A NEW APPROACH FOR THE BULLWHIP EFFECT

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ABSTRACT

Supply chains in industry have a very complex structure. The influence of many parameters is not known. Therefore the control of the orders, material flow and stock is rather difficult. In order to recognize the basic relationships between the parameters, a very simple model was set up. It consists of 4 identical stages. In all stages the stock is closed-loop controlled to a nominal stock. Therefore the only decision which can be done in the entire supply chain is the quantity of an order. In a first simulation run a suitable order strategy will be defined. Good results can be realized, if an order is splitted up in two: A customers order and a stock order. In a second run this strategy will be applied to a seasonal trend of the customers requirements. It will be shown that the bullwhip effect can be minimized with the applied order strategy.

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. A not defined 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). It is questionable if the bullwhip effect can be avoided at all (Bretzke 2008). A mathematical justification for this thesis is not given in that paper. 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 minimize 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.

A very simple model of a supply chain without any cooperation between the particular members has been published on the ECMS2013 (Barbey 2013). The target of this simulation was to develop strategies for a closed-loop control of each stage of a supply chain. These controlling strategies have been applied to a seasonal trend in this simple simulation model. (Barbey 2014).
Now this model will be used with a controlling strategy, which includes a kind of cooperation between the members of the supply chain. The model is designed in the following manner:
The model consists of four identical stages according fig. 1. The behavior of each stage is the same. The time to place an order is 1 time unit (TU). The time for delivery is 3 time units. Therefore lead time to fill up the stock for one stage is the sum of both, 4 time units. If a customer places an order the lead time for the entire supply chain is 16 time units to deliver the material from the very beginning to the end of the supply chain. To be able to fulfill a customers order within the minimum lead time of 4 TU each stage needs a stock.

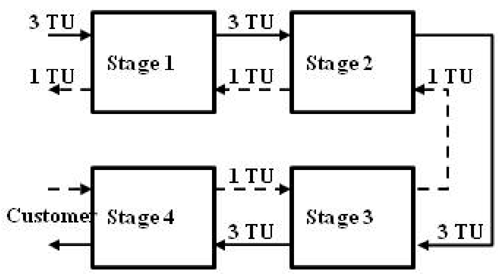

Figure 1: Model of a Supply chain
(TU= time unit)

The only decision, which can be done in this simulation, is to decide about the quantity of the order. This order has two tasks: It fulfills the predecessors order in the supply chain and compensates a difference in the own inventory. The applied controlling strategies for this decision will be described in chap. 2. This decision has been taken each time unit. 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 demonstrates

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with this short order period the bullwhip effect in a more impressive manner.
To demonstrate the bullwhip effect clearly, all other influences like delay in delivery or empty stock have been eliminated.

DYNAMIC BEHAVIOR OF A SUPPLY CHAIN

Before the dynamic behavior of a supply chain will be examined, a suitable closed-loop controller for a particular stage in the supply chain has to be found. 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 the simulation model as described above.

