Chapter 3

A decision aid for make-to-order and make-to-stock classification

Managers in food processing industries find it difficult to decide which products to make to order and which products to stock. This has been a concern for academic researchers as well. A discussion of the existing approaches is presented and is followed by a description of an MS Access/Excel based tool that is an aid for managers in taking such decisions. The tool is easy to use and maintain but still gives managers a front-end that consolidates various theoretical concepts like ABC analysis, order penetration point, and customer order decoupling point.

3.1 Introduction

Most of the textbooks on production management, e.g. Vollman et al. (1997), classify and define the production strategies as make-to-order, make-to-stock, and assemble-to-order. They relate these approaches to choosing a master production scheduling (MPS) approach. This is done using the basic unit of control to be used in MPS. A make-to-order approach to MPS is typically used when the product is manufactured to individual customer order, i.e. a basic MPS unit is a customer order. In make-to-stock, the MPS is based on end items, and these end products are produced to meet forecast demand. The customer orders are filled directly from the stock. In assemble-to-order (ATO), the MPS is based on some group of end items and product options. In these discussions, however, it is assumed that the strategy that a particular product should follow has been decided and is given. In this chapter, we address how to make this strategic
At the outset, readers should note that our definition of MTO is simple—there is no inventory held in stock for MTO recipes. We look at a specific class of MTO recipes: the customer-specific, tailor-made, one-off recipes (products) are obviously MTO but there are certain recipes that could be produced either to stock or to order. Such recipes are considered for the MTO versus MTS categorisation decision in this chapter. Assemble-to-order is, however, kept out of discussion since in many food processing industries intermediate storage possibilities are limited or do not exist at all.

Traditionally, food and process industries have been associated with commodity products and flow-oriented processes (p.7-8, Vollman et al. 1997) and hence MTS is the most likely policy. However, as suggested in chapter 2, with increased competition, shorter product life cycles, and growth in number of SKUs, the choice of MTO or MTS is increasingly becoming an important topic for these industries as well. This MTO versus MTS decision is more strategically oriented, as it has a direct impact on the customer lead-time that can be offered, and is complicated due to various factors involved. The solution needs to consider the trade-offs between costs, product-process characteristics, and the demands from the market along with the plant capacity. A lot of concepts have been proposed previously to make this decision viz. ABC analysis, ‘customer order decoupling point’ (Hoekstra and Romme 1992), ‘order penetration point’ (Olhager 2003), ‘lead-time gap’ (Christopher 1998). While these concepts make valuable contributions, their application in practice is rather difficult. The application is further worsened by the use of various terminologies floating around. The aim of this chapter is twofold—(i) to integrate various existing theoretical approaches that could be used for MTO versus MTS decision, and (ii) to translate them into a practical instrument.

The chapter is organised as follows—First, the literature that helps us take MTO or MTS decision is reviewed in the next section. The key factors affecting the MTO/MTS decision are identified and are used to develop a practical decision aid to solve the problem. A decision aid which allows manufacturers to partition the products into MTO and MTS categories while respecting the delivery service requirements and the constraints posed by products, processes, and market is described in section 3.3. This tool can be used on any computer running Microsoft Access/Excel with no extra investment. Conclusions and further comments are provided in section 3.4.
3.2 Literature review

A few useful concepts and models are available in the literature. ABC analysis (sans product value) has been widely used with high volume A class items produced to stock while low volume B and C class items considered as MTO. Many papers (Williams 1984, Carr et al. 1993) suggest the use of such simplistic rules. This way of classification, however, considers only the demand factor.

Li (1992) takes a marketing perspective. He studies the impact of market competition and customer behaviour based on price, quality, and expected delivery lead-time on the MTO/MTS production decision in a single product case. Here, the discussion is on ‘what happens when’ one of the factors changes. He concludes that competition can breed a demand for make-to-stock, just as other economic phenomenon such as economies of scale, uncertainty or seasonality, and that delivery-time competition decreases producer’s welfare. Arreola-Risa and DeCroix (1998) provide optimality conditions for the MTO/MTS partitioning in a multiproduct, single machine case with the first-come-first-served scheduling rule. They study the effect of manufacturing (processing) time diversity on the MTO/MTS decision for backorder-cost cases of dollar per unit and dollar per unit per time. Their result, using M/G/1 queuing analysis, shows that holding cost rate, backordering cost rate, and distributions of manufacturing times play an important role in MTO versus MTS decision. They conclude that reducing manufacturing time randomness leads to more MTO production.

