Production Planning and Inventory Control in the Pre-deco Industry
Ashayeri, J.; Heuts, R.M.J.; Strijbosch, L.W.G.; Lansdaal, H.G.L.

Publication date: 2003

Citation for published version (APA):

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

Take down policy
If you believe that this document breaches copyright, please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Download date: 07. Dec. 2018
No. 2003–92

PRODUCTION PLANNING & INVENTORY CONTROL
IN THE PRE-DECO INDUSTRY

By J. Ashayeri, R.J.M. Heuts, H.G.L. Lansdaal,
L.W.G. Strijbosch

October 2003

ISSN 0924-7815
Production Planning & Inventory Control  
in the pre-Deco Industry

J. Ashayeri†, R.J.M. Heuts†,  
H.G.L. Lansdaal‡, L.W.G. Strijbosch†

Affiliations:                      † Tilburg University, P.O.Box 90153, 5000 LE Tilburg,  
The Netherlands                    ‡ Syntec B.V., Department of Logistics, P.O.Box 244,  
                                 4200 AE Gorinchem, The Netherlands

Mailing addresses:  J.Ashayeri@uvt.nl  
                        R.M.J.Heuts@uvt.nl  
                        H.Lansdaal@syntec.nl  
                        L.W.G.Strijbosch@uvt.nl
Abstract

Production Planning and Inventory Control (PPIC) is an essential dynamics of the logistical performance of manufacturing organizations. In this paper, we discuss the development of a PPIC system in a process industry. The process manufacturing industry has not embraced the new Advanced Planning and Scheduling (APS) software solutions due to the complexities involved in the software solutions, which do not fit the process industry environment well. Our contribution is to underline the need for a simple and easily understood methodology for this industry. The paper is based on a real-life case study in a batch process industry with high-volume/low-value products. It explains how the company currently operates and how the situation is improved significantly using simple PPIC optimization models. Finally, we give an overview of an area that can further be improved in such industries.

Keywords: Batch Process Industry, Inventory Control, Production Planning
1 Introduction

Over the last 20 years a great deal of research effort has been put into the development of Production Planning and Inventory Control (PPIC) software solutions for discrete industries. The developers of these tools and techniques have claimed significant savings in operating costs and increasing working capital. The business, however, in process industries at large, has not changed significantly and manufacturing planning and inventory control in industrial practice is still primarily a ‘manual’ spreadsheet based task. This is despite the continual rise in the number of software packages available for PPIC problems. The limited applications of these tools have two major reasons: a) the nature of the process varies and depends heavily upon the type of products produced; b) the APS tools developed are mainly reflecting the discrete manufacturing environment.

In the following we outline the nature of process industry and its main differences. The APICS dictionary (APICS 1995) defines process manufacturing as “production that adds value to materials by mixing, separating, forming or chemical reactions.” This definition provides the key elements to classify industries either as ‘process’ or as ‘manufacturing’. The dictionary also proposes a further distinction between batch and continuous processing, where batch processing is needed as “a manufacturing technique in which production is accumulated and processed together in a lot”, while continuous flow production is “lot-less production in which production flows continuously rather than being divided”. A comprehensive overview of the main issues at stake can be found in Ashayeri et al. (1996), Taylor et al. (1981a; 1981b). Ashayeri et al. (1996) described twenty-eight features distinguishing process industries from discrete industries.

Our main focus in this paper is on the batch process industry and herewith the nature of batch processing is discussed.

Batch processes play a significant role in many sectors of the process industry. They are most widely used in the manufacture of high value-added products like ‘fine chemicals’ (such as additives, pesticides and pharmaceuticals) which are produced at relatively low volumes. Batch or semi-batch operations also occur within many continuous processes. And finally, batch process is also used in low-value but large-volume products, like soap, washing powders, etc. These sectors depend on batch processing to meet their goals of:

- High product quality;
- Flexible production, in response to the dynamics of the market place and the supply and distribution chains; and
• Best use of resources.

