

## Demand management as a tactical decision tool in capacitated process industries

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**Demand Management as a Tactical Decision Tool  
in Capacitated Process Industries**

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# **Demand Management as a Tactical Decision Tool in Capacitated Process Industries.**

## **Abstract**

A considerable number of firms in process industries are faced with a necessity to formalize the demand management function. This formalization is triggered by the limited availability of capacity compared to the aggregate demand level, and additionally the limited flexibility of available capacity in the short term. This paper presents a concept for long-term capacity coordination in process industries, incorporating the demand management function as a tool to balance capacity in the long run. An implementation of the concept is presented to illustrate the practical validity.

## **1. Introduction**

Ever since companies have increased in size during the last century, the problem of coordination between manufacturing and sales has expanded in relevance. Usually, some informal guidelines for the sales department are available which represent the capabilities of the production department. In semi-continuous process industries, however, informal general guidelines are not adequate to represent these capabilities. This is due to the extreme inflexibility of production capacity in such industries.

This inflexibility is caused by the high utilization rate of the installations, which can be understood from an economical point of view. In general, the production installations in semi-continuous process industries are very expensive. Additionally, the share of raw material cost in the selling price is high (50-80%). Consequently, profit maximization means maximizing the throughput of the expensive production installation, resulting in round-the-clock production and long production runs.

In this paper, a process industry installation is modelled as a multi-product single machine resource. Lotsizing and scheduling problems of these installations have received considerable attention in the literature (e.g., Doll and Whybark [1], Elmaghraby [2], Haessler [3], Park and Yun [4], Leachman and Gascon [5]). The heuristics presented in these papers, however, do not cover the high utilization problems encountered in semi-continuous process industries. In general, the scheduling procedures only perform well, if the capacity load to be handled by the machine is managed well at a higher (tactical) decision level. Managing the capacity load in semi-continuous process industries therefore not only involves the detailed work load control (see, e.g., Bertrand *et al.* [6]), but also the aggregate coordination of capacity comprising both the allocation of production capacity and the selection of demand (demand management).

In this paper we present an approach to model this capacity coordination function. In the next section, we outline the theoretical background of the model. In Section 3, an implementation of the model in a bottling company is described. The bottling company is located in Europe and bottles beverages into paper packs and tin cans. The production planner of the company has developed a spreadsheet program which is based on the theoretical model. The spreadsheet model is used for the coordination of capacity. We complete the paper by drawing some conclusions, specifically focusing on the organizational consequences of performing the demand management function at the tactical decision level.

## 2. Theoretical framework

Our framework makes a number of assumptions about the actual characteristics of semi-continuous process industries. These assumptions are based on the results of empirical studies in glass, steel, paper, chemical, food and beverage companies. Consequently, we consider the following characteristics for the semi-continuous production systems:

- (a) The production installation can be considered as a single machine. An installation can be considered as such if the production time is short and if the various consecutive parts of the installation can only be operated jointly. If a number of

parallel installations exist, we assume there is no interchangeability of products between the installations.

- (b) The number of different products manufactured on this single machine is limited. In general, this number will typically not exceed twenty.
- (c) The various products may differ in terms of demand or other characteristics.
- (d) The impact of change-over time on the availability of capacity is high.
- (e) The demand level is high compared to the available capacity.

Additionally, the added value per unit of product sold is generally low. Therefore, maximizing profit means maximizing throughput and expending as little time as possible on setting up. However, avoidance of setting up can only be achieved by increasing the batch sizes, resulting in increased inventory cost and thereby reducing profit. In all cases, the selection of the ratio of capacity used in actual production to that expended in setting up determines the quantity of products which can be delivered and the average level of inventory that needs to be held (given the demand characteristics and the required service level).

In order to be able to develop a feasible production schedule, this ratio needs to be determined. The ratio can be expressed as a function of the cycle times of the individual products. In this respect, the cycle time of a product is defined as the elapsed time between two consecutive starts of a production run of that specific product. Cycle time has been used as a parameter in early ELSP approaches (e.g., Doll and Whybark [1], Elmaghraby [2]). However, capacity consequences of the cycle time selection have not been addressed in these early approaches, since this research primarily focused on the scheduling problem instead of on the capacity requirements planning and check. In posterior research, capacity checks have been incorporated into the determination of cycle times. Leachman and Gascon [5] introduce a capacity check embedded in the cycle time determination procedure by Doll and Whybark [1] and adapt the initially determined cycle time to ensure capacity feasibility.