Sox et al. (1997) focus on total quantity of inventory and on-time delivery, rather than costs. The goal is to fulfill orders within a certain service time window of \( T \) periods. The primary stock control parameter is the total base stock. They provide expressions for fill rate using \( M/M/1 \) queue with multiple products, base stock inventory policy, one-for-one inventory replenishment, and first-in-first-out order scheduling with service within \( T \) periods. These results are used to allocate the aggregate inventory to the items. The high demand items get stocks assigned to them while low demand items do not. The service of these low demand items is maintained by giving them higher production priority when a demand occurs. Though the authors do not explicitly talk about the MTO/MTS decision, it is clear that their model can be used for that decision. It is felt that despite some restrictive assumptions, like no setup or changeover time, the model can be extended for certain food (process) industries. A lot of food industries have special storage requirements, e.g. cold storage, and a limited storage capacity. This may allow only a few products to be stored. This model can be used to decide which products get base stock assigned to them, i.e. which products
The ‘customer order decoupling point’ (CODP) concept, developed by Hoekstra and Romme (1992), is more comprehensive and looks at market, product, and production related factors to arrive at the MTO/MTS decision. The customer order decoupling point separates the order-driven activities from the forecast-driven activities and is the main stocking point from which deliveries to customers are made. Using the product-market and process characteristics, and considering the desired service level and associated inventory costs, this concept helps in locating the decoupling point and thus, the MTO/MTS decision. This concept has been used in a number of case studies across various manufacturing sectors including food processing e.g. Van Donk (2001). This concept is also known as ‘order penetration point’ (OPP) and has been discussed in Olhager (2003) and the references therein. Olhager (2003) further presents a conceptual impact model for the factors affecting the positioning of the order penetration point. Most of these papers on CODP and OPP discuss ‘what happens when’ a certain factor forces the CODP to shift forward and backward. These papers recognise that the decoupling point choice involves a trade-off between delivery time and inventory costs. This trade-off can viewed as a problem of minimising the costs while meeting market requirements and satisfying process constraints. Regarding delivery time, the major factor is the production to delivery lead time ratio (P/D) ratio (Christopher (1998) uses the term lead-time gap for relation between production and delivery lead times) while the costs are mainly affected by relative demand volatility (RDV). The RDV is defined as the coefficient of variation, i.e. the ratio of standard deviation of demand and the average demand.

We now take a closer look at P/D ratio and RDV since we will be making use of these factors in section 3.3.

If P/D is greater than one, MTO strategy is not possible and MTS is the only choice. If the ratio is less than one, MTO is possible but it may also be possible to produce to stock to gain economies of scale. This is expressed through the RDV, such that a low RDV indicated that some recipes can be produced to stock. If the RDV is high it is not reasonable to use MTS policies since this would mean carrying excessive safety stock inventory. RDV has also been prescribed by D’Alessandro and Baveja (2000) for MTO-MTS classification. They use RDV and average demand volume to categorise products into MTO and MTS. The products with high volume, low variability are MTS products; while products
with low volume and high variability are MTO products.

While the concepts discussed in this section help us understand the complex trade-offs involved in MTO or MTS decision and provide guidelines for it, there is no easily available, ready-made instrument that will achieve the same in practice. Moreover, the capacity considerations are ignored in these concepts since each product is considered in isolation during the decision process. It is felt that there is a lack of an instrument that considers product, market, process characteristics and also takes into account capacity constraints. The next section fills this void. An attempt has been made to develop a decision aid for MTO or MTS decision that takes into account the key factors stressed in the above literature viz. service delivery requirement, demand variability, cost considerations etc., and process constraints, mainly in the form of limited available capacity.

