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Synchronizing the Supply Chain: A Practical Application of Multi-Echelon Stock Theory

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1 Background

Mustad is the world leading producer/supplier of fish hooks and fishing tackle. Mustad has facilities for manufacturing, assembly, packing and distribution in seven counties worldwide, including Norway, China, Philippines, USA, Dominican Republic, Brazil and Portugal. Mustad is the leading hook brand world wide, and products are exported to more than 160 countries. Customer requirements are differing within different geographical regions, application type (recreational, sport, industry, sea) and customer type (wholesalers, retailers, OEMs).

Traditionally, the supply chain is characterised by fully decentralised control. Decisions regarding inventory levels and product programs are made independently on each site. Replenishment is by order and based on order-point models or manual control. Production and market forecasts are shared only to a limited degree, and there is an overall lack of coordination across the different SC sites. Mustad's fish hooks have a Y-shaped product variant structure, with very few raw materials (mainly steel wires) and a large number of sizes, shapes, surface treatments and packaging, totalling up to about 12.000 finished product variants. A broad range of product variants is seen as a necessary condition for maintaining Mustad's leading position. Additionally, Mustad is offering trading products of complementary fishing equipment, in order to meet requirements from retail chains that demand single-source supply of a complete range of fishing products. New hooks are introduced to the market frequently, but exclusion of products from product programmes is troublesome as customers require full product series, even though some variants are seldom sold. Together, this has led to a situation where Mustad now has about 20.000 stock keeping units (SKU).

The major production processes at Mustad are machining, hardening, plating, and packing. The hooks are produced in batches, and due to high set-up costs in machining, the minimum production run is approximately 30 000 hooks. For some small volume products, this implies that more than one year of demand may be made in one batch. Finished goods inventories are used as buffer against demand and lead time variations. Inventories of bright hooks (before plating) and bulk hooks (before packing) are used as buffer against production capacity constraints.

The company has been facing major logistics challenges. The total stock turn is low, at about 1.5, meaning that a product is kept in stock for about 35 weeks in average. The lead times in their supply chain are large, with an average manufacturing lead time of 8-12 weeks, and transportation lead times between 1-12 weeks (depending on whether air or sea transport is used). The total number of SKUs in addition to the global localisation of sites makes the SC complexity significant. Certain products can be produced only at certain sites, and there is a large degree of internal transactions and transportation. A mapping of material flows in their supply chain showed a true "spaghetti" structure (see Figure 1).

