How human behaviour amplifies the bullwhip effect – a study based on the beer distribution game online

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Abstract

The bullwhip effect is one of the main reasons for inefficiencies in supply chains. Since Forrester discovered around 45 years ago that variations of demand (and based on that of orders and stocks) increase up the supply chain from customer to supplier [1], researchers look for reasons and try to find countermeasures. Nevertheless the role that human behaviour plays in the bullwhip effect is still overlooked. This article will – after a literature survey of classical reasons for the bullwhip effect, that have been found so far – describe the beer distribution game online, which is a web-based simulation of a supply chain with four co-makers. Results of this simulation (with so far more than 400 people taking part) allow for the first time to analyse, how humans perform as a co-maker in a supply chain compared to simple agent-based strategies. The analysis shows, that aspects in human behaviour have to be added to the list of reasons for the bullwhip effect.

Readers familiar with the bullwhip effect may want to skip the first chapter, such knowing the beer distribution game the first sub-chapter of the second chapter.

Keywords:

Supply Chain Management, Bullwhip Effect, Beer Distribution Game

The bullwhip effect – a literature survey on its reasons

A short summary on the bullwhip effect and its negative impact on supply chain performance

The bullwhip effect describes the phenomenon that the variation of demand increases up the supply chain from customer to supplier. The further away a company from the end customer (in terms of lead time), the larger is this variation. Considering a supply chain that consists of an OEM (original equipment manufacturer) and a 1st-, 2nd- and 3rd-tier supplier, the OEM faces the lowest and the 3rd-tier supplier the largest variation of demand (see figure 1).

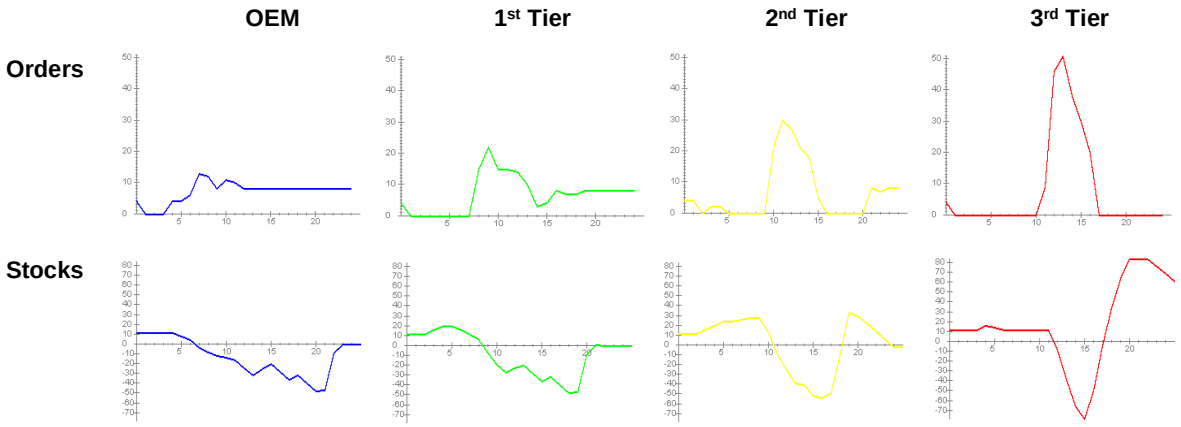

Figure 1: The bullwhip effect – Increasing demand variation in a supply chain

This effect leads to inefficiencies in supply chains, since it increases the cost for logistics and lowers its competitive ability. Particularly, the bullwhip effect negatively affects a supply chain in three respects:

- Dimensioning of capacities: A variation in demand causes variation in the usage of capacities. Here companies face a dilemma: If they dimension their capacities according to the average demand, they will regularly have delivery difficulties in case of demand peaks. Adjusting their capacities to the maximum demand leads to poorly used resources.
- Variation in inventory level: The varying demand leads to variation in inventory levels at each tier of the supply chain. If a company delivers more than the next tier passes on, the inventory level increases. Vice versa, the inventory is reduced in case a company delivers less than the next tier passes on. A high level of inventory causes costs for capital employed while a low level of inventory puts the delivery reliability at risk.
- High level of safety stock: The safety stock that is required to assure a sufficient service level increases with the variation of demand. Thus the stronger the bullwhip effect is in a supply chain, the higher is the safety stock required.