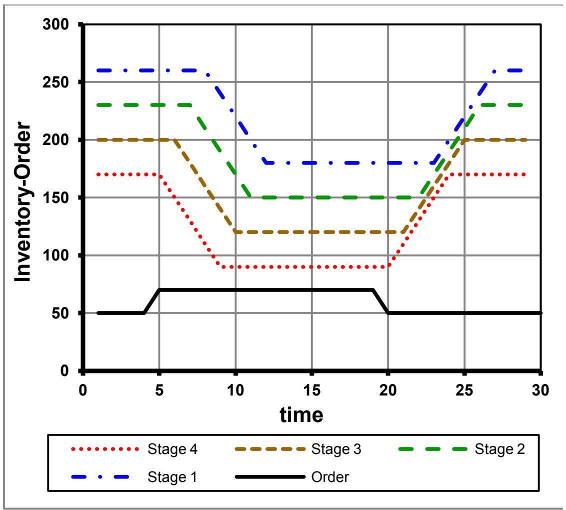

Figure 2: Stock with input=output strategy

If the customer increase his order, here from 50 to 70 items, the stock of stage 4 decrease in a linear manner (fig. 2). 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 value, the behavior is vice versa.
An improved strategy is a one-order-strategy. That means a stage orders material at his supplier, which covers the requirements of his customer and compensates the deviation in his own stock. Assuming the increase or decrease in the order is permanent, the aim of each particular stage is to equalize this difference, which occurred with the strategy "input is output", to the nominal stock. Therefore the orders have to be increased for a certain time above the customer order (fig. 3). In this example the time for compensation is 16 time units in one particular stage. If the compensation time is constant for all stages, the stages upstream have to increase their orders more and more. The reason is that they have to compensate their own stock difference and additional the stock differences in the stages downstream. Only the stage at the very end of the supply chain (stage 4) is able to compensate the stock difference within the scheduled time, here 16 time units (fig.3 and fig. 4). For all other stages it requires more than double the time.

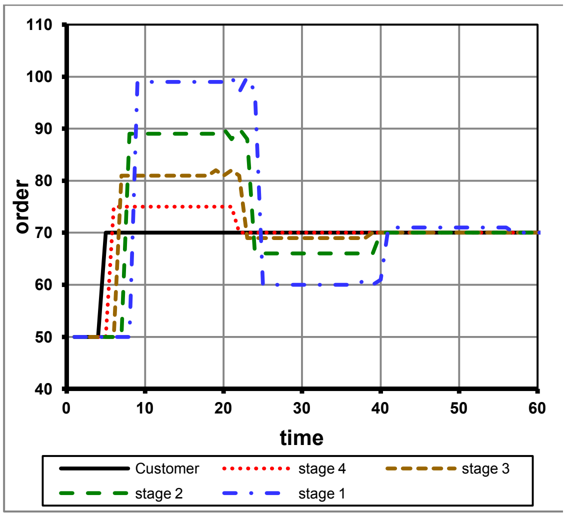

Figure 3: One-orders-strategy with compensation within 16 time units

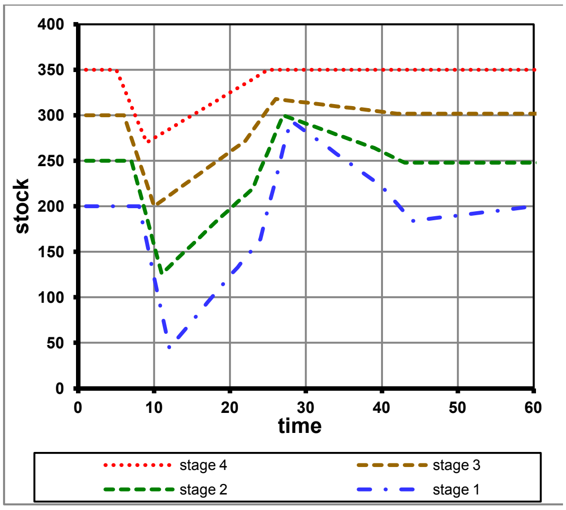

Figure 4: Stock with one-order-strategy: constant order within 16 time units

This is quite obvious: The last stage has only to fulfill the customers requirement. All other stages have to fulfill the customers 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 why the bullwhip effect also occurs in the stock (fig.4).

The second strategy seems to be relative similar, but it is quite different. The best strategy to fulfill a customers order is:

Order in = order out

This strategy leads to a deviation of the stock from the nominal stock in each stage of the supply chain as explained above. To fill up the stock to the nominal stock has nothing to do with a customers order, it is only related to the behavior of a particular stage of the supply chain. Therefore a second order, the stock order, should be done. The only decision is now how long the compensation of the stock will take.

