DYNAMIC BEHAVIOR OF SUPPLY CHAINS

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ABSTRACT

The bullwhip effect has been well known since many years and often takes place in supply chains. It is caused by wrong order policy in real systems. The bullwhip effect can be demonstrated easily through the beer game. It was developed by the MIT in the 60s. All stages of the supply chain operate independently. The only decisions that can be taken in the particular stages of this simulation game are the size of the orders. This beer game was depicted as a simulation with two additional simple control algorithms for the decision of the order quantities. The first algorithm set the time to compensate a difference in the inventory to a specific value, in the second algorithm the quantity of the order is limited. Both algorithms were taken to compensate a sudden and steady increase of the orders. Both control algorithms generated a bullwhip effect. The limited duration strategy for compensation a difference in the inventory led to rising orders in the upstream stages. The limited order strategy led to an increasing time to compensate a difference in the inventories of the upstream stages.
The limited duration strategy was applied to an ordering behavior with a linear trend und to a random ordering behavior. For the linear trend it has been found that the shorter the time for compensation the lower the difference to the nominal stock and the higher the bullwhip effect in the stages upstream. In contrast to that for random orders the time for compensation has to be longer to minimize the bullwhip effect. That is why the setting of the closed-loop control of the stocks in supply chains is an optimization problem. It can only be solved for a real supply chain, if the ordering behavior of the customer is known.

1 INTRODUCTION

Dynamic behavior of the material flow in a supply chain is influenced by the order policy of each particular company of a supply chain. The interaction of all companies creates the bullwhip effect, which has been described first by (Forrester 1958). It is the increasing of a small variation in the requirements of a customer to an enormous oscillation with the manufacturer at the beginning of a supply chain. In many articles, this phenomenon is only described in general terms without a mathematical definition (i.e. Erlach 2010 and Dickmann 2007). Without any mathematical description, the question is if the bullwhip effect can be avoided at all (Bretzke 2008). The main influences of the bullwhip effect are as follows (Gudehus 2005):

- Independent orders of the particular companies in a supply chain
- Synchronic orders (i.e. subsidiaries of one company)
- Wrong order policy in an emergency case
- Speculative order policy or sale actions

To avoid the bullwhip effect, cooperation between all members in a supply chain is necessary. Basically, informations about i.e. orders of customers have to be provided to all subsuppliers in the supply chain. This kind of cooperation is rather difficult in reality. The question is if the bullwhip effect can be avoided without any cooperation and providing of information to all members in a supply chain.

A very nice demonstration of the bullwhip effect gives the beer game. This simulation game was developed by the MIT in the 60s. It simulates a supply chain with 4 stages. The task of this supply chain is to produce and deliver units of beer: the factory produces and the other three stages deliver the beer units until it reaches the customer at the downstream end of the supply chain. The target is to keep the stock at a minimum and to have a 100% service level. The game is designed so simple, that the only decision is to decide about the quantity of the order to compensate a difference in the own inventory. All other influences are eliminated. This decision has been taken each time unit. The time to place an order is 1 time unit. Delivery time is 3 units (fig.1). In total there is a lead time of 4 units for an order. It is obvious that these parameters do not simulate a real supply chain. Normally the lead time is much shorter than the time for the next order. However, this simulation game demonstrates the bullwhip effect

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in an impressive manner. Additionally in a computer simulation the reasons of these effects can be explained.

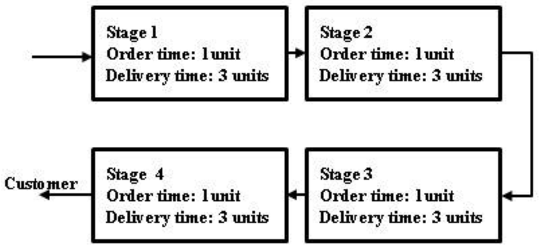

Figure 1: Model of a Supply chain

In principle each particular stage of the supply chain is closed-loop controlled. An Order of a customer reduces the stock. With the delivery of products from a supplier the stock will be filled up to a nominal stock. The closed-loop control of the stock in supply chains has been examined in different articles (Barbey 2011). These examinations demonstrate minimization of the bullwhip effect with a suitable controller. However, the reasons of bullwhip effect are not given there.

