A Computerized Beer Game and Decision Making Experiments

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Abstract

This paper has two goals: The first is to present a computerized version of "Beer Game" originally developed as a board game to teach managers the principles of supply chain management. The multiplayer interactive simulation game we develop is 100 percent faithful to the original game, so that experimental results from the physical and computerized environments can be safely compared. The simulation model used to represent the game also illustrates some subtleties that a model builder must be careful about while simulating a discrete and physical game. Secondly, the game was used as an experimental platform and experiments were done in order to analyze game medium (computer vs. board), demand pattern and learning effects on performances of players. One striking result is the fact that subjects who played the board game scored significantly better than those who played the computerized version in the same conditions.[1]

[1] Supported by Bogazici University Research Fund, grant number: 02R102

1. Introduction

Beer Game is a well known example of a supply chain structure. This game was developed originally as a board game by the System Dynamics Group of MIT Sloan School of Management to teach principles of management science. In the game each player of a team manages a single inventory along a supply chain through deciding on her order rate each period. Each team consists of four players positioned as: Retailer, Wholesaler, Distributor and Factory. Each sector of the game orders from the sector in the upstream position and supplies goods downstream. In case of stock-outs, there are no lost sales in that backlogs are allowed. Between each level of the supply chain there are two periods of shipping delays and two periods of order receiving delays. For the factory, the delay between placement of production orders and receipt of products is three periods. The team's objective is to minimize the total team cost, where costs are calculated cumulatively (on-hand inventory costs are $0.50/case/week and backlog costs are $1.00/case/week). Each player has local information but severely limited global information. Each player has information regarding her inventory/backlog level and her orders placed, he/she is also allowed to check the amount of goods he/she will receive in the next term. Communication between the players is not allowed during the game to better simulate real-life cases.

The analysis of experiments with the board game reveals that the inventory and order levels of sectors, independent of the given demand pattern, exhibit three major patterns of behavior: Oscillations, amplifications and phase lags. These behavior patterns occur even under very stable market conditions. [3] Players recognize the fact that their own actions are the real causes of these cyclic behavior patterns, whereas in real life most people are inclined to attribute the causes of undesirable effects to external factors rather than the internal system structure.

Several computerized versions of Beer Game exist, however none of them simulates the multiplayer board game with 100 percent fidelity. For example, the computerized beer game on the website of MIT [8] uses a different cost calculation than the one described in the board game instructions [5] and it assumes there is a total of three periods of delays between when a facility places an order, and when the results of that order arrive in inventory. However in the board game, this delay is four periods. We place special emphasis on this fidelity issue. The computer network simulation game we develop is a 100 percent exact replication of the Beer Game's board version. This equivalence was proven in the verification stage of the model design.

In the second part of the paper, we carry out a series of gaming experiments using the computerized game so as to analyze the effects of game medium (computer vs. board), demand pattern and transfer of learning (from one medium to the other) on the performances of players.

2. Constructing the Simulation Model

The model used for the computer network simulation game was based on the model developed by Sterman J.D. We modified the model so that order quantities became the inputs from players. Powersim Constructor Version 2.51 was used as the simulation software.

The model is discrete, in that all the adjustment time variables and DT is selected equal to one; and the formulations in the model are based on discrete modeling techniques. The basic model consists of four inventories, which are arranged along a single supply chain: Retailer, Wholesaler, Distributor, and Factory. Orders are placed from retail end towards manufacturing end, and goods flow in reverse direction. Each sector of this chain has a single customer, whose orders it should satisfy, and a single supplier, which it places all of its orders to. The same shipping and ordering delay structures exist as in the board game.

In the model the order rates of each sector were defined as constants which were replaced by the ordering decisions of players in the game version. The order rates were rounded to the nearest integer, since in the game version players can enter non-integer order decisions, which would be unrealistic.

In the game, the orders given by the players at each period are the only external inputs to the model. The shipment rates are automatically calculated, since each sector must ship all of the requested orders from them, as long as they have sufficient inventory on hand. Below are the critical issues we encountered while developing the model. Note that time t corresponds to the beginning of period t+1.

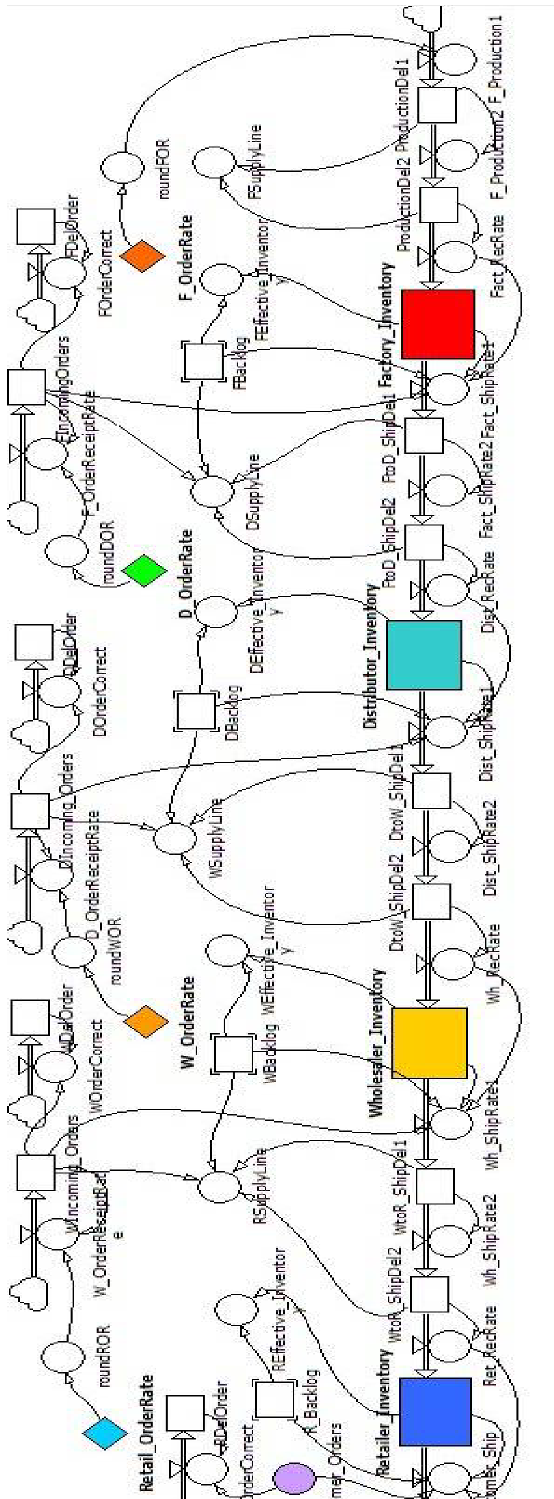

Figure 1. Part of the model used for the computerized game

Customer Demand Pattern

In the board game, customer orders have the classical pattern of 4,4,4,4,8,8,8,8,8,... , where there is a step increase in the beginning of fifth period. Since the fifth period begins at time 4, the orders must become 8 at time 4 in order to be consistent with the original game instructions. [5]