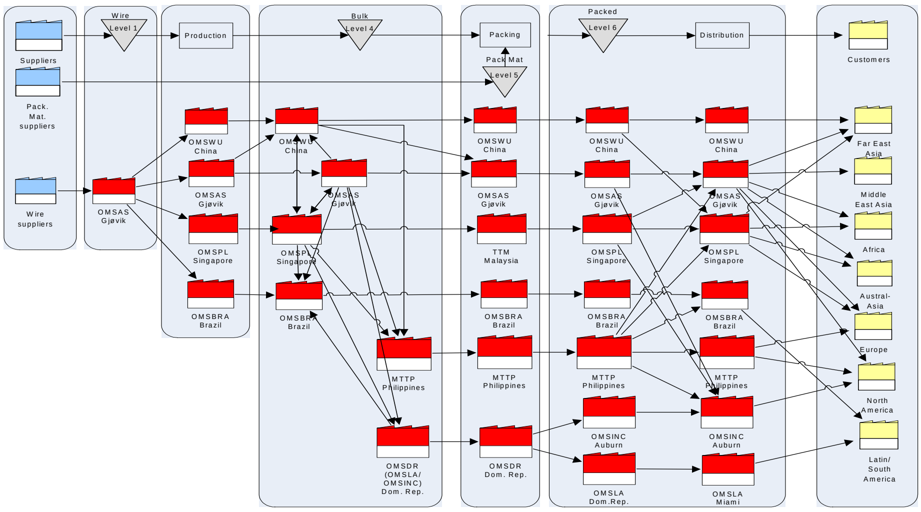

Figure 1 The supply chain structure of Mustad

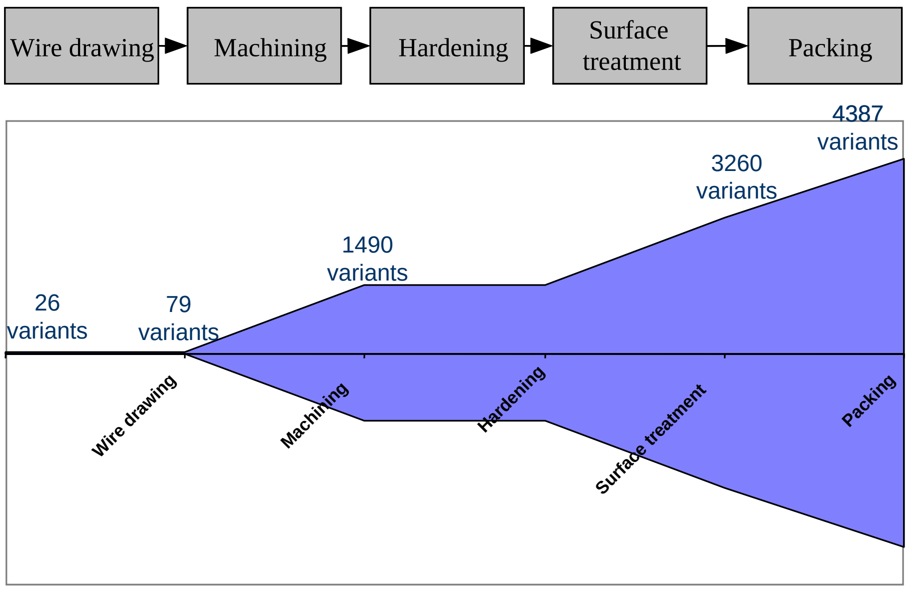

Figure 2 Product variants at Mustad Norway

The company has been trying to reduce the structural complexity by concentrating activity in fewer sites as well as separating non-essential activities in subsidiaries. There are however few plans for large reductions in product variants as this is seen as a prerequisite for keeping their world leading position. The combination of the complex production structure and the many different finished products however shows a true arborescent structure where each stock-point/product has only one predecessor. Mustad intends to use parametric decentralised control for managing finished product stocks, but will manage the supply in a centralised Global Logistics Centre.

This paper describes the new control model for Mustad based on multi echelon stock theory. The control model aims at reducing overall costs of supplying fish hooks and other products in a global setting at the promised predetermined service levels.

The paper is structured with an initial review of literature on the subject of multi echelon inventory control, followed by a description of our control model. The description of the control model touches upon the subject of forming product/stock programmes for the different markets. The main part however concerns achieving synchronized product flows in the supply chain. Finally we discuss our model with respect to alternative approaches.

2 Multi echelon stocks

2.1 State-of-the-art: Multi-echelon

Supply chain management is the handling of materials and information through a supply chain, from suppliers to component producers to final assemblers to distribution and at the end the customers (Silver et al., 1998). To control and plan a supply chain there are two kinds of network structures. The upstream part of the chain is often a *convergent* structure. That means that several components are assembled into one subassembly or finished product (Diks et al., 1996). After the assembly the finished products are placed in a central inventory. Distribution of a finished product from the central inventory to the end-stock point is characterized by a *divergent* structure. The distribution system of the supply chain is what this paper will deal with. In some literature, they use the *serial* structure to show the quantitative analysis (Silver et al., 1998; Axsäter, 2003; Federgruen, 1993), and this structure is the easiest version of the divergent structure.

A *divergent multi-echelon* system is a system where each stock point is supplied by only one stock point and supplies one or more stock points (Diks et al., 1996). There are often a central inventory, called the depot, and N retailers. The end-stock points face a stochastic customer demand. Most literature on the subject handles two-echelon systems (van der Heijden, 1997; Diks and Kok, 1996; van der Heijden, 2000; Barnes-Schuster et al., 2006). The main goal with multi-echelon control is to minimize the total cost for ordering, capital tied up in the supply chain and for not providing customer service (Silver et al, 1998; Axsäter, 2003).

Scope:

Our focus in this research is divergent multi-echelon systems or distribution systems with centralized control. For many multi-echelon systems periodic review with order-up-to is regarded as the most suitable to apply.

