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PLANNING NERVOUSNESS IN A DEMAND SUPPLY NETWORK: AN EMPIRICAL STUDY

Kaipia Riikka
Korhonen Hille
Lakervi Helena

Abstract

Planning processes along a demand supply network in an environment characterized by rapid market fluctuations and product changes are studied. The relationship between demand planning and the bullwhip effect is investigated by comparing planning accuracy in different demand supply network echelons and locating where there is most nervousness. The results show that planning accuracy varies between the parties in the supply chain. A proposal is made to stabilize planning in an environment characterized by fast market and product changes. Besides the increased complexity of the network the frequent changes in product portfolio makes the management of demand supply networks more challenging.

Introduction

The characteristics of the electronics supply chain make it prone to demand fluctuating [1]. Electronics industry supply chain includes features like global supply, multiechelon structure, distant location of the manufacturers from customers, strong role of the focal company and global distribution network. The complex structure of electronics supply chain causes delays in the information flow and in the physical goods flow and requires long planning cycles. These features include factors that are connected to the causes of the bullwhip effect; the demand variation amplification effect along the supply chain [2],[3], originally founded by J. Forrester [4].

The structure of the supply chain makes planning processes challenging. The requirements of each network party, for example suppliers of long-lead time components, needs to be addressed. Access to demand data may be limited or the information it receives may be distorted and delayed [5]. In addition, many electronic OEMs, original equipment manufacturers, belong to a network characterized by high degree of dynamics [6] setting more requirements for planning quality. Difficulties in combining long planning cycles and the market requirements for speed and flexibility may end up in distorted demand and high inventories in the network. This is the purpose of this research: to study the connection between planning processes and the bullwhip effect in an electronics supply chain.

A common understanding of a supply chain is that it is a streamlined pipeline that transforms raw materials to finished goods, which are then delivered to the customer [7]. Another definition emphasizes the dual aspects of the chain, demand and supply: A set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services finances and/or information from the source to the customer [8]. However, as the structure of supply chains has become more complex, it is described as a network of companies and organizations, where one company has several suppliers, who in turn have several suppliers. Downstream linkages also are multiple, as one company has more than one customer, who serves several customers [9]. Supply networks should be separated from supply chains since they involve lateral links, loops and two-way exchanges, and include a view of resource acquisition, development and management and transformation [10].

Later on, greater emphasis is placed on the demand side of the network, on customer operations and fulfilling the customer needs. Therefore a more suitable term is proposed to be the demand supply network. The demand supply network links the supply chain and the demand chain and emphasizes the interactive character of the linkage. Demand supply chain management aims to serve customers better by understanding the customers demand chains and realizing collaborative, interactive relationships to offer added value for the customer [11].

However, when researchers treat networks, a usual approach is to take one part of the demand supply network, and illustrate it as a chain or a single relationship, where the research is carried out. This is also the case in this study. We have taken out of the network one situation, where each company plays a certain permanent role. We investigate the chosen situation consisting of several parties

thoroughly. In this article is used the terms demand supply network, demand chain and supply chain in parallel depending on what exact situation and structure we mean.

In this article the connection between planning processes and the bullwhip effect is investigated. The research is based on empirical findings from the case demand supply network. The European operations of the case company, an electronics durable manufacturer, are considered. The case company, the OEM, original equipment manufacturer, runs three factories in the area, which are supplied by 150 suppliers. The goods are delivered to consumers through a multilevel distribution channel and numerous point-of-sales. In order to observe the bullwhip effect, demand data at the customer and sell-through data in addition to order and replenishment data throughout the network was investigated. Special attention was paid on the role of demand supply planning processes and planning results.

The paper is structured as follows: first, a literature review is conducted addressing the challenges of demand supply management in the electronics industry, the bullwhip effect and planning nervousness. The case demand supply network is described, and the used methodology to study the case is presented. The planning quality throughout the demand supply network is analyzed. A proposal is made to stabilize planning in the supplier interface. Last, conclusions are treated.

New challenges to demand supply network management

The growing speed of change in the marketplace sets new requirements for the management of demand supply networks. New product introductions take place more frequently, at the same time when product life cycles shorten. Figure 1 shows the growth in the number of active product families and product introductions in an electronics company. Such growth increases the complexity in planning for demand and supply. For example, a new printer model or a mobile phone is launched to the market every month instead of once or twice a year, as in previous years. In the electronics industry, the product life may be only months, after which it is replaced with a new model. The number of customer-specific product variants in the market grows concurrently. All this means that managing the products in different life-cycle phases becomes more important and, furthermore, the management of the product portfolio must become routine day-to-day business for companies.

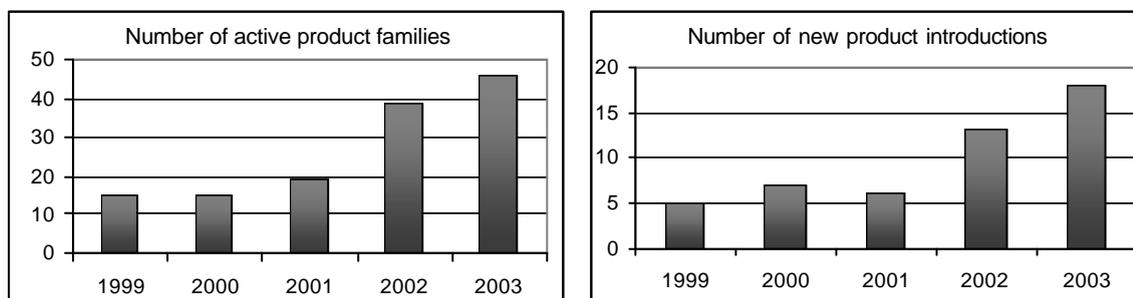


Figure 1. Changes in the product portfolio in an electronics company during 1999-2003. On the left is the number of active product families and on the right the number of new product introductions to the market annually.

Another recent change affecting the performance and management of supply chains is the increased visibility to downstream demand. Access to point-of-sales data, sell-through data and channel inventories across company boundaries throughout the supply chain sets new possibilities for the performance of the chain. A supply chain participant is no longer solely dependent on the information of the next echelon in the chain, but can base its decisions on the transactions made downstream in the network.

Increased competition and global operations, as well as the speed of change in the marketplace require more flexibility from manufacturing. These factors force companies to concentrate on their core competencies, such as product development and pursue increased capabilities in non-core competencies from outsourcing. The original equipment manufacturers (OEMs) need flexibility and speed in manufacturing and also optimum capacity utilization for their own costly production capacity. Contract manufacturers bring a solution for them by offering production capacity capable of producing a broad range of low-cost, high-quality products with short lead times in varying lot sizes according to customer specifications [12].

