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RESEARCH MEMORANDUM

INTEGRATION OF DEMAND MANAGEMENT AND PRODUCTION PLANNING IN A BATCH PROCESS MANUFACTURING SYSTEM: CASE STUDY

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Abstract

This paper discusses the benefits and savings realized by implementing an integrated and structured planning system in a batch process manufacturing environment. The paper first discusses the characteristics of the environment under study and points out the planning method advantageous to the company. Then, the methodology and optimization model adopted are applied to historical data collected in order to show the potential benefits of the approach.

Key Words: Integrated Production Planning, Batch Process Manufacturing, Optimization

1. Introduction : Company Sketch

The company under study is a process industry which operates internationally and produces different products mainly for "Project Markets". Project Market as defined in this environment is a customer whose demand is a rough estimation of certain products to be used in a given project carried over a period of time varying from several days to several years. The exact quantities are known during the course of project and are needed to be fulfilled within a short lead time (a few days). The international character results in different sales prices. This is due to the fact that the costs of distribution and transport are on the account of the company. Quantity discounts are playing also an important role in establishing these prices.

Given the turbulent nature of "Project Markets", short delivery lead time requirement, and increased competition, the company tries to prevent selling "no" and late-deliveries as much as possible in order to stay market leader. As a result the company keeps large inventory to offer the customer a high level of service. Therefore, the net working capital and inventory holding costs are very high. The usual planning is far from systematic. Monthly production plan is made manually.
The factors to determine the production quantities of each final product are:

- rough historical sales.
- the available inventory.
- the "feel" of the market.

The final production plan, which indicates when a product has to be produced and in what quantities, is obtained based on the following rules:

- minimize the number of setups.
- respect the sequence-dependent setups to minimize the total setup time.
- setups should be performed during the day shifts.

The manually preparded production plan focuses only on reduction of setup times as they are time consuming and expensive. The plan is usually changed once a week on the average due to the adjustments of production quantities. It is important to mention that current situation does not take into account any safety stock for any product despite of large inventory on hand which is on the average twice the sales of one month.

Next to the production plan a rolling forecast is made every month that contains rough estimates of the required raw materials. This rolling forecast has a time span of four months. Within the company prior to this study there was no system available which could determine quantitatively the sales forecast. Studies about production planning have showed that a good forecasting system is a necessary prerequisite to implement an integrated production planning system (see Vollmann et al. (1988)).

It is clear that no economic returns can be expected from this company without an effective means of production planning and control. The lack of structured planning and control system is not only limited to the company under study but is quite common in many process industries (see Taylor (1981)). Process industries when compared to discrete manufactures, have been slow to embrace the planning techniques developed during the last 30 years. However more recently, design and implementation of an integrated and structured planning system is receiving increasing attention in the process industries. Among many other reasons, the trends in globalization have forced many process industries to improve the use of their expensive resources in order to stay competitive.

In what follows, we discuss in section 2 the integrated planning system adopted for the company understudy. Section 3 presents the important element of this system, demand management. Section 4 discusses the model implemented for the company along with the results. Finally section 5 draws some conclusions.

2. Integrated Hierarchical Planning System

The need for an integrated hierarchical production planning has been extensively discussed in the literature and we do not elaborate that. Early work on this subject belongs to Anthony (1965). For extensive discussion, the reader can consult Hax and Golvin (1978), Gelders and Van Wassenhove (1981), Bitran et al. (1981), Graves (1982), Boskma (1982), Hax and Candea (1984), Axsäter S. and Jönsson (1984), Liberatore and Miller (1985), and Seward et al. (1985).

In order to describe the adopted planning system, first, we elaborate more on the nature of production. A detailed analysis of the production process was carried out. The results were used to group the machines and the production process into two stages (see figure 1). The first stage is the production of the base product and in the second stage the final products are manufactured. Inventories between the two stages have to be avoided due to the nature of products.

The company shows six specific characteristics:

1. The production is a flow shop process, which is capital intensive.
2. There are few kinds of raw materials.
3. Every final product has few levels in the Bill of Material.
4. Major part of production is made to stock (see section 3).
5. New products are frequently developed by modifiying the existing types.
6. The sales volume is high with relatively few final products.