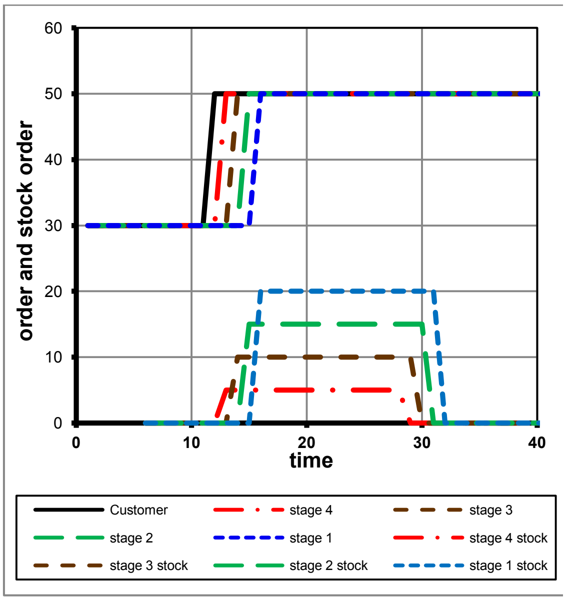

Figure 5: Order strategy of the closed-loop controller: Customers order and stock order with a compensation within 16 time units

Fig. 5 shows the in=out strategy for the customers order and the stock order with a compensation time of 16 to eliminate the stock deviation. The customers order is the same for all stages only with a time difference of one time unit. The stock order increases from stage to stage. This is obvious because a stage has to compensate his own stock difference and all

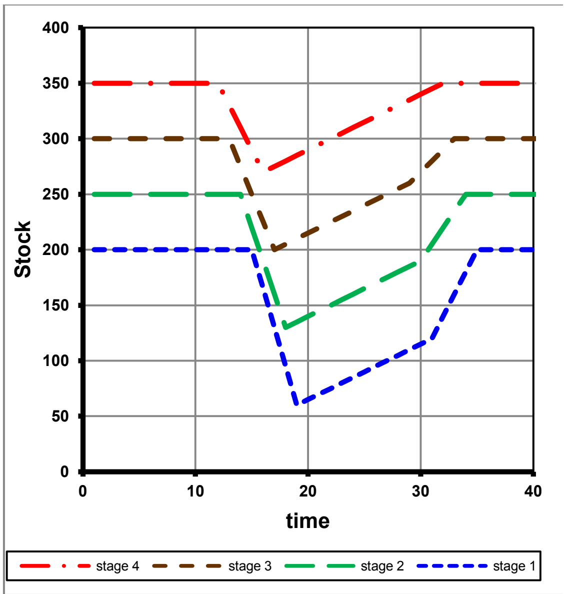

Figure 6: Stock compensation to the nominal stock within 16 time units

differences of the stages downstream. Therefore the bullwhip effect is only created by the stock orders.

Each stage upstream has a higher stock difference (fig. 6). The bullwhip effect occurs in the stock difference too. However each stage can compensate the stock difference in the same time.

Comparing both strategies for the 2nd one there are three advantages:

- All stages can compensate their stock differences in the same time
- The total order (customer order + stock order) is lower
- The bullwhip effect in the stock difference is slightly lower

This strategy is perfect, if customers order changes only one time. If there is a linear trend in the orders of the customer (fig. 7), a permanent deviation in the stock occurs (fig. 8).

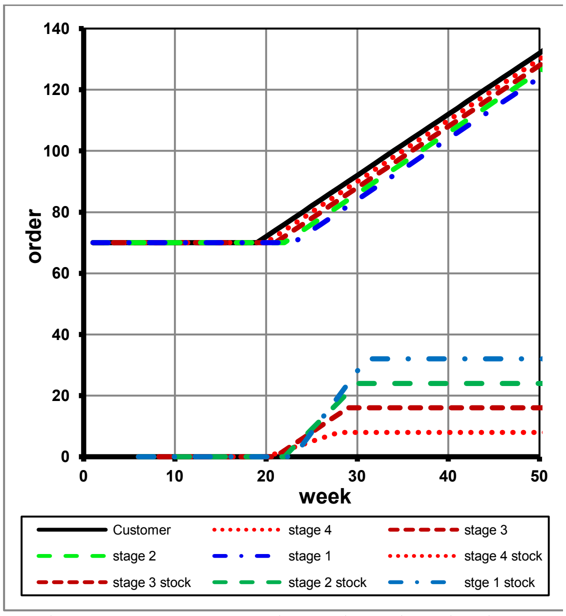

Figure 7: Customer order and stock order for a linear trend with a compensation time of 8 TU