However, contract manufacturers are more than mere extensions of production capacity. They have become partners in product design and development, and essential extensions of the OEMs service. Contract manufacturers also perform operations other than pure manufacturing; they purchase raw materials, plan and design products and, in some cases, take responsibility of distributing products to customers as well [13], [14]. One challenge for contract manufacturers is in the purchasing of long lead-time raw materials and components from 2nd tier suppliers. Adapting rapidly to market trends requires end-customer demand information with a short information lead-time. Accurate advance information is needed to manage this part of the supply process efficiently.

In the apparel industry, for example, contract manufacturing is widely used. Zara, a Spanish apparel manufacturer has a demand supply network with high flexibility requirements. Market trends are captured from Zara's retailers through effective linkages between stores, headquarters and manufacturers. Design and the production of new models and deliveries to the retailers are carried out in only two weeks at the fastest. In production this has been made possible by using a large number of small contractors, that are mostly located in the north of Spain, as extensions of Zara's own production capacity. These sewing workshops perform the labor-intensive steps of the production and they are connected with necessary information technology and logistics capabilities to enable collaborative co-operation [15].

Causes of the bullwhip effect

The discovering of the bullwhip concept is shortly presented here and the causes for the effect are collected in Table 1. The causes for the effect can be divided into four groups[16]: Forrester effect, which is caused by demand signal processing and lead times, Burbidge effect (order batching) and Houlihan effect, which deals with rationing and gaming against uncertainty, and promotion effect caused by price changes, discovered by Lee et al. [17] and Fisher [18].

The phenomenon of demand amplification, where demand experienced upstream along the supply chain is more variable than end-customer demand, has been named *industrial dynamics* by Forrester [19]. He has shown how this effect, also referred to as the Forrester-effect, leads to many problems in the supply chain, such as high and fluctuating inventory levels, low capacity utilization, delivery problems and unfilled orders. Parties upstream in the supply chain are forced to keep inventories in order to respond to the fluctuating demand that they face. Other negative effects that the Forrester effect has on business performance are quality problems, high raw material costs, overtime expenses, high shipping costs and longer lead times.

Burbidge [20] presented new reasons for the same effect that are due to the ordering practices. Multiple cycle ordering caused by unsynchronized ordering cycles, for example weekly and monthly cycles, causes order batching. He also speaks about multiple phased ordering, which is a result of ordering each time the same fixed quantity based on economic order quantity calculation. Later on, he proposed that economic order quantity calculations and materials resource planning should be discarded because of their disastrous impact on supply chains [21].

Uncertainty is a major cause of bullwhip, and in addition to Forrester and Burbidge, Houlihan [22] has presented how the actions caused by uncertainties in the chain may result in amplified orders. If a shortage of a product occurs, this may cause overordering because customers want to protect themselves against future shortages. This may cause demand amplification in two ways: first, the forecasts made by the parties upstream are based on larger demand, and, second, the over-order may cause more shortages, which in turn cause over-orders and increased safety stocking.

Lee et al. [23], [24] introduced the term bullwhip effect and presented four reasons for the phenomenon: demand signal processing, order batching, price variation and rationing game. Demand forecasting is one reason for the fluctuation in orders. As each echelon of the demand supply network forecasts individually, a small change in the end-customer demand impacts the demand forecasts throughout the network leading to high amplification upstream in the network. Order batching is due to the ordering practices of companies, such as ordering at certain time intervals or in fixed quantities. Price fluctuations cause advance buying and raise inventory levels, when companies try to secure the cheapest price. Rationing and shortage gaming is a result of companies wanting to be sure to secure the amount they want in the case of shortage. Fisher [25] has treated the effect of price changes also.

	<i>Focus</i>	<i>Sources</i>	<i>Offered solutions</i>
Forrester effect, Forrester 1961	Time-varying behavior of industrial organisations - Industrial dynamics	Feedback logic, feedforward logic, uncertainties, time delays and lead times	Faster order handling, eliminating distribution level, changing inventory policy
Burbidge effect Burbidge 1984	Production management	Problems in shop-floor control systems, uncertainties, time delays, multiple-cycle ordering, multiple-phased ordering, economic batch quantities	Avoid suing EBQ and MRP. Using systems theory principles to production management
Houlihan effect Houlihan 1988	Balancing inventories, production capacity and customer service in international supply chains	Local protection against shortages caused by upswing in demand, overordering causes unreliable delivery and increased safety stocks	Balancing inventories, production capacity and customer service
Promotion effect Lee et al (1997), Fisher 1997	Effects of price changes	Price variation	Stabile pricing strategies

Table 1. The development of the bullwhip effect. Classification adapted from Disney and Towill [16].

Sharing downstream demand information is considered as one of the main means in eliminating the causes of the bullwhip effect in many recent studies. For example a research group [26] investigated the phenomenon in a two-stage supply chain with a retailer and manufacturer. In general, the manufacturer benefited more from the improved visibility. Sharing only customer order information did not bring any benefits for the retailer, but the manufacturer could reduce a part of the uncertainty. POS data visibility is not relevant in every demand supply network, but when a fresh grocery supply chain was investigated it appeared to be beneficial because of the products' short shelf life, and especially in reducing out-of-stocks and reducing price discounting [27]. In a multi-echelon multi-company environment was showed information sharing is beneficial especially in demand supply networks where demand is significantly correlated over time, when demand variability is high and when lead time is long [28]. Lee et. al [29] support the opinion that when demand variance is high the manufacturer benefits from information sharing.

Four types of information sharing strategies were compared [30] in a two-stage supply chain with one product. It was found that when more information is shared and when demand variability is low then the performance of the chain was improved. In addition, they have studied a demand supply network with customizable products and have developed a hybrid information sharing policy, where demand information is shared in the demand chain and inventory information is shared in the supply chain. This is proposed to be a powerful solution to manage the product mix.

In addition to studying the impacts of increased visibility on the bullwhip effect, some studies have concentrated on the connection between planning processes and the bullwhip effect. For example Chen et al. [31] have focused on determining the impact of demand forecasting on the bullwhip effect in a situation where the retailer uses standard forecasting technique to estimate demand. One of their goals was to quantify the bullwhip in different stages of the demand supply network. First, a two-stage supply chain with one retailer and one manufacturer was analyzed; secondly a multi-stage supply chain was analyzed. In the first analysis, the variance of orders is reduced when more observations were used in the forecast. In the multi-stage demand supply network the impact of centralized customer demand information on the bullwhip effect was tested. The result was that the bullwhip effect still existed, although reduced, even though every member had got the same demand information.