Given the above characteristics, according to Karmakar and Shivadasani (1986) it can be concluded that the production process of the company understudy is a batch-process manufacturing.

To introduce an integrated Hierarchical Production Planning (HPP), taking the characteristics of batch process manufacturing into consideration, we are dependent on the Regular Knapsack Method (RKM) of Bitran and Hax (1977). According to Hax and Meal (1975), the starting point is to define the different levels within the product structure. Since the production process consists of two stages we also distinguish two levels for the products:

1. Items : These are the final products sold to customers. This is in conformity with the second stage of the production in the company.

2. Families : Each family consists of a collection of items with similar production processes. Within the company a family shows the same production costs and the level of family corresponds to the first stage of production since stage one determines the total throughput of the production as stage two involves no extra setup. The total of the sixty end items of the company under study can be aggregated into twenty families.

Examination of the RKM in the HPP proposed by Bitran and Hax (1977) shows that on a group level (collection of families that have the same production costs and demand patterns), an aggregated production plan needs to be set up that minimizes the costs of production, inventory, regular and irregular work force over the whole planning horizon subject to the available capacities.

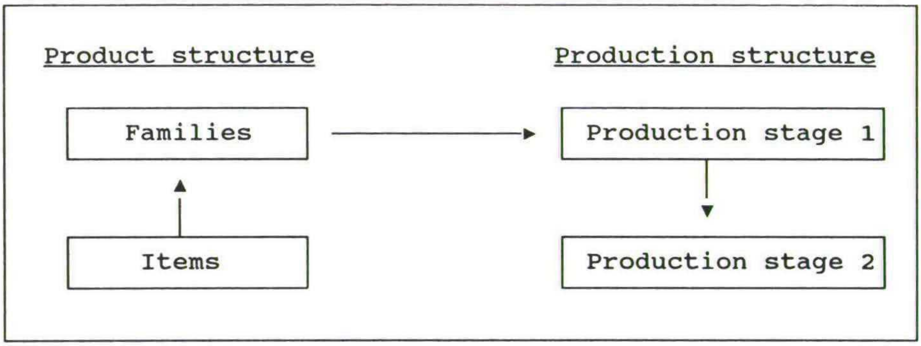

Figure 1. A two-stage structure

The obtained production quantities of the groups set the conditions for determining the production quantities at family level. This occurs by minimizing the setup costs since they have usually lower impact on the overall production strategy.

Since within the company understudy the setup times are long and costly, it is necessary to take the setup costs into account directly in the aggregated production plan. Therefore, this case requires an integrated system addressing simultaneously both objectives of group and family levels to achieve a good solution for the aggregated production plan.

The aggregated model of Chung and Krajewski (1984), a Mixed Integer Program (MIP) model, offers with several modifications the solution for the company. Because the production occurs 24 hours a day, the whole year through, and the work force remains constant regardless of which machines are producing, we assume fixed labour costs. Therefore, there is no overtime work what so ever.

The following model is adopted :

Indices

J := number of different families, $j \epsilon \{1...J\}$;
t := month number $t \epsilon \{1...T\}$;

Decision variables :

I_{jt} := final inventory of family j in month t;

Y_{jt} := number of products of family j produced in month t.

δ_{jt} := 1 if family j is produced in month t, 0 otherwise;

Parameters :

a_j := production rate of family j in time / unit;

$\bar{d}_{jt}$:= "effective demand" for family j during month t;

h_{jt} := inventory holding costs per unit of family j in month t;

k_{jt} := production costs per unit of family j in month t exclusive the labor costs;

L := the length of the production leadtime;

MW_t := maximum production capacity in time units in month t;

s_j := setup time of family j;

sc_j := setup costs of family j;

Q_j := a large number to insure the effects of binary variables

__The MIP-model__

The proposed LP-model at family level can be formulated as follows:

$$\text{Minimize} \quad \sum_{j=1}^{J} \sum_{t=1}^{T} (k_{jt} \; Y_{jt} \; + \; h_{jt} \; I_{jt} \; + sc_{j} \, \delta_{jt})$$

