A New Computerized Beer Game:
A Tool for
Teaching the Value of Integrated Supply Chain Management[1]

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Introduction

If you've taken or taught an Operations Management course in the last twenty years, you are no doubt familiar with the Beer Game[2]. This role-playing simulation of a simple production and distribution system has been used in countless undergraduate, graduate, and executive education courses since it was first developed at MIT in the 1960's.

The Beer Game is typically played on a large board. Locations on the board represent four components, or stages, of the Beer Supply Chain: the factory, the distributor, the wholesaler, and the retailer. Orders placed by each of the component managers, as well as inventory in transit and at each of the locations, are represented by markers and pennies that are

[1] Appeared in: *Supply Chain and Technology Management*. Hau Lee and Shu Ming Ng, *eds.*,©1998 The Production and Operations Management Society: Miami, Florida.

[2] The beer game is described in the following references:

Sterman, John D., Modeling Managerial Behavior: Misperceptions of Feedback in a Dynamic Decision Making Experiment *Management Science* **35(1989)**, pp. 321-339.

Sterman, John D., "Teaching Takes Off: Flight Simulators for Management Education" *OR/MS Today* **October 1992** pp. 40 -44.

placed at the appropriate locations on the board. External demand is represented by a stack of cards.

One player manages each of the supply chain components. Each week, the retail manger observes external demand (by drawing the next "demand card"), fills as much of this demand as possible, records backorders to be filled, and places an order with the wholesaler. The manager of the wholesaler, in turn, observes demand from the retailer, fills as much of this demand as possible, records backorders, and places an order with the distributor. The distributor manager repeats this process, ordering from the factory. Finally, the factory manager, after observing and filling demand and backorder, begins production. Order processing and filling delays are incorporated into the game to represent order processing, transportation, and manufacturing lead times.

The rules of the game require that all backorders are filled as soon as possible. Also, at each stage of the supply chain, the manager at that stage has only local information; only the retail manager knows the customer demand. The goal of the game is to minimize the total holding and backorder cost at stage you are managing – each week, a cost of $.50 for each unit in inventory, and $1.00 for each unit of backorder, is accrued.

A typical game is played for twenty-five to fifty weeks. During the game, communication between players is limited. Inventory and backorder levels usually vary dramatically from week to week. At the end of the game, the players are asked to estimate customer demand. Except for the retail manager, who knows the demand, players often estimate wildly varying demand. After being informed that demand was constant at four units per week for the first four weeks, and then eight units per week for the remaining weeks, players are often surprised. Instinctively, they blame the other players for following inappropriate strategies.

At this point, the instructor typically interrupts the discussion to make several points about the outcome of the game. Usually, these include:

- Since customer demand doesn't vary much, there must be another cause for wildly fluctuating inventory and backorder levels. As Sterman[3] points out, this is due to the many "feedback loops, time delays, and non-linearities" in the system, coupled with the tendency of managers to over-react to unexpected changes in demand or inventory levels.

- Much of this tendency to over-react can be attributed to a lack of information about the system. In particular, players have no knowledge of the customer demand or of order policies utilized by the other players. In addition, this lack of information prevents players from working together to improve overall performance.

The implication of these points, of course, is that in a real world supply chain, these observations, both concerning supply chain management problems, and **the causes of those problems**, will also apply. Specifically, the game implies that a major problem in the supply chain is high costs resulting from oscillations in inventory and backorder, and that the irrational behavior of managers without complete information is one of the causes of these oscillations[4].

The Difficulties with the Beer Game

When the Beer Game was first introduced, in the 1960's, the concept of *integrated supply chain management*, as well as advanced information systems that support this concept, was not

[3] Ibid.

yet developed. In many cases, the supply chain was managed by different managers at each stage based on their individual intuition, experience and objectives. Since then, however, both the theory and the practice of supply chain management have improved significantly. Unfortunately, the Beer Game, as traditionally played, does not necessarily reflect current supply chain practices, and perhaps more importantly, the Beer Game does not necessarily provide students with insight on how to **better manage the supply chain.**

These weaknesses of the traditional Beer Game can be attributed to several of its characteristics. Our experience with the game suggests that the **students typically are so occupied with the mechanics of the game**, making sure that they correctly follow the game rules, that they have no time to develop an effective strategy. Even if a participant uses a sophisticated strategy, he may tend to attribute the inventory and backorder problems, as well as higher than expected cost, to the other participants' strategies, rather than to search for potential flaws in his own strategic decisions.