In order to achieve the last two goals, good production planning and inventory control are essential to logistical performance improvement. However, the existing APS tools for production planning problems are better suited for the discrete manufacturing environment. These problems can be roughly divided into flow-shop, job-shop or open-shop problems. For batch processing plants, this characterization is not sufficient since additional constraints and specific characteristics have to be taken into account which result from features such as:

• Shared resources;

• (Semi-) continuous units;

• Limited connectivity by piping networks; and

• Limited storage sizes.

Moreover, the way the process is operated as well as features of the product recipes may impose uniqueness, which have to be taken into account, including:

• Sequence dependent change-over times;

• Maintenance plans;

• Recycling flows; and

• Process based fixed batch sizes.

The properties of the substances of material cause additional constraints such as limited storage time or limited storage capacity, typically due to special requirements concerning how the material must be stored, or to storage cleaning requirements. The variety and combination of problems make it difficult to apply the standard APS tools and to solve the batch process industry production and inventory control problems; see e.g. Heuts et al. (1993). Therefore, more tailor-made solutions are needed.

The following sections describe the development of PPIC for a batch process industry with high volume and low value products. Section 2 presents the company background and the nature of the process. Section 3 explains the solution approach. Section 4 outlines the data requirements, while Section 5 presents the results of applying the approach. Finally, in Section 6 we present the conclusions and avenues of improvements.
2 Company Background

Alabastine Operations is the business unit of Imperial Chemical Industries PLC (ICI) in Europe that makes pre-Deco products. The pre-Deco products are materials that can be used to level-out an object before decorating that object. Alabastine Operations manufactures about 250 different products, packaged in more than 1000 stock-keeping units (SKU’s) requiring about 300 different raw materials and about 2800 different packaging materials. In the rest of this paper the word article is used for a SKU which is a unique product, uniquely packaged; a product is the content of an article. Nearly all articles are made for the Do-It-Yourself (DIY) market. A limited range of articles is also made for the professional market. The pre-Deco market is a niche market with healthy margins. The articles can be characterised as high-volume/low-value articles. The total production volume is growing rapidly.

The pre-Deco products can be divided into four categories: powders, ready-mixed, liquids, and others. The powder volumes for the DIY market are shrinking at the moment, as consumers prefer more and more ready-mixed products. For many powder products, a comparable ready-mixed product has been developed in the last few years. The powder based articles have the advantage that the cost price for the consumer is relatively low.

Four different mixers manufacture the powders. The powder is transported from the mixers to inventory silos. The powder can be transported from these inventory silos to eight different filling lines. There the powder is packed into cartons, bags, buckets or foil. The ready-mixed pastes are mainly made in tubs. From these tubs, the paste can be brought to ten different filling lines which pack the paste into tubes, pots, bottles or cans. The liquid products are products with varying sales growth patterns. The liquids are made at a separate place in the plant. From there they are transported to three filling lines by a network of pipes where they are packed into bottles, cans or jerry cans. The articles containing the remaining products are mainly made externally. Most of these articles need specific technical facilities, like packaging into spray cans, which is not possible at Alabastine Operations. Also, many ingredients are slow-moving and can be produced more efficiently by others. Another part is made as semi-finished goods elsewhere, leaving the last production steps to the plant of Alabastine Operations.

The articles that are manufactured by Alabastine Operations are sold to eight ICI sales units in Europe. These sales units report their weekly sales and their inventory level per SKU. On SKU level, the sales units also report a rolling forecast for the
next twelve months at the beginning of every month. Some of the sales units use forecasting software, e.g. Mercia Lincs, and others use self-developed heuristic solutions. Alabastine Operations determines both a production cycle and a batch size for every SKU by experience. The sales units determine a safety stock for every SKU mostly by a time-supply rule. A production run is planned on a cycle moment whenever the inventory position of the respective SKU at the next cycle moment would be below the safety stock. This means that the reorder point equals the safety stock plus the forecast during a production cycle. Depending upon the forecast during the cycle, the production quantity can be one or more batches. This process is repeated every week. The raw and packaging materials are ordered and the people are hired based on the information of the production plan. At the end of each week, the planning division provides a production plan for the next week to the production division, which in turn decides on the precise production order.