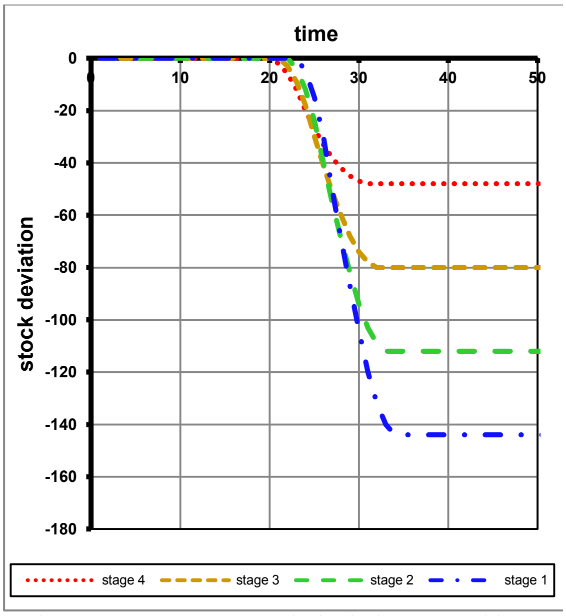

Figure 8: Permanent stock deviation caused by a linear trend in the orders, compensation time 8

When the linear trend starts the stock orders have a linear increase. After the compensation time they come in a steady state (fig. 7) and the stock deviation is in a steady state too (fig. 8). It can be shown that this permanent deviation depends from the increase of the trend, the duration of compensation time for the stock order and the position of a particular stage in a supply chain. In the next step the deviation has been calculated with these parameters and was included in the stock order (fig. 9). After starting the trend there is an increase of the stock orders over a time length of the compensation time. After that time the stock orders are constant with the same values as in fig. 7.

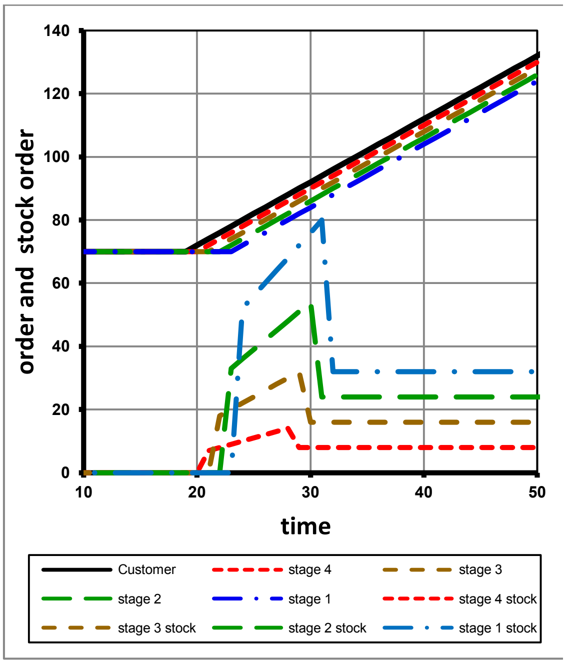

Figure 9: Compensation of the linear trend with a stock order, compensation time 8

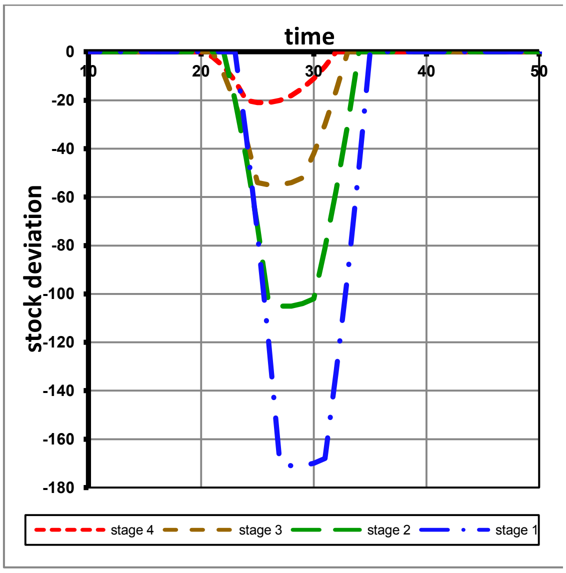

Figure 10: Stock deviation with the compensation of the linear trend, compensation time 8

For the first three stages the deviation from the nominal stock is better than without the calculation of this compensation. For the last stage the deviation is worse (fig. 10). But all stages can reduce the deviation to zero. A further examination of the linear trend will be not done in this paper. Seasonal trends seem to be more important.