Software

There already exist a number of commercial software solutions for multi-echelon inventory optimization (e.g. Optiant, ToolsGroup, i2 Technologies, Manhattan Associates and Logility). Some US companies have implemented these systems with a 20-30 % inventory reduction (AberdeenGroup, 2006). These systems generally focus on reductions in safety stocks irrespective on inventory control policy. As our objective is total cost reductions through application of inventory policy, our focus will not be on these software solutions, but rather on practical application of multi-echelon inventory control.

Research method

In this review, we focus on the previous research within the field of multi-echelon. We limited our selection of articles to divergent multi-echelon systems. Some of the key words that are used are divergent multi-echelon inventory systems, arborescent, distribution system, centralized, periodic review, order-up-to, synchronize and fixed lead time. We reviewed a search using library databases covering the major journals in management science and operations management, such as *European Journal of Operational Research, International Journal of Production Economics, Omega, Logistics of Production and Inventory, Global Logistics & Supply Chain Strategies, Operations Research*, *International Journal of Production Research,* etc. We also searched books in *Handbooks in Operations Research and Management Science* and *Inventory Management and Production Planning Schedule*. The selected articles span from 1993 to 2008.

Table 1 Review of literature of multi-echelon

Author	Topic	Objective
Federgruen, A. (1993)	Distribution systems with and without a central inventory	Discuss planning models for multi-echelon systems which allow for uncertain and non stationary demand and lead time processes.
Axsäter, S. (1993a)	Continuous review policies	Considerate various methods for control of multi-level inventory systems with Poisson demand
Diks et al (1996)	A service measure perspective	Determine service measures like external customer service level and inventory holding costs
Houtum et al (1996)	Materials coordination	Show that multi-echelon models provide an

	problems	excellent tool to control the material flow in large production/distribution chains with focus on applicability
Diks and Kok (1996)	Transhipments	Determine the control parameters so that service levels are attained at the retailers at minimal expected total costs.
Van der Heijden (1997)	Inventory rules for stockless central depot without lot sizing	Improve the control parameters to reduce the inventory imbalance and better approximate the target fill rates
Van der Heijden et al (1997)	Stock allocation rules	Achieve differentiated target customer service levels in situations with and without intermediate stock. Compare a number of practically applicable allocation rules.
Diks and Kok (1998)	Periodically ordering	Minimize the expected holding and penalty costs per period with prove that it is cost optimal to control every facility by an order-up-to-policy
Van der Heijden et al. (1999)	Control parameters like order-up-to-levels and parameters of BS rationing rule	Derive a computational method to obtain the order-up-to level and the allocation fractions required to get the given target fill rates.
Van der Heijden (2000)	Cost-optimal inventory control policies	Minimize the total holding costs with calculations of control parameters and stock levels
Chen et al (2002)	Uniform distribution of inventory positions	To show that each location's inventory positions are stationary and the stationary distribution is uniform and independent of any other's.
Abdul-Jalbar et al (2003)	Policies with common and different replenishment times	Determining the optimal reorder policy which minimizes the overall cost, which means, the sum of the holding and replenishment costs
Minner (2003)	Multiple supply options	Show multiple supply options with strategic aspects of supplier competition, and inventory problems in reverse logistics and multi-echelon systems
Barnes-Schuster, D. et al. (2006)	Allocation of the system inventory	Determine the optimal delivery lead time and the resulting location of the inventory system
Xiaoming and Sridharan (2008)	Order processes with (R,nQ)	Provide a convenient way to construct inventory control policies for upstream suppliers

Most of the literature with respect to multi-echelon control concerns subjects like divergent, centralized, periodic review multi-echelon systems and lot sizing within these supply chains.

Graves and Willems (2003) focus on safety stock placement in the design of a supply chain, and the optimal configuration of the supply chain to minimize total supply chain costs. However, in most of the reviewed multi-echelon literature, the authors assume a given product structure, with only one product. In the real world situations, the supply chain design and the inventory allocation need to be specified before the inventory policy is determined.