For the examination of the bullwhip effect a model of a supply chain according fig. 1 will be used. The behavior of each stage is the same. The time to place an order is 1 time unit. The time for delivery is 3 time units. The lead time to fill up the stock is for one stage 4 time units. If a customer place an order in the supply chain it needs 16 time units to deliver the material. To be able to deliver immediately each stage needs a stock.

2 DYNAMIC BEHAVIOR OF A SUPPLY CHAIN

The question is now, what is the best strategy of one stage in a supply chain to order material with a supplier. Assuming the unrealistic precondition of a zero lead time the best strategy is: “input is output”. Under this precondition there is no need for a stock at all. Now this strategy is applied to a supply chain as described above (fig. 2).

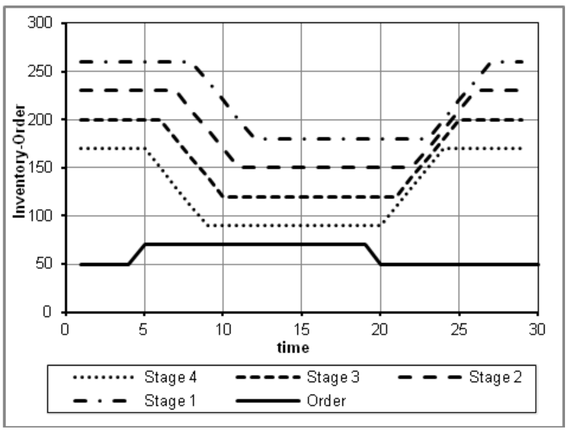

Figure 2: Stock with input=output strategy

If the customer increase his order, here 20 items, the stock of stage 4 decrease in a linear manner. The other stages follow after the order time of 1 unit. After the lead time the stock is constant, because now the output of the stock is equivalent to the input. However there is a difference to the nominal stock. Does the customer reduce his order to the original amount the behavior is vice versa.

Assuming the increase or decrease in the order is permanent, the aim of each particular stage is to equalize the difference to the nominal stock. To get this aim two strategies will be applied. The first strategy is: Each stage equalizes the stock in a definite time.
The result is a stock according fig. 4. The order quantity increases for the upstream stages of the supply chain (fig. 3).

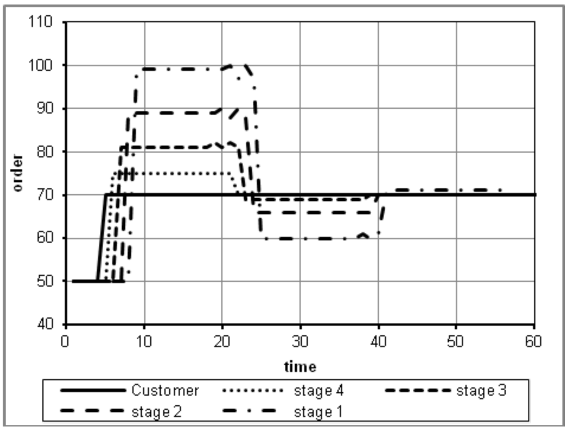

Figure 3: Orders with compensation strategy: four times the lead time

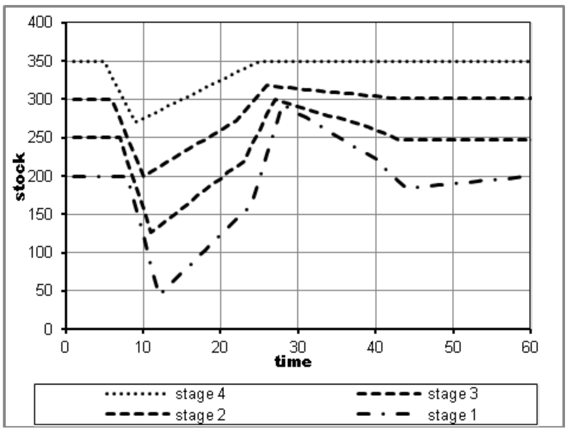

Figure 4: Stock with compensation strategy: four times the lead time

Only the stage at the very end of the supply chain is able to compensate the stock difference within the scheduled time. For all other stages it requires more than double the time. This is quite obvious: The last stage has only to fulfill the customer’s requirement. All other stages have to fulfill the customer’s requirement and have to compensate the stock difference of all stages downstream. Only when the first stage in the supply chain has balanced the stock difference, the order is reduced to the value of the customer. This is the reason that the bullwhip effect also occurs in the stock (fig.4).