Hence, an important issue for supply chains is to cope with the bullwhip effect. For that purpose, the reasons for the amplification of the demand variation need to be identified.

Lead time of information and material as the primary reason for the bullwhip effect

The lead time of information and material is the primary reason for the bullwhip effect [1, 2, 3, 4]. A supply chain's reaction on a change in end customer demand is delayed firstly because it takes time to pass on information about the change to suppliers and secondly because these suppliers need time to adjust their capacities and deliveries. The longer a supply chain is unable to react on a changed demand, the heavier it needs to react as soon as this is possible. Thus the bullwhip effect increases with longer lead times.

This mechanism is illustrated by the example given in figure 2: This supply chain is adjusted to an expected constant demand of 1,000 products per period, i.e. there are 1,000 products on stock and there is enough work in progress to cover a demand of 1,000 products during the lead time of material, which in the example is three periods of time.

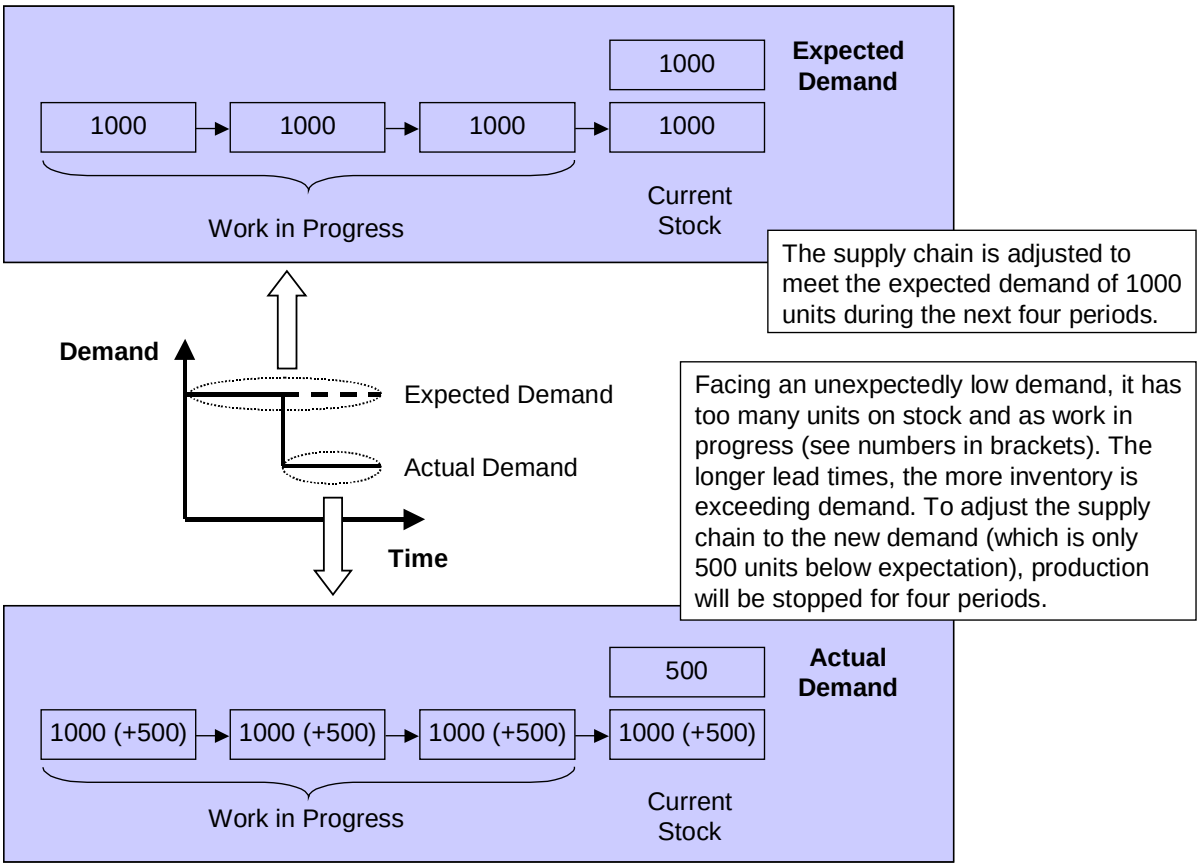

Figure 2: Bullwhip effect caused by lead time of information and material

The supply chain faces an actual demand of the end customer, which is by 500 products lower than expected. As a result, there are too many products and there is too much work in progress in the supply chain. To reduce inventory to a level appropriate for the new demand, production has to be reduced by 1,000 (to zero) during four periods, though the end customer demand is only 500 units lower than expected. Moreover, the example shows, that the variation in production level increases with lead time: For a lead time of two periods, the inventory would have be to reduced by 1,000 items, for three periods of lead time by 1,500 and in case of four periods by 2,000 items.

Secondary reasons for the bullwhip effect: Planning and behavioural aspects

In addition to the lead time of information and material, the bullwhip effect is caused by other reasons:

- Demand forecast based on orders of the succeeding tier: If the demand forecast of a company is based on orders of the succeeding tier instead of the effective demand of the end customer, the variation of demand is amplified up the supply chain [2, 3, 5]. This fact is analytically proven under the assumption of constant planning lead times [6].