Subject to

1. Inventory constraint:

$$Y_{jt} + I_{j,t+L-1} - I_{j,t+L} = \bar{d}_{j,t+L} \qquad \text{for all } j \epsilon J,\ t \epsilon T$$

2. Production and setup time constraint:

$$\sum_{j=1}^{J} (a_{j} \, Y_{jt} + s_{j} \, \delta_{jt}) = MW_{t} \qquad \text{for all } t \epsilon T$$

3. Setup constraint:

$$Y_{jt} \leq Q_{t} \, \delta_{jt} \qquad \text{for all } j \epsilon J,\ t \epsilon T$$

4. Integer constraint:

$$\delta_{jt} \epsilon \{ 0 , 1 \} \qquad \text{for all } j \epsilon J,\ t \epsilon T$$

5. No-negativity constraint:

$$Y_{jt} , I_{jt} \geq 0 \qquad \text{for all } j \epsilon J,\ t \epsilon T$$

The setup time of all items within a family are assumed to be constant. In practice these times are sequence dependent. But due to the small differences (max. 45 minutes in an extreme case), this assumption has negligible consequences on the sequence of production in a month. Therefore, the setup time for a family is calculated as the mean of the setup times within that particular family. Sensitivity analysis shows later that the assumption made is valid.

Furthermore, it is assumed that setup can always take place. No day shift restriction is considered. This is an important issue for the company for improving the flexibility of the production. Including extra variables and constraints to limit the setups to day shifts complicates the model. The results of several scenarios studied using the model indicate that only a few times per month setup is required during night shifts. These setups can be arranged by trained night shift operators while the setup materials are made ready by the day shift operators.

The model considers a zero lead time (L). This implies that changes in the production schedule can be made along in the following rolling schedule since it takes a full production lead time to implement the changes (see Balek and Peterson (1979) and Carlson et al. (1982). The variable production costs per family unit, the setup times and setup costs was provided. However, no proper information was available on the inventory holding cost for which an apart study was carried out.

At the same time the term "effective demand" is used within the model. This is introduced to avoid infeasible solutions at an aggregated level because initial inventory at an item level, belonging to a family, are no substitutes for each other. The effective demand is a derivative of the forecasted demand and is defined as follows:

$$\bar{d}_{kt} := \max\,[0, \sum_{l=1}^{t} d_{kl} - BV_k + VV_k\,] \qquad \text{for } t=1,\ldots,t^*_k$$

$$\bar{d}_{kt} := d_{kt} \qquad \text{for } t=t_k^{*+1},\ldots,T$$

$$\bar{d}_{jt} := \Sigma_{k\epsilon j}\ \bar{d}_{kl}$$

with:

BV_k := initial inventory of item k

d_{kt} := forecasted of item k for period t

$\bar{d}_{kt}$:= effective demand of item k for period t

$\bar{d}_{jt}$:= effective demand of family j for period t

t^*_k := time period where the initial inventory of item k will reach zero

VV_k := safety stock of item k; this stock is derived from the quantitative approach of the forecasting system, which will be discussed in the next section.

Introduction of the effective demand has as a disadvantage that forecasts at item level have to be calculated. For the company understudy, it is therefore of a great importance to apply a forecasting system that can determine the final forecasts at the item level. As such introduction of a Demand Management is necessary for the integrated planning system.

3. Demand Management

Demand Management is an activity that collects and coordinates the total potential demand for the available production capacity (see Vollman et al. (1988), and Blackstone (1989)). A well developed Demand Management leads to a better planning and control. Demand Management includes among others the forecasting, order-entry, order-delivery-date-promising and inventory control. In this way quantities and timing that are relevant to the customer demand are being planned and controlled. The primary target of Demand Management is to cross the bridge between the company and the final market (see figure 2).

As mentioned earlier, due to the time span of the projects, demands placed to the company, can vary from several days to several years. Given a project, the date of order is very difficult to define. Has the order-entry been made, then delivery have to take place within several days.

