Preprints of the 13th IFAC Symposium on Information Control Problems in Manufacturing, Moscow, Russia, June 3 - 5, 2009

From Supply Chains to Supply Networks: the Beer Game evolution

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Abstract: The Beer Game is a didactic tool to simulate information and material flows along a supply chain from a factory to a retailer. The continuous evolution of inter-organisation configurations is challenging such a traditional concept of supply chain. Concepts more "market-oriented" are necessary to describe scenarios in which manufacturers operate as nodes of a network of cooperative or competitive suppliers, customers, and other specialised service functions. The aim of this paper is to propose and evaluate a new didactic tool and simulation, based on the rules of the Beer Game. The extension is based on a simple network joining two supply chains. Risk management is also simulated in order to understand the strategies underlying the subject's behaviour in the face of risk within a means-end chain. This study describes the tests carried out on the original game, the variables that we proposed and the simulation results.

Keywords: Beer Game, Networked Enterprises, Stock Costs, Supply Chain Management

1. INTRODUCTION

The Beer Game was developed in the 1960s by the MIT Sloan System Dynamics Group (*Sterman, 1984*) as a didactic tool to simulate information and material flows along the supply chain from the factory to the retailer. The main goal of this business game is to show the existence and the characteristics of the "Bullwhip effect" (*Lee et al. 1997)*. The Beer Game has four players: retailer, wholesaler, distributor and factory. These players are distributed along a single supply chain, communicating with each other only about the beer orders that each player sends to the nearest one. The only exception refers to the retailer's order, represented by the requests of the final customer, which are established in advance and are not known by other participants.

Many critics raise questions about the limitations in the original Beer Game (for convenience, we will refer to as MIT Beer Game) and suggest some alternatives. Kaminsky and Simchi-Levi (1998) highlight the limits of the Beer Game in providing a better way to manage the supply chain. These critics also highlight that the game structure does not provide a realistic view of the behaviors involved in the supply chain. Indeed a linear chain does not allow any choice about the suppliers. Kimbrough et al. (2002) describe the players behavior when they join the supply chain. In their view, players are not motivated to share information; their choices are taken in situations of bounded rationality and their individual rational behavior sometimes goes against the group's interests. These and other critics (*Chen and Samroengraja 2000*) suggest a number of digital versions of the MIT Beer Game in order to take into account the variables involved.

Other studies (*Ming 2001, Anderson 1994, Beamon 1998*) show how the supply chain evolves into network solutions based on collaborative and communicative interactions between two or more enterprises and oriented towards the coordination of different activities. These new trends in inter-organisation configurations have lead to introduce the definition of a Networked Enterprise to characterise the global supply chain of a single product in an environment of dynamic networks between companies engaged in many different complex relationships (*Martinez et al, 2001*). In a Networked Enterprise, manufacturers no longer produce complete products in isolated facilities. They operate as nodes in a network of suppliers, customers, and other specialised service functions. In such contexts, transaction costs are a key issue to be taken into account (Williamson 1981, Lajili and Mahoney 2006) and some formal representations have been proposed in the literature for modelling issues such as transaction costs and risks in virtual enterprises (*D'Atri* and *Motro, 2009*). Consequently, studying players' policies and behaviors involved in both supply chains and networks is extremely interesting when either the choice of the suppliers or transaction risk management issues are introduced.

This paper reports an activity that has been carried out in the context of the "Expert Training Course (ETC)", a post-graduate one-year training programme in "collaborative management of the supply chains" currently running in the CeRSI Center of the LUISS University in Rome (see www.cersi.it/sfidapmi). ETC has a special focus on interoperability issues and critical relationships among companies in many productive sectors.

ETC students firstly tested the standard version of the MIT Beer Game. The collected results were in line with previous findings. Following the above proposals in the literature, a team, composed by two teachers and five students, designed three alternative versions of this game. Such an activity has been done according with a "learning-by-doing" approach. These versions have been proposed in order to highlight the specific features of modern supply chains such as the network enterprise structure and the possibility of transaction failures. The main goal was to understand the policies underlying the behavior of players involved in supply chains and networks through simulations. These simulations also led us to obtain a proof of concept of such new versions of the Beer Game that are now available both for educational purposes and for further investigations about the dynamics of cooperation among the supply chain participants.

During the simulations players were supposed to make their choices independently from any given policy and with the goal of reducing their own stock costs. In order to compare their strategies (*Davenport and Harris, 2005*) and their willingness to take risks we defined the following policy matrix based on two variables: unsold stock and placed order.

