ANALYSING INVENTORY MANAGEMENT PERFORMANCE BY SIMULATING SUPPLY CHAIN MANAGEMENT STRATEGIES

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ABSTRACT
SCM strategies like information sharing achieve improvements of the performance in supply chains; however, due to the usual unbalanced improvement allocation they are not implemented very often. In order to analyse the benefits of SCM strategies, simulation experiments were carried out. In particular a five-stage linear supply chain (four suppliers, one plant, one retailer) was modelled and evaluated concerning the effects of the company-crossing information sharing strategy (planning-relevant and company-internal transmission of information to other involved companies) in contrast to sequential information exchange (pure information exchange about respective orders). Depending on the demand volatility as well as on the utilisation situation of the companies, effects of the inventory, the degree of utilisation as well as the adherence to delivery dates was analysed. Experiments showed that suppliers can profit especially through inventory reduction; the plant mainly profits through a more homogenous production utilisation and a higher adherence to delivery dates.

Keywords: Supply Chain Management, Simulation of SCM Strategies, Information Sharing, Inventory Management

1. INTRODUCTION

New strategies for the collaborative management of supply chains aim to fulfil increased customer requirements and strive at the same time to minimise the production and logistics through harmonised planning execution processes of the different companies of a supply chain. The core idea of these SCM strategies is to improve the customer satisfaction through better logistics service, especially in respect to lead times, due date reliability and product availability whereas at the same time the product and logistics costs are reduced as well. Examples of these collaborative strategies are Supply Chain Monitoring (SCMo) (Odette Recommendation SCMo 2003), collaborative demand and capacity management (Kuhn and Hellingrath 2002; Bock et. al. 2003; Krog et. al. 2002), Vendor Managed Inventory (VMI) (Waller et. al. 1999), information sharing (IS) (Cachon and Fisher 2000) and CPFR (Seifert 2003).

The realisation of such an SCM strategy leads to changes of the material flow, the planning and execution management processes, organisation structures, as well as supporting information systems. These changes involve costs for the introduction and the subsequent application of the respective SCM strategy. Moreover, the future costs and the potential benefits may differ between the participating enterprises. Consequently, companies hesitate to introduce new SCM strategies because they can not evaluate their costs and benefits in advance. Another obstacle for the proliferation of these strategies is the fact that even a single SCM strategy has a considerable design scope: With VMI, e.g., both supplier and customer have to agree on the minimal and maximal inventory levels as well as the planning frequency. So, companies within a supply chain face the question which is the most beneficial SCM strategy and how should the strategy parameters be defined.

Consequently, for configuration and evaluation of SCM strategies efficient instruments for cost-benefit analysis are needed. A reliable cost-benefit-assessment requires a detailed consideration of material flow and information processes factors such as transport lead times and their statistical distribution or the lead time for planning and information transfer. Hence, a dynamic time-related modelling and analysis such as event-based discrete simulation is required. The respective methods need to model the physical supply chain aspects including network structures and resources. Further on, it is necessary to model the information and planning processes of the various SCM strategies. An event-discrete simulation tool for the modelling of order-to-delivery processes in supply networks is OTD-NET, which was developed by Fraunhofer IML. OTD-NET allows detailed modelling of complex production networks with all their constraints and planning, execution and material flow processes (Wagenitz 2007).

Within the scope of the collaborative research centre “Modelling of Large Logistics Networks” (Collaborative Research Centre 559 1998-2008, funded by the German Research Foundation, www.sfb559.uni-dortmund.de) we have evaluated the effects of different

SCM strategies. One of these strategies is information sharing, which is characterised by a transmission of inventory or point-of-sales data from a customer up-stream of the supply chain to suppliers and sub-suppliers. An overview of simulation studies concerning information sharing shows inconclusive results (Schmidt and Knolmayer 2006): The studies show that several partners of a supply chain can benefit from information sharing; however, the degree of the effect varies considerably. Some studies describe improvements for suppliers only; other studies state that advantages by information sharing result also for customers, for example in terms of higher service levels. These contrary findings of the simulation studies trace back to the probable fact that often verification and validation of the models are missing, relevant measure variables are neglected, and partly model designs are highly simplified.

2. SIMULATION EXPERIMENTS

Using the OTD-NET supply chain simulation software developed at Fraunhofer IML, we carried out experiments for a multi-stage linear supply chain within the automotive industry. The purpose of these experiments was to derive how IS influences the performance of the supply chain in comparison to a conventional strategy in which information from a customer is exchanged only the direct supplier.