In addition, the demand pattern exhibited in **the Beer Game does not reflect a realistic supply chain scenario**. In the traditional game, demand unexpectedly doubles in the fifth week of play and remains at that level. In real life, it is unrealistic to expect that managers of each one of the supply chain facilities would not be informed of such a huge change in demand patterns.

Finally, the traditional Beer Game doesn't demonstrate several other important supply chain management issues. For example, in many real world supply chains, several (or all) of the stages have a single owner. Thus, the real objective is to minimize the total system cost, and not

[4] Ibid.

individual performance. Unfortunately, **there is no way in the traditional Beer Game to judge how much is lost by managing stages individually**.

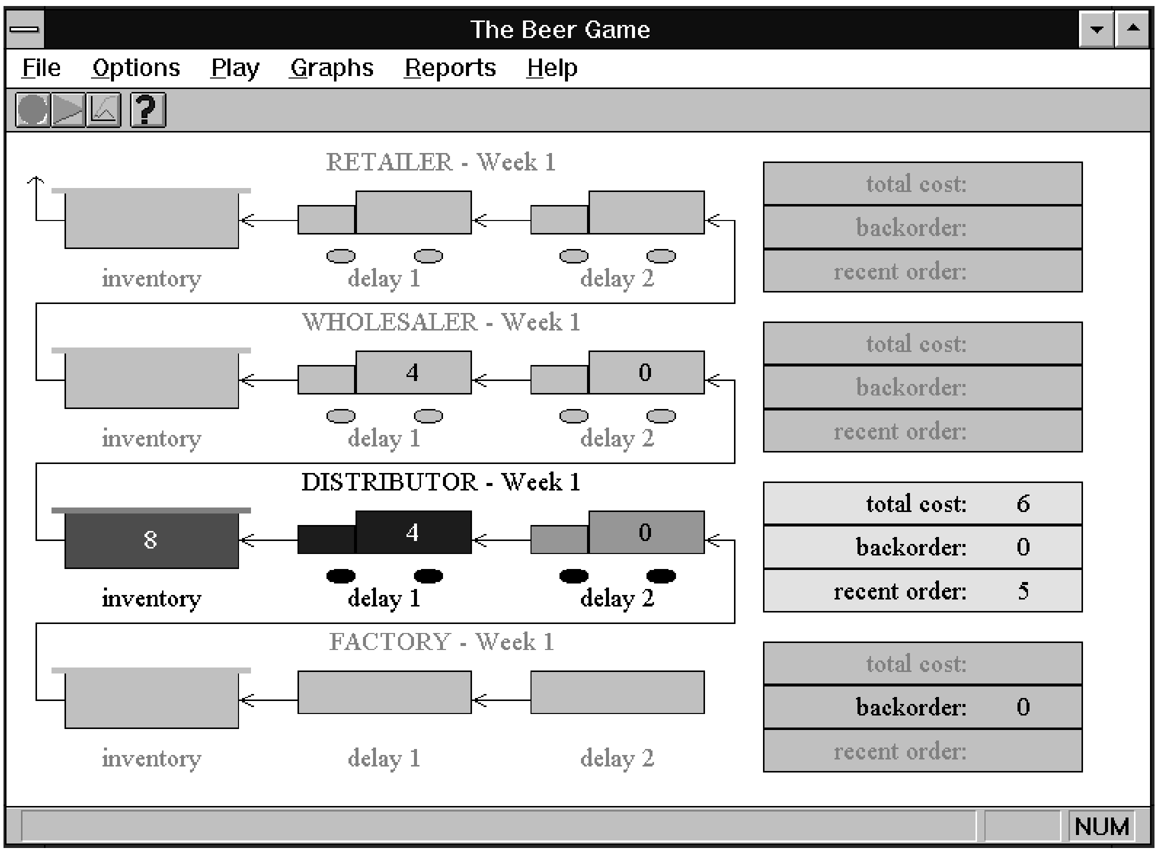
Many of the difficulties in managing the supply chain that are highlighted by the Beer Game can be addressed by shortening cycle times, and centralizing information and decision making. Unfortunately, these approaches to **solving many supply chain management problems** are not typically demonstrated in the traditional Beer Game -- students can only learn about them in the lecture following game play.