- Historically oriented-techniques for demand forecast: Simchi-Levi and Kaminski analysed the impact of historically oriented methods for demand forecast on the bullwhip effect [4]. They assume that co-makers apply the order point technique for materials management. Since order point and order quantity depend on mean and variance of historic demand data, they change even in case of a long-term constant demand. Considering a high number of measure points for the calculation reduces this effect.

- Batch ordering: Companies subsume demand in batches in order to reduce set-up costs and order-fixed costs. This leads to suppliers facing distorted and delayed information on end customer demand. The constant demand of the end customer is on the one hand transformed in points of time with demand at the level of the order batch size and on the other hand in periods without demand [4,5].
- Price fluctuation: Companies vary the prices of their products and offer temporary price reduction to end customers or retailers for marketing reasons. As a consequence customers start speculating with the products. They buy more in times of low prices and postpone demand in times of high prices. This behaviour of the customers increases the variation of end customer demand, which is then amplified up the supply chain by the bullwhip effect [2,3].
- Exaggerated order quantity in case of delivery bottlenecks: If the demand for a product exceeds the supply, suppliers often ration their products, for example by delivering only a certain percentage of the quantity ordered by customers. This can induce customers to order more than their actual demand. As soon as bottlenecks are overcome, orders exceeding actual demand are cancelled [2,3]. This phenomenon again results in an increased variation of end customer demand.

These reasons are important and offer clear starting points for measures that are useful for the reduction of the bullwhip effect. This paper adds two further reasons for the bullwhip effect.

The beer distribution game online

Simulating a supply chain: The beer distribution game

The beer distribution game, which was developed by the Systems Dynamics Group at the Massachusetts Institute of Technology in the 1960s, demonstrates the bullwhip effect by simulating a make-to-stock supply chain with four tiers. Participants of the beer distribution game take the role of either the retailer, the wholesaler, the distributor or the factory (see figure 3).