The investigated supply chain consists of one retailer, one plant, and one build-to-order supplier (BTO) and three build-to-stock suppliers (BTS). Figure 1 shows the respective supply chain structure. For the analysis scenario two different experiments were carried out in order to analyse the effect of the SCM strategies "Information Sharing" in comparison to the "Conventional Strategy (CS)", in which information is transferred only from stage to stage with a certain delay. Furthermore, the following scenarios have been investigated:

- Five different distributions (uniformly distributed) of the end customer demand were considered in order to analyse the sensitivity of the SCM strategies to the demand volatility. The initial situation is a constant end customer demand. In addition, volatilities of the end customer demand for +/- 10% (EDV 10), +/- 25% (EDV 25), +/- 35% (EDV 35) and for +/- 45% (EDV 45) per month were analysed.
- A further dimension of variation for the performed experiments was the ratio of the available production capacity to the capacity demand induced by the end customer. Therefore, experiments were carried out for nearly full load situations (average end customer demand/utilisation = 98% (U 98) respectively 95% (U 95) of the production capacity) as well as for relaxed load situations (end customer demand/utilisation = 80% (U 80)).
- Finally, two different scenarios concerning the delivery time (short delivery time from tier to tier – less than 12 hours (DT 1) – versus delivery times of one month (DT 2)) were considered. The simulation period covers one year, from January 1 until December 31.

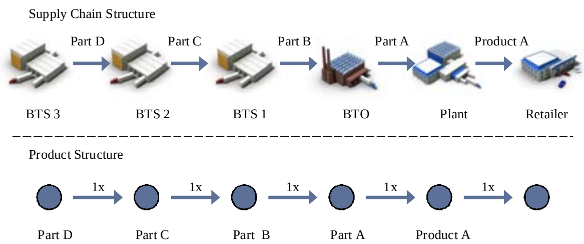

Figure 1: Supply Chain and Product Structure of the Created Model

As figure 1 shows, among the actors only an exchange of one product or one part takes place. The BTS supplier 3 is the source of the material flow in the supply chain; the retailer is the sink of the material flow. The BTS supplier 3 produces units of part D to stock and ships the ordered amount to the BTS supplier 2. This supplier makes units of part C to stock and forwards the amount of ordered units to BTS supplier 1. BTS supplier 1 proceeds with product B in analogous way but with the exception that its sink concerning the material flow is the BTO supplier. The BTO supplier works closely together with the plant. This supplier produces part A per order, activated by the plant. The plant produces in turn per order activated by the retailer. The retailer constitutes the interface to the end customer and transfers the orders to the plant once a month.

The target of each single company of the supply chain is a preferable homogenous production utilisation (nearby full load), the minimising of inventory for parts and for finished products as well as an assurance of a preferable high adherence to delivery dates.

For the evaluation of the effects of the SCM strategies following performance indicators are specified in the simulation experiments for all considered companies:

- Utilisation:
  Utilisation means production utilisation of the respective bottleneck resource of the companies. Here the average utilisation was defined.
- Inventory of finished products and parts:
  Average goods receipt and goods issue inventory were collected. Work-in-Progress inventory were not considered.
- Adherence to delivery dates:
  Degree of performance of the orders at the end customer (retailer in the existing model). For this, arrival time of ordered products A in the goods receipt at the retailer was used. The adherence to delivery dates is a value between

0 (no delivery was delivered on time) and 1 (all deliveries were delivered on time). In the following, however, the adherence to delivery dates will be converted into percentage and described in percent.

In the model it is assumed that for BTS supplier 3 there are infinite parts available which are needed for production if required.

3. SIMULATION RESULTS

3.1. Effects of IS on the Inventory

Figure 2 shows that at all suppliers' inventory level are highly varying. At the beginning of the period of consideration the inventory of the suppliers increase and are again on the decrease, shifted about approx. three months to the respective upstream supplier. During the months 6 to 8 the increase of the inventory at the BTO supplier proceeds almost linearly. Even at the end of the year the BTO supplier cannot decrease its inventory. However, the plant keeps its inventory almost constant and relatively low throughout the whole year. This is possible since the BTO supplier simply builds to order, orders activated by the plant. In a way the plant uses the stock of the BTO supplier and can therefore keep internal inventory relatively low.