If all of these points are true, what exactly is the value of playing the Beer Game? More importantly, what makes managing the supply chain so complex, and how can we teach this? We will argue that in fact, there are three important supply chain management concepts which students can learn from a new version of the game, if it is played using the appropriate tools. These concepts are a result of the *dynamic nature* of demand and are some of the main reasons why managing supply chains is so complex. To help students understand these concepts, we have developed a new, **computerized version** of the Beer Game.

It is important to point out that several other computerized versions of the game exist, including those developed at the Wharton School, the University of Michigan, and MIT. However, our computerized game includes modifications and enhancements of the original game in order to teach important supply chain management concepts, whereas as far as we know, the other computerized games are "automated" versions of the traditional game, primarily intended to make the game run faster.[5] In what follows, when we refer to the *Computerized Beer Game*, we are referring to our version of the game as described below.

A Computerized Version of the Beer Game

The computerized version of the Beer Game is an easy to use Windows based program written in C++, and is shown below.



It follows the rules, timing, lead times, and all other parameters of the original Beer Game, with a few exceptions. Instead of players taking the roles of managers of *each* of the supply chain stages, a human player takes on one role, and the computer manages the remaining stages, using one of several policy options that are chosen by the instructor. In addition, demand in the computerized game can be either deterministic or random, and may have a step change in

[5] We have recently been informed of a computerized game, developed at MIT, which incorporates some of the types

mean demand at any time chosen by the instructor. As the game progresses, costs are calculated slightly differently. Instead of paying inventory costs only on items in the warehouse, each player also pays inventory holding costs for downstream items in the "trucks" en route to that player's downstream customer. For example, the *Distributor* pays not only for items at the *Distributor* warehouse, but also for items en route to the *Wholesaler*.

To further enhance teaching possibilities, the *Computerized Beer Game* has three new important options: a **global information option**, a **centralized option**, and a **short lead time option**. When playing the global information version of the game, all information, including customer demand and inventory at all of the stages, is always available to the player. When playing the centralized version of the *Computerized Beer Game*, the player takes the role of *Factory* manager. Once again, all information is always available. Because the system is centralized, stages other than the *Factory* do not place orders; all inventory is moved through the system as quickly as possible. Also, since in the centralized version of the game there can be no backorder at any stage except for the first one, we adjust system costs *in this version* by setting backorder cost at the *Retailer* to $4.00 (up from $1.00). This enables a fair comparison between centralized and decentralized policies. Because three sets of orders are eliminated, product moves through this supply chain three weeks faster than in the original game.

Also, the **short lead time option** allows play with a one week delivery delay between stages, rather than the two weeks originally employed. This option can be used with or without the centralized option. Finally, to demonstrate the effect of strictly utilizing a particular policy, the *interactive player* role can be eliminated, so that the computer takes all of the roles, and the students observe the consequences of the pre-set policies.

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of changes described here.

All of these settings and parameters address problems that often arise when teaching modern supply chain management using the traditional Beer Game. They also provide us with an effective tool to teach about some advanced and complex supply chain management issues.

We have had the opportunity to use this game to teach several classes. In each class, we play the game using several different settings. Along the way, we are able to illustrate three important and interrelated supply chain management effects: **the Bullwhip Effect, the Centralization Effect,** and **the Lead Time Effect**. We discuss each of these in more detail in the following sections.

The Bullwhip Effect

The first time a class plays the game, we play a *decentralized* game, and each student takes the role of the *Distributor*. Typically we divide the class into groups of 2-3 students, each with a computer and a copy of the software. The students do not know the form of the demand, which we have previously set to be **normally distributed**, with a mean of six and standard deviation of two. All of the computer-managed supply chain stages are managed utilizing a simple *(s,S)* policy, where *s* is updated by continuously updating estimates of demand mean and variance, and *S* is set to 30. As mentioned earlier, other classical inventory policies can be selected, but the effects described here seem to appear in almost all cases. We generally split the class into two groups, one using the regular lead time, and the other using the **short lead time option** described above.

