Analysis of the Order Penetration Point Alternatives in the Nordic Paper Industry Supply Chains

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Abstract

The paper analyses the order penetration point alternatives under various situational variables in the Nordic paper industry setting. The analysis is carried out as a factorial experimental design on a simulation model constructed for the purpose. Order data from seven cases and previous research are used to arrive at meaningful factor values. The situational variables are found to affect the inventory vrs. delivery time trade-offs and with some situational variable values choice OP3 is not pareto-optimal in comparison to OP2.

Keywords

Paper industry, Logistics, Order Penetration, Simulation.

1. INTRODUCTION

The Nordic paper producers are located far away from their main markets in Central Europe and UK. Traditionally the delivery time disadvantage to local competition has been compensated by holding large customer specific call-off

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stock at various port terminals at or near the markets. There are several studies that give evidence of operational slowness in Nordic paper industry (Hameri & Holmström, 1997, Lehtonen, 1995, Holmström, 1995). However, the ideas of Just-in-time paradigm to speed up the supply chain like reducing lot sizes and cutting inventories may not be readily applied in the paper industry setting.

One key decision variable in the supply chain is order penetration point. Sherman (1984) defines the concept of order penetration (OP) point as being a point in the logistical chain at which a product is assigned to the specific, known customer.

According to Mertens and Houben (1996) there are four different possible OP-points, or which they call decoupling stocks, in the paper production process. These OP-point choices are shown in figure 1.

Figure 1 Possibilities for decoupling stock in the paper production process (Martens and Houben, 1996).

Order penetration points and their advantages are (Mertens & Houben, 1996)

- Make-to-order production with long and difficult to control delivery times due to paper machine (PM) cycle and finishing lead time. Low amount of stock.
- From PM onwards production to order. Drawbacks are difficult storage due large jumbo reel size and slow quality feedback. Also due to the large size of a jumbo reel, small orders are hard to make both fast and economically.
- Decoupling stock of winder reels. Fast service can be provided up to 2 days or less. The drawback, in addition to the stock itself, is the possible increase in winder and sheeter trim loss.
- Decoupling stock of sheets on pallets. The advantage is a very short delivery time. The disadvantage is that many different sheet sizes, ream heights and wrapping papers make the required inventory investment large.

However, this classification does not take into account a possibly large lead time from the mill to the markets which is the situation in the Nordic paper industry. In the Nordic situation, sheeting can be located either at the mill or locally at the markets. This also applies to finished sheets inventory.

2. OBJECTIVE OF THE PAPER

According to Sherman (1984), each product design has its optimum OP-point that depends on the balance of competitive pressures in the chain, product cost, product complexity and target customer segment requirements.

The objective of the paper is to analyse the order penetration point alternatives under various situational variables in the Nordic paper industry setting. The analysis attempts to establish delivery time and inventory trade-offs that can be achieved with each OP-point choice under different situational factors.

The analysis is constrained to include only paper products that are delivered to the customer as sheets. The analysis is further restricted to three OP-point alternatives that are

- delivery from the PM (OP1)
- delivery from intermediate reel inventory at the mill (OP2)
- delivery from local sheeting units (OP3).

These alternatives can be thought to correspond to the situation in practice where a large number of customer specific sheet dimensions and wrappings force sheeting to order.

3. RESEARCH METHOD

The research method for studying the OP-point choice in the Nordic paper industry supply chain is discrete event simulation modelling. A model of paper industry supply chain is constructed for each OP-point alternative.

A two-factor experimental design is used for analysing the supply chain model. The relevance of a two level factorial design hinges on the ability to select realistic factor levels. In this paper special emphasis is put to factor level selection. For this purpose, real order data samples from six Nordic and European case mills that produce sheeted paper is used. Table 1 presents the case sample.

Table 1 Case summary

Case	Case1	Case2	Case3	Case4	Case5	Case6	Case7
Number of sheet orders	1267	1553	5789	8346	4406	5158	1087
Number of weekdays	142	127	37	38	118	119	-
Number of grades	159	496	52	67	26	27	-

A previous research by Lehtonen (1996) is used for defining the model structure as well as determining relevant values for those situational factors that do not arise from incoming orders.

