times to validate the results obtained from each game.

Supply Chain Games: The different types of games considered are:

- Normal game with 1 week lead time
- Normal game with two weeks lead time

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

Data from the Beer Distribution Game:

Game Type: No constraints, Lead Time 1 Week, Random Demand Pattern. (Normal)

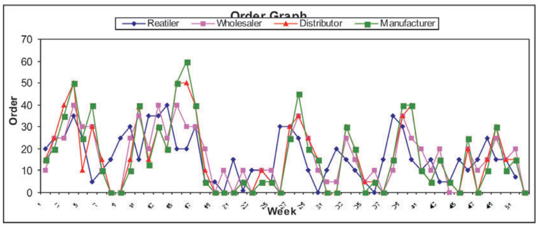

Figure 10: Ordering Curve for Normal Game

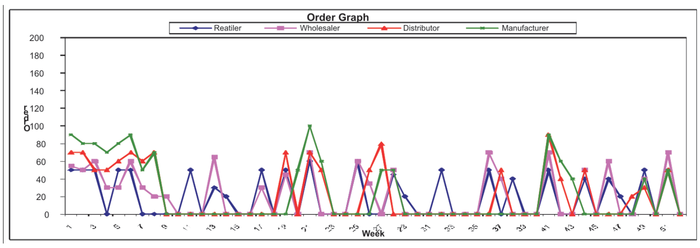

Figure 11: Ordering Curve for 2nd Game of Lead Time Two Weeks

It is also quite evident from the graphs (Figure 10) that the Bullwhip Effect is present in the above discussed Supply Chain. The three indicators of Bullwhip Effect — i.e. oscillation, amplification, and phase lag — can easily be seen in the demand curve. The graph clearly shows the magnified variability in demand from customer to supplier, with the phase shift due to the lead time to complete orders. The demand posed by the downstream member to the immediate upstream member may not be the actual demand of the customer, hence resulting in the amplification of demand. 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 Type: Lead time two week, (no info sharing or batching):

From Figure 11 it can be seen that there are very large oscillations present in the demand pattern that can be attributed to very large ordering costs, as compared to the holding cost. Therefore, the members of the Supply Chain place a very high order for one week, followed by no orders in the subsequent weeks, as compared to ordering weekly to reduce the cost of the respective member. Also, it is seen that there is increase in the phase lag which may be attributed to the increased lead time.

3.3.1 Data Quantification and Analysis: The analysis in each case was carried out in three stages 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: Correlation between order and demand patterns.

It is 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 insignificant. Also, as the lead time increases, the correlation between the demand and ordering pattern decreases.

Stage II: Formulation of hypothesis.

Hypothesis I: Increase in lead time within the Supply Chain will increase the level of order oscillations throughout the Supply Chain related to the mean order value.

Stage III: Comparison between means and Comparison between variances.

Null hypothesis: We assume the means and variances of the data are the same and check for its significance. If the value is insignificant, the hypothesis is accepted else rejected.

The comparison consists of two parts:

a) Comparison within a game.

b) Comparison between games.

3.3.1a Comparison within a game

- Comparison between means (t-test).

  It is seen that the t-values from the games in the above Tables are less that 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).

It is seen that most of the F-values are greater than the significant F-value, proving evidence of oscillation presence within a game.

3.3.1b Comparison between games

- Comparison between means (t-test).

It is found that the mean value of the order pattern of all the members in all games is similar. Therefore, they can now be tested for oscillations using F-test.

- Comparison between variances (F-test).

Table 12: F-value for N.W.C. & LT2.W.C

Normal Vs 2 Week L.T. with cost F-Value (E)				
N.W. / LT2.W.C.	Retailer	Wholesaler	Distributor	Manufacturer
Retailer	**2.2504**	2.8432	3.6478	4.6329
Wholesaler	0.9323	**1.17**	1.5111	1.9190
Distributor	0.7855	0.9924	**1.2732**	1.6171
Manufacturer	0.6985	0.8825	1.1323	**1.438**

Considering only the diagonal elements from Table 12, the F-values of Retailer, Wholesaler, Distributor, and Manufacturer, when compared with F-significant value at a 95% level of confidence, are significant. This also provides evidence of amplification presence of order oscillation when the lead time is increased from one week to two weeks in the Supply Chain, proving our hypothesis.

3.3.2 Findings: The simulation of four member supply chain under different controlled conditions, followed by quantification and analysis of data obtained, have helped us arrive at the following major findings (refer Appendix I)

- The ordering curves plotted indicate towards reduced amplification in the case of lesser lead time.
- The difference in means within a game and between games is insignificant for all the game with the help of t-test, so valid for F tests.
- The F tests performed within the game indicated towards a significant difference in variances of demands for all the games, establishing presence of the bullwhip effect in all types of games.
- Further F tests performed between different types of games to test for significant difference in variances of demands, indicated towards significant reduction of order amplification with lesser lead time.

4. Conclusion

The bullwhip effect is undesirable and makes the supply chain unproductive, resulting in increased cost and losses to the organizations and sometime customer loss. Reduction of bullwhip effect is possible, but complete removal of bullwhip effect in the supply chain seems to be impossible.

Through this paper, we have identified the importance of information sharing, reduced order batch size, and lead time to reduce bullwhip effect From the correlation analysis, it was found that correlation among the demand decreases as we move farther from one member and sometimes is insignificant. The study indicates that human behavior is also one of the major factors affecting bullwhip effect, but its effect can be reduced by appropriate training and learning.

Beer games played under different conditions have been compiled, 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 information sharing at any level is beneficial in reducing bullwhip effect, and that complete information sharing is the best proposed solution to reduce the bull whip effect, as compared to upstream information sharing and downstream information sharing. It has been indicated that small order batch size and lesser lead time help supply chain managers to reduce bullwhip effect.

This work can further be improved and extended with more realistic simulations performed by including parameters such as government policies, price fluctuations, and order cancellations. The simulation which has been carried out for consumer good may be extended to a variety of goods to evaluate the impact of information sharing on the bullwhip effect.

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