The influence of the type of demand information on the planning stability in a supply chain is investigated by Donselaar *et al.* [32]. They found out that a company's own planning logic using end customer demand results in more stable planning compared to a standard software package with MRP logic and orders. The nervousness of the MRP systems has been noticed in other studies, too. For

example Blackburn [33] advises strategies to dampen the nervousness of the system such as using forecasts, extending time horizons, using frozen periods and buffer stocks or minimizing lot sizes. De Kok and Inderfurth [34] have investigated inventory nervousness and the impact of control rules on planning stability. Wilding [35] states that both management decision-making and the computer control algorithms used can generate nervousness in supply chains. In a nervous system, which Wilding describes using chaotic systems characteristics, spikes in demand may cause an overreaction resulting in demand amplification and fluctuation in production planning. Therefore long-term planning is very difficult. Wilding's (*ibid*) investigations in automobile demand supply networks show that variability between forecast and actual demand cause problems, which may end up even in stoppages by the parts vendors or in assembly.

Disney and Towill [36] have identified in a model-based study another type of bullwhip, namely that of inventory bullwhip. They claim that continuously recalculating inventory control parameters according to the demand signal causes fluctuation in target inventory levels or in production quantities. Their approach is similar to Forrester's [37] and they suggest that to control the inventory level fluctuation, slow reaction to the noise in demand signal in the demand supply network is essential. In their model, they filter out the impact of peaks in the demand signal and realize the change for example in inventory levels over time periods. This slow reaction results in a more stable inventory level and fluctuating of production quantity reduces.

There are two main sources, how VMI can impact on the bullwhip. The first is eliminating one layer of decision-making and the second is eliminating information delays in the process. They tested by simulation which sources of bullwhip can be reduced with VMI in a relationship between one customer and a supplier. According to their results, gaming becomes unnecessary and order batching is balanced through more open information sharing thus eliminating two of the sources of bullwhip. Altogether VMI significantly improves the dynamics of supply chains[38], [39], [40].

However, the VMI system may not be too complex [41]. When testing different information sharing strategies in a student group playing the Beer Game, it came out that although the players had information available, the decision making became too complex and the game resulted in increased inventory costs.

We point out three issues in current bullwhip literature. First, the supply chains under investigation in recent studies seem to be simplified. Specifically they contain only two levels and have limited product range. Mathematical modeling is used for the quantification of bullwhip effect and differences are sought in different information sharing scenarios. Some exceptions exist, like Fransoo, et al. [42] who have investigated inventory planning in a multi-echelon multi-company demand supply network. Second, many papers propose that planning processes including forecasting and management decision making are causes for bullwhip. However, planning processes are not investigated throughout the supply chain. Therefore, in addition to studying the bullwhip of orders, we need to address the planning processes. In a complex demand supply network, variable process lead-times, information delays and the number of players make managing the planning processes challenging. The third issue is that in the bullwhip literature there is not often mentioned the characteristics associated with new product introduction. Some aspects of this issue are treated in this research.

Description of the case and used methodology

The research question of this paper is, first, how nervousness in the planning processes increases the demand fluctuation across the case demand supply network and, second, how its effect could be dampened. The research is carried out as an empirical study as a part of a larger project that focuses on end-to-end visibility in the case demand supply network. The goal of the project was to identify how downstream visibility can be better utilized in the demand supply network.

The case company is a global electronics manufacturer, and it is further called the OEM (original equipment manufacturer) in this article. The goods the company is producing are consumer durables. The OEMs regional operations in Europe, where the company runs three factories, are of interest. The 17 sales units of the company are responsible for the sales to so called trade customers. Trade customers consist mainly of operators, distributors and retail central warehouses. Trade customers are OEMs direct customers, who order products from the OEM via sales units, and deliveries the products to point of sales. Usually trade customers keep inventories to be able to respond to fluctuating demand at the point-of-sales (POS). There are approximately 80000 different sized points of sales in the

Europe region selling products to consumers. The parties in the supply chain and their roles are presented in Figure 2.

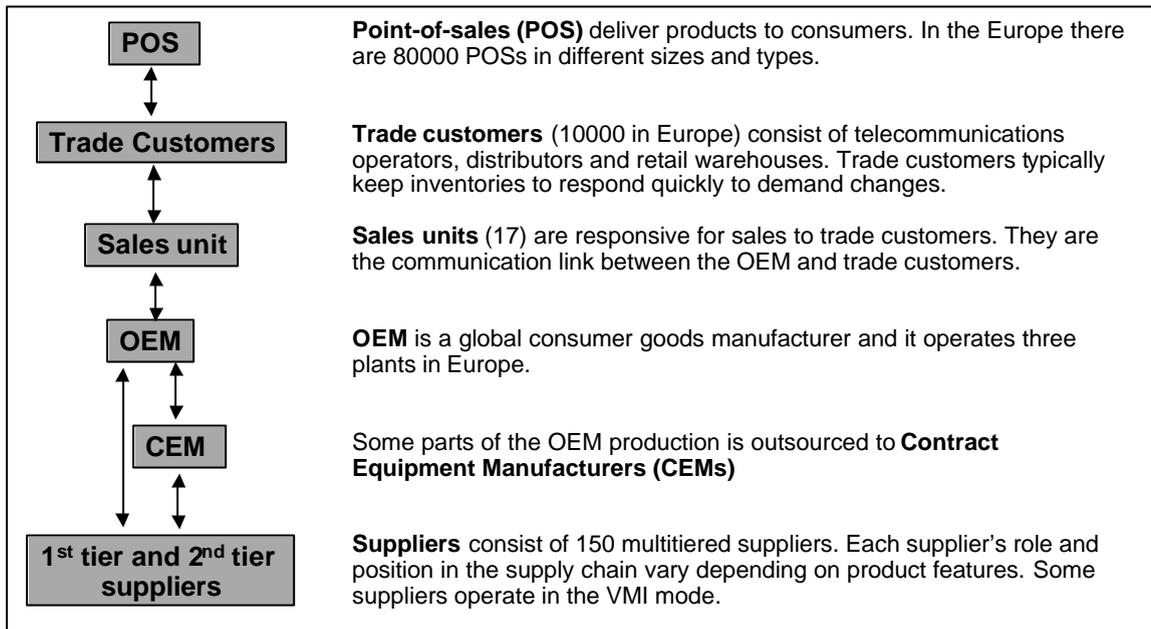


Figure 2. The structure of the case supply chain.

The OEM has outsourced a part of production to contract equipment manufacturers (CEMs), which provide the chain with flexible production capacity. The OEM and CEM plants receive materials and components from 150 suppliers. The supply network is multitiered and the suppliers' role may vary depending on product features and required production process. At the same time a supplier may play several roles in the network. One company may be a CEM, to level the OEM production capacity, a 1st tier supplier, or a 2nd tier supplier, who supplies parts or components to 1st tier supplier.