There are mainly two different order policies discussed, continuous and periodic reviews (Axsäter, 2003). When the inventory system is continuous controlled so that actions can be made at any time, we have a *continuous review* inventory system. A continuous review system is, in general, slightly more efficient but more expensive to operate. A *periodic review* inventory system is only reviewed periodically. This is preferable for items with high demand, and suitable if we want to coordinate orders for different items to get smooth capacity utilization. By using a periodic review system with a relatively long review period we can force the system to order in batches while still avoiding to use more complex batch ordering policy (Axsäter, 2003).

Most authors discussing periodic review also assumes an *order-up-to* (R, s, S) policy (Diks et al, 1996; Axsäter, 2003; Federgruen, 1993; Diks and Kok, 1998; Heijden, 2000; Chen et al, 2002). At every R time the inventory is inspected, and the orders are placed so that the stock level equals inventory level S.

In a multi-echelon system where the inventory and the retailers belong to the same firm we have centralization. In this case, the firm can try to minimize the costs for the total of the distribution system, instead of having each retailer minimizing its own costs independently (Abdul-Jalbar et al., 2003). Since the firm will make decisions about the stock for the whole chain, it can also force the retailers to order with the same intervals so that the orders get synchronized but improved efficiency through coordination of ordering across echelons is poorly or not covered at all. Heijden et al (1999) mention *synchronization* of the replenishment timing, but the most common assumptions are either ordering at fixed intervals based on calculated order-up-to levels or that intermediate points in the supply chain should hold little or no stock.

To decide the size of batches that should be used, some authors say that EOQ can give a recommendation. When using lot sizing, there will be different cost factors. As mentioned above, the goal of multi-echelon is to *minimize the total costs* incurred when handling the inventory control. Between the parts in the supply chain there can be set up costs, ordering costs, handling costs, capital tied up, and costs associated with not delivering the target service level (Diks et al., 1996). Diks and Kok (1998) and Heijden (2000) focus on holding and penalty costs. Diks et al. (1996) and Federgruen (1993) considerate the costs associated with handling the different batches, the ordering or the set up costs.

Most of the literature mentioned above handle the topics; divergent, centralized, periodic multi-echelon systems with lot sizing. Each author covers a part of the problem targeted in the Mustad case, but none targets all the aspects. Although some models only allows stocks at the endpoints or in the beginning of the supply chain and others propose a order-up-to policy for all stockpoints, we have not seen a discussion of under what conditions intermediate stocks are necessary and where they can be avoided, except for in Axsäter (2003).

A much discussed topic in multi-echelon inventory control is how to decide *inventory allocation* in cases of where inventory position will not cover all incoming orders. Heijden et al. (1997) give instructions of how to handle multi-echelon distribution systems when there is not enough stock in inventory. In Diks et al. (1996) they use transshipments to reduce the safety stock. Other authors that consider the stock levels and the allocation problem are Diks and Kok (1998), Heijden (2000) and Heijden (1997). Barnes-Schuster et al. (2006) optimize delivery lead time and the location of the system inventory. They conclude that the supplier holds inventory for the buyers with the smallest standard deviations, while the buyers with the largest standard deviation hold their own inventory. Heijden (2000) has developed a procedure to determine stock levels. It says that significant stocks at intermediate stock points are only useful if unit holding costs in these stock points are considerably less than in the end stock points that deliver directly to the final customer. Heijden et al. (1999) give an algorithm for practical applications where the intermediate depots do not carry stocks and are only used as allocation points.

Since we want to apply the multi-echelon system to a practical example, we have tried to find *practical applications* of multi-echelon systems. The only applications we can find are numerical experiments and simulations like Van der Heijden (2000), Van der Heijden (1999), Van der Heijden (1997) and Abdul-Jalbar et al. (2003). Application and the practical aspects of e.g. capacity planning, is poorly or not covered at all.

There is done a lot of research in the field of multi-echelon. But we see a need to try out the developed research on some practical examples. None of the authors cover all the areas we want to include in our control model. In our view there need to be more focus on synchronization of the orders between the parts in the supply chain, to minimize the ordering and set up costs. With synchronization of orders from the retailers, the central production unit may only need to produce a single batch for many retailer/product combinations. By introducing the same tact in the supply chain, the centralized divergent multi-echelon inventory system's stocks may be reduced both with respect to safety stocks and cycle stocks. In total, simpler applicability rules are needed to make inventory allocation easier.