In the approach presented here, the cycle times are to be kept stable. In order to clarify the idea of the approach, consider Figure 1 and Figure 2.

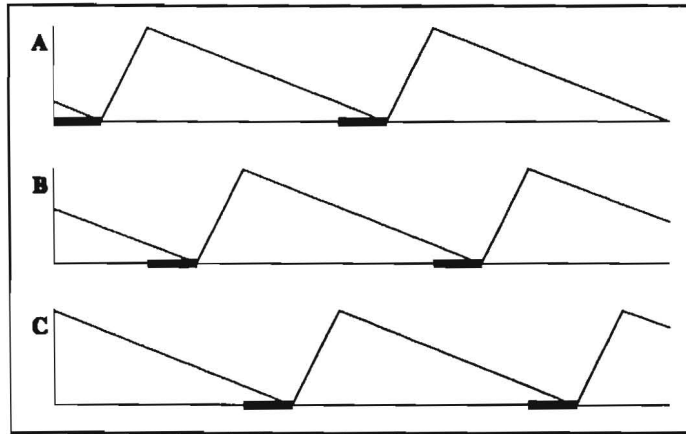


Figure 1. Regular inventory pattern with constant demand rate

Suppose that three products (A, B, and C) are manufactured on a single installation. If demand is constant, the inventory patterns will approximate the pattern shown in Figure 1. In Figure 1, the horizontal axis is the time axis, whereas the vertical axis represents the inventory quantity. Set-ups are represented by the black rectangles on the horizontal axis.

Suppose the demand rate for product A temporarily increases. If the production department reacts by advancing the start of the next production run of product A, then the cycle time of A reduces, and the production run of product C cannot be completed as planned (see Figure 2). This is caused by the fact that the set-up for product A has to be performed earlier than planned (the white rectangle in Figure 2).

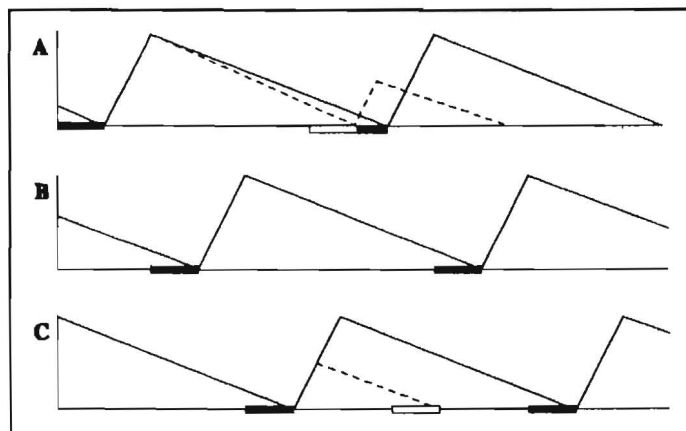


Figure 2. Inventory pattern if demand exceeds the cycle time capability


All else remaining the same, in the next cycle, product C will run out of stock earlier than planned, since the run length of product C was shortened. This would cause a similar

reaction, i.e., reducing the run length of product B to advance the start of the next production run of product C. Ultimately, a chain reaction sets in and as a result of the spike in the demand rate for product A and the shop reaction to shorten the run length of product C, the cycle times of the products are reduced. The reduction in cycle times affects the distribution of the available capacity in such a way that less capacity is available for production and more capacity is spent on setting up. Consequently, the regular demand level (which is assumed again after the temporary increase) cannot be met. Restoring the original distribution of available capacity requires an increase of the cycle times (and in corresponding inventory levels). If the production run length of a single product is increased, the extra products produced will mainly be meant to cover demand during the increased length of the cycle. This will eventually restore the service level again to its original level. However, due to the increased production run length of a single product, production of all other products needs to be postponed. Overall, this situation will lead to a considerable period of time with an excessive fraction of demand not being filled.