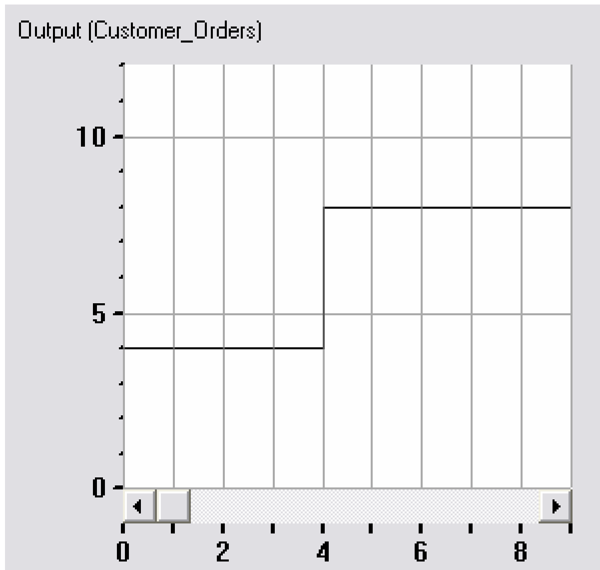

Figure 2. Default customer demand pattern

Shipment Formulations

Shipment rates from each inventory were formulated based on a comparison of the available supply and the requested orders from the sector under concern.

$$ShipRate = MIN(Incoming\_Orders + Backlog, ReceivingRate + Inventory) \qquad (1)$$

Incoming orders represent the orders from the sector's own customers, which arrive in the current period. This term is added to the accumulated backlog amount to find the total amount of orders the sector try to satisfy. This amount is compared to the available inventory on hand before shipping the order, which is exactly equal to *Inventory* plus *ReceivingRate.* In the board game, players first add the incoming shipments to their inventory during a period and then try to satisfy the demand for the period, so the formulation is consistent with the board game.

Verification phase and delay structure analysis

In order to verify that the model simulated the supply chain structure in the intended way, available data from the board game were utilized for benchmarking. The inventories and shipping delays in between -formulated as material delay structures- are basic stock-flow formulations. However, the design of ordering delay structure is more complex. Order receiving delays are represented by information delays in the model, where the number of information delays necessary to reproduce exactly the same structure as that of the board version of Beer Game was found after analyzing alternative delay structures thoroughly. To check the consistency of the models with the board game, a game with some arbitrary retailer orders was played on board. Then, these orders were entered as order-rate decisions into the model and tests were run to examine the stock values; since during the board game only the stock variables are observed. The resulting variable values were compared with the records in the board game. Three alternative ordering-delay structures were considered. We focused on the propagation of retailer orders only, because the delay formulations for wholesaler and distributor orders are similar. Retailer shipments are determined by customer orders with no delay, so no delay structure is necessary for customer orders. For the factory, three periods of product receiving delay was obtained without any need for information delay.

The retailer orders used for benchmarking and the corresponding wholesaler stock records from the board game are as follows:

Time	Retail_OrderRate	Wholesaler_Inventory	Wh_ReceivingRate
0	4,00	12,00	4,00
1	10,00	12,00	4,00
2	8,00	12,00	4,00
3	0,00	6,00	4,00
4	5,00	2,00	4,00

Table 1. Board game records for benchmarking

Alternative 1: Two-stock information delay structure

The formulations for the variables in this alternative are:

$$R\_order = (Retail\_OrderRate - R\_Orders\_Placed) / 1 \quad (2)$$
$$R\_Orders\_Placed = 4 + dt*R\_order \quad (3)$$
$$W\_OrderReceiptRate=(R\_Orders\_Placed - Wincoming\_Orders) / 1 \quad (4)$$
$$W\_Incoming\_Orders = 4 + dt*W\_OrderReceiptRate \quad (5)$$