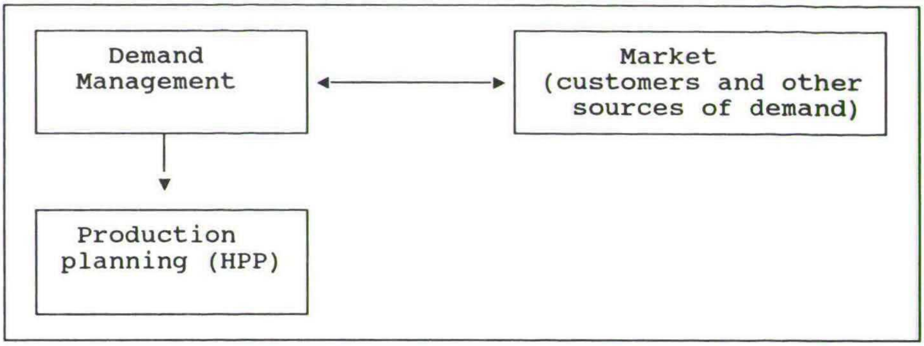

Figure 2. The position of Demand Management

Therefore, the company is dependent on the introduction of safety stocks to satisfy the service level desired. Before proceeding to the appropriate forecasting system, the analysis of the demand has to be carried out to determine which items are important for the company and which items have to be produced to stock or on order (see Herron (1975)). For this purpose figure 3 is used. The 20-80 rule is applied for the combinations of sales, turnover and operating income specified at item level for several years. The sales are the number of units of an item sold. The turnover is defined as the multiplication of the sales and the unit selling price. The operating income is here defined as a gross profit that will occur through:

sales * (unit selling price - unit production costs - unit R&D costs - variable unit selling costs)

Class A concerns the items which are in the category of 80% of the sales, 80% of the turnover and also 80% of the operating income. These items are of great importance to the company.

Class B concerns the items which show a high operating income and sale but low turnover. Since the selling price is low, the costs must be relatively lower. The risk of such products is that at certain moments, the high sales may be attained with high variable selling costs (like transport costs) and thus such situations bring pressure to bear upon the operating income.

Class C concerns the items which are of great importance to the company because of the high turnover and operating income. These items can contribute to a still greater operating income if the sales can be increased.

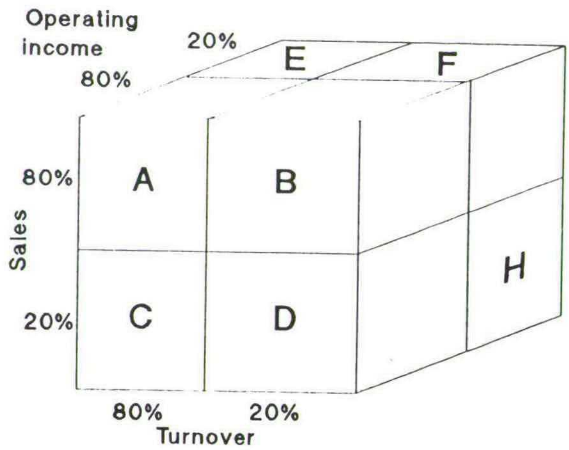

Figure 3. Classification of the items

Class D concerns items which contribute effectively to the operating income. Because of the low sales and turnover one can get only a high operating income by using relatively very low costs.

Class E concerns items which their costs are relatively near to their selling prices. The sales are high. Too often the strong competition does increase the costs for commercial activities in such a way that these items yield low profits.

Class F concerns the items where through the high sales, high costs are involved. These items generate low operating income and they are not profitable for the company.

Class G concerns the items that are in the category of 20% of the sales, 80% of the turnover and 20% of the operating income (the block below E in figure 3). Usually, such items are high quality products but contribute relatively little to the profits. Considering the high research and development costs for these products, special attention is needed in order to investigate the possibilities to earn back those costs in the future.

Class H concerns the items that are in the category of 20% of the sales, turnover, and operating income. These are mostly the items which have just been introduced on the market (new developed products), or items which are going out of market, or those which have not met the expectations. The latter two types are the products that must be taken out of the assortment or just have to be produced on order. Of course Class H concerns the largest group of items and therefore determines the size of the total product assortment. The size of the assortment offered to the market can play an important role for the organization.