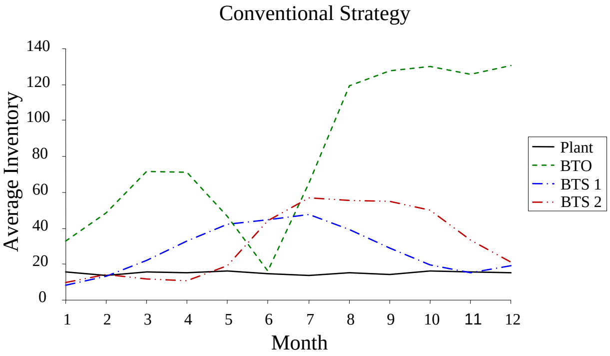

Figure 2: Companies' Inventory Situation with CS (Scenario EDV 35 / U 98)

On the other hand figure 3 shows the inventory situation of the actors by utilisation the information strategy throughout the supply chain. It becomes clear that inventory level at all suppliers is in average much lower than with the conventional strategy. Whereas the inventory situation of the plant changes hardly, the suppliers' inventory situation is considerably improved. Indeed, the BTO supplier's inventory increases over the period of consideration continuing; however, there are no inventory variations any more. Also BTS suppliers' inventory curves proceed relatively constant throughout the whole year – merely in August inventory decreases for a short time. Their inventory situation looks very similar, just with some little varieties.

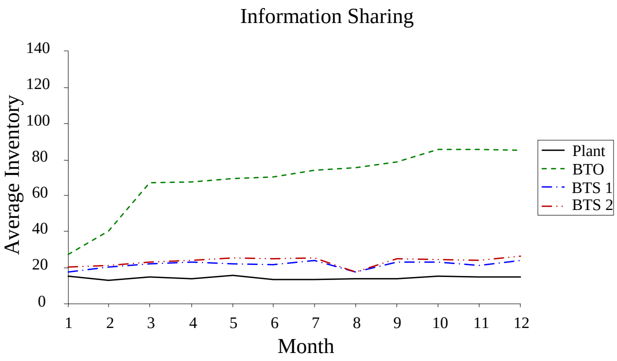

Figure 3: Companies' Inventory Situation with IS (Scenario EDV 35 / U 98)

Figure 4 shows these coherences with the aid of the example of BTS supplier 1 for different demand volatilities (10% and 35%) as well as for different degrees of utilisation (80% and 98%):

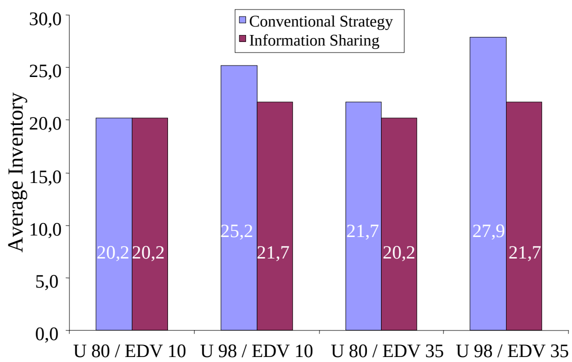

Figure 4: Inventory Situation of BTS supplier 1 for Different Scenarios

The strategy-related variation parameter "end customer demand information" has in the context of information sharing the biggest influence on the inventory. By transmission of the current end customer demand (retailer demand in the existing model) to all business partners of the logistics network, company-internal sales forecast becomes much more precise compared to conventional prognoses, based on past-related orders of the respective customer. Gained simulation results show that IS has different influences on the inventory situation of the companies; depending on which demand variation as well as depending on which production utilisation is prevailing. Most significant improvements through IS were expected when having high demand variations and high degree of utilisation of the actors at the same time. Furthermore, especially the upstream supply chain, the suppliers, profit by the inventory improvements.

3.2. Effects of IS on the Plant Utilisation

The analysis of the simulation results concerning the parameter degree of utilisation again made clear that the information sharing strategy achieves improvements compared to the conventional strategy. By transmission of information in-between the companies the respective utilisation can be formed more evenly.

However, the smoothing of the production utilisation carries low weight when another initial situation is focused. Therefore, a slight demand variation anticipates simply a little optimisation of the load situation. This is clearly shown in figure 5 and figure 6 taking the plant as an example in turn. While achieving a strong smoothing by the application of IS with the scenario EDV 35 / U 98 (figure 5), the improvement with the scenario EDV 10 / U 98 (figure 6) is considerably lower.

Further analysis showed that information sharing has no influence on the utilisation situation of the companies when having long delivery times. Different scenarios showed no changes of companies' production utilisation. The evaluation of the utilisation situation for different scenarios illustrate clearly that an information sharing concept is only worthwhile when a high end customer demand fluctuation is existent.