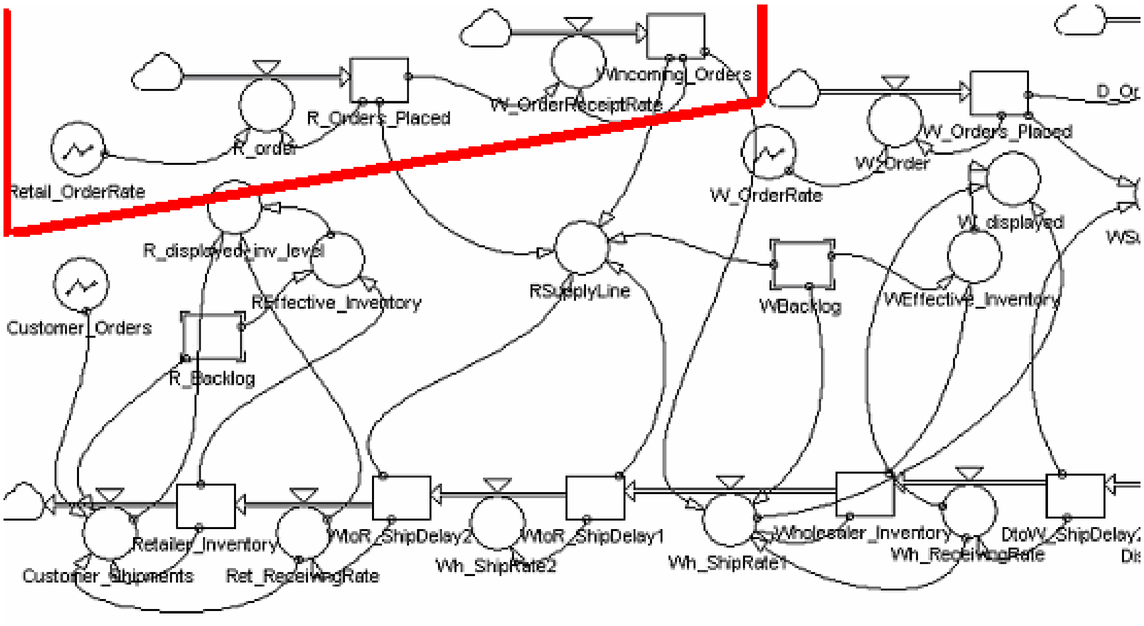

Figure 3. Ordering-delay structure of alternative model 1

Time	Retail_OrderRate	R_Orders_Placed	WIncoming_Orders	Wh_ShipRate1	Wholesaler_Inventory	DtoW_ShipDelay2
0	4,00	4,00	4,00	4,00	12,00	4,00
1	10,00	4,00	4,00	4,00	12,00	4,00
2	8,00	10,00	4,00	4,00	12,00	4,00
3	0,00	8,00	10,00	10,00	12,00	4,00
4	5,00	0,00	8,00	8,00	6,00	4,00

Table 2. Orders and inventory levels of alternative model 1

The rationale behind the above structure is that two delay stocks match the two delay boxes that exist in the board version. But simulation is needed for full verification. The Retailer order at time 1 is 10 units and at time 2, this order passes to the stock “R_Orders_Placed” and at time 3 to the “WIncoming_Orders” stock. Again at time 3, “Wh_Ship_Rate1” is 10. However, there is a major problem due to calculation sequence of the simulation software: This 10-unit order influences the “Wholesaler_Inventory” at time 4, i.e. the wholesaler inventory decreases at time 4. Nevertheless, in the board game it decreases at time 3. So, in this model there is one redundant delay structure, which results in a shift of inventory levels by one time period.

Alternative 2: One-stock information delay structure

To address the above problem, the formulations for the variables in this alternative are:

$$W\_OrderReceiptRate = (roundROR - Wincoming\_Orders) / 1 \quad (6)$$
$$W\_Incoming\_Orders = 4 + dt * W\_OrderReceiptRate \quad (7)$$

Note that roundROR is the nearest integer to Retail_OrderRate.

Time	Retail_OrderRate	WIncoming_Orders	Wh_ShipRate1	Wholesaler_Inventory	Wh_ReceivingRate
0	4,00	4,00	4,00	12,00	4,00
1	10,00	4,00	4,00	12,00	4,00
2	8,00	10,00	10,00	12,00	4,00
3	0,00	8,00	8,00	6,00	4,00

Table 3. Orders and inventory levels of alternative model 2

The delay problem encountered in alternative model 1 was resolved in this model by deleting the second stock "R_Orders_Placed" from the information delay structure. The order decision made by the retailer at time t is effective on the wholesaler inventory at time t+2, which is the case in the board game. All the stock values exactly fit to the figures in the board game, i.e. stocks take the right values at the right time points. However, a problem does exist in this game regarding the information available to players. The information directly available to a board game player (except the calculations he/she makes) while placing orders at time t are:

i) Inventory/Backlog level at time t

ii) Shipments that will have arrived at time t+1 (i.e. the next box on his/her right in the board game)

iii) Incoming Order at time t-1, placed by the downstream player (This is the order that the player automatically meets at time t if he has sufficient inventory or this order increases player's backlog)

In the above version, the player does have correct information regarding his/her inventory/backlog level and shipments to arrive ("Wh_ReceivingRate"), whereas incoming orders are not correctly displayed to decision-makers. The shipment rate from wholesaler inventory ("Wh_ShipRate1") at time t is calculated using the orders arrived to the player at time t ("WIncoming_Orders" at t). However, this shipment will be subtracted from the inventory at time t+1; in the board game, the player sees this order at time t+1. So, the value of "WIncoming_Orders" at time t-1 should be displayed to the decision maker at time t. This can be accomplished by adding an information delay structure consisting of a stock to store the 1-period past value of "WIncoming_Orders" for display purposes only, as seen below.

Correct delay structure: One-stock information delay structure with an additional information delay for display purposes

The formulations for the variables in the information delay structure are:

W_OrderReceiptRate = (roundROR – Wincoming_Orders) / 1 (8)
*W_Incoming_Orders = 4 + dt*W_OrderReceiptRate* (9)
WOrderCorrect = WIncoming_Orders – WdelOrder (10)

$$WDelOrder = 4 + dt*WOrderCorrect \quad (11)$$

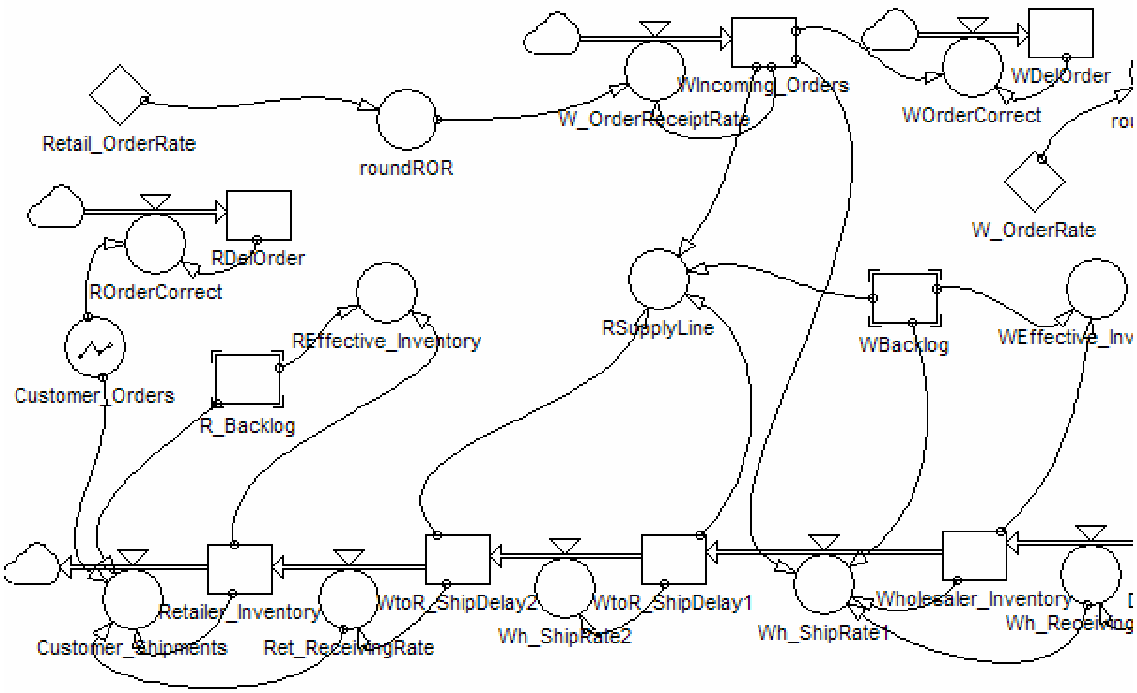

Figure 4. Ordering-delay structure of alternative model 3

Time	Retail_OrderRate	WIncoming_Orders	WDelOrder	Wholesaler_Inventory	Wh_ReceivingRate
0	4,00	4,00	4,00	12,00	4,00
1	10,00	4,00	4,00	12,00	4,00
2	8,00	10,00	4,00	12,00	4,00
3	0,00	8,00	10,00	6,00	4,00