The PPIC related problems of Alabastine Operations are in two areas. Firstly, production costs usually exceed budget. Secondly, inventory levels of the SKUs at the sales units, for which Alabastine Operations is also responsible, seem to be too high. To solve the problems in these two areas, Alabastine Operations launched a study to find out the optimal batch size and cycle length in order to minimize the supply chain cost, and the optimal safety stock level to meet the desired customer service. The scheduling method to be proposed should focus on the following goals:

- **Minimizing the number of changeovers.** Changeover costs should be reduced.

- **Increasing the stability of the production moments.** Problems with regard to procurement and hiring people should be reduced.

- **Decreasing the influence of forecasting.** The large differences between forecasted and realised sales invoke a lot of problems to the current control.

- **Developing an easily understood model.** Alabastine Operations is reluctant to invest in a new software solution or hire highly experienced people.

- **Developing a realistic and stable production plan.** The production plan must become more stable over time, and realistic with regard to the maximum production hours per filling line per week.

- **Facilitating easier realisation of the production plan.**
3 Solution Approach

The strategy that has been proposed to solve the problem of Alabastine Operations is a so-called \((T_i, k_{ij}, S_{ij})\)-strategy, which is a cyclical production-inventory modelling concept. The idea is as follows (see Figure 1). Articles that are made on the same machine and have relative short changeover times, are called a family (indicated by index \(i\)). The length of the time between production starts of the same family \(i\) is \(T_i\), and is called a family cycle. For each article \(j\) within a family \(i\), a certain integer \(k_{ij}\) is determined, which indicates the number of family cycles between two subsequent production starts of article \(i\), yielding an article cycle \(T_i k_{ij}\). Atkins & Iyogun (1988) proposed an efficient algorithm to generate an optimal article cycle for each article that minimizes the changeover and inventory costs. Rounding the integers \(k_{ij}\) according to the powers-of-two method of McGee & Pyke (1996) makes the production plan more stable (Silver et al. (1998)). A description and a case application of the algorithm for a pharmaceutical company in the Netherlands is described in a paper by Strijbosch et al. (2002). The Appendix contains a method to determine the production duration per family per production run after establishing the scheduling and sequencing of the families.

[Insert Figure 1 about here]

The difference between the order up-to-level \(S_{ij}\) and the inventory position of article \(j\) of family \(i\) determines the quantity to produce at a production start. Performance is measured based on ‘on-time’ and ‘in-full’ which respectively represent \(P_2\) and \(P_3\) criteria. However, ‘in-full’ was hardly measured by the company. Therefore, we choose the ‘fill-rate’ performance which is the \(P_2\)-criterion. Given the \(P_2\)-criterion a \(P_2\)-service equation for a periodic inventory model of the type \((R_{ij} = T_i k_{ij}, S_{ij})\), cf. Silver et al. (1998), must be solved to determine \(S_{ij}\). Strijbosch et al. (2002) apply a simple numerical approach for the determination of the optimal order-up-to-level. This approach has the advantage that it can be easily programmed in a spreadsheet as preferred by Alabastine Operations. This cyclical production-inventory model has certain advantages and disadvantages in the area of the supply chain. The advantages are:

- **Reduction of changeover times**: by creating a sequence in which articles with relatively short changeover times are produced one after another, the number of large changeovers and thus the total changeover time can be reduced.
• **Increase of capacity**: reducing total changeover time on a machine results in more capacity to satisfy peak demand.

• **Materials requirement is more predictable**: the future production moments are fixed in the planning; the suppliers can be informed in advance about the moments that one needs certain materials.

• **Stability of the work load and the work force requirement**: the time between two production runs is nearly stable and the articles that are produced are very similar every cycle; the production people will be less disturbed by delay and stress.

• **More robust production scheme**: whenever a certain article does not have to or cannot be produced (e.g. due to the lack of raw materials) during a production cycle, the production plan remains the same.

• **Reduction of the lead time for customer orders**: since the planned production moments are known in advance, the lead time reliability is increased and customers can place their orders later; therefore customer cycle plus safety stock can be reduced.

• **Better transport load**: the stability of the production scheme leads to a better distribution plan of the articles, so the transport load will be higher.

• **Ease of use**: the parameters of the model can easily be calculated in a spreadsheet.