In the next sections we will describe the case of Mustad, and how multi-echelon concepts can be used to synchronize the supply chain.

3 The case – O. Mustad AS

The proposal for inventory policy in Mustad concerns both the structure of product inventories and the control model for these inventories. The case is therefore described first in terms of designing the supply chain and then with respect to supply chain planning and control. The first aspect of this proposal is generally missing in the multi-echelon literature which normally is restricted to single product control mechanisms.

3.1 Designing the supply chain

The Mustad supply chain exhibits a true arborescent structure. Both the Y-shaped variant structure and the market channels display this property. There are no converging or assembly-like activities in the Mustad parts of the value chain. Thus the Mustad supply chain may be viewed as a distribution system with respect to control strategy.

Mustad's products are marketed worldwide in four different ways. Retail customers mainly in North America and northern Europe are offered quick delivery of hooks and fishing gear in consumer packs. Mustad allows 48 hrs for order processing and packing for these orders. Wholesale customers are offered a wider range of products with order lead times of typically 1 month. Fishing industry and some wholesalers prefer time planned orders which will be delivered on a specific date. Finally hooks are also sold to equipment makers in a spot market fashion.

The major considerations in designing the Mustad supply chain have been that the product programmes offered in the different markets should be predictable both in terms of products and lead times. Retail customers demand quick delivery with a high level of precision and thus imply delivery from stocks of finished products. Production, inventory and transportation activities are all controlled based on this strategy due to the characteristics of the products, production and the global structure of the SC (Fisher 1997). Other customers however are supplied from distribution centres within a month, thus leaving some flexibility in the choice of mode of supply.

The proposed supply chain has been designed to meet the requirements for all these markets. The supply chain will be differentiated according to customer requirements and characteristics of the different supply processes. The different possible customer decoupling points are shown in the figure below (fig 3).

A major proportion of customer orders are time planned orders with typical lead time of more than 3 months which more or less imply a make-to-order control strategy. The Mustad supply chain contains two obvious decoupling points for serviceable in a make-to-order type strategy; bright hooks before plating and bulk hooks before packing. For the most important distribution centres, finished product stocks, plating and packing facilities are either collocated or located within short transport lead time. The uses of postponement techniques (plate-to-order or pack-to order) are thereby possible for all orders except 48 hrs delivery.

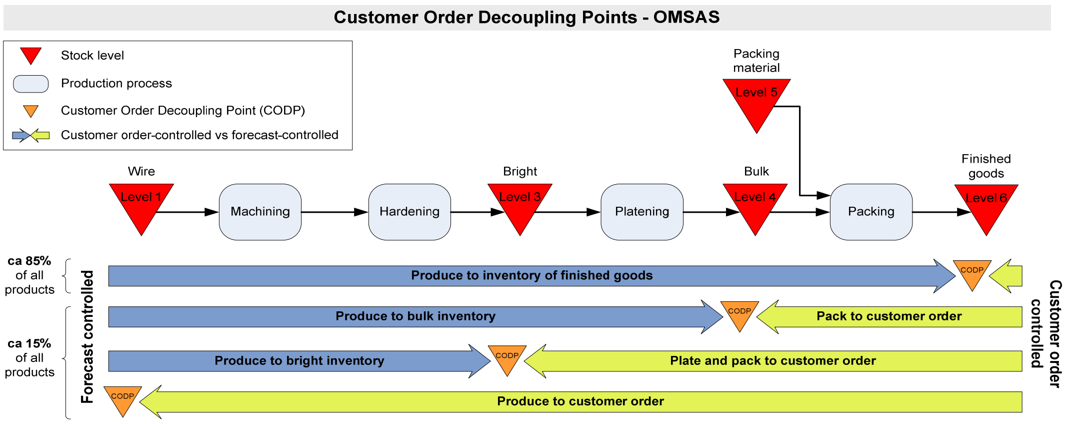

Figure 3 Mustad's supply chain and decoupling points

Stock programmes for each of the distribution centres are worked out based on considerations of historic/expectations of sales value, order frequency and demand variability/ predictability (ABC methodology). High value/high frequency items are directly included in the stock programme and low value/low frequency items are considered candidates for exclusion. High value/low frequency products are candidates for supply by postponement (pack-to-order or plate-to-order), but may also be kept in stock depending on the variability/predictability of demand. In addition supply may come from a centralised finished product stock by the use of airfreight. Low value/high frequency products are costly to keep in stock, but may be important in filling out a range of products. The use of postponement techniques are therefore considered also for these items. High frequency prohibits the use of airfreight in most of these cases.