In fact, in the above described situation short-term interests (flexibility) are preferred to long-term interests (total throughput and profit). A policy aimed at short-term results will focus on realizing a high service level on any short-term demand. However, this influences considerably the distribution of capacity. More specifically, it reduces the fraction of capacity available for production. Due to the high demand levels, this will lead to long periods with unfilled demand and influence considerably the long-term profitability of the business. Therefore, under the assumption that the business's objective is its long-term profit, the basic principle for production control in highly utilized single-machine production systems with high set-up times is to keep cycle times stable.

Under a stable cycle times policy, the variance of cycle time for each product, over time, is low. When the product cycle times are kept stable, it will enable minimizing the amount of capacity expended on set-up and thus increase productive use of capacity. This, in turn, will enhance the coordination between long-term tactical plans and short-term operational decisions. However, a problem might occur, if the actual demand for individual product(s) is consistently different from the average rates used for long-term

planning. When the demand level is greater than anticipated and the cycle time is held constant, the excess demand is lost and the service level decreases. Note that in this case there is no loss of productive capacity since run-lengths are not decreased. When the demand level is less than anticipated and the cycle time is held constant, however, inventory can increase in an uncontrolled fashion. Thus it may be necessary to correct for this, by adjusting the batch size (and, perhaps, the cycle time) if and only if inventory rises above a pre-set upper limit. Thus, it is clear that operating under a regimen of stable cycle times will reduce cycle time variance and, in turn, will increase productive capacity.



Adopting this policy has its consequences for the demand management function. Consequences can be distinguished at two decision levels: the operational and the tactical level. At the operational decision level, lost sales have to be accepted. If the inventory level drops below zero, rescheduling of production (and thus reduction of cycle times) cannot be used as a corrective measure. This increases the importance of demand management at the tactical decision level, since both target sales levels and customer priorities need to be determined in the medium-term.

### **3. Formalization of demand management**

Definitions of demand management and an overview of published research are extensively discussed by Guerrero [7] and we refer to that article for further references. Since Guerrero's research concerns the analysis of the demand management function in assemble-to-order production environments, we will develop our own definition for demand management. Several aspects need to be included in this definition. First and foremost, when aggregate demand is greater than capacity, some demand will be lost in the short term. Consequently, it is important to balance demand to capacity in the medium term in order to satisfy long-term business objectives. This implies that the demand management function needs to be incorporated at this tactical decision level. Secondly, the demand management function needs to take two separate decisions. First, it needs to be decided what will be the aggregate level of production. This determines



the policy of the company regarding cycle times and inventory levels. Therefore, the production management function and the inventory management function within an organization need to be involved in taking this decision. Secondly, once the aggregate production level has been determined, it needs to be decided how this productive capacity will be allocated to the various products and customers. Initially, the allocation of productive capacity over various products can be based on the gross margin per unit of capacity used for each of the products, assuming the company's objective is profit maximization. However, serious attention should be given to customer prioritizing. If customers take a number of different products from a supplier, then the supplier has a limited amount of freedom in allocating capacity to the various products in that the supplier needs to be cognizant of customer order packages (i.e. mix of products demanded) Depending on the kind of market addressed by the company, the prioritizing of customers is either first in priority before or second in priority after the allocation of capacity to individual products. In most semi-continuous process industries, with a limited number of products and generally industrial customers, the following procedure is used. First a limited number of class A customers are selected. The products required by these customers will be produced in any case. The selection of the remainder of the products may then be based on the gross margin of each of the products, under a profit maximization objective.

Therefore the demand management function in the production environments addressed in this study will be defined as follows:

*Demand Management is a decision function at the tactical organizational level, taking decisions covering the medium term (e.g., one year) and concerning:*

1. *aggregate sales level (together with production and inventory management)*  
*and*
2. *target sales levels per product.*

*These levels serve as guidelines for the operational sales departments. The operational sales function is not considered part of the demand management function.*

The operational sales function performs the actual order acceptance within the restrictions provided by the demand management function. The position of the demand

management function within the production control framework is graphically presented in Figure 3.