This research is based on the results of a current state analysis, which aimed to find out the current state of visibility and the utilization of the demand information in the case demand supply network. The current-state analysis was conducted in two ways. First, by interviewing key decision-makers throughout the demand-supply network from retailers to second tier suppliers a general view was formed. Based upon the information gathered in interviews, the current demand supply planning process flow was described. Second, a data analysis of the quality of plans for demand and supply was analyzed in each decision-making point by collecting planning and actual data of two products. This was made on a very detailed level to ensure accurate results and to avoid the trap of treating only average figures and making conclusions based on them. Data was collected from the case company's various IT-systems, consisting of planning systems and operational systems. Information sharing reports, called demand visibility reports were used. Some data was accessed from collaborative customers.

This analysis provided the project team with an in-depth understanding of the state of visibility in the demand supply network, the planning processes and planning results and about the reasons for demand distortion.

The results of the study are presented concerning the whole demand supply network as available. First, it is showed that the bullwhip effect exists in this demand supply network and the planning process is described. Then, the planning results are analyzed for a snapshot of the network and some issues affecting the planning quality in each echelon are presented.

The planning quality results have been combined from different parts of the demand supply network to address where in the demand supply network the most nervousness is located. Finally, one solution is proposed to stabilize planning in a vendor managed inventory -model.

Planning accuracy in the case demand supply network

In the case demand supply network, the bullwhip effect is a problem especially in new product introductions. The demand faced by channel customers, the OEM and one variant material supplier is presented in Figure 3. The figure contains the demand for one product in the beginning of its lifecycle. The supplier in this example supplies variable components to OEM assembly line. The supplier was required to deliver high volumes in the beginning of the product life cycle, because sales expectations were high. When sell-through data from the channel was received, the supplier deliveries dropped only with a delay of several weeks. In maturity phase the swings in supplier production quantities are smoother.

It becomes clear that the fluctuation of demand amplifies in the chain and the demand by parties upstream the network does not reflect end customer demand. The supplier faces larger swings in demand than the previous echelons and the changes in the slope are sharper.

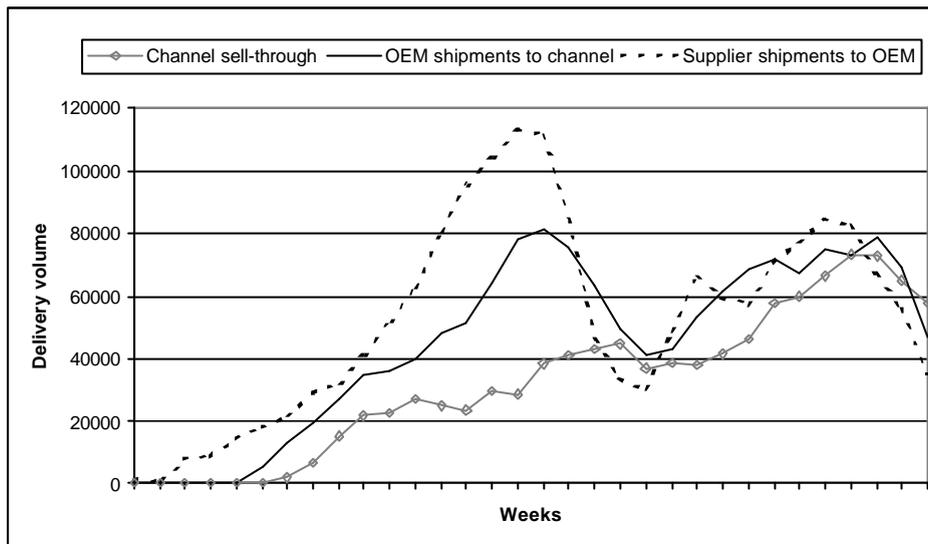


Figure 3. An example of delivery quantities of one product in three echelons of the case supply chain in product introduction and maturity phases.

The demand the suppliers face is very unstable, which can be seen when considering the production quantities of 45 weeks. Average weekly production quantity is about 27 700 pieces, maximum quantity is over 120000 pieces, standard deviation being about 30000 pieces. Therefore it is not uncommon that weekly production quantity at the contract manufacturer (CEM) may change 80 % or more from one week to the next (Figure 4). There is no inventory between CEM and OEM that could smooth the demand changes and therefore level the changes in production quantities.

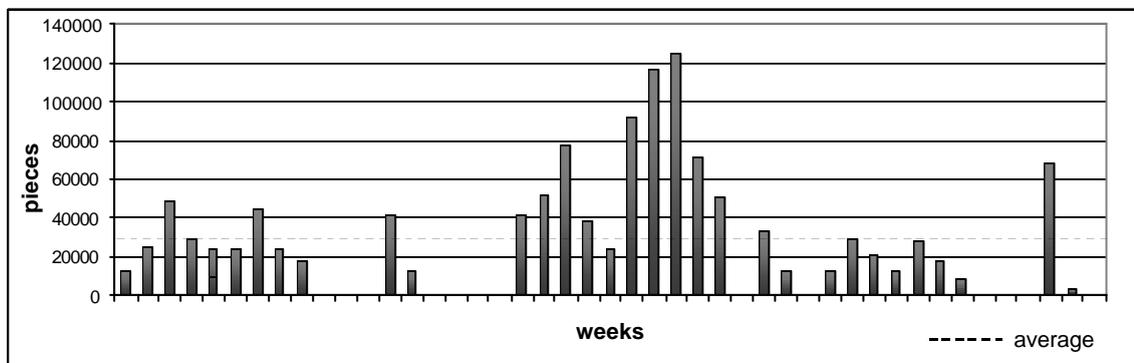


Figure 4. Weekly production quantities in pieces at a contract equipment manufacturer (CEM).

The planning process in the examined demand supply network is depicted on the high level in Figure 5. On the demand side, for example in sales units, the forecasting is carried out without considering constraints from the upstream parts of the demand supply network. In OEM's regional management, the supply constraints from suppliers and own production are combined with the demand plans. This constrained plan is then communicated to both the demand and supply sides.