The data for a typical class is shown in the table below. Notice that in this table, the standard deviation of orders placed by the students (distributors) is much greater than the standard deviation of customer demand. We have observed this effect in every class that has played the game. In addition, in many of the cases, at each stage, the standard deviation is greater than the immediate downstream stage[6]. This is precisely **the Bullwhip Effect discussed** in the seminal paper by Lee et al.[7]

Table 1

Group	Lead-Time	Distributor Cost	System Cost	Retailer Demand (mean/SD)	Wholesaler Demand (mean/SD)	Distributor Demand (mean/SD)	Factory Demand (mean/SD)
1	long	1188	2613	4.44/7.03	5.16/9.33	8.40/14.20	9.12/14.81
2	long	622	1634	5.52/6.40	5.84/8.91	7.68/6.74	8.40/7.25
3	long	449	1517	6.28/4.32	6.60/7.43	6.92/6.61	7.24/8.32
4	long	543	1715	6.16/4.72	6.64/7.80	7.16/7.96	7.88/8.53
5	long	510	1610	6.28/6.03	6.64/8.80	6.00/8.25	6.72/9.59
6	long	464	1612	6.08/5.11	6.44/7.94	6.92/7.62	7.52/8.32
7	short	1090	2285	5.92/7.84	5.96/9.99	7.92/17.75	8.64/19.99
8	short	447	1361	6.08/7.80	6.90/10.63	6.56/8.75	7.12/9.99
9	short	1639	2915	6.36/7.87	6.84/10.69	12.56/15.57	13.44/15.70
10	short	400	1302	6.96/7.77	7.16/9.99	7.20/13.93	7.52/14.59
11	short	444	1186	6.16/7.93	6.28/9.92	6.56/7.58	7.28/9.06
12	short	347	1248	5.96/8.36	6.84/11.21	5.92/12.54	6.80/13.47

Note that even in the cases in which the students, taking the role of the *Distributor*, managed to decrease the standard deviations of their orders relative to those of the *Wholesaler*, this decrease was slight. In no cases was the standard deviation of *Distributor* orders even close to the standard deviation of external demand, which was set at two.

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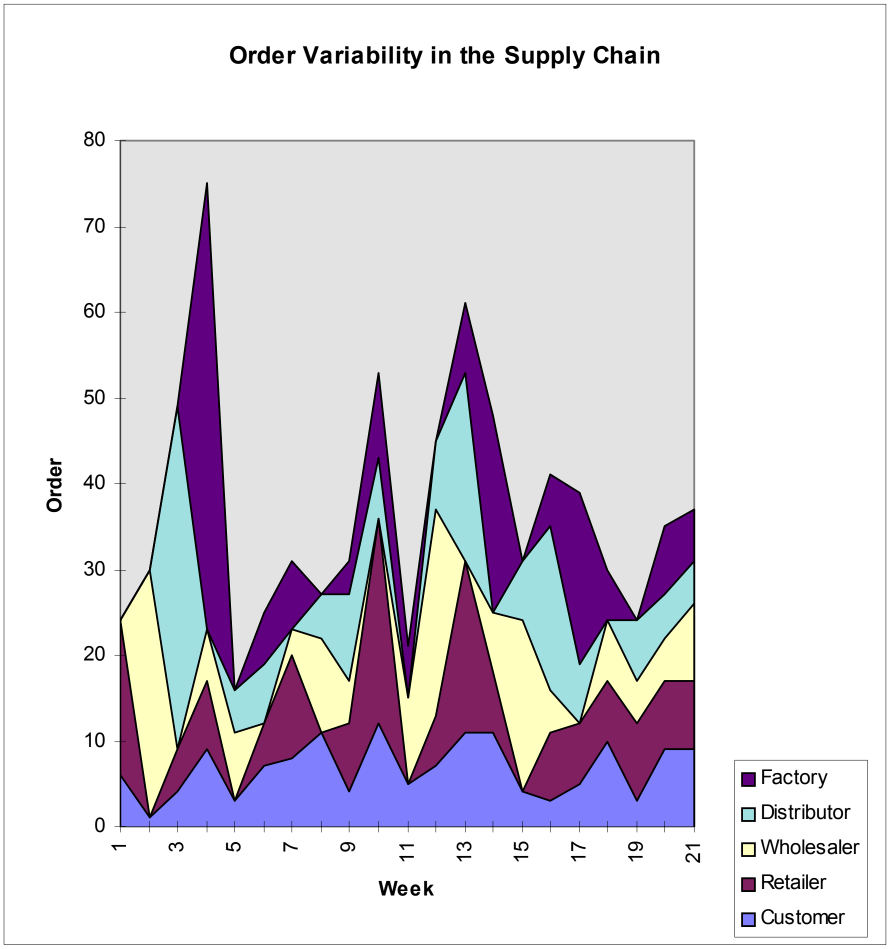
[6]Although traditional inventory theory calls, in this situation in which there is no setup costs, for an *order up to S* policy, we utilize a simple *(s,S)* policy with fixed *S*, which serves to limit the size of the orders. Indeed, in testing the game, we have discovered that using an *order up to S* in which *S* is continuously updated causes variance to propagates even more rapidly upstream, quickly reaching more than twenty times the variance of the original demand for the settings described above.