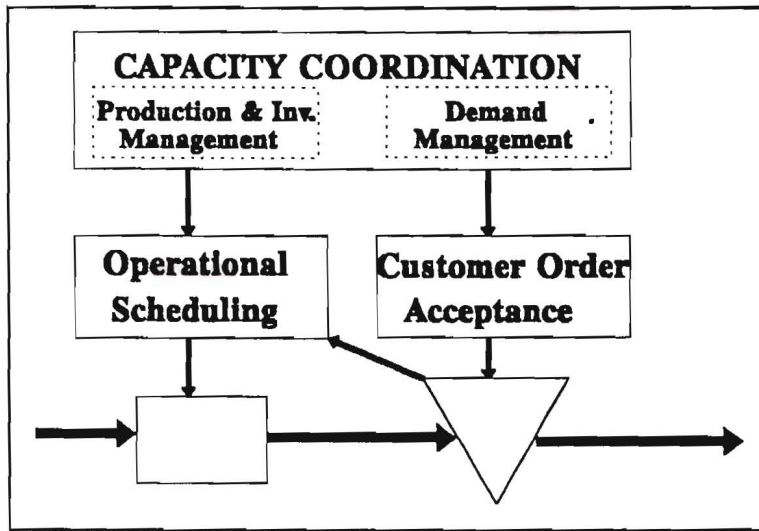


Figure 3. General production control framework for capacitated flow process industries.

The capacity restriction for the demand management decision can be easily formulated as a function of the individual product cycle times:

$$\sum_{i=1}^n \frac{c_i}{T_i} + \frac{\hat{d}_i}{p_i} \leq 1 \quad (1)$$

where

$n$	number of products
$i$	product identifier ( $i=1..n$ )
$c_i$	set-up time of product $i$
$T_i$	cycle time of product $i$
$\hat{s}_i$	sales rate of product $i$
$p_i$	production rate of product $i$

In this restriction, the first term of the left hand side represents the fraction of capacity expended on set-up, while the second term represents the fraction of capacity expended on production. The set-up times and the production rates are given characteristics of the production system studied. It should be noted that the selection of cycle times determines the aggregate level of sales. Likewise, the selection of the product sales levels determines

the average cycle time needed. As indicated earlier, it is necessary to determine the cycle times in advance, at the tactical level, in order to realize a predetermined output of the production system. Since the determination of the product cycle times is very closely related to the determination of the sales level, this restriction also shows the necessity of positioning the demand management decision at the tactical decision level.

In the next section, we will describe the implementation of the stable cycle times concept (including the cycle times determination and the consequences for the demand management function) at one of the largest brand-independent European bottling companies.

## **4. Case description**

### **4.1 The Company**

The Bottling Company makes beverages from concentrated juices and extracts [8]. Partly, the beverages are packed in paper packs, partly they are packed in tin cans. In this article, we will only consider the paper packs department, which mainly bottles all kinds of juices, such as apple and orange juice. In the first part of the production process, a syrup is composed by mixing fruit concentrates with other raw materials and water. This syrup is temporarily stored in large tanks, awaiting the right production line to become available. Once the production line is available, the syrup is diluted with water in order to get the right concentration of juice. This juice is then transported through pipes to the filling process, where the packs are filled. Finally the packs are packaged in transportation units (e.g., twelve packs of juice on a tray) which are again combined on pallets. These are then moved into the warehouse, from where they are distributed to the customer. The production processes from filling to pallet packing are built into a production line and can be considered as a single machine, since no products are being produced while one of the units is rebuilt. The storage capacity between the various processes (buffers) is negligible. The company has 11 packaging lines for paper packs.

The syrup composition department is not considered in this study, since this department is not a capacity bottleneck.

The department's product range consists of a number of different juices (recipes). Each of the recipes is processed into a number of packs, differing in size and/or print. In between two production runs of a different recipe, it may be necessary to clean the production lines. For some lines, this takes about half an hour, for other lines, this may take up to three hours. Changes in pack size do not occur, since each production line is only suited for a specific pack size. Changes in design (same recipe and same size) only take a few minutes.