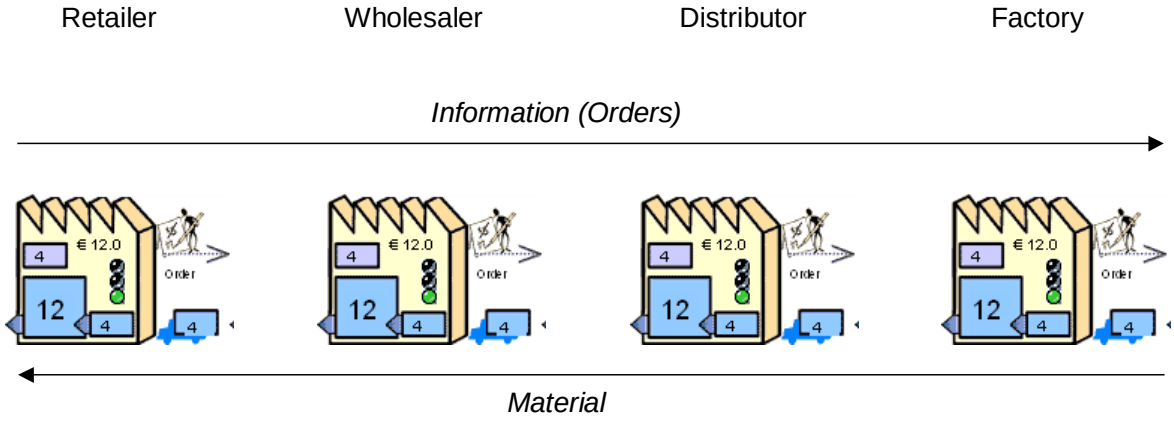

Figure 3: The four-tier supply chain simulated in the beer distribution game

An end customers places orders at the retailer of the supply chain. His demand pattern is given, but unknown to the participants. The retailer is asked for four units during the first five and for eight units during the following periods of the simulation. The co-makers up the supply chain receive orders from their customers and decide – based on their current stock

situation, the products in transport, which will reach their stock within the next periods, and the orders they received – how much to order from their supplier for replenishment. This way, information on the end customer demand is passed on up the supply chain with a delay of one period of time at each tier.

Material is forwarded in the other direction – down the supply chain. The material flow is delayed as well: Material has to be transported (see lorries between tiers in figure 3) and it has to pass materials receiving. Therefore it takes two periods until material received from a supplier can be delivered to a customer from stock at each co-maker.

The goal is to minimise the over-all logistics costs of the simulated supply chain. A product on stock costs 0.5 per period. If a co-maker cannot deliver, this causes costs of 1 per product per period. Thus co-makers have to take into account a trade-off between minimising the cost of capital employed in stocks on the one hand and avoiding of out-of-stock situations, on the other hand.

The beer distribution game online: A supply chain with human and agent-based co-makers

If the beer distribution game is played as a board game, the feedback given to participants is limited for time reasons. Usually giving feedback takes two persons: One presents diagrams of orders placed by the co-makers and of their stock situation during the game while the other is manually calculating the resulting costs for capital employed in stocks and backorders. The idea of giving an instant feedback on the beer distribution game originally led to the concept of the beer distribution game online [7].