[5]Lee, H. L., P Padmanabhan, and S. Whang (1995) The Paralyzing Curse of the Bullwhip Effect in a Supply Chain *To appear in* ***Sloan Management Review***.

In addition, the figure below provides a graphical representation of orders, as a function of time, placed in a typical round of the *Computerized Beer Game* across the supply chain. Again we clearly see the increasing variability across the supply chain.



The term Bullwhip Effect was coined by executives at Proctor and Gamble. Examining the demand for Pampers disposal diapers, they noticed an interesting thing[8]. As expected, retail sales of the product were fairly uniform – there is no particular day or month in which the demand is significantly smaller or larger than any other. However, these executives noticed that their distributors placed orders to the factory that fluctuated much more than retail sales. Even

[8] Ibid.

more surprisingly, P&G's orders to its suppliers fluctuated even more. This increase in variability as we travel up in the supply chain is exactly the Bullwhip Effect.

The consequences of the Bullwhip Effect are obvious: it increases safety stock and therefore inventory costs, or alternatively, it reduces service level. In addition, it tends to increase total transportation costs since there is a lack of coordination of the transportation and inventory management policies due to the inability to accurately estimate requirements in a particular period. In general, it makes it more difficult to efficiently manage and operate the system since available resources are not utilized efficiently. For example, sufficient warehouse capacity and staffing is required to meet peak demand even though this high level of demand may only be seen infrequently. But where does this effect come from? Lee et al.[9] identify several potential causes of the Bullwhip Effect.

Of course, irrational managerial behavior might lead to this effect, but as we have previously mentioned, the Bullwhip Effect is present even if managers behave rationally. Typically, managers use standard forecast smoothing techniques to estimate average demand and demand variability. In fact, in our experience with the *Computerized Beer Game*, some more sophisticated groups have used variations of these techniques. Interestingly, these sophisticated techniques may actually increase variability up in the supply chain. This is explained as follows: as the *Retailer* manager receives more data, she, through an exponential smoothing technique, updates her estimate of demand variability, and therefore updates her safety stock requirements and reorder point. Since safety stock levels and reorder points are functions of lead time, and lead time is several periods, the change in *Retailer* orders is greater than the change in the demand estimators. This change in order policy increases the estimated variance of the next manager upstream, at the *Wholesaler*, who in turn updates his order policy. Once again, due to lead time multiplier effects, the change in *Wholesaler* order policy is greater than the change in the *Wholesaler's* demand estimators. As this process of estimating and modifying order policies propagates up the supply chain, variance is increased at each stage. This is exactly what the students see in the *Computerized Beer Game*.

Of course, in real life, there are many other causes that can lead to the Bullwhip Effect. For instance, price fluctuation is one such cause. If prices fluctuate, retailers often attempt to "stock up" when prices are lower. This is accentuated by the practice in many industries of offering promotions and discounts at certain times, or for certain quantities. Also, as transportation costs become more significant, retailers may order quantities that allow them to take advantage of transportation discounts (for example, full truck load quantities). Since these quantities may not correlate exactly with customer demand quantities, this practice may lead to irregular order periods, and thus to increased variance across demand periods in the system.

