Balancing the Costs for Finished Goods Inventory and Production Capacity in a Make-to-Order Company

A Case Study at Tetra Pak

Sara Brolin
Lund University, Faculty of Engineering, LTH
Division of Production Management

In most manufacturing companies, it is necessary to carry inventory to a greater or lesser extent in order to disconnect the activities in the supply chain that are not conducted at the same pace. This way, a smoother flow through the chain is achieved, but different parts of a company often have conflicting goals when it comes to inventory decisions. Benefits in one department will bring costs in another, and it is therefore vital to have a common understanding within the firm of the relationship between the conflicting goals and the total cost of ownership in order to facilitate decision making regarding inventory and production.

Background
This study has been carried out in cooperation with Tetra Pak, a manufacturer of equipment for filling and packaging of liquid foods, which applies make-to-order production. Today, the company focuses on an even level of production and a high level of customer order fulfillment, and even though statistics are kept on inventory levels and storage costs, the relationship between finished goods inventory and production costs is relatively unexplored.

Not having investigated the connections between production decisions and inventory costs makes it difficult to evaluate the financial effects of deciding to produce for stock or avoiding doing so. The ambition of this project has therefore been to enhance the understanding of the inventory cost situation within Tetra Pak, and provide a good overview of the connections between inventory costs and production planning in general.

Purpose
For Tetra Pak to acquire a better overview of the cost situation related to finished goods inventory of filling machines, the purpose of this study is to identify and quantify the cost parameters that affect the total cost for holding inventory, and the cost consequences of avoiding putting equipment in stock. Apart from this, a way of determining the most cost efficient balance between inventory and capacity costs should be suggested.

Method
The costs of and interrelationships between activities relevant for this project have been identified through an interview based, deductive case study focusing on finished goods inventory at Tetra Pak. These company specific parameters have then been used for setting up an aggregate planning model and making calculations to obtain a near cost optimal production plan.
in an example case. Furthermore, the cost factors have been compared individually in order to establish an understanding of how they are interrelated in an isolated decision situation.

Results
The results of the project consist of two main parts. First, the cost parameters related to finished goods inventory have been identified and determined, and second, a model for cost optimization has been developed based on the company specific situation at Tetra Pak. Each of these parts will be discussed separately below.

Cost parameters
The relevant costs to be evaluated in this particular case were the following:

- Inventory holding costs,
- Regular production costs,
- Costs for external resources,
- Backorder costs and
- Costs for missed production slots

The inventory holding cost is dominated by the cost for capital. This fact implies that the cost for holding inventory can be approximated as a linear function of a variable replenishment cost of a product and the opportunity cost for tied up capital, as suggested in previous research (see e.g. Silver et al. 1998). To obtain as exact results as possible, however, it is recommended that as many of the cost parameters that make up the holding cost as possible are included in the cost calculations. For Tetra Pak, these additional parameters to be considered are the cost for storage space and the cost for insurance of machines in stock.

When it comes to production performed entirely by Tetra Pak’s internal workforce, the cost for this activity is based on a fixed rate per hour, which applies independent of the production level. The fixed nature of this cost makes it, in a short-range perspective, independent of production decisions, and it can therefore be set to zero as long as the number of machines requested can be produced without hiring extra personnel. If the level of production exceeds what can be produced by Tetra Pak’s internal workforce, however, the total cost for production will increase as external resources are required. These extra costs follow a linear relationship depending on the price of external manpower and the number of machines produced per time unit.

The cost for a backorder is not easy to determine, due to the fact that the value of customer service cannot be measured only in financial terms. Soft aspects such as customer relationships and damaged reputation have to be taken into consideration as well, which means that in order to get a correct value of the backorder costs, such aspects have to be translated into money. The procedure of doing so requires far more time and effort than has been possible to devote within the scope of this project, which is why the decision was made to base the backorder cost on an estimated penalty fee per week of delay of a particular machine.

This cost will grow linearly with increased order value and the number of weeks the machine is backordered. It is however important to notice that the penalty fee does not always apply in reality, since there are several conditions that have to be fulfilled in order for the customers to be
entitled to economic compensation for order delays. Furthermore, the penalty cost used as an estimation of the backorder cost does not take neither soft nor long term aspects into account. These observations imply that the backorder cost does probably not correspond to the real value of customer service.

The last cost that is relevant in the case of Tetra Pak is the cost for missing a slot in production. A missed slot will bring two main consequences for the company; first, there will be capacity available in the factories, which will not be utilized for value adding activities, and second the suppliers that deliver modules to the production will have dimensioned their inventory levels according to a higher expected level of production, which will result in more capital tied up for a longer period of time on the supplier’s side. Both of these consequences will result in increased costs for Tetra Pak, and the estimations made within the company show that a single missed slot will cost approximately six times more than a week of inventory for a machine.