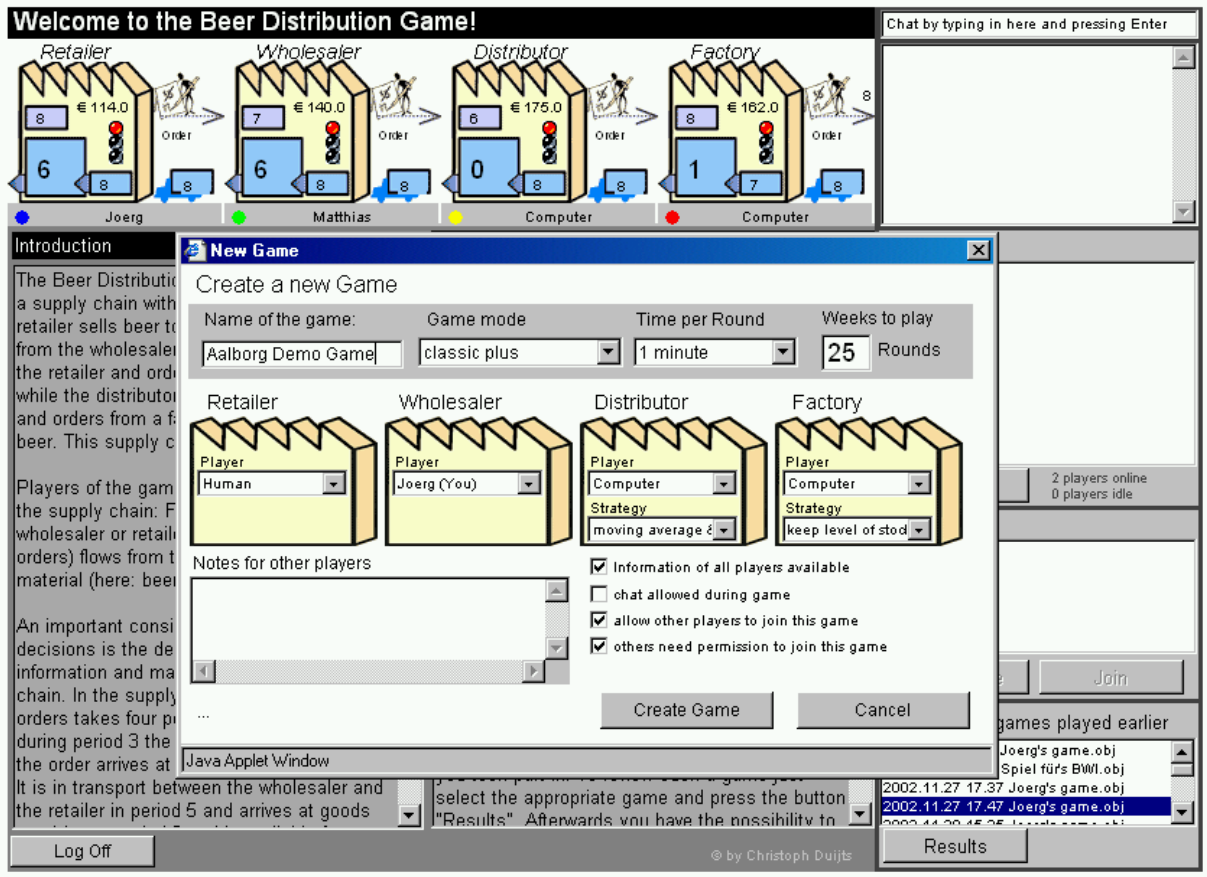

Figure 4: Screenshot of the beer distribution game online – creating a simulation

Participants from all over the world meet on the web site and arrange games. There are two game modes: The classic version has the rules of the physical beer distribution game implemented while the version "classic plus" allows parameterisation. Participants decide how many periods they would like to simulate, whether they want to have a full visibility on the stock situation throughout the supply chain and whether they want to allow information exchange between players or not. Other participants can join the game created and choose a co-maker position (see figure 4).

Alternatively, participants can assign agent-based strategies to the co-maker positions. There are two strategies to choose from. The first is "moving average / standard deviation", where the agent orders the amount that was in average ordered from him during the last five periods, plus an amount to create a safety stock depending on the standard deviation of orders he received. The second strategy, "keep level of stock", is even simpler: Each order received from a customer is passed on to the supplier. Surprisingly enough, this simple strategy is the best solution to the beer distribution game (see next sub-chapter).

By means of the beer distribution game online for the first time a significant amount of simulation results could be collected. Currently results of more than 200 simulations with more than 400 participants are available. This allows comparing performance of the simple agent-based strategies to that of humans (see last chapter).

The best solution to the beer distribution game – easy to achieve

If each co-maker in the supply chain would target at refilling his stock after delivery to his customer by just passing on the customer's order to his supplier, the initial stock levels would cover the unexpectedly higher demand during the lead time of information and material. Figure 5 shows orders (the left graph is the customer's order, the right one the factory's) and stock levels (the left graph is the retailer's stock level, the right one again the factory's) of a simulation in which all co-makers followed this strategy.