		UNSOLD STOCK	
		HIGH	LOW
PLACED ORDERS	HIGH	NEVER BACKLOG **Condition:** variable demand. **Target:** executing orders. **Risk:** collapse or decrease in demand generates high storage costs.	FULL WAREHOUSE **Condition:** Predicting an increase in demand **Target:** increasing stock levels to avoid backlogs. **Risk:** oversized warehouse
	LOW	LOW COST **Condition:** the warehouse is able to respond to positive changes in demand. **Target:** Stable inventories with predictable costs. **Risk:** balanced	PASS ORDER **Condition:** constant demand. **Target:** low warehouse costs. **Risk:** risk of backlogs due to a variable demand increase and to delays in good delivery.

Four possible strategies have been identified depending on the level of the two variables: Never Backlog, Full Warehouse, Low Cost and Pass Order. We will refer to these definitions for discussing and classifying player behaviours.

In the next sections we first describe the main characteristics of each version of the Beer Game in terms of rules, objectives and simulation results. Then we perform a comparative analysis of the findings through a discussion focused on costs and policies. Finally, we summarise the results by providing some observations about the limitation of this approach and possible further developments.

2. BEER GAME 1.0

2.1 Description

On the basis of the studies on networked enterprises, transaction costs, and risk management, we defined three versions of the MIT Beer Game in order to analyze the policies which affect the supply chain actors behaviour. The first version (also referred to as Beer Game 1.0) is very similar to the original version in terms of chain structure. It differs only in the shape of the market requests since we applied random orders ranging in a 0-10 set of values corresponding to 44 cards taken from a deck. The motivation for this choice lies in the fact that our goal differs from the traditional MIT Beer Game which is mainly focused on the concept of Bullwhip effect. We prefer to analyse the simulation results in a random market request scenario.

The game has four players with the following roles: retailer, wholesaler, distributor, and factory. All of them are on the same linear chain. The retailer receives a beer order from the final consumer (card deck) hiding it from the other players; then, according to his/her personal policy, the retailer forwards an order to the wholesaler. The wholesaler sends the order to the distributor and when the order reaches the factory, the last player decides how many beers to produce. Each step has a 2 week lead time for both goods and information. The quality of each single policy undertaken by the players is assessed on the basis of stock cost values. In other terms, players share the common goal of reducing their own stock costs and they are free to define a personal policy according with their understanding of the situation and their personal attitude to risk.

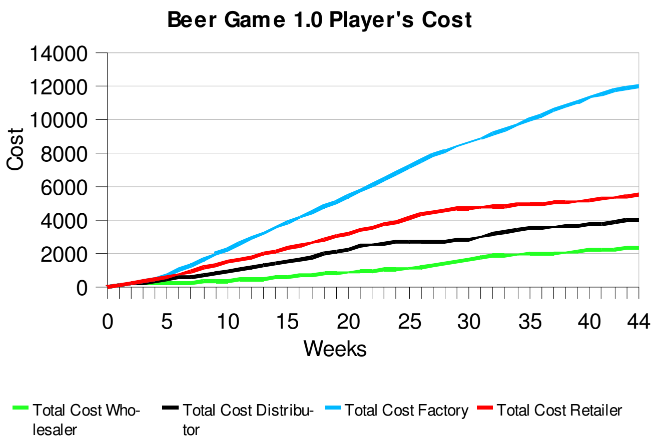
In order to support data collection and analysis, each player uses an electronic spreadsheet, which includes data related to sent and received orders, and goods.

2.2 Simulation

In this simulation the Bullwhip effect is not as clear as in the original simulation because, at the beginning of the game, players try to increase their inventories and thus the related costs. In this case, backlog events are briefer than the original simulation, which is the most important element of the Bullwhip effect. This is mainly due to the demand faced by the players, which is different from the one of the MIT Beer Game; this has a stable value at the beginning of the game, then it has an instant positive change that leads to a new constant higher value for the rest of the game. This step increase inevitably leads players to backlogs.

In Beer Game 1.0 we explored the case of the stochastic demand where demand was randomly generated from a known distribution, e.g., uniformly distributed between a set of values ranging (we supposed from 0 to 10 supply units). At first, players increased stock levels to avoid backlog events. Then, they tried to estimate the variation range production chain. The cost analysis of the first simulation shows very similar levels to the MIT Beer Game costs (higher in players farthest from the final market).