Each product has a strong preference for a specific production line. Therefore, we may consider each line separately and do not have to take into account the (limited) interchangeability of products between production lines.

Demand has a seasonal pattern. Demand peaks occur just before the Summer (June and July) and before Christmas (November/December). Demand is lowest from January till April. During the Summer peak, regular production capacity is insufficient to fill all demand. Therefore, two measures are taken. The first one is the expansion of work force from two to three shifts. Since labor law limits frequent and unannounced changes in work force, careful planning is required of the date when the capacity is changed from two to three shifts and of the date when it is changed back to two shifts. The second measure taken to manage the Summer demand peak is the creation of capacity inventory during the pre-season period in Spring. This also requires careful consideration, since extensive stocks cost a lot of money (low added value in a voluminous product) and products are perishable.

Virtually all products are produced to stock. The main reason for this is the imbalance between the frequency of production of a specific product, and its required delivery time. The required delivery lead time is typically a few days, while every product is being produced typically every other week or even less frequent.

The company's account managers generate sales forecasts on a rolling horizon basis, 12 months ahead. For the weeks ahead, the production planner tries to construct more detailed forecasts and delivery schedules. Based on these forecasts the production plan is made. The production plan consists of a long term plan, which mainly determines work force size (two or three shifts) and the inventory build-up, and a short term operational schedule based on more detailed forecasts. The detailed schedule is made typically with a two-week horizon.

Problems in the present situation include the following:

- the end product inventory level is high while the service level is relatively low, meaning that generally the "wrong" products are kept in stock.
- frequent changes occur in the production schedule, which result in loss of capacity (due to generally shorter production runs).
- measures to account for the seasonal demand pattern are insufficient and uncoordinated.

The first two problems have been tackled by introducing the stable cycle times concept described above. The measures to account for the seasonal demand have been incorporated in this model at a higher decision level.

## **4.2 Model implementation**

A revised decision structure for the operations management function in the company has been developed. This decision structure is based upon the model outlined in Figure 3. The new company decision structure is presented in Figure 4.

The capacity coordination decision function is represented in the top tier of Figure 4. The capacity plan represents the determination of the work force level. The sales plan represents the annual sales forecast. The annual sales forecast is time-phased with monthly time-buckets. A spreadsheet model has been developed by the production planner in which the sales are represented in capacity requirements and thus a capacity