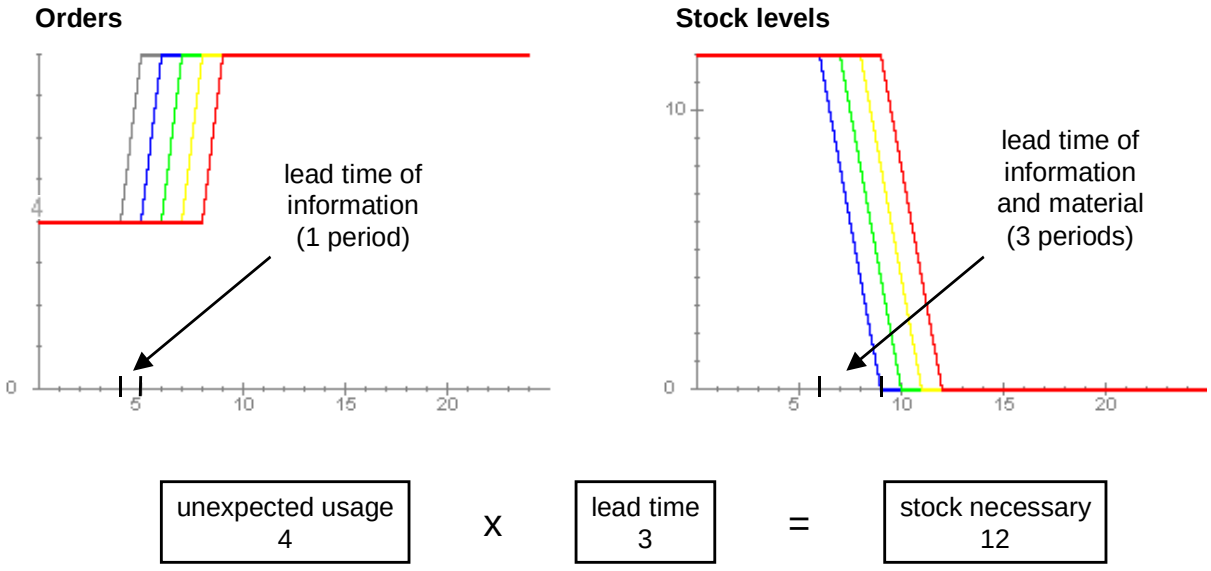

Figure 5: The best solution to the beer distribution game online

At each tier of the supply chain it takes one period to inform the supplier on the change of demand. It takes further two periods for the material to be shipped from the supplier's to the customer's stock. Thus, at each tier the supply chain can react on the demand change within three periods. During these three periods, co-makers are required to meet – according to the

demand pattern mentioned above – an unexpected demand of four additional units without being able to react on it. The initial stock of twelve units allows them to cover this unexpected demand. Stock level in period one after demand change is eight, in period two it is four and in period three it is zero. As soon as the stock is empty, the supply chain is adjusted to the new demand and eight instead of only four units arrive at the stock enabling co-makers to fulfil orders.

The Role of Human Behaviour in the Bullwhip Effect

Human strategies in the supply chain: "Safe Harbour" and "Panic"

Each dot in the diagram of figure 6 represents a result of a co-maker in the classic version of the beer distribution game online (for space reasons only some representative results were chosen). The more to the right a dot is located, the higher the costs of capital employed in stock caused by the co-maker were. The more to the top it is located, the higher costs caused by out-of-stock situations caused at a co-maker were.