4. THE MODEL

The structure of the simulation model and logic are explained 4.1. The situational variables are listed in 4.2. In 4.3 the case order data is presented. This data is then utilised to arrive at meaningful choices for situational factor levels. In the end of 4.3 the factor values are listed. The performance measures applied for evaluating the OP-choices are in 4.4 and the experimental design is documented in 4.5.

4.1 Model Structure and Control Logic

The simulation model cannot be completely documented in a short article. However, the essential elements and control logic is explained in the following.

The PM production is modelled as consisting of consecutive cycles. All the grades are grouped to product groups whose number equals PM cycle in weeks. Just prior to the beginning of the production of a product group, all the open PM orders for that group are released to production. If open orders for that group exceed one week's production capacity, the last orders wait for the next cycle. After the production of a product group, the production of next group is commenced unless the group is the last in the cycle. A new cycle is started after PMcycle weeks. The PM may be used all the time. The orders, however, arrive only six days a week.

For OP1 the sheeter follows the production at PM. For OP2 and OP3 there is a sheeting minimum batch that is set to 40 units or 0.04 % of PM daily capacity. Each day it is checked for each stock_i whether orders_i ≥ 40. If the condition is true and also material_i ≥ orders_i, all the orders are released for sheeting. If material_i < orders_i, only a part of the orders are released. If material_i < 40, all the orders must wait for material replenishment.

The modelling of ships is straightforward. Shipping time is a time-delay and shipping frequency indicates how many times a week units may enter the ship.

Modelling of the markets becomes central in OP3. The markets are modelled so that there are three markets of equal size. Also all the other situational factors are equal to all the markets, e.g. shipping times are equal.

The stock replenishment policy is a periodic reorder point (ROP) control. Before the production of each product group at PM, a replenishment order for stock *i* is placed if material_i - orders_i < ROP_i to all the stocks *i* that include grades belonging to that product group. The replenishment order size (ROS) is

$$ROS_i = d_{ti} + ROP_i + orders_i - material_i \quad (1)$$

where d_{ti} is demand during replenishment lead time to stock *i*. However, due to the minimum sheeting batch size, a minimum for ROS was set to two sheeting batches and for ROP to one sheeting batch size.

The original intention was to make all the comparisons at equal fill-rate level. The idea was quickly abandoned for two reasons

- setting each of inventory parameters ROP_i (and ROS_i) over the entire experimental design at equal fill-rate by simulation was not feasible given the computing capacity and time limitations.
- fill-rate is not unambiguous measurement when the sheeting lot size is used .

Instead, the inventory parameters were set so that the probability of stocking out during replenishment cycle would be 5 %. The approximate formula given by Bowersox and Closs (1996) is

$$SS_i = Z_{(0,95)} * \sqrt{\bar{t} * \delta_{di}^2 + d_i^2 * \delta_t^2} . \quad (2)$$

where

SS_i = safety stock and the reorder point (ROP_i).

$\bar{t}$ = average lead time in the experiment.

d_i = daily demand at stock i.

δ_{di}^2 = variance of the daily demand of stock i.

δ_t^2 = variance of the lead time in the experiment

$Z_{(0,95)}$ = value from the cumulative normal distribution, 1,64.

The values of the parameters δ_t^2 , d_i , δ_{di}^2 , and $\bar{t}$ were evaluated by simulation.

4.2 The Situational Factors

The situational factors under study are

- **product range:** the number of different grades (NumGrades).
- **shipping frequency:** the number of weekly shippings to a market (Shipfrq).
- **shipping time:** time from Nordic port to destination at a market (Shiptime).
- **paper machine cycle length:** The amount of time in weeks when the production of the first product group is commenced (PMcycle).
- **demand variability:** demand variability is modelled to arise from two sources: the distribution of number of daily orders and the distribution in order size. These are assumed depended (Orderparam).
- **demand level in comparison to PM capacity:** (Util).