Table 4. Orders and inventory levels of alternative model 3

In this final version of the SC model, 1-period past value of "WIncoming_Orders" is stored in the stock "WDelOrder" to be displayed to the decision-maker in game version. This information delay allows the display of the correct incoming orders to players in Wholesaler, Distributor and Factory positions. The same problem existed for Retailer and the same additional information delay structure was employed although customer orders are stored in a converter instead of a stock variable. The stock "RDelOrder" takes the same values as the variable "Customer Orders" but with a shift of one time period.

This finalized version of the Supply Chain model was selected as the appropriate design due to the reasons listed above. This way, consistency between board game records and computerized game records was obtained and players are provided with the correct information at correct time points. This step completes the design and verification phases of supply chain modeling.

The computerized game interface

The computer network simulation game is the computerized version of the board game in which players decide on their orders for each period. Since the user interfaces are very similar, wholesaler interface will be explained also representing the other sectors. Below is the user interface used in the game:

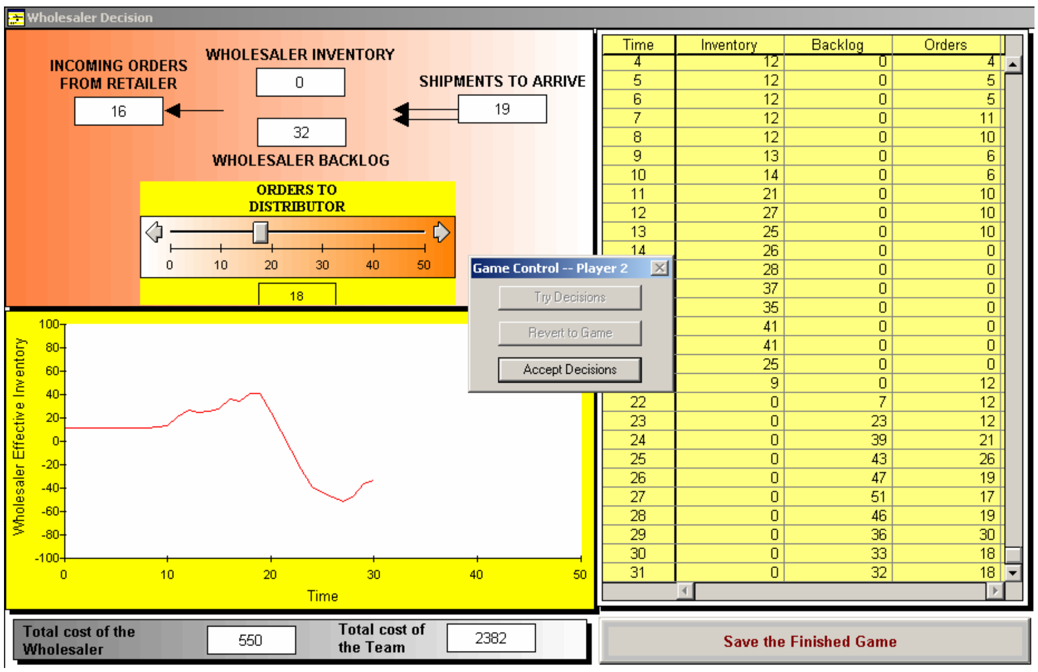

Figure 5. Wholesaler user interface

- **Wholesaler Inventory:** This box displays the current inventory at hand.
- **Wholesale Backlog:** This box displays the current backlog.
- **Shipments to Arrive:** This box displays the amount of goods to be received in the next period. It corresponds to the "DtoW_ShipDelay2" stock in the model.
- **Incoming Orders from Retailer:** This box displays the orders that the retailer has received in that period. It corresponds to the "WDelOrder" stock in the model the use of which is already mentioned.

The following equation is valid while calculating the variables:

$$(\text{Inv}_t - \text{Inv}_{t+1}) + (\text{Backlog}_{t+1} - \text{Backlog}_t) = \text{Inc.Orders}_{t+1} - \text{Ship. to Arrive}_t \qquad (12)$$

The graph displays the effective inventory versus time, whereas the table on the right keeps the past inventory, backlog and orders which are variables recorded by the player in the board game.

At the bottom of the screen the player sees the total cost of the team and his own during the game. Also the current period of the game is displayed on the simulation screen. Simulation time advances as all the players make their decisions.

3. Experimentation

After four sets of experiments with the board game, sixteen trials with the computerized game were carried out in order to see if the typical behavioral patterns of oscillation, amplification and phase lag were observed in the computerized game setting. The duration of all of the experiments was 35 periods. The subjects were recruited from undergraduate and graduate students. The results of the experiments were also analyzed to compare the performances in two different mediums of the game. Table 5 gives a summary of the design of the experiments.

version	number of teams	number of subjects
computerized	16 (4 teams with each demand pattern)	64
board game	4 (with the first demand pattern)	16
total	20	80

Table 5. Design of experiments

The experiments in the computer medium were carried out with different customer demand patterns to test the demand pattern effect on the performances of the groups. Another purpose of the experimental study was to test the learning effect. Three teams played the board game prior to playing the computerized game in order to detect any learning process occurring during the board game trial. Conclusions were made without claiming any statistical significance, considering the limited number of the experiments.

Board game vs. computerized game

Both the inventories and the order rates showed common behavioral patterns of oscillation, amplification and the phase lag in both settings. (See Sterman 1989 paper for a thorough discussion of these patterns.) Generally large amplitude fluctuations were observed in every team (See Figure 6). One common characteristic of the results from different teams was that the amplitude of orders increased from retailer to factory in the same team, known as bullwhip effect (See Figure 7). An example to phase lag behavior is illustrated in Figure 8.