The disadvantages are:

• **Possible increase of the inventory**: the cyclical plan may suggest an increase in average batch size in order to realize savings on changeover times; in that case the average inventory level may increase.

• **Regular adjustment of the plan**: as demand is usually not stationary, the plan must be recalculated regularly.

Having determined the production cycles and the order-up-to-levels of the articles within each family, the families and the articles still have to be scheduled. The optimal production sequence of the different families needs to be determined based on the mutual changeover times. There are different methods applicable to solve this problem:

• Use an asymmetric travelling salesman algorithm (Lawler *et al.* 1985).
- The size of the package can be a criterion. One can start with the smallest packages and then gradually move to the largest ones.

- Use the experience within the company to obtain a good sequence. When the number of families is small and the changeover times do not change too often, one good option is to determine a good sequence by hand.

In the case of Alabastine Operations it is very easy to determine the optimal production sequence of the different families because the mutual changeover times are more or less the same. The appendix describes an approach to determine the production run times of each family based on the family production rates and total demand per year, among others.

4 Data requirements

The data required to determine the optimal production cycles contains the following parameters:

- $D_{ij}$ the yearly forecast for article $j$ within family $i$
- $v_{ij}$ the cost price of article $j$ within family $i$
- $a_{ij}$ the minor set-up cost of article $j$ within family $i$
- $A_i$ the major set-up cost of family $i$
- $r$ the inventory cost per euro invested in inventory per year

The minor set-up (e.g. changing labels) costs consists of at least four components. Each changeover costs time during which production stops, leading to labour cost and loss of capacity (opportunity cost) whenever running close to full-load capacity; both at the start and the end of a production run material is lost because the packages are not full and therefore unsaleable: material cost; for each production start, a lift truck driver has to bring new materials and restore the materials of the last run: cost of internal logistics; if a minor set-up includes cleaning, the changeover leads to cleaning costs. The major set-up (e.g. changing the package size) cost consists of at least two components. A major set-up mainly takes time, again leading to labour cost and loss of capacity (opportunity cost); if it includes cleaning, the set-up leads to labour and removal costs.

The components of the inventory costs are fourfold: capital cost (inventory is part of the working capital); risk cost (inventory may become obsolete by technical or economic
reasons); storage cost (most inventory is stored at hired places, so this component is easy to determine); insurance (service) costs.

The following extra data is necessary to determine the order-up-to levels: $P_2$ (desired service level), $L$ (lead time), $V(L)$ (lead time variance), $V(D)$ (demand variance). The lead time consists of production time, production delay, waiting time for transport, and transport time.

5 Results and discussion

The financial benefits for Alabastine appeared to be large when implementing the proposed cyclical production inventory modelling concept. A cost reduction of 105,000 euro could be realized on a total cost of 330,000 euro (32%) for two analysed production lines (filling, packaging, labeling). It was estimated that the cost reduction on the other production lines would be at least 25%, which would lead to a total expected cost reduction of more than one million euro per year. The investment that Alabastine should make to implement the cyclical production inventory modelling concept is negligible. Most of the investment expense will be made for changes in the ERP system of Alabastine to make the implementation possible; however, those expenses will be made once while the retrenchments return every year. The general advantages of the cyclical production model are already described in Section 2. The proposed concept leads to a more realizable and stable production plan. The use of the powers-of-two method makes it relatively easy to schedule articles for which $k_{ij} > 1$. The cyclical production inventory model leads to a closer realisation of the production plan. Managing the production plan is easier due to the stability and robustness of it; especially the labour planning will be less complex: the sequence of activities on the short term is known in advance, vacations can be better planned.

The effect of the cyclical production inventory model has been tested on two of the twenty-two filling lines of Alabastine Operations. The first is for powder articles and the other for ready-mixed articles. Determining the order-up-to levels requires a model for the demand distribution. We used the gamma distribution for the weekly sales as for 80% of 48 (randomly chosen) articles produced on two filling-lines, the goodness-of-fit $\chi^2$-test statistic yielded a non-significant result at $\alpha = 0.05$.