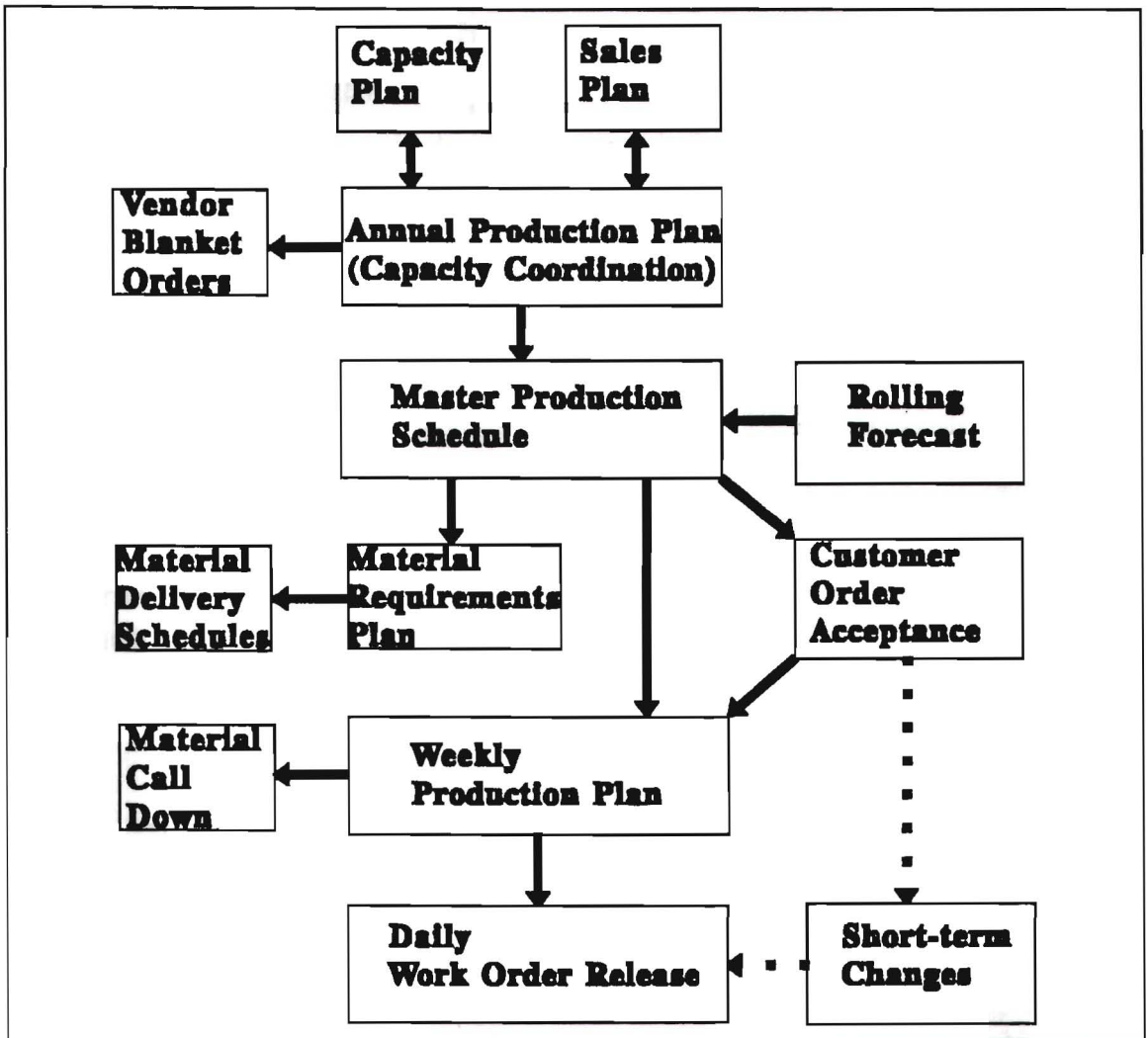


Figure 4. Production control framework of the bottling company.

plan per production line can be made. If the capacity level and the target sales levels for each production line are known, the capacity coordination function can be performed. Using the heuristic provided by Doll and Whybark [1] multiples are determined for each of the products, which represent the relative frequencies by which these products are produced. These are based on cost considerations and basically a trade-off between inventory carrying cost and set-up cost is made. Given the total sales plan per production line, it is then determined how much capacity is required for production. Given equation 1 and the integer multiples, the resulting individual product cycle times may be determined and the corresponding required inventory levels calculated. All these relations are incorporated into the spreadsheet model.

Since this is a sequential procedure, it is certainly not optimal. However, because of the simultaneous determination of cycle times in accordance with the capacity check, feasible production targets are set and its consequences are known. Since the entire procedure has been incorporated into a computer spreadsheet, a number of alternative scenarios can be generated, which form a proper basis for discussion between the manufacturing and marketing departments. In this way, the required capacity coordination is obtained, while quantitative arguments can be given to the demand managers.

The implementation of the new concept at the company has given tools to the production planner for managing capacity and inventory of the company more tightly. This has resulted in a considerable decrease of inventory, while maintaining the (high) service level. Additionally, the new way of working has caused considerably more stability on the production floor (due to the stable cycles). Although effects of this stability are not yet fully evident, an increase in productivity is expected.

## **5. Conclusion**

This article showed that in situations with tight capacity, such as semi-continuous process industries, it is necessary to manage demand more consciously at a tactical decision level. This change in decision structure is caused by the mechanism which affects available productive capacity in the short term. It also demonstrated that cycle time changes in the short term (affected by uncoordinated acceptance decisions) decrease productive capacity.

A clear advantage of the proposed decision structure is the simplicity of the balance equation (1), which can be easily understood by the production planner and simply implemented into a spreadsheet program. The ideas were conveyed to the production planner in a two-day course and implementation support was provided to the company by a graduate student.

## Acknowledgment

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