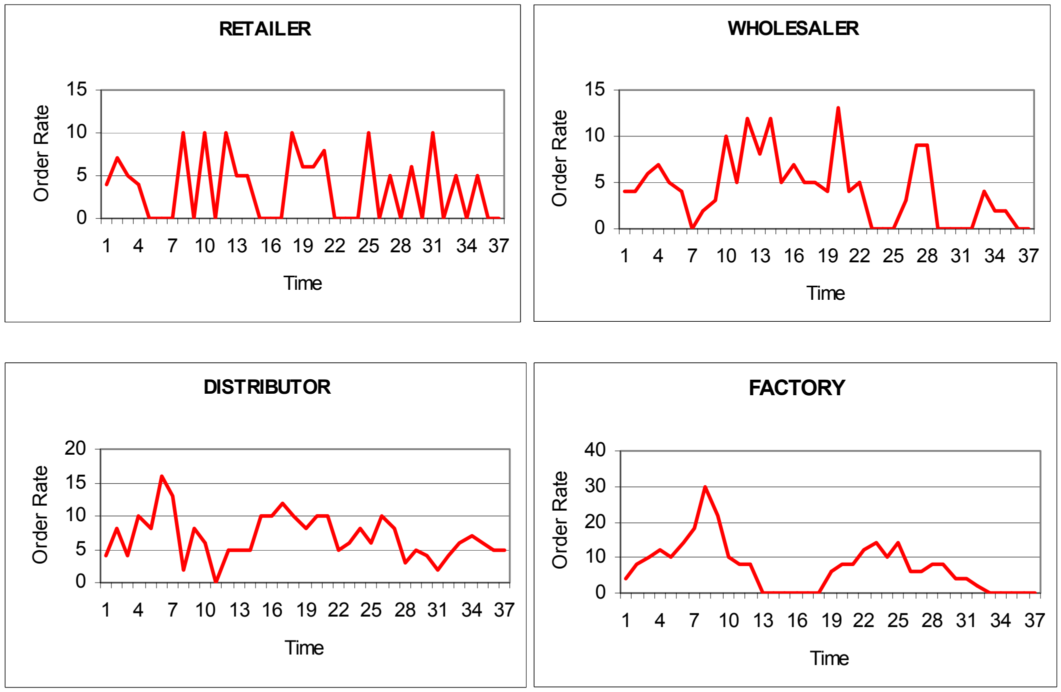

Figure 6. Order rate graphs of group 16 as an example to oscillation behavior

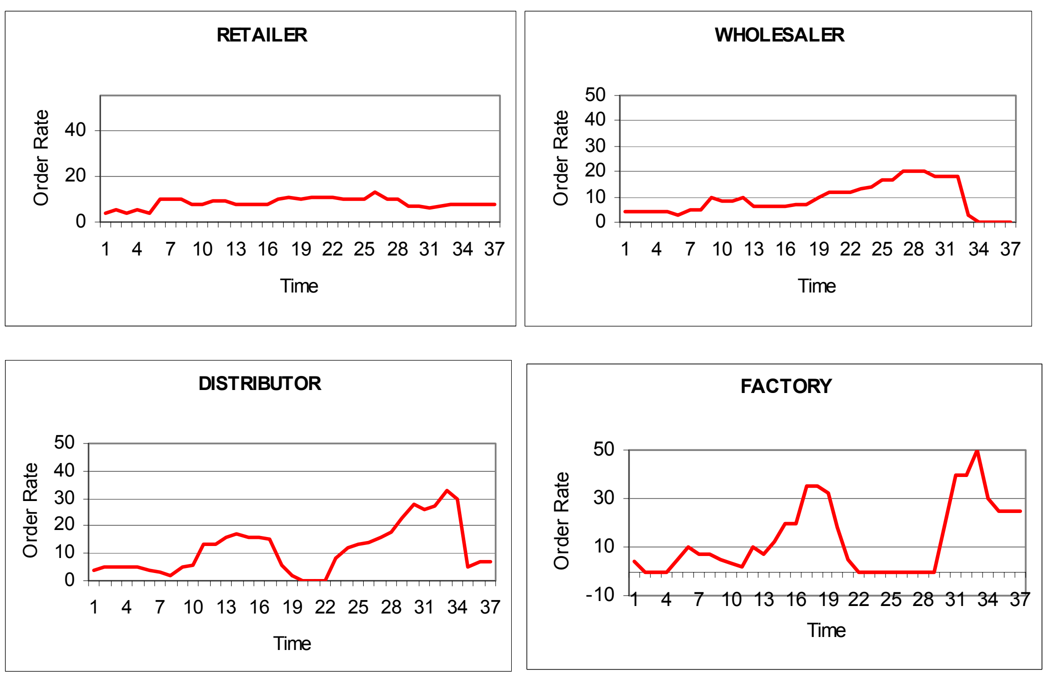

Figure 7. Order rate graphs of group 4 as an example to bullwhip effect

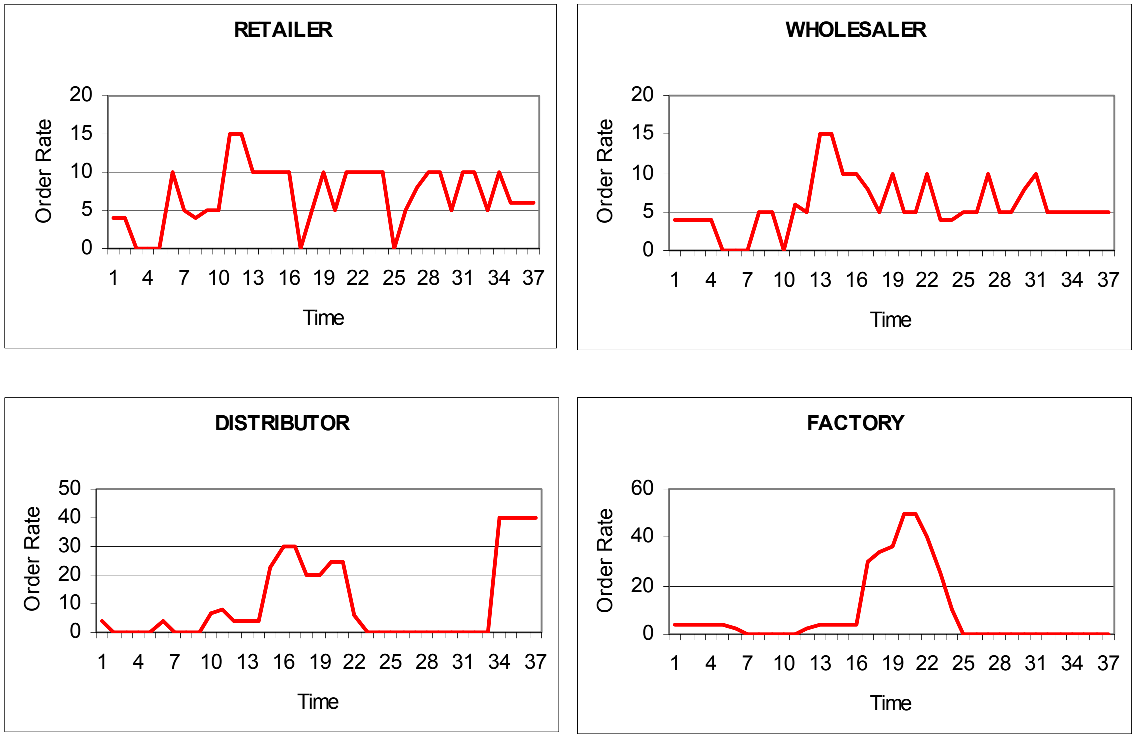

Figure 8. Order rate graphs of group 7 as an example to phase lag

Another major observation regarding the comparison of the board and computerized games was that the players performed better in the board game compared to the computerized game. This was figured out by comparing the board game results with the computerized game results belonging to the same demand pattern group. The variables used in the analysis were:

<u>Total cost of the team:</u> This is the primary measure of the performance of the teams since they are instructed to minimize the total cost of the team.

<u>Minimum inventory:</u> For each of the four parties, minimum inventory level reached during the game was recorded. "Minimum inventory" is the minimum of those minimum inventories.

<u>Maximum inventory:</u> For each of the four parties, maximum inventory level reached during the game was recorded. "Maximum inventory" is the maximum of those maximum inventories.

<u>Maximum amplitude:</u> For each of the four parties the difference between the maximum inventory level and the minimum inventory level reached during the game was recorded. "Maximum amplitude" is the maximum of those differences.

Computerized	Cost	Min Inv	Max Inv	Max Amp
44448888				
PATTERN I:				
Group 1	4958.5	-37	340	344
Group 2	3,301.5	-120	89	148
Group 3	3794	-99	26	121
Group 4	1931	-55	95	138
Average	3496.25	-77.75	137.5	187.75
Board Game				
Group1	1703	-44	36	62
Group2	2590	-76	42	107
Group3	2536	-59	29	85
Group4	2484	-71	32	83
Average	2328.25	-62.5	34.75	84.25

Table 6. The data relevant to computerized game vs. board game comparison

The data used for the comparison of performances in two mediums of the game are summarized in Table 6. The average cost generated by the players of board game was $2328, significantly smaller than that of computerized version, $3496. This result was also supported by the two tailed t-test for total cost values with a p-value of 0,079. Also note that the averages of all the variables have higher magnitude for the computerized game than the board game. T-test results regarding all the variables of analysis are summarized in table 7.

Cost	0.079
Min Inv	0.250
Max Inv	0.117
Max Amp	0.071

Table 7. T-Test results for the computerized game vs. board game comparison