SEASONAL TREND

A seasonal trend with oscillating orders also leads to major changes in inventories. Therefore the aim must be to minimize the oscillation of the stock by an appropriate closed-loop control. If the oscillation of the stock is minimized, then the average stock is at a minimum too.

A seasonal trend is simulated by a sine function very well. In this simulation the amplitude of the sine is +/- 40% of the average, which is 500 in this simulation. The period of this sine is 300 time units. The following simulations examine the fluctuation of the stock for the individual stages in the supply chain and the variations in the orders. Three different control strategies are applied:

1. Order in = order out
2. One-order-strategy (fig. 11 and fig. 12)
3. Customer order and stock order including compensation of a trend. (fig. 13 and fig. 14)

The first strategy is not a real controlling strategy. It is only applied to get a basis to compare the other strategies. The variation in the orders according to the sine from minimum to maximum is 400. In all stocks the variation of the stock items from minimum to maximum is 1600 (fig.11).

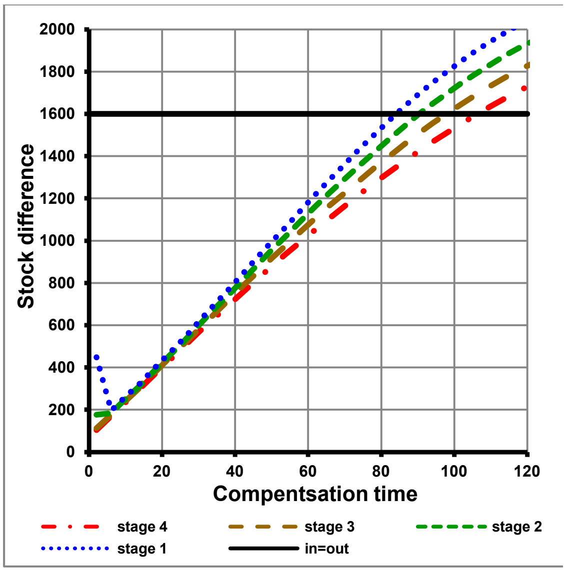

Figure 11: Stock difference with strategy 2

Important for the other strategies of the closed-loop control is the duration of the compensation time. Therefore in the next simulation runs varies the compensation time from 2 to 120.

For strategy 2 exists for very short compensation times a bullwhip effect in the stock. Then the stock difference diminishes to a minimum and increases again with elongation of the compensation time (fig.11). At a compensation time of 80 for stage 1 and 100 for stage for the stock difference becomes worse than with the in=out strategy. Now the closed-loop controller is to slow to compensate the variation in the stocks.
For the order differences occurs an extreme bullwhip effect especially for stage 1 (fig.12). After a minimum the order differences increases slowly again with an increasing compensation time. It is obvious that in=out strategy has better results all the time. The reason is that with this strategy no additional stock order for compensation has to be created.