The product programmes for each of the distribution centres are thereby worked out based on history/predictions of demand and considerations of the cost of supply. For each product in the product programmes, the mode of supply (MTS/MTO) as well as costs is considered before deciding the stock programmes. A fairly straight forward cost model has been established for this purpose. Determining the product programmes is therefore seen as joint responsibilities of the GLC and local sales units. Inventory position programmes (stock programmes) are revised yearly.

With a fixed product/inventory structure established in this way, we turned to the proposal for control model.

3.2 Supply chain planning and control

The objective for the control model is to establish control of the supply chain in the most efficient way. In the Mustad case this is interpreted as establishing control that provide customers with products at a predetermined service level with the least amount of costs incurred in the supply chain. In addition to production costs the major cost elements in the supply chain are set-up or order costs, transportation costs and costs for keeping inventories.

The set-up costs for the machining processes represent the largest costs in the supply chain. Although there exist set up costs and other batch oriented costs for later activities in the supply chain, the contribution of these elements towards total finished product costs are on a different magnitude than the machining set up costs. The lot sizing problem in the supply chain has therefore been simplified by assuming that lot sizes determined from the machining activities also are close to optimal for the supply chain seen as a whole.

In a serial system stocks should be kept either at the beginning or the end of the supply chain (Axsäter 2003). In most cases the differences in holding costs between different steps would not be sufficient to prescribe stocks at the start of the chain. The lot sizes determined for the machining activities as we have proposed for the Mustad supply chain would thus also determine replenishment intervals for the serial system. In a distribution or arborescent system like the Mustad supply chain the placing of stocks is generally not so straight forward.

The advantage of keeping stocks at an earlier point in the supply chain is connected to the opportunity to redistribute quantities among the descendants. In other words the advantage is connected to the size of safety stocks. In addition holding costs are usually somewhat higher towards the end of the supply chain. On the other hand more frequent resupply of finished products stocks implies higher order and transportation costs. In terms of replenishment intervals a case could be made for shortening replenishment intervals by keeping stocks at one level if the cost reductions due to reduced safety stocks and the general holding costs are greater than the increase in order/transportation costs. Generally this is found when the number of descendants increase.

In the Mustad supply chain there are no dramatic increases in product value and thereby dramatically increased holding cost towards the end of the supply chain. The products are usually shipped together in less than full load shipments. The order and transportation costs of an extra shipment are thereby quite high given the global nature of Mustad's operations. We have therefore found that stocks should be kept at the end of the supply chain except when the intervals between production cycles are so large that the necessary safety stocks become too large. "Too large" in this setting we define as large compared to the necessary safety stocks due to physical lead times, i.e. large compared to safety stocks in a continuous review system. In such cases we suggest storing part of the production batch as bright hooks, that is in the beginning of the supply chain.

In cases where a mid echelon stock has many direct descendants one could argue that overall inventory could be reduced by keeping stocks at the parent node. So far we have not found any such cases in the Mustad supply chain where the differences in costs are significant. We have therefore kept the simpler model where stocks are either kept at the beginning or the end of the supply chain. The control model is at present being implemented and we have so far only examined examples of product structures. In the future we might have to adjust the model for stocks at other levels.

In our discussion of value chain structure we propose high value/low frequency and low value/high frequency items as candidates for pack-to-order or plate-and-pack-to-order control. With respect to the value chain structure the necessary stocks to implement these policies are considered a special case of finished product stock even when they coincide with higher echelon stocks. In other words, the stocks that are kept for make-to-order purposes should conceptually be considered separate from stocks that are kept for replenishing other finished product stocks. Thus the supply chain closely resembles the system described by Van der Heijden et al (1997).