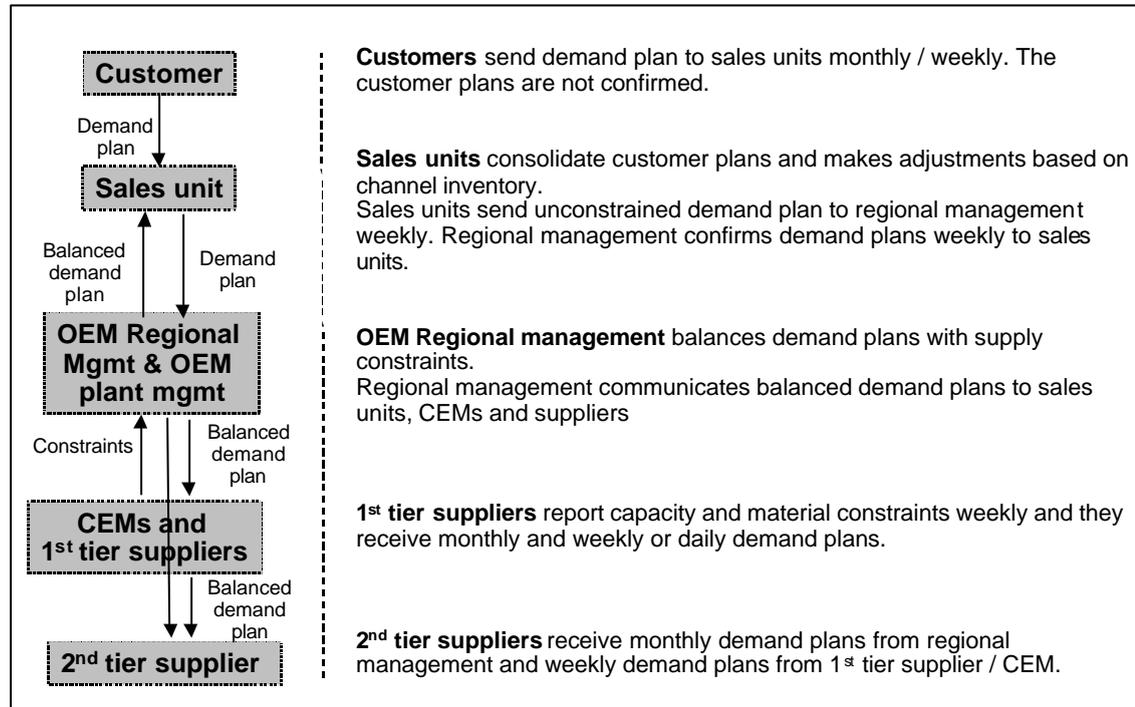


Figure 5. Demand supply planning process in the examined demand supply network.

The customers' demand plan does not reach suppliers as-is because there are several decision points in between, for instance in sales units and in regional decision-making. In these points, additional information is combined with the original information. It may be for example information about campaigns, future products, price changes, or supply constraints. Intuitively, the management adjustments should improve the quality of the plans since additional information is used. However, this is not always the case.

Each demand supply network party was investigated from the planning quality point-of-view. The relationship between demand planning and the bullwhip effect is investigated by comparing planning accuracy in different demand supply network echelons, beginning from trade customers and ending at first tier suppliers. The focus is on the weekly planning process, which conducts the execution of operations, deliveries and material planning at suppliers. In addition to the weekly planning process there is a monthly planning process, which focuses on capacity reservations. Planning quality is measured as mean absolute percentage error (MAPE) in the plans compared to actual orders or deliveries.* The planning quality of each echelon is presented in a figure with a time horizon on the x-axis and magnitude of planning error on y-axis. The first column in each figure presents the current week, when the plan and actual are the same and the planning error is thus 0 %. The next columns present the value of MAPE one to nine weeks before actual demand, i.e. the MAPE on week 5 describes the error in a plan that was made five weeks before actual demand. The results are gathered in Table 2.

Channel customers' ordering practices affect the quality of information throughout the network. Sales units have agreed with customers on a frozen order period during which the customers are not supposed to make changes in orders and which length varies from two weeks to two months

* $(MAPE = \Sigma (| \text{forecast} - \text{actual} | / \text{actual}))$

depending on the market area. However, in practice, not all orders are placed sufficiently in advance and customers may change their orders until the last minute. This means that the demand for the coming weeks, even for the next week, is often unsure and the visibility to customer demand in the network is much shorter than the frozen period.

Customer sales forecasting is done on a sales package level, which makes forecasting difficult since the sales of different color variants needs to be addressed. In general, customers forecast on a monthly basis, but the OEM has several collaborative customers who compile joint plans weekly.

In the OEMs sales units, the customer demand plans are aggregated to a sales unit level plan on product variant level. The forecasting error is approximately 60 % for the next week and it worsens further for the coming weeks. The demand plan is updated weekly on customer and variant level for the current month and next two months based on customer forecasts and channel information.

Sales unit demand planning forms the basis for variant planning and therefore it impacts the planning quality throughout the network till variant material suppliers. On the regional level, the demand plans from sales units are balanced with the available production capacity and supplier capability. At this point, allocation decisions are made when there are supply shortages. The planning accuracy on a regional level is very good as the demand has the greatest aggregation in the whole demand supply network.