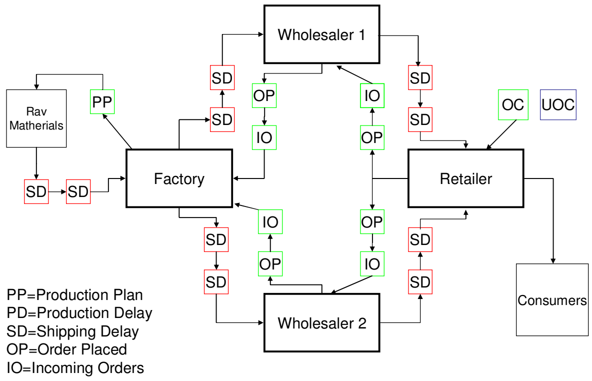
The only significant differences noted were in the costs of the final retailer (higher in comparison to the two middlemen, i.e. equal to 5.508). This can be explained as follows: using a Never Backlog strategy and knowing the variation of the final demand and the decrease of the goods required by the market, the distributor's initial strategy aims at increasing the warehouse levels during the first weeks and then have a constant request equal to the average expected level (equal to 5); in the original game, goods required by the market had a constant value equal to 8, while, in the simulation, the average value was approximately 4,75. Despite taking into account the producer's total costs (reaching the value of 11.952), the lack of the Bullwhip Effect caused many difficulties to sell off warehouse stock. As to the middlemen, the wholesaler provides interesting insights: he adopted the Just in Time model but, due to the delay of orders and delivery of goods (leading to a 4-week postponement), he was not able to avoid an oversized warehouse or backlog events. However, he managed to have the lowest cost (equal to 2.376).



3. BEER GAME 2.0

3.1 Description

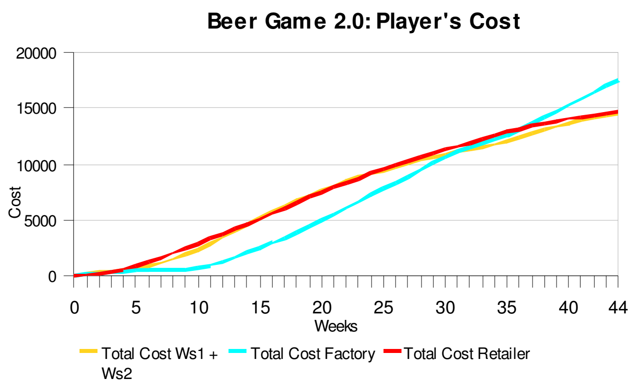
In this version of the game, Beer Game 2.0, we introduced some differences in comparison to the previous version. Firstly, players are not in the same linear chain. Starting from the retailer, a new diagram is created and the two middlemen are placed on parallel lines. Secondly, the retailer can choose to send the orders to both the wholesalers or only to one of them. Finally, the factory manager, on the basis of his own policy and on stock levels, can choose how many orders to deal with.



Beer Game 2.0 Supply Network

In this simulation we used another spreadsheet and, unlike the previous version (1.0), it is customized to each player. Firstly, the orders placed by the two wholesalers are separated and distinguished. Secondly, the factory manager can choose which order to deal with on the basis of his/her personal policy. Thirdly, the retailer dashboard is used to register the beers received by the two different wholesalers, their incoming orders, and orders placed.

3.2 Simulation



The second simulation provided interesting results. The players' total costs are proportional to the levels achieved in simulation Beer Game 1.0 (the factory is the player with the highest cost, followed by the retailer that adopted the same strategy and finally the two wholesalers). The sum of the wholesalers' total costs are equal to the retailer's cost during this simulation (after 44 weeks, the retailer scored 14.712 and both wholesalers scored 14.574).

The Factory generally has the highest costs (17.490) because it is the player farthest from the market and from the information relating to the demand. The sum of the two wholesalers' costs is very similar to the retailer's cost. From this perspective, the retailer has high costs due to the implementation of a Full Warehouse strategy, which is not the most suitable strategy in a market with such a low variability.