- The current situation

The first line produces 63 different powder articles, which are divided into three families, based on the changeover times between the different sizes of the packages.
Currently, all articles of one of the families has a cycle time of one week. Most articles of the other two families have a cycle of six weeks, except some articles that have a cycle of nine weeks. The second line produces 62 different paste articles that can be divided into seven families, based on the changeover times between the different products. All the articles of these families have a cycle of three weeks in the current situation.

In addition to the production cycles, Alabastine Operations fixes a batch size for every article. These batch sizes are approximately equal to the yearly forecast times the article cycle time in years, applying a so-called time-supply rule. Because Alabastine Operations has decided to produce only full batches, not every article has to be produced every cycle. In practice one can even observe situations in which only two or three articles of a family of twelve articles are produced in one cycle. As can be observed, the article cycle times are rather arbitrarily decided. As such, this production strategy is one possible reason that the inventory of the SKU’s is high. Another reason is the use of a time-supply rule to determine the safety stock of a article. This decision rule is easy, but does not take into account the demand variance of an article. The current way of working leads to a total yearly cost for production (changeovers) plus inventory of 330,000 euro.

• The cyclical production inventory model

Applying the procedures of Atkins & Iyogun (1988) and McGee & Pyke (1996) we determined a family base cycle of seven weeks for the first line and article cycle times of 7, 14 and 28 weeks. For 57% of the articles it holds that the economic order quantity is larger than the current batch size. Due to this result and to the abandonment of the time-supply rule, the changeover costs can be reduced with 44,000 euro and the inventory cost can be reduced with 19,000 euro. In total, 42% cost reduction or 63,000 euro can be realized on the first line. This cost reduction is mainly the effort of the larger production cycles of the articles that have a current production cycle of one week. We determined a family base cycle of nine weeks for the second line resulting in article cycle times of 9, 18, 36 and 72 weeks. With regard to the current production cycle it is not surprising that the economic order quantity is larger than the current batch size for 82% of the articles. The cost reduction in changeover costs that can be achieved at this line is 33,000 euro. The cost reduction with regard to the inventory costs is 9,000 euro. In total 25% cost reduction or 42,000 euro can be realized on the
second line. Thus total cost reduction on the two lines is 63,000+42,000 which is 32%. The cost reduction that Alabastine Operations can achieve on the other 20 filling lines is expectedly around 25%. No other filling line has lower current production cycles and batch sizes than the first line. The implementation of the cyclical production inventory model would lead to a decrease of the inventory of Alabastine Operations, but the decrease of the number of changeovers reduces costs most. Furthermore, nervousness in the factory will decrease resulting in less stress among the production people.

Summarizing, we can conclude that Alabastine Operations has mainly been minimizing the minor set-ups costs instead of the total set-up time costs. Together with the time supply rule that is used to determine the safety stock levels, this resulted in high inventory levels with a high risk of un-saleable inventories.

**Improvement opportunities**

After implementing the cyclical production inventory model some improvement steps for a better performance may be necessary. Some of those steps require a cost effort that could not be expressed in the model:

- Improve the communication between the different departments of the company;
- Produce forecasts over the same period as is used in the ERP system;
- Do not include action articles or articles with an irregular pattern into the model;
- Recalculate the parameters of the model whenever the realised customer service is too low or too high;
- Investigate the possibilities to reduce the changeover times; and
- Change the current cost accounting system to Activity Based Cost accounting.

The cyclical production inventory model may be inappropriate (and needs to be adjusted) when, e.g.:

- The suggested production quantities are too low to guarantee an excepted level of quality; and
- The total changeover time increases to a level that makes it impossible to produce all the articles that are on the production plan (see the various assumptions in the Appendix).
6 Conclusions

In this paper we discussed that advanced planning and scheduling systems are not often used in practice in the process industry. Commercial software solutions are mostly interactive ‘simulation’ tools, or heuristics, to support the user. Most of these lack the incorporation of advanced inventory control models and are designed for discrete industry. The above case discussion points toward the need for a more thorough investigation of the specificities of planning models in process industries. In particular, it is essential to design a production planning and inventory control-system using a finer description of the production process itself within long- and short-term planning horizons. The paper also shows that tailor-made PPIC solutions can be simple and easily understood by the users. Such tools are increasingly needed in the PPIC decision-making process for the process industry. The approach can be easily implemented in a spreadsheet, a familiar and user-friendly environment for the production planners. Hopefully, this work will persuade readers to develop more tailor-made solutions and methodology to solve the PPIC problems in different sectors of process industry.
References