	Planning focus	Planning accuracy	What impacts the planning accuracy	Examples of planning error figures. Each stack is the difference between a plan made 1, 2,...9 weeks before implementation and actual delivery.																						
Customers	Customers forecast both volume and product mix on sales package level.	Forecasting accuracy for collaborative customers is good.	Many changes in orders despite of a frozen order period. Lack of processes, only collaborative customers forecast.	<table border="1"> <caption>Customers Planning Error Figures</caption> <thead> <tr> <th>Weeks before implementation</th> <th>Percentage Error</th> </tr> </thead> <tbody> <tr><td>Order</td><td>0%</td></tr> <tr><td>-1 wk</td><td>12%</td></tr> <tr><td>-2 wk</td><td>18%</td></tr> <tr><td>-3 wk</td><td>48%</td></tr> <tr><td>-4 wk</td><td>10%</td></tr> <tr><td>-5 wk</td><td>35%</td></tr> <tr><td>-6 wk</td><td>22%</td></tr> <tr><td>-7 wk</td><td>18%</td></tr> <tr><td>-8 wk</td><td>22%</td></tr> <tr><td>-9 wk</td><td>22%</td></tr> </tbody> </table>	Weeks before implementation	Percentage Error	Order	0%	-1 wk	12%	-2 wk	18%	-3 wk	48%	-4 wk	10%	-5 wk	35%	-6 wk	22%	-7 wk	18%	-8 wk	22%	-9 wk	22%
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Sales Unit	Forecasts on sales package level.	Even for the next week the error is 50 %.	Long planning horizon combined to accurate planning level. Gaming in shortage situations. Optimistic sales plans due to sales bonuses.	<table border="1"> <caption>Sales Unit Planning Error Figures</caption> <thead> <tr> <th>Weeks before implementation</th> <th>Percentage Error</th> </tr> </thead> <tbody> <tr><td>delivery</td><td>0%</td></tr> <tr><td>-1 wk</td><td>52%</td></tr> <tr><td>-2 wk</td><td>38%</td></tr> <tr><td>-3 wk</td><td>48%</td></tr> <tr><td>-4 wk</td><td>42%</td></tr> <tr><td>-5 wk</td><td>48%</td></tr> <tr><td>-6 wk</td><td>38%</td></tr> <tr><td>-7 wk</td><td>35%</td></tr> <tr><td>-8 wk</td><td>30%</td></tr> <tr><td>-9 wk</td><td>38%</td></tr> </tbody> </table>	Weeks before implementation	Percentage Error	delivery	0%	-1 wk	52%	-2 wk	38%	-3 wk	48%	-4 wk	42%	-5 wk	48%	-6 wk	38%	-7 wk	35%	-8 wk	30%	-9 wk	38%
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Regional management and planning	Volume level. Balancing of planned demand and available supply capacity, consisting of own and supplier capacity.	Good, for the whole planning period.	Planning is done on total volume level per product family.	<table border="1"> <caption>Regional management and planning Planning Error Figures</caption> <thead> <tr> <th>Weeks before implementation</th> <th>Percentage Error</th> </tr> </thead> <tbody> <tr><td>Delivery</td><td>0%</td></tr> <tr><td>-1 wk</td><td>10%</td></tr> <tr><td>-2 wk</td><td>15%</td></tr> <tr><td>-3 wk</td><td>15%</td></tr> <tr><td>-4 wk</td><td>20%</td></tr> <tr><td>-5 wk</td><td>15%</td></tr> <tr><td>-6 wk</td><td>15%</td></tr> <tr><td>-7 wk</td><td>20%</td></tr> <tr><td>-8 wk</td><td>18%</td></tr> <tr><td>-9 wk</td><td>18%</td></tr> </tbody> </table>	Weeks before implementation	Percentage Error	Delivery	0%	-1 wk	10%	-2 wk	15%	-3 wk	15%	-4 wk	20%	-5 wk	15%	-6 wk	15%	-7 wk	20%	-8 wk	18%	-9 wk	18%
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OEM plant	Volume and product mix level.	In assembly good (in picture) Planning quality is worse in previous production phases.	OEM fulfils own production capacity first and CEMs are used to level demand peaks.	<table border="1"> <caption>OEM plant Planning Error Figures</caption> <thead> <tr> <th>Weeks before implementation</th> <th>Percentage Error</th> </tr> </thead> <tbody> <tr><td>shipment</td><td>0%</td></tr> <tr><td>-1 wk</td><td>18%</td></tr> <tr><td>-2 wk</td><td>18%</td></tr> <tr><td>-3 wk</td><td>18%</td></tr> <tr><td>-4 wk</td><td>18%</td></tr> <tr><td>-5 wk</td><td>12%</td></tr> <tr><td>-6 wk</td><td>18%</td></tr> <tr><td>-7 wk</td><td>18%</td></tr> <tr><td>-8 wk</td><td>35%</td></tr> <tr><td>-9 wk</td><td>35%</td></tr> </tbody> </table>	Weeks before implementation	Percentage Error	shipment	0%	-1 wk	18%	-2 wk	18%	-3 wk	18%	-4 wk	18%	-5 wk	12%	-6 wk	18%	-7 wk	18%	-8 wk	35%	-9 wk	35%
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CEM supplier, 1st tier suppliers	Receives plans on material code or component level.	Planning is very inaccurate, even for the next week error is over 70 %.	Accurate forecasting level and long planning horizon due to long lead times of some components. Plant changes close to production.	<table border="1"> <caption>CEM supplier, 1st tier suppliers Planning Error Figures</caption> <thead> <tr> <th>Weeks before implementation</th> <th>Percentage Error</th> </tr> </thead> <tbody> <tr><td>delivery</td><td>0%</td></tr> <tr><td>current</td><td>72%</td></tr> <tr><td>-1 wk</td><td>72%</td></tr> <tr><td>-2 wk</td><td>82%</td></tr> <tr><td>-3 wk</td><td>100%</td></tr> <tr><td>-4 wk</td><td>100%</td></tr> <tr><td>-5 wk</td><td>100%</td></tr> <tr><td>-6 wk</td><td>100%</td></tr> <tr><td>-7 wk</td><td>100%</td></tr> <tr><td>-8 wk</td><td>42%</td></tr> </tbody> </table>	Weeks before implementation	Percentage Error	delivery	0%	current	72%	-1 wk	72%	-2 wk	82%	-3 wk	100%	-4 wk	100%	-5 wk	100%	-6 wk	100%	-7 wk	100%	-8 wk	42%
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2nd tier supplier	Receives long-term volume plans and short-term plans on component or material code level.	Planning accuracy is good for materials (in picture), but for variable materials worse.	Long raw material lead times require long planning horizon. Time delay in planning process: plans are based on 3-4 weeks old demand.	<table border="1"> <caption>2nd tier supplier Planning Error Figures</caption> <thead> <tr> <th>Weeks before implementation</th> <th>Percentage Error</th> </tr> </thead> <tbody> <tr><td>component</td><td>0%</td></tr> <tr><td>current</td><td>18%</td></tr> <tr><td>-1 wk</td><td>32%</td></tr> <tr><td>-2 wk</td><td>12%</td></tr> <tr><td>-3 wk</td><td>18%</td></tr> <tr><td>-4 wk</td><td>22%</td></tr> <tr><td>-5 wk</td><td>42%</td></tr> <tr><td>-6 wk</td><td>38%</td></tr> <tr><td>-7 wk</td><td>42%</td></tr> <tr><td>-8 wk</td><td>38%</td></tr> </tbody> </table>	Weeks before implementation	Percentage Error	component	0%	current	18%	-1 wk	32%	-2 wk	12%	-3 wk	18%	-4 wk	22%	-5 wk	42%	-6 wk	38%	-7 wk	42%	-8 wk	38%
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Table 2. Summary of planning quality in each network echelon.

The final assembly at the OEM plant is produced against customer orders and market areas. The OEM's strategy is to utilize as well as possible its own plants' capacity and buy extra capacity from contract manufacturers. This can also be seen in the planning accuracy of one OEM plant. The quality of plans is reasonably good, the forecasting error being between ten to twenty percent for the coming weeks.

Communication of the demand plan to the suppliers is based on monthly and weekly demand forecasts. The monthly demand forecast timeframe is the next 1.5 years and it drives suppliers' capacity planning. The weekly forecast timeframe is the next 18 weeks and it drives suppliers' production and material planning. The monthly plan is on the product family level, and the weekly plan is on component level. The planning error at the contract manufacturer is over 70 % for the next week and for third to seventh week it is far over 100 %. This describes how the CEM continuously reserves capacity for a very unsure demand.