Demand is aggregated according to product and supply chain structure. In other words, we aggregate demand forecasts for all products containing the same basic hook over all markets/finished product stocks where these products are sold. Batch size is determined with respect to the machining activities. Bach sizes translate to replenishment intervals for the whole supply chain.

All finished products stocks will employ a periodic review order-up-to control policy for their stocks. This technique gives predictable intervals between replenishments and varying amounts. Order-up-to levels will be worked out centralized based on local forecasts of demand, historic performance of these forecasts and corresponding to the production cycle for the basic bright hook. This way each of the finished products inventories will be submitting replenishment orders to the appropriate intermediate activity/stock at predictable times.

Most authors also calculate order-up-to levels for up-stream stocks. The product flows at these stock-points are however of a deterministic nature when viewed within the timeframe of one replenishment cycle. There are no variations in inflow or outflow introduced at these levels. Stocks at these up-stream stock-points serve to buffer against variations due to the time lag between the inflow of previously ordered replenishments and the ordered outflow to downstream sites. Thus the necessary stock levels at intermediate stock-points are in our view closely related the lead time between stock points. Random lead times will thus as is pointed out by Heijden et al (1999) increase the necessary buffer/safety stocks at intermediate points.

The underlying principle of the Mustad control model corresponds to the lean concept of “Tact”. By synchronizing the replenishment orders with the inflow of intermediate products at the intermediate stock-points, the necessary stock level at these points are kept at a minimum. In our view only a buffer against variations in the ordered amount needs to be kept at these intermediate stocks. Cycle stocks are then eliminated for all inventories except finished products stocks. For some products stocks of bright hooks will be kept when batch sizes and reasonable replenishment intervals doesn’t correspond. The resupply intervals will then be governed by the power of two rule where stock-point are allowed to order only at 2^n multiples of the basic replenishment intervals. In practice this synchronization will be achieved by strictly adhering to defined lead times. All deliveries must be made within the specified time. As it is conceptually easier we have decided upon fixed lead times rather than keeping stocks in the supply chain to accommodate variations in lead times.

All finished product stocks replenished from the same stock-point point must place their orders for all products made from the same bright hook at the same time. In the same fashion parallel intermediate points must place their orders for the corresponding intermediate products at the same time. This means that stocks with different lead times will be at different points in the replenishment cycle, but all intermediate and finished products from the same bright hook will have the same interval between replenishments. For each product family (same basic bright hook) we thereby set up an ordering schedule for each stock-point, but where order intervals for that family is the same throughout the supply chain. This we find to resemble the lean concept of “Tact”.

With a buffer against variations in outflow the upstream stock-points, these stocks need only order a new amount equal to the outflow. In other words the replenishment orders from the finished product stocks may travel more or less instantly to all stock points in the supply chain. The buffer stocks at each stock-point may therefore only relate to the lead time to the previous stock point and the combined variation in the number of replenishment cycles this lead time imply.

The predictability in terms of when production will take place in all activities in the supply chain gives an added benefit for capacity planning. As the whole supply chain will behave in a predictable way with respect to time, the production of the different products/different product families may be scheduled to even out capacity utilization. Capacity utilization can then be planned with buffers against the possible variations in ordered amounts and buffers against conditions that would normally give lead time variations. A complete production schedule may be worked out allowing for variations in the demanded amounts. The proposal is summarised below:

Proposed supply chain design

- *Stock programs:* Product programmes for each market as well as stock programs aimed at delivering the promised service level are worked out for all markets/finished product stocks. The use of postponement techniques for some products/markets is seen as a special case of finished product stocks.

- *Predefined supply chains*: The supply chain for each product at each stock-point is determined uniquely.
- *Product families*: Products are sorted in product families/groups having common predecessors/intermediate products. Products sharing the same basic bright hook are grouped.

Proposed control model

- *Aggregated forecasts*: Locally forecasted demand is aggregated according to product and supply chain structure. This way the aggregated demand for bright hooks reflects the demand for all descendants.
- *Replenishment intervals:* All stock points have the same replenishment interval. Batch sizes for production of bright hooks are determined using EOQ methodology for the machining activities at the most upstream level in the supply chain. Thereby the basic replenishment interval for all stock points is worked out.
- *Order-up-to policies*: Order-up-to or base stock levels are worked out for all finished product stocks based on these same replenishment intervals. In cases where the replenishment intervals correspond poorly to the local demand modifications of the intervals are allowed using either 2^n multiples of the basic resupply rate or 2^n fraction of the basic interval. The last case implies cycle stocks to be held at an upstream level in the supply chain.