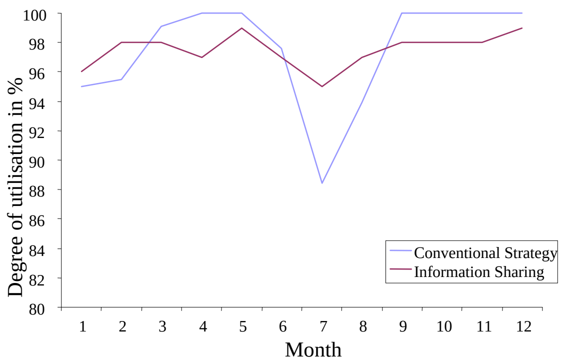

Figure 5: Production Utilisation of the Plant, Scenario: EDV 35 / U 98

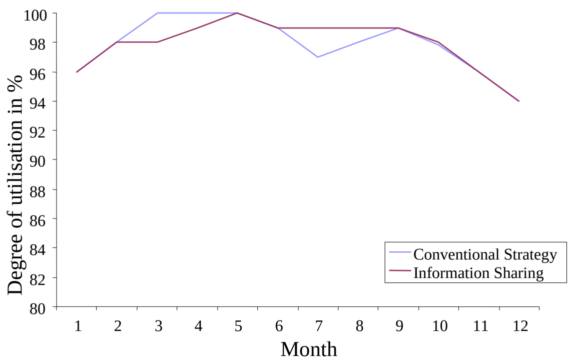

Figure 6: Production Utilisation of the Plant, Scenario: EDV 10 / U 98

In contrast to the demand distribution, the level of the degree of utilisation has no apparent influence on the extent of the smoothing of the production utilisation. This means that already at low degree of utilisation of the companies, smoothing effects can be achieved.

3.3. Effects of IS on the Adherence to Delivery Dates

The adherence to delivery dates is a very important parameter because among other things this parameter concerns the end customer and co-decides decisively the end customer's future buying pattern. A bad adherence to delivery dates effects a high or frequent delay in delivery of the ordered products or parts. A high adherence to delivery dates in contrast means that ordered products arrive at the appointed time at the customer, thus not earlier either.

Gained results show that the adherence to delivery dates of the logistics network is essentially depending on the utilisation situation of the respective company. During low production capacity utilisation (e.g. 80%) for example no or only a low improvement of the adherence to delivery dates can be achieved. However, when companies have full order books, ultimate load or even full load, by IS the adherence to delivery dates of the supply chain can be improved. But also the demand volatility has an influence on the adherence to delivery dates, even though a little less than the utilisation situation of the actors. The results of adherence to delivery dates with different scenarios are illustrated in figure 7.

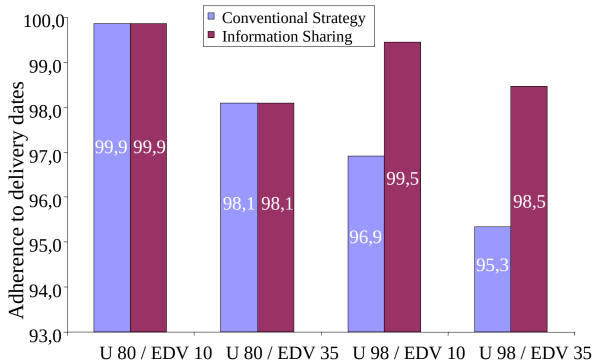

Figure 7: Adherence to Delivery Dates of the SC for Different Scenarios

Figure 7 shows that the adherence to delivery dates of the SC at a companies' degree of utilisation of 80% cannot be increased – neither at low (10%) nor at high (35%) demand volatility. When companies' production capacities are however almost utilised (ultimate load 98%), by information sharing a considerable improvement of the adherence to delivery dates of the SC can be seen. Especially, having high demand volatility (35%) in addition, information sharing seems to be very worthwhile concerning "adherence to delivery dates".

Table 1 shows exemplarily that for extended delivery times (one month) the adherence to delivery dates of BTS supplier 1 and BTS supplier 2 improves by application IS. With extended delivery dates the adherence to delivery dates is not as good as during the initial situation (12 hours) - the delay in delivery is therefore higher. By the information sharing strategy in average the adherence to delivery dates can be improved by 2% in contrast to the conventional strategy. These results implicate that with long delivery times IS is of avail concerning the adherence to delivery dates of the entire logistics network.