There are a couple of facts that can be argued to be the reason behind this performance difference. First, players of computerized version were more isolated from each other compared to the board game players. Players in the board game tended to watch their neighbor's inventory levels although they were told to stay isolated as much as possible. This increased the player's ability to keep track of the team's overall position. Second, the board game was played with bunches of beans which symbolized the "beer inventory". Hence, players physically counted the shipments and inventories. This lowered the tendency of players to give huge orders compared to the "computerized game", in which they could give orders of high amounts just by dragging a slide bar. Finally, the progress of the board game was slower than the progress of the computerized game, giving subjects more time to think about what was going on. They were able to capture the delay effects in the game in fewer periods.

Customer Demand Pattern Effect:

Experiments with four different customer patterns were conducted. Only the data from the computerized game were used for customer demand pattern effect analysis.

The four different customer demand patterns are:

I-) Step-Up Customer Demand (4,4,4,4,8,8,8,8,8,8,.....): Customer demand was constant at 4 until the fifth period. At time five a sudden doubling of demand occurred without any pre-declaration.

II-) Step-Up-and-Down Customer Demand (4,4,4,4,12,8,8,8,8,8,.....): After a one-period peak of 12 at time five followed by a step-down of four units, the demand pattern stabilized at the upgraded level of 8.

III-) Step-Down Customer Demand: (8,8,8,8,4,4,4,4,4,4,4,.....): Customer demand remained constant at 8, till the introduction of a step-down of four units at time 5.

IV-) Steady Customer Demand: (4,4,4,4,4,4,4,4,4,4,4,.....): Demand pattern was kept constant at four with no disturbance along the game.

The results of the experiments sectioned with respect to the demand pattern applied are summarized in Table 8.

Computerized	**Cost**	**Min Inv**	**Max Inv**	**Max Amp**
44448888				
PATTERN I:				
Group 1	4958,5	-37	340	344
Group 2	3.301,5	-120	89	148
Group 3	3794	-99	26	121
Group 4	1931	-55	95	138
Average	3496,3	-77,75	137,5	187,75
4444128888				
PATTERN II:				
Group 5	3945,5	-123	134	223
Group 6	1770	-45	31	69
Group 7	3593,5	-62	117	179
Group 8	2864	-61	71	113
Average	3043,3	-72,75	88,25	146
88884444				
PATTERN III:				
Group 9	1556	-41	74	98
Group 10	1000,5	-36	28	50
Group 11	783	-11	32	43

Group 12	2792	-64	125	158
Average	1532,9	-38	64,75	87,25
44444444				
PATTERN IV:				
Group 13	793,5	-13	28	37
Group 14	729	-12	28	33
Group 15	3263	-40	156	145
Group 16	2259	3	92	82
Average	1761,1	-15,5	76	74,25

Table 8. Results of computerized game experiments sectioned with respect to the customer demand pattern

ANOVA tests were conducted to analyze the demand pattern effect on the variables. The results are presented in tables 9-12.