Cost optimization
To determine a near cost optimal production plan, which to the greatest extent possible fulfills the customers’ requests at the same time as the profit is maximized, an aggregate planning model has been developed based on a general model suggested by Chopra and Meindl (2007). Since all the relevant cost parameters are linear functions, it is possible to solve the problem with linear programming. In this case, the Solver tool in Microsoft Excel has been used for this purpose, mainly due to its accessibility and user friendliness.

The total cost for a period $t$, $C_t$, is expressed as

$$C_t = c_M(S_t - R_t - E_t) + c_I I_t + c_B B_t + c_R R_t + c_E E_t$$

The target function for a planning horizon of $T$ periods will be

$$\min \sum_{t=1}^{T} C_t$$

subject to (for $t = 0, 1, \ldots, T$)

$$I_t = \max(0, I_{(t-1)} - B_{(t-1)} + R_t + E_t - D_t) \quad \text{(inventory balance)}$$

$$B_t = \max(0, -(I_{(t-1)} - B_{(t-1)} + R_t + E_t - D_t)) \quad \text{(backorder balance)}$$

$$I_t \leq I_{max} \quad \text{(max. allowed inventory per period)}$$

$$\sum_{t=1}^{T} B_t \leq B_{max} \quad \text{(max. allowed backorders in total)}$$

$$S_t \leq S_{max} \quad \text{(max. possible capacity per period)}$$

$$R_t \leq R_{max} \quad \text{(max. internal production per period)}$$

$$R_t + E_t \leq S_t \quad \text{(max. total production per period)}$$

$$R_t, E_t, I_t, S_t \geq 0 \text{ for } t = 0, 1, \ldots, T \quad \text{(non – negativity)}$$

$$R_t, E_t, I_t, B_t, S_t \in \mathbb{N} \text{ for } t = 0, 1, \ldots, T \quad \text{(positive integer parameters)}$$

The cost parameters are denoted:

$c_I$ inventory holding cost / week

$c_B$ cost / week for unfulfilled request

$c_R$ cost / machine produced by regular workforce
The input parameters that are assumed to be known in period 0 are:

- \( D_t \): demand in period \( t \)
- \( I_0 \): stock level in period 0
- \( B_0 \): number of backorders in period 0
- \( I_{\text{max}} \): max. inventory allowed per period
- \( S_{\text{max}} \): max. no. of slots possible per period
- \( R_{\text{max}} \): max. internal production per period
- \( B_{\text{max}} \): max. no. of backorders per period

Discussion

Several simplifications of reality have been made in order to obtain a model that is easy to interpret and that has an acceptable solution time in Excel. These simplifications will increase the user friendliness of the model, but will also impact the results in different ways. In this section, the most important drawbacks of the model, caused partly by the simplifications made, will be brought up.

First of all, the model provides a solution that is optimal from a strict cost perspective. This means that no strategic or soft aspects related to customer and partner relations are taken into consideration, unless they are incorporated in the model setup or the input parameters. Moreover, there is no buffer for unforeseen events included in the model setup, which means that the production plan suggested in the optimal solution will be rather inflexible.

The fact that other partners in the supply chain, specifically material suppliers, are not part of the model increases the risk of sub-optimization from a holistic supply chain point of view. A solution that is cost optimal within Tetra Pak might not be
setting the optimal conditions for other parts of the chain. To obtain a solution that optimizes the cost for the whole supply chain, it is necessary to involve suppliers and customers in the project, and understand the connections between the own company and each partner and customer.

Another issue that has to be taken into consideration is the fact that the cost for backorders does not provide a sufficiently reliable picture of reality. This cost parameter is based only on assumptions, and could therefore make the model produce a solution that is not optimal in a real case. It is therefore important to be aware of this drawback when interpreting the results of the model and using them for decision making.

Conclusions
In this study, the relationships between costs for inventory and capacity utilization at Tetra Pak have been investigated. It can be concluded that the inventory holding cost is dominated by the capital cost, and that the total cost for holding inventory is significantly lower than the costs for un-utilized capacity and backorders. Hence, the alternative to produce for stock is, in the case of Tetra Pak, often a preferable option compared to missing slots in production or not fulfilling the customers’ requests.

Since the results of the model do not take any soft aspects such as customer and supplier relations, or production flexibility into account, it is recommended that the optimal solutions are used carefully when making decisions about production planning. Instead of using the solution as an answer key to what the optimal production plan might look like, it should be seen as an indicator of directions. The soft aspects have to be kept in mind upon decision making, as well as an awareness of how the determination of cost parameters and other input data will affect the final results. By doing so, the model can provide useful information about the interrelationships between the cost parameters within a pre-defined planning horizon.

The generalizability of the results can be discussed. As the model setup is based on company specific factors for Tetra Pak, it cannot be directly applied to other situations without modification of the setup and re-determination of relevant input parameters and constraints. However, if such adaptations are done, the overall structure of the model can be used as a basis for determination of a cost effective balance of inventory and capacity costs in production systems similar to the one described in this study. Hence, there are possibilities of generalization of the results, if they are modified to fit the context in which they will be used.

References