4.3 Input Data Modelling

The order size distributions from the seven cases are shown in figure 2. Case data is scaled so that 100 % represents the largest single order. The scaling was necessary as the order sizes in tonnes as well as production capacities varied

among the cases. The average line indicates the average value of all seven cases. The general form of the distribution is very skewed.

Figure 2 Order size distribution.

To model the order size distribution, the case average of figure 2 was used. The order size distribution was also discretized to units corresponding to 0.1 % of PM daily capacity. In practical terms this can be thought to represent a mill with a capacity of around 180 000 tons/a that delivers only full pallets weighing 500 kg.

Figure 3 Distribution of the number of orders per day.

Figure 3 shows the distribution of the number of incoming orders per day. The cases seem to form two groups: cases 1, 5 and 6 have few orders per day and the distribution is skewed whereas cases 2 - 4 show a symmetric distribution and much larger number of daily orders. Based on figure 3, the modelling of the situational variable Orderparam was accomplished by

- exponential distribution shown as Dist1 in figure 3. The standard deviation in cases 1, 5 and 6 was close to average and visually Dist1 seems to fit the data rather well. For modelling of the parameter μ value the average of cases 5 and 6 was used.
- normal distribution as Dist2 in figure 3. This is based on the symmetric distributions in cases 2-4. In the cases the standard deviation divided by expected value varied between 0.221 and 0.256. For modelling a value $\delta/\mu =$

0.25 was used. While production in cases 2 and 3 included also reels, the μ value of case 4 was used.

As the PM capacity was constant, the average order size had to be much smaller to accommodate the larger number of orders in distribution 2 than 1. For exponential distribution the average order size was 39.00 units and standard deviation 38.44 while for normal distribution average size was 4.68 and the standard deviation 4.03.

Figure 4 The cumulative volume by grades.

The cumulative distribution of order volume by grade in each case is shown in figure 4. The grades are ordered by volume. The grade was defined as different PM products. Also a difference in paper grammage is defined as a grade. Cases 1 and 2 have a large number of grades of which only a small percentage forms the majority of the volume. They seem to cope with the well-known 20/80 rule. This type of grade distribution was modelled with 150 grades. The grade volume distribution was formed by applying beta distribution with parameters 2,60 and 2,91 that gave a reasonable close approximation to a ABC-classification of stock control (e.g. in Bowersox & Closs, 1996). This grade distribution is shown in figure 4 as Dist150. The cases 3-6 showed much more even distribution of volume among the grades and also fewer total number of grades. Their distribution was modelled by letting the difference between two consecutive grades be a constant. With 25 grades this constant was 0,3077 %. This grade distribution is shown in figure 4 as Dist25.

The values for shipping time and frequency can be thought to describe shipping times and frequencies from Nordic ports to destinations in England and Northern Europe with perhaps the only exception of deliveries from southern Sweden to Northern continental Europe.

Due to the cyclical nature of paper industry, an utilisation factor was included. Practical considerations, however, limited the range of available

alternatives. Utilisation approaching to 100 % increases greatly variation and the problem of initial values also becomes much more accentuated. On the other hand, utilisation values much lower than 80 % are not very realistic. Utilisation was modelled as changing the expected value of orders per day and its standard deviation by a multiplication factor.

Table 2 summarises the high and low situational factor values in the model.

Table 2 Situational factor values

	NumGrades	Orderparam	Shiptime	Shipfrq	Pmcycle	Util
Low (-)	25	1:exponential	2 days	1/week	2 weeks	80 %
High (+)	150	2:normal	5 days	6/week	4 weeks	95 %

4.4 Performance Measures

The main performance measures used are the total inventory (INV) after production at PM and delivery time (DT) from order placement to receipt. An auxiliary measure is availability (AVB) that is the percentage of stock_i where orders_i > material_i. AVB is measured daily. The machine utilisations for PM and sheeter were measured for model verification purposes but are not shown in results. Specifically, costs are not included in the model. In addition to inventory, also the situational factors and OP-point affect the operating costs.