Total Cost						
	ANOVA					
		SS	**Dof**	**MSD**	**F Ratio**	**P Value**
	SSPattern	11047884	3	3682628	3,06425063	0,069189
	SSE	14421646	12	1201804		
	SST	25469530	15	1697969		
		Replications				
	1	2	3	4	**Average**	**Sum**
PATTERN I	4958,5	3.301,5	3794	1931	3496,25	13985
PATTERN II	3945,5	1770	3593,5	2864	3043,25	12173
PATTERN III	1556	1000,5	783	2792	1532,875	6131,5
PATTERN IV	793,5	729	3263	2259	1761,125	7044,5
					y..	39334
					ybar	2458,375
					SST =	25469530
					SSPattern=	11047884
					SSE=	14421646

Table 9. Anova results for total cost values

Min Inventory						
	ANOVA					
		SS	Dof	MSD	F Ratio	P Value
	SSPattern	10471,5	3	3490,5	4,04989123	0,033402
	SSE	10342,5	12	861,875		
	SST	20814	15	1387,6		
	Replications					
	1	2	3	4	Average	Sum
PATTERN I	-37	-120	-99	-55	-77,75	-311
PATTERN II	-123	-45	-62	-61	-72,75	-291
PATTERN III	-41	-36	-11	-64	-38	-152
PATTERN IV	-13	-12	-40	3	-15,5	-62
					y..	-816
					ybar	-51
					SST =	20814
					SSPattern=	10471,5
					SSE=	10342,5

Table 10. Anova results for minimum inventory value

Max Inventory						
	ANOVA					
		SS	Dof	MSD	F Ratio	P Value
	SSPattern	12329,25	3	4109,75	0,6051574	0,624148
	SSE	81494,5	12	6791,208		
	SST	93823,75	15	6254,917		
	Replications					
	1	2	3	4	Average	Sum
PATTERN I	340	89	26	95	137,5	550
PATTERN II	134	31	117	71	88,25	353
PATTERN III	74	28	32	125	64,75	259
PATTERN IV	28	28	156	92	76	304
					y..	1466
					ybar	91,625
					SST =	93823,75
					SSPattern=	12329,25
					SSE=	81494,5

Table 11. Anova results for maximum inventory values

Max Amplitude						
	ANOVA					
		SS	Dof	MSD	F Ratio	P Value
	SSPattern	33494,19	3	11164,73	2,10714075	0,152727
	SSE	63582,25	12	5298,521		
	SST	97076,44	15	6471,763		
	Replications					
	1	2	3	4	Average	Sum
PATTERN I	344	148	121	138	187,75	751
PATTERN II	223	69	179	113	146	584
PATTERN III	98	50	43	158	87,25	349
PATTERN IV	37	33	145	82	74,25	297
					y..	1981
					ybar	123,8125
					SST =	97076,44
					SSPattern=	33494,19
					SSE=	63582,25

Table 12. Anova results for maximum amplitude values

Analyzing the order and inventory graphs of subjects from teams with different demand patterns, it was seen that typical behavioral characteristics were observed regardless of the demand structure (See Figures 9 and 10 for sample inventory graphs to 2 most different demand patterns). However, using %10 significance level, demand pattern has a significant effect on the cost and minimum inventory variables. The cost values and absolute minimum inventory levels of demand patterns III and IV have a mean significantly smaller than those of I and II. This may simply be caused by steady demand figure of 4 in demand patterns III and IV instead of 8 in demand patterns I and II. The magnitude of the demand had a significant role in determining the value of these parameters rather than changing the behavioral pattern observed. Oscillation, amplification and phase lag are the common characteristics observed in the inventories and order rates independent of the demand pattern.

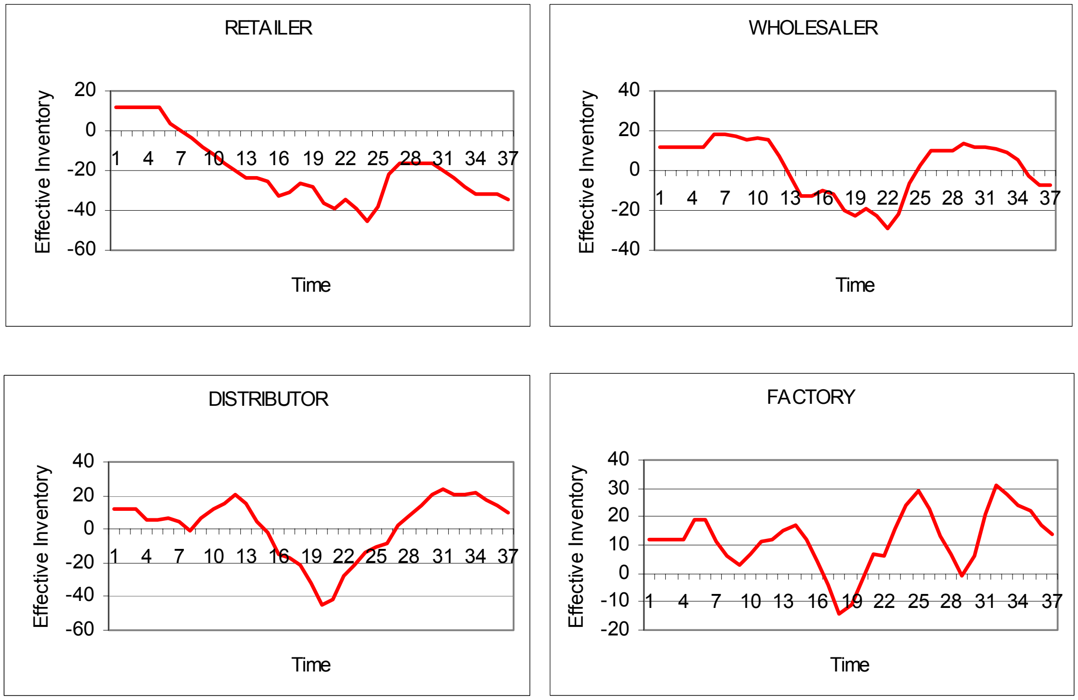

Figure 9. Inventory graphs of group 6 (demand pattern II)