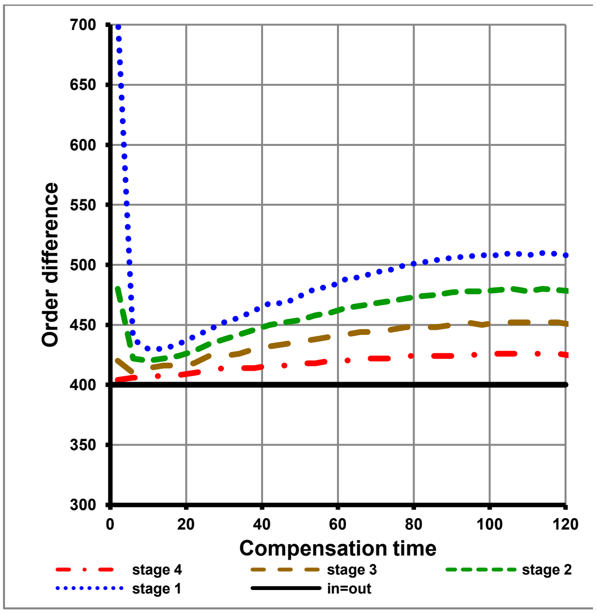

Figure 12: Order difference with strategy 2

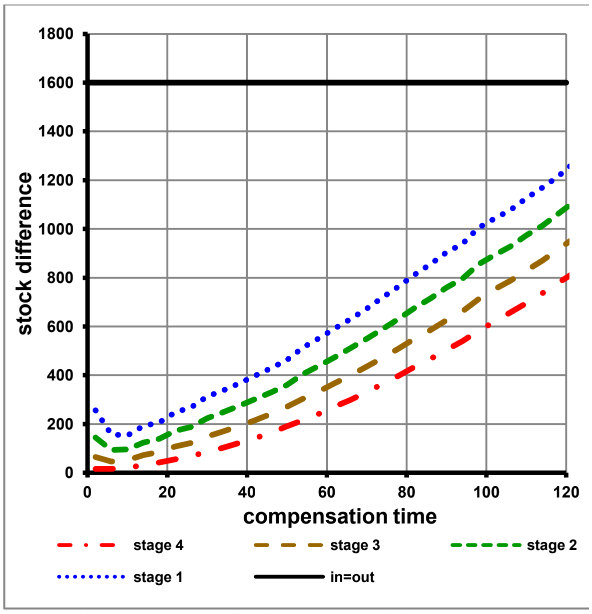

Figure 13: Stock difference with strategy 3

Much better results can be realized with strategy 3 (fig.13). Just as with strategy 2 a bullwhip effect exists a short compensation times too. After a minimum the stock differences increase with an increasing compensation time. However, even with large compensation times the results are much better than with the in=out strategy. The order differences are very similar to strategy 2 (fig.14). Only some rounding effects caused by the simulation occur in the diagram.

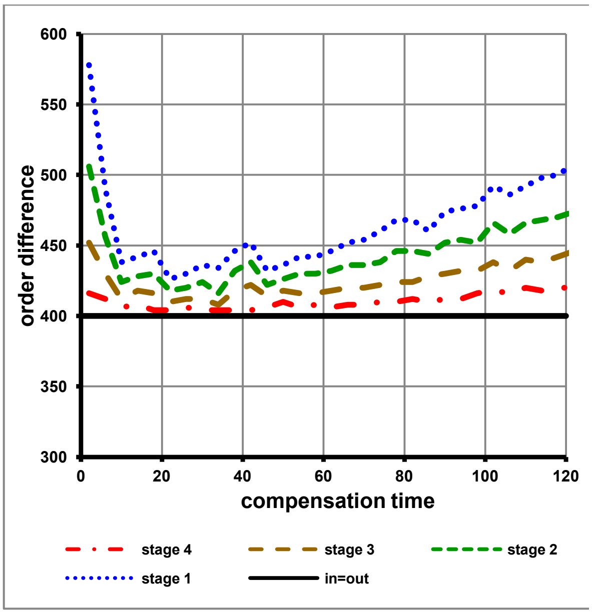

Figure 14: Order difference with strategy 3

CONCLUSIONS AND SUMMARY

This study is a theoretical view of the dynamics in a supply chain. For this examination a quite simple model has been used. The advantage of a model like that is to see the main influences of the dynamic behavior of the supply chain.
The target of all stages is to keep the stock at a minimum with a seasonal trend of the customers orders. This has been realized by a closed-loop control. In this closed-loop control the only decision which could be done was the quantity of the orders. Due to lead times caused by orders and delivery, it is difficult or better more or less impossible to get a constant stock by applying a closed-loop control. The seasonal trend has a strong influence on the stock. Two effects can minimize the stock. First it should be applied a short compensation time. Is that time to short, a bullwhip effect can occur. Second a split of the order should be done: Customers order and stock order. The customers is handled like the in=out strategy and only the stock order is close-loop controlled. This split of the order is a kind of cooperation between the members of a supply chain: A supplier of a stage in the supply chain gets information in terms of the order about the customer of that stage.

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