Therefore, the following first thesis can be formulated: If the inventories are compensated in a certain time, then this leads to a bullwhip effect in the amount of order. And the shorter the time, the higher the order!

For this reason, the second strategy is now considered: Each stage may order only a maximum order quantity from the supplier.
The maximum order quantity is limited for all stages to 90 units. Therefore the stages, which are further upstream, need more time to compensate the difference in stock (fig. 5). The result is a stock according fig. 6.

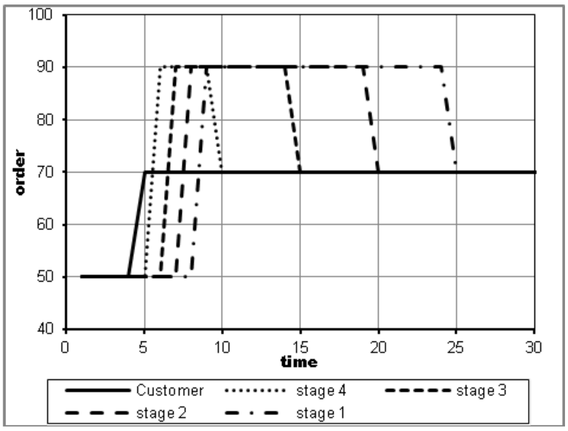

Figure 5: Order with compensation strategy: limited maximum order

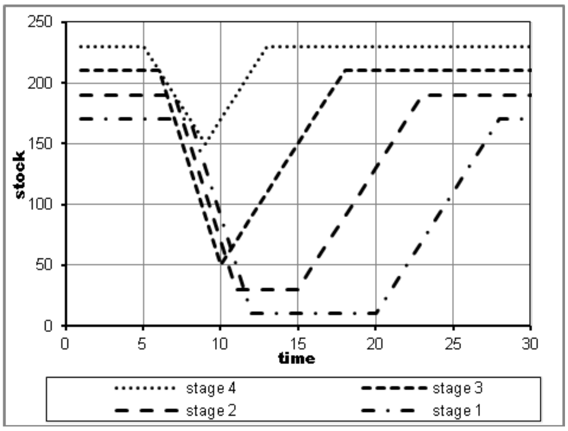

Figure 6: Stock with compensation strategy: limited maximum order

This leads directly to the second thesis: Limiting the orders leads to a bullwhip effect in time to compensate the stock differences.

The conclusion of both theses is: The bullwhip effect is unavoidable in a supply chain. It`s just a matter of optimizing how far and in what way it can be reduced.

3 TREND BEHAVIOR

Seasonal ordering behavior is generally predictable. Therefore it can be included in an order strategy of a supply chain with a predictive controller. This behavior is not included in this simple controlling algorithm. For this study an unexpected trend with a linear increase is assumed. The inventory of each stage is controlled by the algorithm: Compensation in a definite time.
For the stage 4 close to the customer it is clear that a linear increase of the orders create a decrease of the stock (fig.8). After a certain time there is a constant difference to the nominal stock. For the other stages a bullwhip effect is visible. The bullwhip effect occurs in the orders too (fig.7).