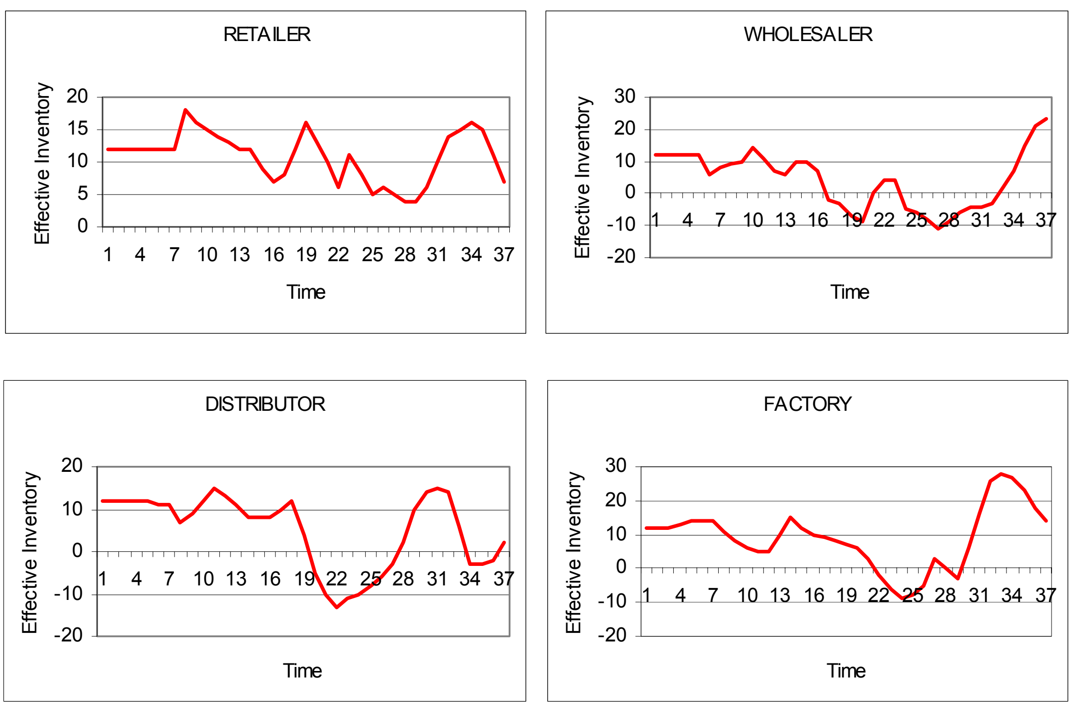

Figure 10. Inventory graphs of group 13 (demand pattern IV)

Analysis of Learning Effect

The final experimental analysis issue was existence of transfer of learning from the board medium to the computer medium. Three teams played the board game with pattern 4,4,4,4,8,8,8,8,... prior to playing the computerized version with pattern 4,4,4,4,12,8,8,... Two groups of comparisons were done. The results of the replications in the computer medium were compared both to the prior board game experiments conducted with the same team and other computerized game results with the same customer demand pattern.

Playing the game on board had a positive effect on the score. Although second pattern was slightly more difficult compared to the first, *"learning*" subjects scored better with respect to their previous performance in the board game, with a p-value of 0,081. Even though their behaviors generated higher amplitude and maximum inventory levels, they were able to reduce their minimum inventory levels ending up with lower cost values.

The *learning* subjects performed better also compared to the same demand pattern results in the computerized games (p-value: 0,039). Regarding total cost values, all of their results were even better than the best performance achieved by the relevant demand pattern group, which is a cost figure of 1770 (See Table 8). Table 13 shows the detailed results of these learning subjects.

Performance of Learning Teams								
	Computerized (after board)				***Board***			
	Demand pattern:4444(12)88				Demand pattern:44448888			
	Cost	**Min Inv**	**Max Inv**	**Max Amp**	**Cost**	**Min Inv**	**Max Inv**	**Max Amp**
Group 1	1570,5	-42	53	87	2536	-59	29	85
Group 2	1173	-29	56	83	1703	-44	36	62
Group 3	1564	-27	65	81	2590	-76	42	107

Table 13. Performance of "Learning Teams"

4. Conclusion and Discussions

In this study, a multiplayer interactive simulation game version of the "Beer Distribution Game" was developed. Since conducting experiments is much easier in computerized environment than on board, several computerized versions of Beer Game exist but none of them is an exact replica of the board version. Having an exact replica has both scientific and practical importance. We developed a computerized game completely faithful to the board game. Several critical issues in this effort are emphasized. 3 alternative model structures are analyzed and the one finally proposed not only mimics the board game, but also presents the players exactly the same information as the board game does.

Using the game developed, several gaming experiments were conducted. Subjects were selected from university students. Oscillation, amplification and phase lags are the common characteristics in other studies about the Beer Game and these behavior patterns are also observed in this study independent of the demand pattern used. Results of both the board game and computerized game reveal that players lack the understanding of the structure that involves higher order delays. Although they are instructed to take caution of the accumulating supply line, they try to adjust their inventory levels by over-reacting as if no delays exist between the placing of an order and its arrival. The high amplitudes of inventory cycles are the result of this misconception.

Four different customer demand patterns were used in the experiments with the computerized game and these experiments were compared in terms of total cost, minimum inventory reached, maximum inventory reached and maximum amplitude variables. The demand patterns have a significant effect on the total cost and minimum inventory. This numerical difference can be attributed to the amplitude of the orders.

Players who played the board game scored significantly better than those who played the computerized version with the same demand pattern. There are several possible reasons of this fact. Firstly while playing the board game one touches the inventories, records the inventory levels herself and since the game advances much more slowly than the computerized version she has more time to think on her ordering strategy. In the computerized game it is very easy to give very high orders, just slide the order bar, and this generally results in high-amplitude fluctuations whereas in the board version one counts the shipments one by one and realizes that placing too big orders like forty or fifty is not convenient. All these are possible reasons for the significant score differences. In any case, these differences have important implication for research and practice and must be further investigated.

Another conclusion drawn upon the experiments is that players that first played the board game before playing the computerized game performed significantly better than those of who directly played the computerized game. These players also improved their own performances in their second games. These results can be attached to the learning effect.

Finally, we have also constructed a supply *network* model in which each sector has more than one supplier and more than one customer. This model can be used to figure out how the network structure affects the amplification, phase lag and inventory oscillations. Comparisons with respect to these criteria can be done between supply chain and supply network structures. Another important future research direction would be to further analyze the nature and sources of differences of players' performances between the computerized and board versions of the Beer Game.

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