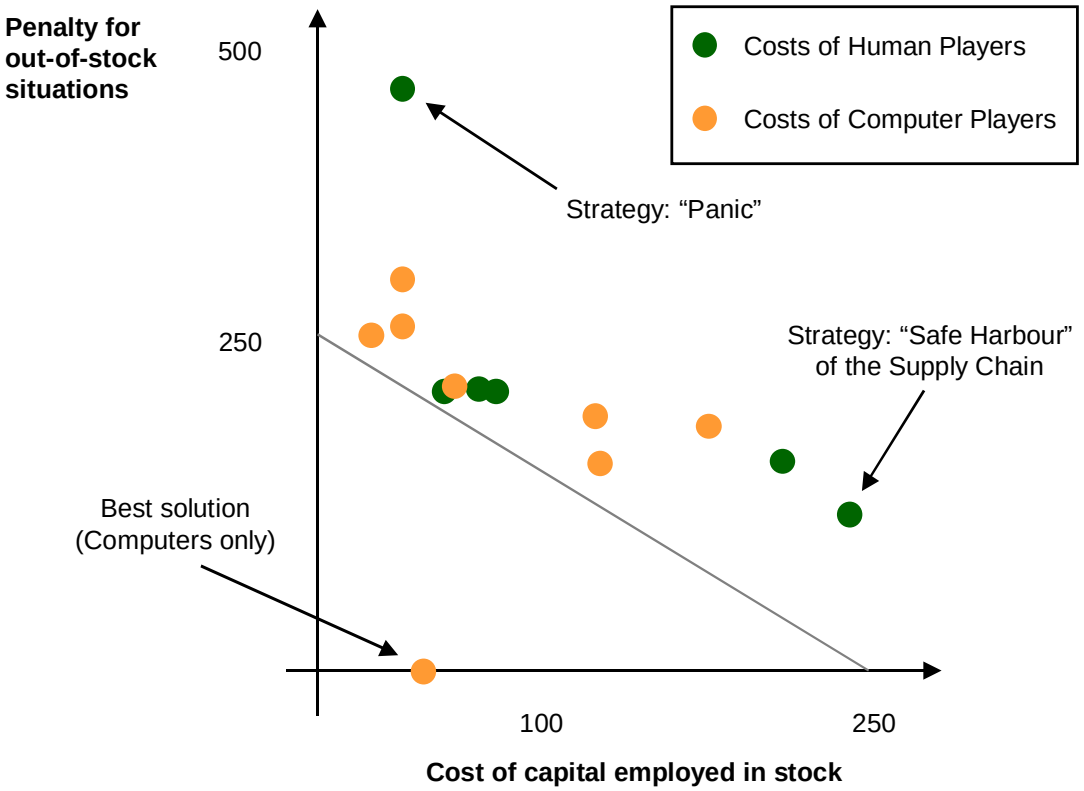

Figure 6: Performance of human co-makers vs. agent-based strategies

The best solution with four co-makers ordering according to the "keep level of stock"-strategy, which was described in the previous chapter, results in costs of 57 per co-maker. These are costs for capital employed in stock during the first rounds of the simulation (as shown in figure 5 the stock empties when the end customer's demand rises). Since the stock fully covers the unexpected demand, there are no costs for out-of-stock situations in the best solution.

The total costs of the best solution are 228 (4 x 57). Disappointing for us humans is that the more humans take part in the simulation and try to "optimise" its operations, the worse the result is. In average groups with humans have total costs of 800-900 . The worst result ever has been achieved by a group of four humans with total costs of more than 4000 .

The reason for humans performing worse than the simple best strategy lies in two types of extreme behaviour:

- Some humans try to act as the “safe harbour” of the supply chain, i.e. they order more than actually necessary and by that increase their safety stock. They cause not only high costs for capital employed in stock at their tier but they also force the supplier either to increase his orders as well or to pay for out-of-stock situations. Thus only one co-maker following the “safe harbour”-strategy has a negative impact on the whole supply chain.
- The second extreme strategy, “panic”, is to empty the stock before the end customer’s demand increases. This first does not affect other co-makers negatively. But as soon as end customer’s orders increase, a co-maker following this strategy has to order more than a co-maker, who has safety stock left. Then, this strategy has the same negative impact on the whole supply chain like the “safe harbour” strategy.

The more the behaviour of a co-maker deviates from the best solution and tends to one of these two strategies, the higher are the costs he causes. Like shown, other co-makers are affected by his behaviour as well. This is why also the agent-based strategies perform worse if humans are present in the supply chain (see brighter dots in figure 6).

Under-estimating the value of information

A further aspect in human behaviour amplifies the bullwhip effect. In the context of a survey among 200 European companies (see [8]), operations managers were asked, how valuable certain information from customers is for their production planning and how often they receive it from customers. Their answers are represented by grey dots in figure 7. Generally speaking, the more important information from customers is, the more often it is available to a company. Accordingly, the dots representing information lie on a diagonal line in the diagram.

Operations managers were also asked to estimate the value of the same information for the production planning of their suppliers. It was found, that they consider information to be less valuable to their suppliers than this information is to them. As a consequence they pass on this information less frequently than they receive it from customers (see black dots in figure 7). The same applies to information, like capacity available, which a company receives from customers and which it should pass on to suppliers. Thus, each co-maker acts as an obstacle for information flow up as well as down the supply chain.