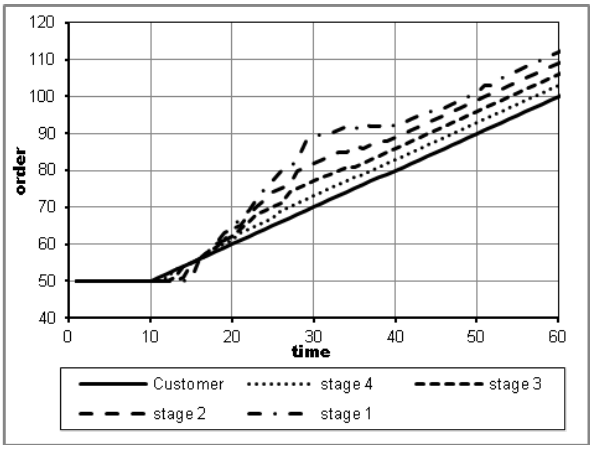

Figure 7: Orders with compensation strategy: four times the lead time

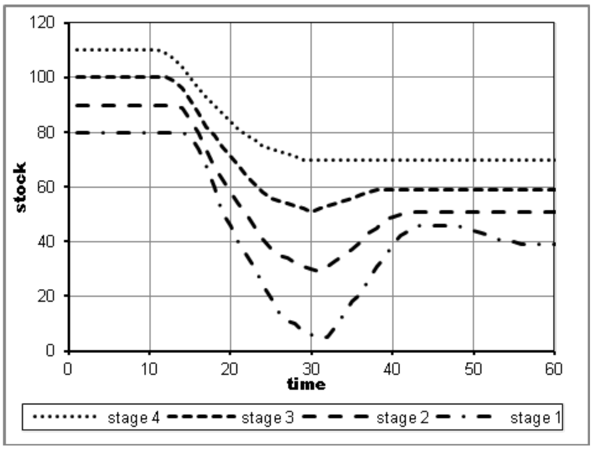

Figure 8: Stock with compensation strategy: four times the lead time

It is possible to reduce the differenc to the nominal stock, by reducing the compensation time. However, this is only an advantage for the stage close to the customer. Due to the occuring bullwhip effect for all other stages the minimum stock is lower than the constant value. However, for a 100% service level the minimum stock is substantial.

4 RANDOM ORDERS

Each order has random fluctuation around a mean value. These fluctuations are so fast that a closed-loop control is not able to compensate the deviation. This is one of the reason to have a stock for compensation of these fluctuations. For all other deviations as trend or a permanent increase a closed-loop control is provided. The question is now how a random fluctuation of the orders affects the closed-loop control. For that the orders of stage 1 has been simulated with three different compensation times (fig.8).

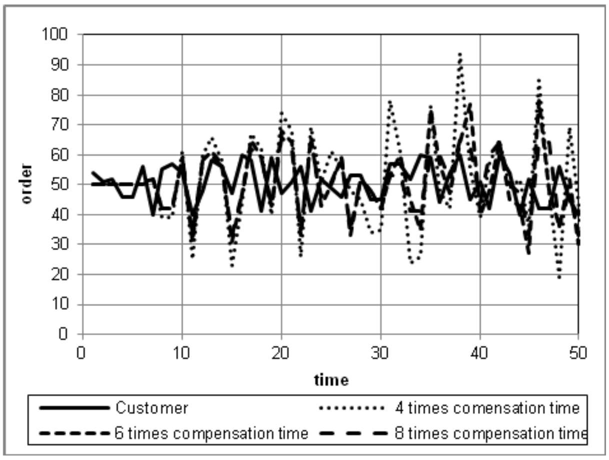

Figure 9: Random orders with different compensation times for stage 1

The customer order has a fluctuation of +/-10% of the average. With the 4 times compensation times the orders of stage 1 has a fluctuation of more than +/-30%. With these parameters a strong bullwhip effect occurs. With the increase to the 8 times compensation time the fluctuation of the orders is nearby to the customer's order.

5 CONCLUSIONS AND FUTURE TASKS

This study is a theoretical view of the bullwhip effect. It based on the beer game created from the MIT. The supply chain model has quite a simple structure. The advantage is to see the main influences of the bullwhip effect. Due to dead times caused by orders and delivery, it is difficult to get a constant stock through a closed-loop control. In this supply chain, the bullwhip effect is manageable if this simple control algorithm is applied, even if the companies handle their stock independently. Different order policies for the customer at the end of the supply chain have been applied. The first policy was a permanent and constant increase of the orders, which could be closed-loop controlled to the nominal stock with a constant time strategy or a maximum order strategy. The second policy of the customer was a linear trend. Here the constant time strategy was applied. A constant deviation from the nominal stock occurred. The third policy was a random order. Here the bullwhip effect was only manageable, if the compensation time increases.

This simulation demonstrates that it possible to handle the bullwhip effect in a supply chain with a quite simple algorithm. The minimizing of the bullwhip effect in a supply chain is an optimization problem. Only with analyzing of the orders it is possible to find an optimum for the compensation time

Not included in this simulation was the examination of the behavior of a supply chain with a seasonal trend. A seasonal trend is comparable with an oscillation. These oscillations are often very difficult to control (Barbey 2011). The impact of a seasonal trend to the bullwhip effect has to be exanimated in a next simulation study. Subsequently, it has to be checked if this theoretical knowledge can be transferred to a real supply chain. A real supply chain has to be simulated then.

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