In this study, we studied one supplier who supplies variant material to the OEM as the first tier supplier, but who also supplies non-variant material as an OEM's second tier supplier. As the variant material supplier, the supplier continuously faces approximately 40 % planning error. As the raw material lead-times for variant material are quite long, possibly months, the low planning accuracy sets challenges for the operations upstream in the demand supply network.

In Figure 6 we combine the above results of planning accuracy. This figure shows, which parties in the network receive the most uncertainty in the network. In the figure, the planning accuracy of one unit at each network echelon, that is one customer, one sales unit, one region, one OEM plant, one CEM plant and one supplier are presented. The results concern one product. The swings we show in the Figure 6 locate the echelons where the degree of uncertainty in the network is at its greatest and where the most flexibility is required.

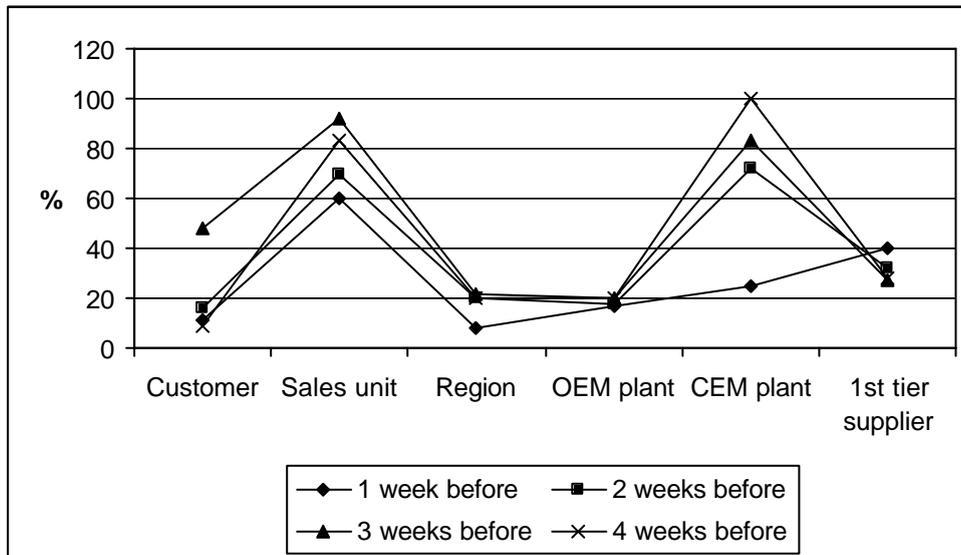


Figure 6. Short-term planning errors in different echelons in the demand supply network. The lines show the difference between execution and plans made 1, 2, 3, and 4 weeks before execution.

The planning quality differs depending on the demand supply network parties. In general, best planning quality is reached at the roughest plan in the regional level, where the planning error is only a few percents at its best. This plan contains volumes per each product family and it is generated from sales unit plans and supply constraints. The planning quality drops at each end of the demand supply network. Sales unit planning is carried out on the most detailed level, on product variant level. The sales unit's demand planning error is for the case product approximately 50 %.

There are two issues that cause extra nervousness in the suppliers' operations. One is change of production batches from one plant to another for products that can be manufactured at several plants. These changes are made at the OEM's regional planning and they can be done very near to the actual demand date. The aim of these changes is to optimize the use of production capacity, but, however,

they cause many problems in the network. For example, the OEM may face timetable difficulties due to longer transportation times, or difficulties in availability of components. In some cases the variant material suppliers may be different for different OEM plants and thus plant allocation changes cause high demand fluctuating by such suppliers.

The second issue is that the present communication method of demand in the vendor managed inventory (VMI) model causes demand fluctuation by suppliers. This will be discussed in more detail below.

Stabilising decision making in vendor managed inventory -model

One reason for the demand amplification in the case supply chain is hidden in the vendor managed inventory (VMI) model between the OEM and suppliers. VMI means the mode of a supplier-customer relationship, where the supplier has access to the demand data of the customer, typically to inventory level or inventory movement information and the supplier's responsibility is to replenish the customer's inventory based on this shared information according to its own timetables [43]. This mode of operation eliminates one decision-making point and one level of information distortion from the process. The supplier has got access to the information earlier and wins a time benefit to be used in production planning and scheduling [44].

VMI reduces the bullwhip effect since it can totally eliminate two groups of reasons for bullwhip: the ones caused by ordering cycles, economic order quantities and time delays in ordering (the Burbidge effect) and gaming and overordering to ensure availability in shortage situations (Houlihan effect). It also proved to be possible to reduce the other sources of bullwhip and especially concerning the operations concerning low-volume products and high-volume products [45], [46].

In the case VMI model, the OEM defines the minimum and maximum inventory levels of the components, and the suppliers are responsible to keep the inventory between those target levels. The minimum level for inventory is equivalent to the next week's planned demand volume, and the maximum level is equivalent to the next two weeks' planned demand volume. The minimum and maximum target levels are updated each time a demand forecast is sent to suppliers, which at the moment is weekly. This causes that the target inventory levels change from week to week or even more frequently. The swings caused by this calculation method are large as can be seen in the example in Figure 7. The changes are increased in power by the used calculation units: inventory levels are counted in days of supply (DOS) based on current demand. If demand rises, the required inventory level rises even more, because the rise is counted in DOS. However, the suppliers do not supply DOS, they supply items counted in pieces.

The problems are emphasized in new product introduction phases. When the demand rises as a new product is brought to markets, the inventory levels for VMI components rise as well. The VMI-supplier has to use available production capacity to respond to demand changes, and to fill up the required rise in inventories. In product introduction, when capacity may be in short, this is misuse of resources.

The target inventory levels are expressed as minimum and maximum figures and the inventory should be kept in between. However, some suppliers have considered the minimum inventory figure as production target and the range between minimum and maximum figures is not utilized to smooth the production quantities. This interpretation is one additional source of demand fluctuation.