After studying which items need to be considered for production on order, it appeared that it is more profitable to produce 28% of the total assortment on order. Thus, the ex-strategy in the company to produce all items to stock was erroneous. Here, it has to be mentioned that the above analysis is only valid when a relative long period is studied (longer than average product life cycle). The products which are introduced recently on the market are compared with those to be replaced and disappear soon from the market in order to determine how the items need to be produced (on order or to stock). For the products which are new and cannot be compared with the existing ones, the qualitative marketing view points are used.

Production on order here means that certain products (28% of the total assortment) with a production plan of one month, can only be realized a month later. Therefore, when sales department negotiates these products with a customer, the customer has to be informed that exclusive products are at stake and he has to take into account a longer delivery time.

For the items which have to be produced to stock, a forecast has to be made with a length of four months. The planning horizon is short because of the nature of "Project Markets" as the uncertainly increases rapidly for periods longer than four months. With this forecast the effective demand at family level has to be determined for the input of the MIP adopted model.

The forecasting system developed for the company understudy is an integration of quantitative and qualitative approach (Makridakis and Wheelwright (1977). The quantitative approach considered for the company is exponential smoothing through application of a forecasting package. This is a suitable method for short term forecast. The monthly historical sales are the basis for the forecasts. The other use of such package is in recording the reliability intervals where in the forecasts most probably will fall, which is of importance for setting the safety stocks. As the forecasts are updated monthly, the safety stocks can be adjusted also monthly. The hierarchical production planning model takes into account these variable inventory levels.

The qualitative approach is very important for the company since the marketing view has considerable influence on the ultimately monthly forecasts of four months. Such an approach reduces the forecast errors of the fluctuating demand quantities at item level per month.

Marketing therefore needs to study the behavior of customers in several regions. The important factors are the special promotions of certain items in certain periods, competitive actions, determination of the probability that some projects will succeed, the socio-economic changes, and the cannibalistic effect of the new items introduced on the other items. The responsible managers of each region must submit a monthly forecast. The responsibility of providing accurate forecasts needs to be delegated also in part to the partners and the agents of the company. They must also record their own prospected sales per month. Currently, the company does not put any pressure to effect this.

The next step is to compare the quantitative and qualitative approaches with each other and explain the differences so that the ultimate forecasts can be made.

To demonstrate the benefits and savings of the proposed approach, in section 4 a shadow plan of four months is made by implementing the adopted MIP model and only the quantitative forecasting. The shadow plan is then compared with the real-life decisions made over the same period.

4. Application of the Solution Approach

For the planning horizon of the months I to IV a forecast is determined. On the basis of the defined safety stocks and physical end inventories of month I-1, the effective demand for each family can be found out.

Item k	Initial invent.	forecast month I	II	III	IV	Safety stock
1	15720	3475	3475	3475	3475	6500
2	3978	3140	3140	3140	3140	5400
3	29106	3708	3708	3708	3708	11000
4	14688	12285	12285	12285	12285	25000
5	0	0	5000	5000	5000	5000
		Effective demand				
1		0	0	1205	3475	
2		4562	3140	3140	3140	
3		0	0	0	0	
4		22597	12285	12285	12285	
5		5000	5000	5000	5000	
Family j		32159	20425	21630	23900	

Figure 4. An example of Effective Demand determination for a family.

It is the intention to determine for the months I through IV, using the discussed MIP model, the production quantities of each family. To solve the MIP problem, the optimization package OMP (Beyers and Partners (1987)), which is the best suited for our case beacuse of its model generator and interactive pilot module, is implemented on a PS-2 55SX-computer. The CPU-time for getting a near optimal solution ($\pm$ 10% larger than LP solution) is about one hour. To arrive faster at solution, Branch and Bound method based on a priority list is used. Optimal solutions are not available within this time span due to the number of binary and integer variables.