4. BEER GAME 2.1

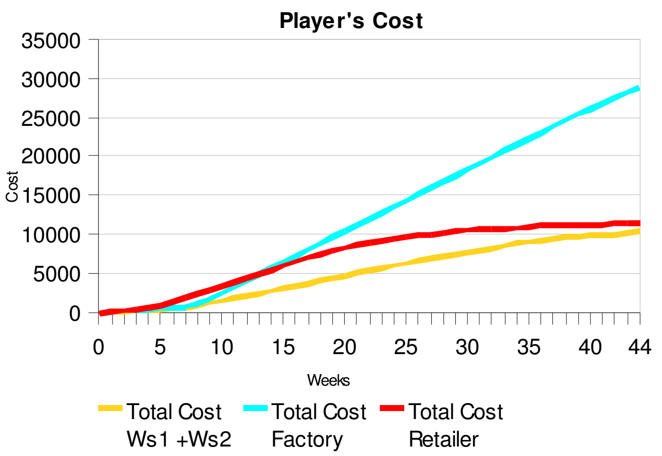
4.1 Description

In comparison to the previous version, Beer Game 2.1 takes risk management into account. The two wholesalers might not be able to receive the goods sent by the factory. In that case, they can transfer the beers available in stock and try to fulfil the new orders. The other players do not know how many times this could happen. This variable is predetermined: the high risk wholesaler has higher probability to fail (P=0.5) and lower backlog costs (C_r= C·(1-P)); the low risk wholesaler has a lower probability to fail (P=0.16) and higher backlog costs. In particular:

- The high risk wholesaler pays 3 euros per week for each beer crate in the warehouse and 6 euros for each backlog order.
- The low risk wholesaler pays 5 euros per week for each beer crate in the warehouse and 10 euros for each backlog order.

The retailer does not know which of the wholesalers poses the greatest risk, but they can try to implement policies to find this out (for example, by estimating failed orders).

4.2 Simulation



Analysing the total costs of simulation Beer Game 2.1, we observed that the Factory has the highest costs (28,752), as well as in other simulations. The two wholesalers adopted different strategies; the low-risk wholesaler adopted the Low Cost strategy, allowing him to successfully meet the changes in demand, while the high-risk player, much inclined to take risks, adopted the Pass Order strategy to reduce the inventory's cost. Nevertheless, the wholesalers' costs were lower in comparison to the Retailer. The total of their cost (i.e. 10.348) is less than the cost of the Retailer (i.e. 11.430) because the high risk wholesaler maintained a Pass Order strategy.

5. DISCUSSION

The results of the three simulations can be analysed from two different perspectives: *(i)* the policies implemented by each player and *(ii)* warehouse and backlog costs. From a methodological point of view, each player was asked to review data collected on their behaviour and to describe the strategy adopted. As to the cost analysis, data collected on each dashboard were compared.

5.1 Policies

The policies implemented by the players can be summed up as follows:

BEER GAME 1.0

Factory: On the basis of the first orders, the factory tries to create a warehouse able to meet the market demand, avoid backlogs and, afterwards, to set up a strategy aimed at reducing stock levels (Never Backlog strategy).

Wholesaler no. 1: Wholesaler no. 1 firstly implements the "Never Backlog" strategy aiming at having stock levels able to successfully meet the estimated maximum market demand (10); then, once he has reached stock levels equal to 10, he starts sending orders to wholesaler no. 2 which are equal to the orders received by the distributor (Pass Order strategy).

Wholesaler no. 2: Wholesaler no. 2 uses a balanced strategy in order to have a low-cost warehouse and, at the same time, to meet the market demand and avoid backlogs (Full warehouse).

Retailer: On the basis of the first orders, the retailer tries to create a warehouse able to meet the market demand and, afterwards, to set up a strategy aimed at reducing stock levels.

BEER GAME 2.0

Factory: by adopting a strategy with a cautious attitude to risk, the factory aims to have unsold stock levels capable of satisfying demand from the two middlemen, without running the risk of building up a backlog.

Wholesaler no. 1: By adopting a balanced strategy, wholesaler no. 1 aims to keep stocks not particularly high but always capable of serving orders, minimize costs and avoid backlogs.

Wholesaler no. 2: By adopting a strategy with a cautious attitude to risk, wholesaler no. 2 aims to have enough stock levels to avoid building up a backlog and deal with new orders.

Retailer: By adopting a strategy with a cautious attitude to risk, the retailer firstly aims to have a warehouse able to meet the market demand without running the risk of building up a backlog; then, he tries to slowly reduce unsold stock.

BEER GAME 2.1

Factory: At first, the factory aims at creating a warehouse able to meet the demand of the two middlemen, both of whom are risk subjects. Then, the factory assesses the most suitable strategies to reduce unsold stock.