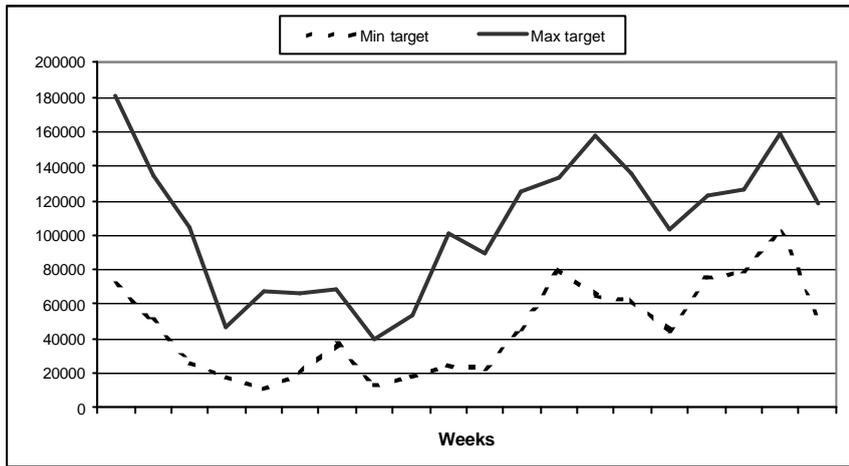


Figure 7. An example of VMI target inventory levels communicated to a supplier by the OEM. Continuously changing target figures cause fluctuation in production quantities.

The purpose of vendor-managed inventory (VMI) is to reduce one step causing fluctuation in the supply chain. Instead of batching demand into orders, the customer allows the supplier to observe the demand, for example consumption, sales or inventory level, and base replenishment decisions on it. The supplier can decide both on the timing and size of deliveries.

In the case supply chain, it seems that the VMI does not smooth the workload experienced by the supplier. On the contrary, an additional decision making step is realized, and furthermore, the calculation logic strengthens the swings in the information flow. In addition, the supplier does not have any further visibility over the target inventory figures.

The logic underpinning the current calculation impacts several ways on the performance of the VMI-supplier. Undoubtedly, it strengthens demand fluctuation amplification towards the supplier, i.e. it increases the bullwhip effect. In addition, it affects manufacturer's performance in ensuring materials availability and also the upstream costs.

A new model for communicating the demand to the VMI suppliers is proposed, with the following rules. First, the inventory should be used to balance demand fluctuations enabling suppliers to level its production quantities and at the same time maintain materials availability. Second, inventory target levels should be updated only when there are remarkable changes in demand. If a change in inventory target level is needed, the change is realized slowly by dividing it over several time periods, and only a fraction of the change is realized at each time. Third, in product introductions setting the right target inventory level is especially important, because if a large inventory is required, the limited production capacity is used to fill up the inventory, not to respond to end customer demand. Therefore the maximum target inventory level should be set closer to minimum in product introductions than in the maturity phase. The characteristics of the proposed model compared to the current model are presented in Table 3.

Current	To-be
Inventory min-max logic creates more fluctuation to suppliers than actual customer orders	Inventory is used to stabilize demand fluctuations
Target inventory level is changed continuously.	Target inventory level is changed only if a remarkable change in demand occurs. Change is divided slowly.
Supplier is asked to keep close to minimum (or maximum) target level.	Supplier can balance production volumes by letting the inventory fluctuate between minimum and maximum target levels.
OEM owns inventory	Supplier owns inventory
<p>Supplier production when target is to keep inventory level stable</p> <p>CURRENT</p>	<p>Supplier production when target is to stay between min and max</p> <p>TO-BE</p>

Table 3. Comparison of the current and proposed states of the VMI model.

The new model, however, has some issues that are yet to be solved. Currently, the target inventory levels are approximately 1-2 weeks of inventory. If the inventory levels were reduced to less than a week (e.g. 3-5 days), there would be a need for daily demand information to suppliers so that they can plan their production and shipments. There may also be some issues in from the information system point-of-view; the current systems are scheduled to generate weekly reports and at the same time update the inventory levels. The new model suggests that the inventory targets should be updated only when necessary. As the number of components is large in the SMI model, it is important that the updating of inventory targets is done automatically.

Conclusions

We have studied planning processes across the demand supply network to show that planning quality varies between the echelons in the network. Good planning quality at customer plans could not be maintained in upstream echelons, but it fluctuates from one supply chain party to another. The fluctuations in planning quality are due to varying planning level, delays in information flow, multiple decision making phases in the chain, long planning horizons or lack of planning processes. We called this phenomenon planning nervousness.

It was highlighted that there are many decision making points and planning phases that increase distortion and fluctuation experienced by the parties in the network. The mode of operation in the demand supply network was found out to be very reactive. A lot of effort was put on to plan on a very detailed level in multiple planning phases. Capacity utilization targets are high and this ends up in large changes in plans even at the last moment. These changes cause demand fluctuation in supplier operations in addition to end customer demand changes.

There exists bullwhip in the case supply chain. The connection between planning nervousness and the bullwhip was investigated in detail through a VMI model in the chain. It came clear that planning nervousness causes bullwhip, as the changes in demand were amplified in the used information sharing process in VMI. In product introduction phase, the phenomenon was emphasized, because when demand grew in the beginning of the products' life cycle, the growth was strengthened by the used calculation logic. In this case the target inventory calculation logic in VMI is a source of bullwhip.

To improve the quality of planning and eliminating the nervousness in the planning processes some managerial implications are suggested. The first is to stabilize and simplify the planning processes. Need for frequent detailed planning should be minimized, and the focus could be set on reacting to

exceptions. Especially in the products maturity phase exception-based planning needs to be realized. The short-term changes between plants cause nervousness in the chain. Synchronizing planning calendars with customers and suppliers planning cycles eliminates delays in the process and ensures the use of freshest demand data in planning. One concrete solution is to eliminate manual planning phases between different system plans. All these changes aim to improve the quality of plans.

Second change is to develop the communication practices with suppliers. At present suppliers receive information from different planning phases. Information in different reports may be inconsistent and confusing. The goal, however, should be to provide one set of numbers for suppliers. Depending on the supplier type and operational model, additional visibility information should be provided. Providing for example contract manufacturers qualitative information behind official figures, like reasons for volume changes, management adjustments or the share of uncertain orders in demand helps CEM in capacity planning.

The third improvement affects the vendor-managed inventory (VMI) model. In this model communicating demand to suppliers takes place in the form of target inventory levels. Instead of changing the targets continuously, a solution was proposed to react only to remarkable changes and to smooth the inventory change over time periods. This stabilizes the production quantities by SMI suppliers, because the inventory is used to level the demand, not to increase fluctuation of demand.

In general demand supply planning process will be improved by more efficient and productive use of demand data. Both the channel customers' inventory and sell-through data and point-of-sale data are useful. Currently the channel data covers 70-90 % of the demand on a one-week delay. Increasing visibility to end-customer demand and skilled use of the data improves the performance in the demand supply network. Electronic commerce offers new sources of information for the companies. In addition to historical demand data or information about prices and promotions, the companies have got access to accurate demand information. Other types of information may be information regarding the marketplace, consumers or product life cycles [47]. The difficulty is in choosing the right information and using the information intelligently. This will be the focus of further research.

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