The total aggregated production plan cost found for the four months is about 200,000 Dutch Guildens lower than what was incurred in practice. According to this production plan the production quantities and setups can be defined for month I. The fact that more accurate information of the quantities of the raw materials to be bought, stands aside and is not considered in the savings.

The factor Run Out Time (ROT) has an important role in the reticulation to item level. This factor is the mean to signal the production in time that the available stock is not sufficient to satisfy the prospected demand. The signal occurs if the effective forecast for a family during the lead time minus the initial stock plus the safety stock is larger than zero:

$$(\bar{d}_{j,1} + \ldots + \bar{d}_{j,L+1}) - BV_j + VV_j > 0$$

or if :

$$(BV_j - VV_j) / \sum_{t=1}^{L+1} \bar{d}_{jt} < 1$$

The ROT of a family can then be denoted as:

$$ROT_j := Y^*_j + \sum_{k \epsilon j} (BV_k - VV_k) / \sum_{k \epsilon j} \sum_{t=1}^{L+1} \bar{d}_{kt}$$

where k is the item that belongs to family j.

With the assistance of the Bitran and Hax (1981) method and given the quantities at family level, the final master schedule can be determined. The method is a quadratic Knapsack problem and formulated as follows:

$$\text{Min } \tfrac{1}{2} \sum_{k \epsilon j} \left[\frac{Y^*_j + \sum_{k \epsilon j} [BV_k - VV_k]}{\sum_{k \epsilon j} \sum_{t=1}^{L+1} \bar{d}_{kt}} - \frac{Z_k + BV_k - VV_k}{\sum_{t=1}^{L+1} \bar{d}_{kt}} \right]^2$$

Subject to :

$$\sum_{k \epsilon j} Z_k = Y^*_j \; ;$$

$$minp_k \leq Z_k \leq maxp_k , \quad k \epsilon j \; ;$$

$$Z_k \in N \qquad , k \epsilon j$$

With:

$$maxp_k := OS_k - BV_k$$

$$minp_k := \max [0, \sum_{t=1}^{L+1} \bar{d}_{kt} - BV_k + VV_k]$$

decision variable :

Z_k := the number of item k that has to be produced;

parameters :

$maxp_k$:= maximum production quantity of item k;

$minp_k$:= minimum production quantity of item k;

OS_k := overstock limit of item k;

Y^*_j := total number of different items belonging to family j.

The purpose of this method is to minimize the squared difference between the ROT of family j and the ROT of its items. The square sign has the consequence that both ROT's approximate each other closer. The algorithm of Birtan and Hax (1981) to solve above problem is implemented in Turbo Pascal and run next to optimization software for the above purpose.

This way, we can determine what the production quantities at item level are for month I, then through the initial stocks and the actual sales one can define what the actual final stocks of month I would have been, if HPP had been applied. Therefore, the total stock costs can be calculated through aggregation.

Using the end inventory of month I of HPP as initial stock for month II, the difference in costs can be calculated like wise above. Continuing the same procedure up to month V, results the following costs differences.

Month I	Produktion costs	Setup costs	Inventory costs	Total
Actual	1.225.669	49.805	75.574	1.351.048
HPP	1.175.696	53.094	64.000	1.293.063
Difference	49.973	-3.289	11.574	57.985

Month II	Production costs	Setup costs	Inventory costs	Total
Actual	1.348.987	43.247	79.705	1.471.939
HPP	1.088.793	58.391	47.864	1.195.048
Difference	260.194	-15.144	31.841	276.891

Month III	Production costs	Setup costs	Inventory costs	Total
Actual	1.520.372	52.404	85.234	1.658.010
HPP	1.486.318	64.668	61.141	1.612.127
Difference	34.054	-12.264	24.093	45.883

Month IV	Production costs	Setup costs	Inventory costs	Total
Actual	1.295.079	58.560	78.695	1.432.334
HPP	1.159.298	68.221	42.240	1.269.759
Difference	135.781	-9.661	36.455	162.575

The cost savings are: month I 4.3%, month II 18.8%, month III 2.8% and month IV 11.4%. Thus, on the average more than 9% per month saving is realized.