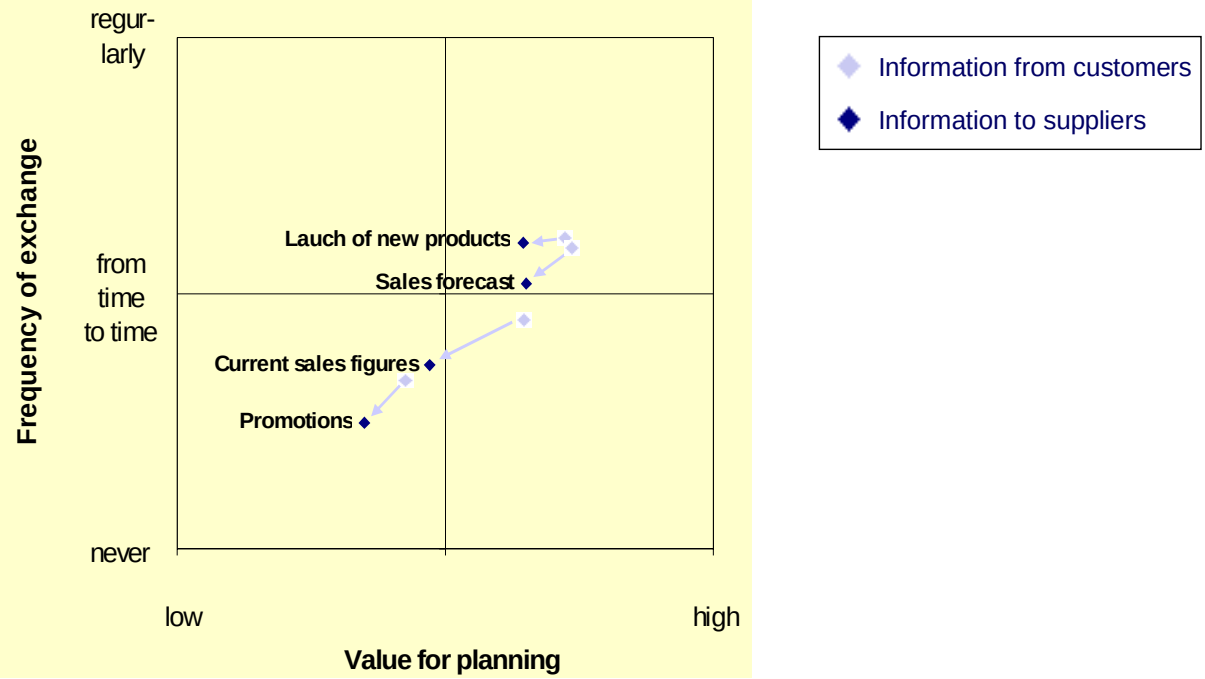

Figure 7: The value of information for co-makers is under-estimated

It was shown above, that lead time of information and material are the primary reason for the bullwhip effect. By under-estimating the value of information for other co-makers, the lead time of information rises and the bullwhip effect is amplified.

Conclusion and Outlook

Aspects in human behaviour, like reactions on price changes and bottlenecks, have been discussed earlier as a primary source of variation in end customer demand. This article showed, that human behaviour also contributes to the amplification of variation, which is observed in supply chains. Results of the beer distribution game online show, that especially two types of extreme behaviour, namely “safe harbour” and “panic”, have a negative impact on the performance of supply chains. Furthermore it was found, that co-makers act as obstacles for information flow and by that increase the lead time of information. Further research based on data from the beer distribution game online will show, how visualisation of stock levels and orders throughout the supply chain, which equals a reduction of information lead time, reduces the bullwhip effect.

References

[1] Forrester, J. W.: Industrial Dynamics. A major breakthrough for decision makers. Harvard Business Review, 36 (1958) 4, pp. 37-66.

[2] Lee, L. H.; Padmanabhan, V.; Whang, S.: The Bullwhip Effect in Supply Chains, Sloan Management Review, Spring 1997, pp. 93-102.

[3] Lee, L. H.; Padmanabhan, V.; Whang, S.: Information Distortion in a Supply Chain: The Bullwhip Effect, Management Science, 43 (1997) 4, pp. 546-558.

[4] Simchi-Levi, D.; Kaminsky, P.; Simchi-Levi, E: Designing and Managing the Supply Chain. Concepts, Strategies, and Case Studies, Irwin McGraw-Hill, 2000.

[5] Slack, N. et al.: Operations Management, Pitman 1995.

[6] Schönsleben, P., Lödding, H., Nienhaus, J.: Verstärkung des Bullwhip-Effekts durch konstante Plan-Durchlaufzeiten – Wie Lieferketten mit einer Bestandsregelung Nachfrageschwankungen in den Griff bekommen. In: PPS Management (2003) 1, pp. 41-45.

[7] Centre for Enterprise Sciences (BWI), Swiss Federal Institute of Technology, (ETH) Zurich, The Beer Distribution Game online, http://www.beergame.lim.ethz.ch (accessed 2003-04-06).

[8] Nienhaus J. et. al.: Trends in Supply Chain Management – A survey among more than 200 European Companies, Centre for Enterprise Sciences (BWI), Swiss Federal Institute of Technology (ETH) Zurich, Switzerland, 2003.