Finally, inflated orders placed by retailers during shortage periods tend to magnify the Bullwhip Effect. Such orders are common when retailers and distributors suspect a product will be in short supply, and therefore anticipate receiving supply proportional to the amount ordered. These inflated orders are often later canceled, leading to all kinds of distortions and variations in demand estimates. For more information, we again refer the reader to Lee et al[10]. For an analytical view of the Bullwhip effect, see Chen et al.[11], Drezner et al.[12] and Lee et al.[13]

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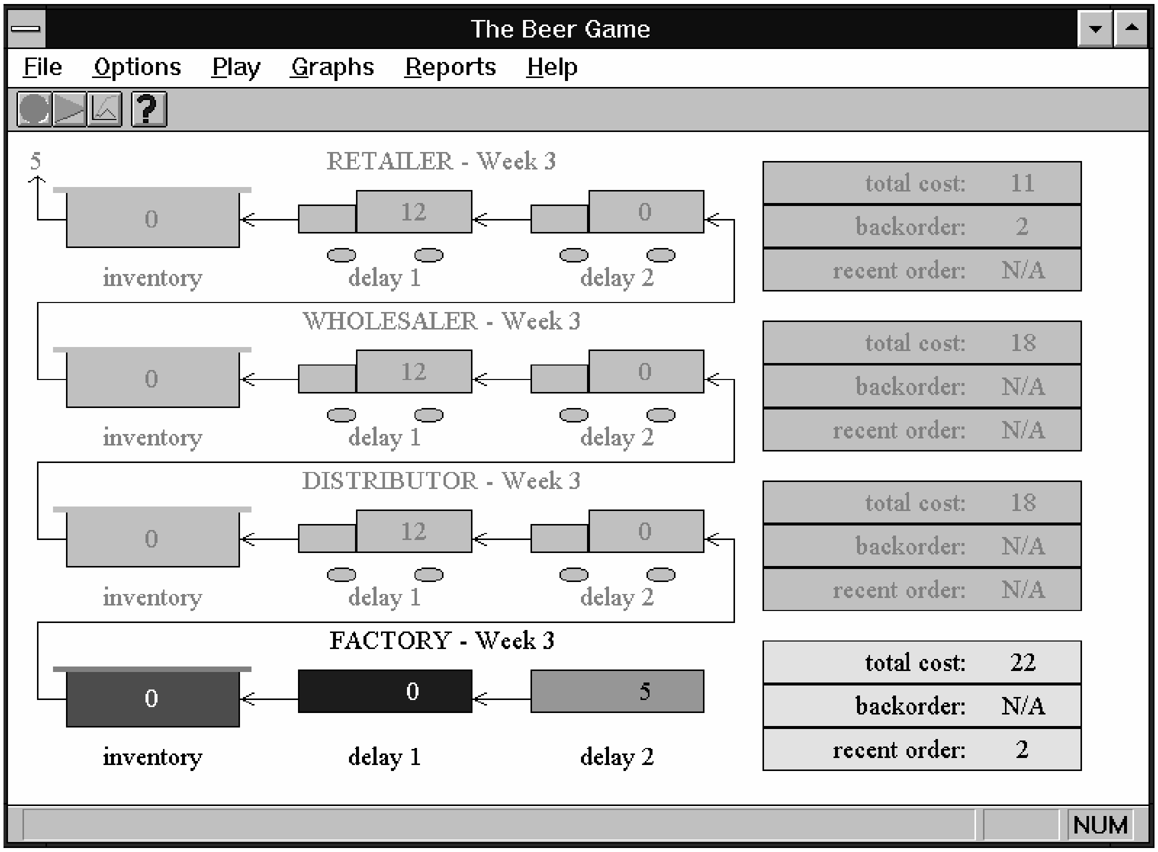
[9] Ibid.
[10] Ibid.
[11] Chen, F., J. Ryan, and D. Simchi-Leiv (1997) The Impact of Exponential Smoothing Forecasts on the Bullwhip Effect. *Working Paper, Northwestern University.*
[12] Drezner, Z., J. Ryan and D. Simchi-Levi (1996) Quantifying the Bullwhip Effect in a Simple Supply Chain: The Impact of Forecasting, Lead Times, and Information. *Working Paper, Northwestern University.*

All of these causes have one thing in common: they are related to distortions of demand and inventory policy information within the supply chain. The obvious question is: What if we made all necessary demand information, as well as complete information on the inventory policies used at each stage, available across the supply chain? This is precisely what we explore in the next round of the *Computerized Beer Game* play.

The Centralization Effect

In the second round of class play, we utilize the **centralized play** option of the *Computerized Beer Game*. As we described above, when this option is selected, the player has complete knowledge of customer demand and inventory levels throughout the system. The screen for this version of play is shown below.