Table 1: Comparison of Adherence to Delivery Dates with an Extended Delivery Time of One Month

Adherence to delivery dates	U 98			
	CS		IS	
	EDV 35/DT 1	EDV 35/DT 2	EDV 35/DT 1	EDV 35/DT 2
January	80%	78%	82%	80%
February	96%	95%	99%	97%
March	97%	95%	100%	97%
April	98%	97%	100%	98%
May	97%	96%	100%	98%
June	96%	94%	100%	96%
July	97%	97%	100%	99%
August	95%	95%	100%	96%
September	98%	97%	100%	98%
October	99%	97%	100%	98%
November	97%	97%	100%	98%
December	95%	94%	100%	96%
Average	**95%**	**94%**	**98%**	**96%**

Table 2 clarifies the percentage improvements of the average adherence to delivery dates through IS. Interesting is that the extent of utilisation has a bigger influence on the improvement of the adherence to delivery dates than the extent of the demand volatility. For instance, it can be noticed that the improvement of the adherence to delivery dates increases considerably when production utilisation of the companies increases while improvement decreases when demand volatility (10% - 45%) declines at the same time. This coherence can be explained with the fact that for low production utilisation there is enough rest capacity available to satisfy fairish high demand volatility in due time. During high utilisation degree, already a little demand volatility can lead to a delay in delivery. Therefore, the information sharing strategy has a significant effect during high and comparatively slight effect during low production utilisation of the companies.

Table 2: Improvement of Adherence to Delivery Dates for Different Scenarios

Demand Volatility / Degree of Utilisation	10%	25%	35%	45%
	Difference %	Difference %	Difference %	Difference %
80%	0,00%	0,00%	0,00%	-0,83%
95%	-0,64%	-2,83%	-3,25%	-3,97%
98%	-2,63%	-2,97%	-3,36%	-4,04%

3.4. Effects of IS on All Factors

In principle the major advancement concerning the three analysed parameters “inventory”, “degree of utilisation” and “adherence to delivery dates” can be achieved with a high production utilisation of the companies. Concerning each individual company of the supply chain following information concerning the parameters can be registered:

- Plant:
  The plant profits from the implementation of IS almost exclusively for the parameters degree of utilisation and adherence to delivery dates. The production utilisation is more homogeneous compared to the conventional strategy. The increased adherence to delivery dates of the supply chain is especially an advantage for the plant. On the other hand, the plant inventory can be only decreased marginally. Regarding this parameter the IS strategy is inconsiderable for the plant.
- BTO supplier:
  The BTO supplier achieves its profit in the context of IS predominantly by the decrease of inventory. During low demand volatility the BTO supplier can improve the inventory situation considerably. The improvement of the utilisation situation however is relatively low and therefore categorised as inconsiderable.
- BTS supplier:
  The BTS suppliers profit in different respects. By application of IS, inventory can be reduced and the utilisation situation can be improved considerably.
- All companies:
  The adherence to delivery dates of the entire supply chain can be improved by information sharing. Noticeable in particular is the reduction of the delay in delivery with a high production utilisation of the actors and high end customer demand volatility at the same time.

Therefore, the biggest effect of information sharing is shown during high production utilisation of the companies of the supply chain as well as during high end customer demand volatility. Based on the simulation results it can be registered that the main profiting actors of an IS concept are upstream tiers of the logistics network. Simulation results show that the percentage improvements of the average inventory of the BTS suppliers throughout all scenarios are above those of the entire supply chain. By reason of this significant reduction of the average BTS suppliers’ inventory, the BTS suppliers are those who profit most from implementing the IS strategy.

4. CONCLUSIONS AND OUTLOOK

The analysis of the simulation results shows that information transmission between the companies of the supply chain leads to an optimisation of company-internal parameters (inventory, degree of utilisation) but also of parameters throughout the network (adherence to delivery dates). The simulation results indicate that particularly upstream stages of a supply chain benefit through the information sharing strategy, especially through inventory reduction. On the other hand, the major profit for downstream stages of a supply chain, e.g. a final assembly plant, is the increase in production utilisation homogeneity as well as the improvement in adherence to delivery dates. The simulation results also demonstrate that the degree of the consequences of information sharing is depending on both the volatility of the end customer demand and the situation of the plant utilisation. If both are comparative high at the same time, significant improvements result out of the information sharing strategy for all companies in the supply chain.

In addition to the presented experiments in this work, in which production utilisation for all companies was assumed identically, different production utilisations could simulate a much more realistic situation. Furthermore, not only inventory costs and costs for non-deliveries but also transport costs, production costs etc. could be considered in the model an in this way allocation decisions in the SC could be influenced strongly.

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