The large saving percentage fluctuations per month can be explained as follows :

1. The large percentages are caused by a too large quantity that was produced in practice without any reason.

2. The cause of the low percentages is explained by the fact that if actual large quantities with low production costs are manufactured, the HPP indicates a production of items with high production costs for those months.

It has to be noted that production of some items could not satisfy the demand. The slight inventory shortage occurred for the months II and III. The shortages are taken into account along with the production of the following months.

Through analyzing the actual production plans for these months, it appeared that the company was well-informed of the developments with regard to the higher sales for the items indicated here above. Thus, it can be made sure that if the qualitative forecast approach had been taken into account, the above mentioned items were not out of stock.

The lower production costs of HPP are not surprising. There is no need to produce so much because of the excessive inventories. The inventories diminish in the case of HPP in month I by 8% and the reduction rate increases in month IV to 23%. The inventories will diminish ultimately about 35%. The rest is the sum of all safety stocks. The lower level of the inventories has direct consequence on the reduction of the net working capital of about 1.2 million Dutch Guildens per year.

The differences in the production costs will be decreasing gradually when the integrated planning system is fully implemented and the perpetual savings are then only made on the inventory costs.

5. Conclusions

The effective use and integration of the Production Planning and the Demand Management is a perquisite when the HPP is applied and implemented. Implementation of the proposed integrated planning system leads to savings of more than 9% per month. In general the result is that the number of setups will increase and the size of the batches will decline. The temporary descent of the production costs will lead to a lower level of the invested capital. A positive structural result will exist because the decrease of the inventory costs will be stronger than the increase of the setup costs.

General conclusions that can be made from this study are :

1. The increase of the production flexibility does not need always large investments. Implementing a well-design integrated production plan can create a more stable production situation and reduce greatly the investment need.

2. "Optimal Planning" does not mean that all items should be produced on order. As mentioned in this study only some items should be produced on order.

3. Forecasting is a must and in many companies such as the one under study a combination of qualitative and quantitative forecasting approaches is required. To achieve the full benefits of forecasting greater responsibility from the marketing department is demanded.

4. The introduction of safety stocks (buffers) is necessary when a fluctuating market exists.
5. The emphasis on the sales and turnover of the items has to be replaced to contribution provided by the use of resources.
6. HPP is comprehensible, simple to implement, consistent with the structure of the organization and as such an important tool for the company.
7. A self-evident condition with HPP is the introduction of the software for the forecasting and the optimization.
8. HPP creates a structured system for further optimization. Examples are the determination of more accurate safety stocks and forecasts.

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IN 1991 REEDS VERSCHENEN

466 Prof.Dr. Th.C.M.J. van de Klundert - Prof.Dr. A.B.T.M. van Schaik
Economische groei in Nederland in een internationaal perspectief

467 Dr. Sylvester C.W. Eijffinger
The convergence of monetary policy - Germany and France as an example

468 E. Nijssen
Strategisch gedrag, planning en prestatie. Een inductieve studie binnen de computerbranche

469 Anne van den Nouweland, Peter Borm, Guillermo Owen and Stef Tijs
Cost allocation and communication

470 Drs. J. Grazell en Drs. C.H. Veld
Motieven voor de uitgifte van converteerbare obligatieleningen en warrant-obligatieleningen: een agency-theoretische benadering

471 P.C. van Batenburg, J. Kriens, W.M. Lammerts van Bueren and R.H. Veenstra
Audit Assurance Model and Bayesian Discovery Sampling

472 Marcel Kerkhofs
Identification and Estimation of Household Production Models

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Games with Permission Structures: The Conjunctive Approach

474 Jack P.C. Kleijnen
Sensitivity Analysis of Simulation Experiments: Tutorial on Regression Analysis and Statistical Design

475 C.P.M. van Hoesel
An $O(nlogn)$ algorithm for the two-machine flow shop problem with controllable machine speeds

476 Stephan G. Vanneste
A Markov Model for Opportunity Maintenance

477 F.A. van der Duyn Schouten, M.J.G. van Eijs, R.M.J. Heuts
Coordinated replenishment systems with discount opportunities

478 A. van den Nouweland, J. Potters, S. Tijs and J. Zarzuelo
Cores and related solution concepts for multi-choice games

479 Drs. C.H. Veld
Warrant pricing: a review of theoretical and empirical research

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De Miles and Snow-typologie: Een exploratieve studie in de meubelbranche

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Are managers indeed motivated by their bonuses?