Appendix: *Determination of the production duration (run time) per family per production run under the condition of no capacity restrictions and assuming no changes in demand mix.*

Notation:
- \( R_i \): production rate for family \( i \) (including the minor set-ups) \#/machine-hour
- \( D_i \): total demand for family \( i \) per year \#
- \( T_i \): family base cycle of family \( i \) (assume \( T_i = c \times f_i, \ f_i \in \mathbb{N} \)) machine-hour
- \( S_i \): set-up time for family \( i \) (known after sequencing the families) machine-hour
- \( P_i \): total required production run time for family \( i \) per year (incl. setups). Assumption: \( \sum P_i \leq AP \)
- \( AP \): total available production time per year machine-hour
- \( NS_i \): Number of (major) set-ups for family \( i \) per production-schedule \#
- \( PT_i \): family production run time of family \( i \) per production run (incl. setups) machine-hour
- \( L \): length of repeating pattern of family productions, i.e. length of production-schedule \( L = \max \{ T_i \} \) if \( f_i = 2^{p_i}, \ p_i \in \mathbb{N} \) machine-hour

Assume that

\[
L = NS_i \times T_i, \text{ for all } i
\]  

(A1)

The total production run-time per year is the sum of the required mere production time (including minor set-ups) and major set-up time

\[
P_i = \frac{D_i}{R_i} + NS_i \times S_i \times \frac{\sum P_k}{L}
\]

or, using (A1),

\[
P_i = \frac{D_i}{R_i} + S_i \frac{T_i}{T_i} \times \sum P_k
\]  

(A2)

Summing over \( i \) yields

\[
\sum P_k = \frac{\sum D_k/R_k}{1 - \sum S_k/T_k}
\]

Assuming

\[
\sum S_k/T_k < 1
\]

and

\[
\sum P_k < AP
\]
we get

\[ P_i = \frac{D_i}{R_i} + \frac{S_i}{T_i} \times \frac{\sum D_k/R_k}{1 - \sum S_k/T_k} \]

The fraction of time for production of family \( i \) per year equals the fraction of time for production of family \( i \) per production cycle. Therefore

\[ \frac{P_i}{\sum P_k} = \frac{PT_i \times NS_i}{L} \]

(A3)

Combining (A2) and (A3) we finally get

\[ PT_i = \frac{L \times (1 - \sum S_k/T_k)}{NS_i \times \sum D_k/R_k} \times P_i \]
Figure 1: The proposed approach
**Jalal Ashayeri** is professor of Supply Chain Management. He has a Ph.D. in Industrial Engineering Management from Katholieke Universiteit Leuven, Belgium. He has more than 19 years experience teaching and advising manufacturing organizations through the managerial and technical changes required to gain value from using management engineering knowledge and information resources to pursue quality, productivity and flexibility. He has collaborated with companies representing a broad array of manufacturing and service industries.

**Ruud Heuts** graduated with an MS and Ph.D. in econometrics from Tilburg University in The Netherlands. As an associate professor in Quantitative Logistics at Tilburg University he is supervising students who are working on external business projects and is teaching on operations management and management science. At the moment he retired from university to spend more time on cultural life, such as visiting concerts and museums, and reading books on historical events.

**Harry Lansdaal** is head of the department inventory management of Syntec B.V. He holds his master degree in Econometrics & Operations Research from Tilburg University. After he finished his study, he started to work for Syntec B.V. As well as his work, Harry likes travelling, cycling and ballroom dancing.

**Leo Strijbosch** is an assistant professor of Logistics Management in the Department of Econometrics & Operations Research at Tilburg University. He holds an Engineering Degree from the Technical University of Eindhoven and a Ph.D. in Medical Statistics from the University of Maastricht. He has special interest for statistics, inventory management, programming and swimming.