[13] H.L. Lee, P. Padmanabhan, and S. Wang(1994) Information Distortion in a Supply Chain: The Bullwhip Effect *To appear in* ***Management Science***.



The player places orders for the factory, and orders are filled and sent through the system to the *Retailer* as quickly as possible. Again, the class is split into regular and short lead time groups. Data from a typical round of play for a regular lead time group is given in the table below. As expected, total system cost has decreased on average, compared to the first, decentralized round. Notice that this happens even though we have adjusted costs (by increasing backorder cost at the *Retailer* from $1.00 in the decentralized game to $4.00 in this game) to account for the fact that there is no backorder at three of the four stages.

Table 2

Group	Lead Times	Decentralized System Cost	Centralized System Cost
1	long	2613	724
2	long	1634	1332
3	long	1517	698
4	long	1715	1001
5	long	1610	912
6	long	1612	787
7	short	2285	763
8	short	1361	424
9	short	2915	387
10	short	1302	1106
11	short	1186	406
12	short	1248	524

Invariably, each player returns a lower overall system cost for a given number of weeks than in the first, decentralized round of play. This is true for several reasons. Most obviously, the player now has information about total system cost at every round of play. Clearly, it is easier to work to minimize costs in an entire system if this information is available.

Also, much of the information distortion that led to the Bullwhip Effect has been eliminated. At the *Factory*, the player can see customer demand, compare it to total system inventory, and react appropriately. There is no need to attempt to predict customer demand, and to estimate the policies used to propagate demand throughout the system. Thus, forecasting errors and ordering policies do not serve to hide actual demand information, and a lower system cost can be achieved.

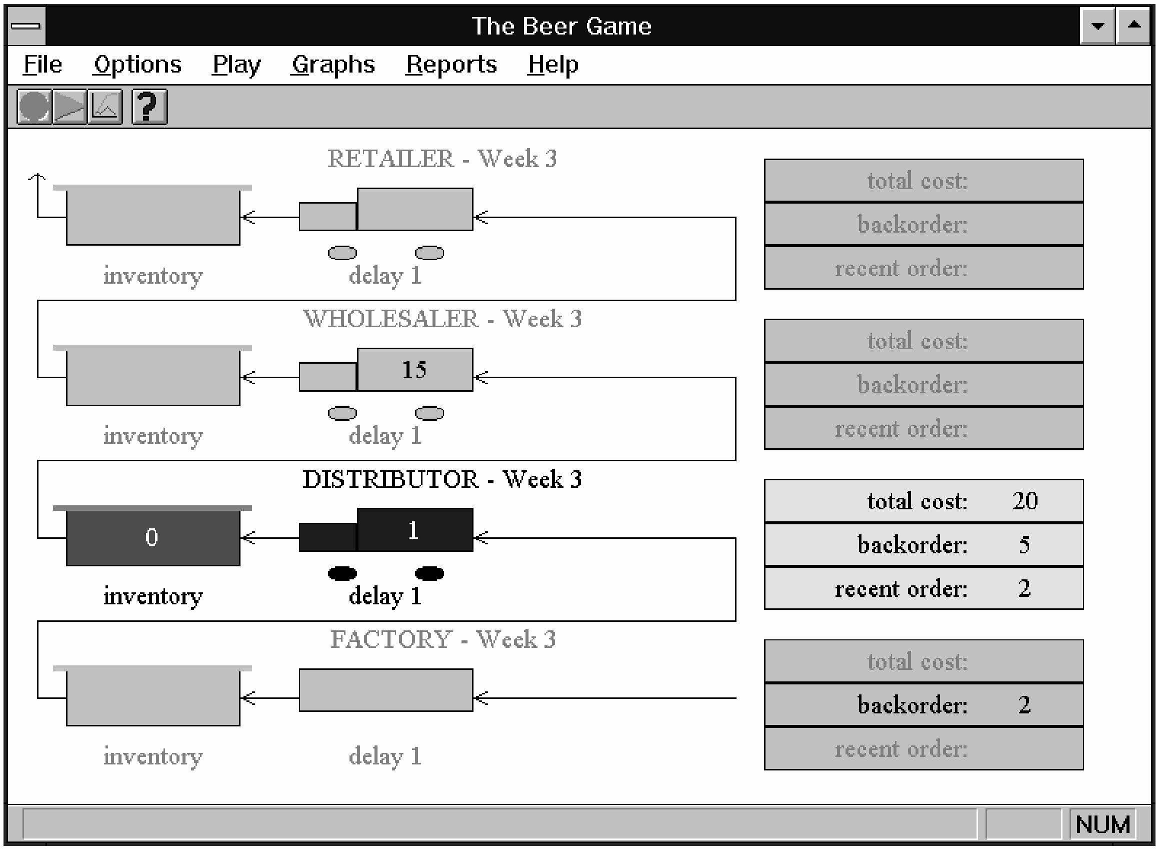
The lesson of this round of play is clear -- increased information and centralized control can only be beneficial to system operation. Indeed, even when centralized control is difficult because different stages of the supply chain have different owners, it is worthwhile to implement some scheme that makes this kind of information sharing possible. For example, Wal-Mart, as well as many other retailers, now make Point of Sale (POS) data available to their suppliers. These retailers have decided that the risks inherent in sharing information with outsiders are far outweighed by the potential benefits.