4.5 Experimental Design

The experimental design applied in each of the OP-point alternatives was a 2^{6-2} factorial design with 10 independent replications. In this design 2-factor interactions may be confounded with other 2-factor interaction effects so reliable interaction estimates are not produced. The interactions are most certainly existent and the choice was based on computing time limitations.

The measurement run length was 720 days which corresponds to two years or 25,7 PM cycles at PMcycle = 4. The initial conditions for OP1 were no inventory and for OP2 and OP3 the intermediate inventories were initialised at 1-3 times ROS, depending on the grade. The first PM cycle starts at $\frac{1}{2} \cdot \text{PMcycle}$. The warm-up period for OP1 was 360 days and for OP2 and OP3 720 days. The reaching of steady-state was analysed by using the Welch-method recommended by Banks et al. (1996). However, it was undertaken only for one factor value combination that was a priori assumed to take the longest time to reach steady-state. As the Welch method is somewhat heuristic in nature and not all the combinations were tested, it may well be that the model has not always reached steady-state. Again, the security provided by long runs was abandoned for the sake of computer run-time.

5. RESULTS

The simulation results are shown in table 3. Table rows contain performance measures and columns are factors. In addition to the overall average, the table shows the difference between low and high values. For example, an entry -2550* found in row OP1 INV. and column Shipfrq 1/6 means that the average effect of increasing the shipping frequency from once a week to six times a week reduces inventory by 2550 units when order penetration point is at the PM and that this result is statically significant at $p = 0.05$ level.

Table 3 Average and factor effects on performance measures for each of the OP alternatives. Star * marks significance of individual factor at $p = 0.05$ level

Factor	Average	NumGr	Or.pm.	PMcycle	Shipfrq	Shiptime	Util
-/+		25/150	1/2	2/4	1/6	2/5	80/95%
OP1 DT	23.1	0.3	-7.7*	6.6*	-2.4*	2.2*	7.1*
OP1 INV	4976	-23	-152*	-6	-2550*	2617*	863*
OP2 AVB	8.4	-7.7*	-6.6*	1.2	1	-1.8	5.4*
OP2 DT	11.6	3.9*	-6.4*	0.6	-3.5*	2.1*	4.2*
OP2 INV	44 875	44 337*	-25 875*	7992*	-2761*	-285*	16 896*
OP3 AVB	4.0	-0.1*	-1.9*	2.6*	-1.2	0.6	2.5*
OP3 DT	11.5	8.1*	-8.4*	1.1	0.9	0.6	4.0*
OP3 INV	71 622	20 736*	-38 053*	8721*	4785*	-4565*	20 908*

6. CONCLUSIONS

As expected, the OP-point at the PM (OP1) resulted in much smaller inventory than the alternative OP-points of sheeting at mill (OP2) or local sheeting at markets (OP3). The drawback, however, is on the average more than twice as long delivery time. The one situational factor that has potential to reduce lead time only in OP1 is the PMcycle. By shortening the PM cycle, the delivery time performance of OP1 approaches the other choices.

High utilisation affects delivery time negatively across all OP alternatives. The sheeting capacity was modelled to equal PM capacity. In practice sheeting capacity is inexpensive in comparison to PM capacity which means that extra capacity to provide faster delivery times is a more viable alternative in OP2 and OP3.

Sheeting batch size limit of 40 produced unexpected results. The 60 % increase in average inventory from OP2 to OP3 was expected, but the extra inventory enabled average delivery time reduction of only by 0.1 days. However, the demand variability (Orderparam) and number of grades had larger effect in OP3 than OP2. In fact, if the effects were additive, OP3 would achieve close to three days for average delivery time with low demand variability and small

number of grades. The conclusion is that generally OP3 with the model market structure and sheeting batch size is not advantageous. However, if the number of grades is low or the demand variability is low, consisting of large number of small orders, there are realisable delivery time benefits in the OP3 choice.

The OP3 choice can also be used to compensate the delivery time disadvantage of far-away mill location because delivery time is unaffected by shipping time and frequency that are significant under OP2. But this comes at the cost of larger inventory than competitors closer to markets.

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8. BIOGRAPHY

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