482 Jacob C. Engwerda, André C.M. Ran, Arie L. Rijkeboer
Necessary and sufficient conditions for the existence of a positive definite solution of the matrix equation $X + A^T X^{-1} A = I$

483 Peter M. Kort
A dynamic model of the firm with uncertain earnings and adjustment costs

484 Raymond H.J.M. Gradus, Peter M. Kort
Optimal taxation on profit and pollution within a macroeconomic framework

485 René van den Brink, Robert P. Gilles
Axiomatizations of the Conjunctive Permission Value for Games with Permission Structures

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The Gewirtz graph - an exercise in the theory of graph spectra

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Intratemporal uncertainty in the multi-good life cycle consumption model: motivation and application

488 J.H.J. Roemen
The long term elasticity of the milk supply with respect to the milk price in the Netherlands in the period 1969-1984

489 Herbert Hamers
The Shapley-Entrance Game

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Insider trading restrictions and the stock market

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The economic explanation of the jump of the co-state variable

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een beschouwing op besturing en verandering

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Applications of statistical methods and techniques to auditing and accounting

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The diffusion of innovations: the influence of supply-side factors

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A decision rule for the (des)investments in the dairy cow stock

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An SLSPP-algorithm to compute an equilibrium in an economy with linear production technologies

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Investigating several alternatives for estimating the compound lead time demand in an (s,Q) inventory model

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Identifying the important factors in simulation models with many factors

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Beheersing van het kwaliteitsperceptieproces bij diensten door middel van keurmerken

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Density of the F-statistic in the linear model with arbitrarily normal distributed errors

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The direction, mode and location of corporate expansions

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Bridging the gap between a stationary point process and its Palm distribution

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Motives for the use of equity-warrants by Dutch companies

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Een etiologie van horizontale internationale ondernemingsexpansie

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On M-functions and their application to input-output models

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Produktiviteit en Arbeidsparticipatie

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Cooperation and communication restrictions: a survey

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Hierarchical trade and downstream information

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The Effect of Systematic Misperception of Income on the Subjective Poverty Line

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Basics of Inventory Management: Part 1
Renewal theoretic background

511 J.P.C. Blanc, F.A. van der Duyn Schouten, B. Pourbabai
Optimizing flow rates in a queueing network with side constraints

512 R. Peeters
On Coloring j-Unit Sphere Graphs

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Regional economic policy, economic technological innovation and networks

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Het functioneren van stedelijke onroerend-goed-markten in Nederland - een theoretisch kader

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European central bank independence and inflation persistence

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Optimal abatement policies within a stochastic dynamic model of the firm

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Expenditure versus consumption in the multi-good life cycle consumption model

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Large, infrequent consumption in the multi-good life cycle consumption model

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Pollution and Endogenous Growth

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Arbeidsongeschiktheid, subjectief ziektegevoel en collectief belang

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Basics of inventory management: Part 2
The (R,S)-model

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Basics of inventory management: Part 3
The (b,Q)-model

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Basics of inventory management: Part 4
The (s,S)-model

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Basics of inventory management: Part 5
The (R,b,Q)-model

525 A.G. de Kok
Basics of inventory management: Part 6
The (R,s,S)-model

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Financial integration and fiscal policy in interdependent two-sector economies with real and nominal wage rigidity

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Gecoördineerde bestelsystemen
een management-georiënteerde benadering

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Multi-item inventory systems with joint ordering and transportation decisions

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Maintenance optimization of a production system with buffercapacity

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Het stochastische variantie optiewaarderingsmodel

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Arbitrage and Walrasian Equilibrium in Economies with Limited Information

IN 1992 REEDS VERSCHENEN

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Two-stage versus sequential sample-size determination in regression analysis of simulation experiments

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