The current trend towards Vendor Managed Inventories (VMI) is also directly related to this Centralization Effect. In these kinds of partnerships, retailers place their suppliers in charge of managing inventory at the retail locations. Thus, the suppliers are harnessing the Centralization Effect to minimize system costs. This cost savings is then split between suppliers and customers.

An astute observer will notice that in this centralized version of the *Computerized Beer Game*, system lead time is shortened. This is because the *Retailer*, *Wholesaler*, and *Distributor* no longer place orders, and thus the one week order lead time attributed to each of these orders is avoided. This raises the question: How much of system saving realized in the centralized scheme is due to decreased system lead time? To answer this question, we compare data collected to this point for regular lead time groups to data collected from groups who played using the short lead time option.

The Lead Time Effect

This short lead time option of the *Computerized Beer Game* allows us to explore the effect of lead time on stage and system cost. Recall that while students are playing the *decentralized* and *centralized* rounds, we also collect *centralized* and *decentralized* ***short lead time*** data. As an example, the *decentralized short lead time* screen is displayed below:



Look back at Tables 1 and 2, to compare long and short lead time results. As you can see, performance is, in general, better when lead times are shorter. The few exceptions can be attributed to different students playing the long and short lead time roles. This dominance of short lead time players is true for two basic reasons. Most obviously, if system lead times are shorter, items will spend less time in the system, and thus will have less time to accrue holding costs.

In addition, we have previously pointed out that much of the demand variation that causes the Bullwhip Effect is caused by the forecast and ordering schemes employed by managers at each of the stages of the supply chain. As we have discussed, these procedures typically estimate average demand for each period, and the variance of that demand, and orders are then placed so that enough will be on hand to cover variations in demand during order lead time. Of course, if this lead time is long, a small change in (forecast) variability will imply a large change in safety stock level and the reorder point and therefore large fluctuations in orders placed by each stage of the supply chain. These changes obviously imply higher total system costs.

These are two of the reasons that lead time reduction efforts can be so valuable. Efforts involving improvements in operational efficiency, such as setup and processing time reductions and the use of **cross-dock** strategies, and efforts improving the management and transmission rate of information, such as **Electronic Data Interchange (EDI)** initiatives, can lower system cost **and** increase customer service.

Conclusions

The interrelated **Bullwhip Effect, Centralization Effect**, and **Lead Time Effect***,* are important for understanding the difficulties inherent in integrated supply chain management, as well as for developing a sense of what needs to be done to overcome these difficulties. We believe that a few rounds of the *Computerized Beer Game* serve to make this clear to current and future managers and executives. Of course, a round of the *Computerized Beer Game* eliminates much of the social interaction, and perhaps some of the fun, of the traditional game, but students familiar with both the traditional Beer Game and our computerized version tell us that they learn more from this new version.

Clearly, there are many complex real-life issues in supply chain management which we do not incorporate into the computerized game. However, we feel that the *Computerized Beer Game* is a valuable tool for teaching students about the difficulties of supply chain management, and also for providing them with insight into how different parameters and elements effect supply chain costs. Hopefully, they will find this insight useful for judging the value of different supply chain management strategies.

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