High risk wholesaler: At first, the high risk wholesaler aims at keeping the warehouse at initial levels and then, on the basis of orders received, aims at reducing stock levels and meeting orders received.

Low risk wholesaler: Aware of playing the role of the “low risk” middlemen, his main aim is keeping the lowest unsold stock levels.

Retailer: The retailer places substantial orders to both wholesalers aiming at creating a warehouse able to face demand variations and, later on during the game, at identifying the riskiest wholesaler in order to reduce stock levels and costs.

	Beer Game 1.0	Beer Game 2.0	Beer Game 2.1
Factory	Never backlog	Never backlog	Full warehouse
Wholesaler no. 1 (high risk)	Pass order	Low Cost	Low cost
Wholesaler no. 2	Full warehouse	Never backlog	Pass order
Retailer	Full warehouse	Full warehouse	Never backlog

According with the policies described in the above mentioned matrix and with the player’s descriptions after the simulations, it is possible to identify two main opposite policies in the warehouse management: “Never Backlog” and “Pass Order”. In the first policy, players try to foresee the customer demand and to be always able to satisfy that request. A negative demand variation (near to zero) leads to high stock levels and higher costs that they are not able to reduce.

In the Pass Order policy, the player shows a greater willingness to take risks, as demonstrated by the intention of keeping low stock levels to reduce costs. Delays in goods delivery are common to all players; they have a negative impact on their choice and often lead players to backlog events. Simulations highlight how players were led to make choices on the basis of these two main policies, trying to fill their warehouse or reduce costs and showing higher or lower willingness to take risks.

5.2 Costs

During the three Beer Game simulations, we observed that the costs of each player reflected the results of the MIT Beer Game simulation; the player farthest from the market always has higher costs. With the exception of the Retailer costs (which are always higher in comparison to the Wholesalers in the three simulations), the Factory has higher costs due to the total absorption of market demand by the players. This resulted in no supply demand by the wholesalers and the factory being unable to clear unsold stock.

	Beer Game 1.0	Beer Game 2.0	Beer Game 2.1
Factory	11952	17490	28752
Both wholesalers	6384	14574	10348
Retailer	5508	14712	11430

A comparison between the cost trend in the three simulations is extremely interesting. A significant cost increase can be observed between Beer Game 1.0 and Beer Game 2.0, due to an insufficient market demand towards the supply chain (this also led to no players demand and stagnation of goods in most warehouses). During simulation Beer Game 2.1, the two wholesalers were given different costs on the basis of their attitude towards risk. For this reason they had lower costs in comparison to the Retailer cost and made their supply chain more cost-efficient.

6. CONCLUSIONS

After defining the original supply chain of Sterman’s Beer Game, we created, tested and analyzed three variants. Then we collected data and interviewed the different players. At the end, we managed to analyze and outline the different strategies and costs involved. We obtained two main results: (*i*) *we* analyzed the relationship between strategies and structures of the supply chains and (*ii*) we endeavoured to provide a new didactic tool to show students the different implications of a supply chain which takes into account transaction costs and risks.

With reference to the first aim, we noticed that players followed four strategies during the three simulations: never-backlog, full warehouse, low cost and pass order.

From a didactic point of view, these results are extremely interesting, highlighting the possibility of defining specific strategies within the distribution chain.

The MIT Beer Game and our versions experienced similar limitations: firstly, the difficulty of providing a realistic vision of the supply chain management. Secondly: it is true that the game structure (where middlemen are placed on parallel lines) allows the retailer to choose suppliers but despite this, it cannot be compared to the actual complexity of multiple supply chains. Thirdly, we cannot forget that information exchange can be very slow and this represents a big limitation for players in the selection and implementation of strategies. Finally, simulations were carried out by the students of the ETC course and collected data may have been influenced both by their role as game designers and by their previous experience.

On the basis of the latter limitation, we might develop new approaches to improve the game itself. It would be interesting (*i*) to involve students with no previous experience with the game; (*ii*) to simulate a supply chain where information is suddenly available for each player, and not have a slow information exchange as it happens with goods delays. In which case, the player would easily opt for a low cost policy, being able to rely on a strongly integrated supply chain.

ACKNOWLEDGEMENTS

This article has been drafted during the “Experts Training Course in collaborative multi-company management of the supply chain” held at the Research Centre on Information Systems, LUISS Guido Carli University in Rome. We thank the support by the SFIDA-PMI 4446/ICT project, funded by the Italian Ministry of Research.

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