- *Synchronized replenishment orders*: Order times are worked out so that all orders for products in the same family/group from all downstream sites arrive at the same time. With different lead times this means that different sites will submit orders at different points in their order cycle, but the length of the cycle will be the same (with the before mentioned modifications)
- *Flow*: Orders for resupply from descendant stock points should arrive at the same time as the replenishment order from a previous period from an upstream site. This way the intermediate stock points need only carry stocks sufficient to cover variations in total ordered amount between replenishment cycles.
- *Capacity levelling:* With fixed lead times and fixed order cycles for all stock points the capacity can be levelled by an aggregated scheduling of product families.

4 Discussion and conclusion

As mentioned earlier the described control model for O. Mustad AS is in the process of being implemented. We thus have no practical experience on how it has performed. We as consultants to O. Mustad AS, were however able to convince them to try this model for several reasons.

First of all a traditional periodic or continuous review system where ordering is not coordinated imply large cycle stocks at all stock-points. Due to the global nature of Mustad's operations, lead times for replenishment of stocks between stock-points are often quite high, up to 10 – 12 weeks in some cases. Stocks would thereby be large which is consistent with Mustad's experience up to now.

Products are produced in China and Norway and shipped out in bulk for packing elsewhere. Even so the order costs and lead times related to transport are often more connected to the size of the shipment than to the singular product. A clear advantage in having predictable order intervals for coordinating transports was thus obvious. We therefore looked into opportunities in using an order-up-to system.

The situation with uncertain demand but predictable order intervals and predictable lead times combined with our experience in designing control models for industry gave the inspiration for looking at possibilities for synchronization of product flows. Our decision to use batch sizes adapted only to the first activity in the supply chain as the "pace-setter" for the replenishment cycles of the entire supply chain is of course a large simplification. Most theoretically oriented development in the field of multi echelon stocks try to account for all order/set-up costs in determining lot sizes/order-up-to levels.

Secondly we have found that there exist several alternatives to the control model we have developed. In other words there exists fall-back opportunities for Mustad if the developed model should in some sense prove inadequate. One such opportunity has already been tested. In 2007 a small scale problem was tested using consultants and software from Optiant. This test delivered on the promise of reducing safety stocks at up-stream stock-points and is considered an alternative if the proposed control model doesn't work out. Reductions of necessary safety stocks were in the range of 25 - 50% which has also been reported by other authors (Graves and Willems (2003))

Some authors propose supply chains where no stocks should be kept at upstream levels. This assumption is usually combined with a study into allocation rules when available supply does not meet ordered replenishments. Van der Heijden (1997) relaxes this assumption by allowing all stock-points to hold stocks and examines the effects of different allocation rules for both a two echelons and N–echelons system. In both cases all stocks are to be controlled by an order-up-to policy. In Heijden et al (1999) this is further developed into algorithms for controlling a multi echelon divergent system with random lead times. Abdul-Jalbar (2003) takes a different approach by first assuming that all retailers (endpoints) order at the same time and then relaxing that assumption. In both cases optimal order quantities are worked out. In other words there exist developed alternatives to our model that closely resembles the Mustad supply chain and where the necessary mathematics for controlling the supply chain has been developed.

We, on the other hand, believe that deterministic nature of the up-stream resupply problem once the finished products stocks have made their replenishment orders, gives added opportunities for stock reductions. We believe that our control model will almost eliminate cycle stock at upstream stock points, leaving only a small buffer in the form of a safety stock. Application of the power-of-two policies described by Roundy (1985) gives some flexibility in determining order times and replenishment for the individual finished product stocks. By fixing the times when the stock-points are allowed to make orders, the possible scheduling of capacity utilization gives an added advantage in a multi-product divergent system. Our work however, has been in practical application rather than theoretical development. Mathematical proofs of our claims are therefore non-existing.

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