3.3 Decision aid

All manufacturers want to meet the service requirements at minimum cost. Therefore, in deciding MTO or MTS partition, we concentrate on two important aspects: (i) inventories are held to attend delivery service requirements, or (ii) to provide cost savings. In order to do this, we start analysing, first, if service considerations force us to keep the item in stock, regardless of the cost considerations, and if this is not the case we do cost calculations to arrive at the decision. The procedure followed is thus sequential. We start with the delivery service requirement analysis, followed by the demand and cost analysis, finally capacity requirement analysis is done to check and achieve the feasibility of the MTO-MTS classification. Figure 3.1 shows the architecture of this procedural tool. Recipe (product) master and the order book are the main input for the system. Figure 3.2 shows a screenshot of a recipe master input while figure 3.3 shows the structure of the order book. One can safely assume that the exercise of getting this data for any company is easy and rather trivial. Since recipe data is the core of food industries and all the orders are recorded, these should always exist in MRP/ERP systems. We now explain the each step in the sequential procedure.

3.3.1 Service considerations

For each recipe one can associate a desired maximum customer delivery lead time that is acceptable to the customer. This delivery lead time can be determined by taking into account the delivery history of the product (available from the order book) and the market benchmarks. Similarly, manufacturing lead time
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Figure 3.1: Architecture of MTO-MTS decision aid

Figure 3.2: Input screen: Recipe Master
3.3. Decision aid

Figure 3.3: Order book
can be computed for each recipe from previous production order book history or by estimates provided by shop supervisors. This can also be computed using the discussion and procedures provided later in chapter 4.

The decision rule is straightforward— if the manufacturing lead time is larger than the desired maximum customer delivery lead time, i.e. if the $P/D$ ratio is greater than one, the recipe is classified as MTS otherwise there is no need to stock it based on service requirements. The demand and cost analysis has to be taken up in that case.

3.3.2 Demand analysis

In this section, we describe the demand analysis that forms the core of the model. The classical $ABC$ analysis can be easily carried out from the input. However, it is felt that this categorisation is too simplistic and does not account for differences in uncertainty that exists in the demand among various products. Instead, a demand variability analysis, in the form of RDV, as suggested in D’Alessandro and Baveja (2000) is followed. Figure 3.4, shows a plot of average weekly demand on the x-axis and demand variability (coefficient of variance) on the y-axis. It is possible to categorise products into 4 groups— (a) High volume, low variability, (b) High volume, high variability, (c) Low volume, low variability, and (d) Low volume, high variability. The products in the high-volume,
low variability are candidates for MTS production. Most of the product recipes belonging to the low volume, high variability category should be produced on MTO basis. Many recipes belong to the high volume, high variability category and may be produced on MTS basis. However, more safety stock levels would be required for such recipes and economic considerations discussed in section 3.3.3 come into the picture. It is also recommended that closer ties should be sought with the customers in order to reduce their variability.

While doing this analysis, some difficulty arises because of the subjectivity involved in drawing up the lines that partition high demand items from the low demand items and high demand variability and low demand variability. These are the likely areas of conflicts as well as newer opportunities for sales and production departments. For example, classifying a particular product as MTO rather than MTS can have serious implication in terms of longer lead-times for customers, less inventory, more setup time but this also allows differentiated service for different customer classes. Sales and production departments should jointly decide on ‘what is high demand’ and ‘what is high variability’. Some simple rules can be defined, e.g. a vertical partition to take place at a certain percentage of total demand.

Figure 3.4: Output report: Demand Variability analysis. Period indicates a week in the example shown.
3.3.3 Economic considerations

In this section, the cost of producing a recipe to stock and to order are compared. This model is adapted from chapter 4 of Magee and Boodman (1967). The assumptions and the data of the problem are as follows:

- The annual expected demand for the recipe is \( D \) units/year, a number of \( N \) orders are received annually from the customer.

- There is a fixed charge of \( A \) euros/order for the manufacturing setup.

- It costs \( PC \) euros/time unit of machine usage (production and setup time)

- The production rate is \( P \) units per time unit and the average setup time for the item is \( S \) time units.

- If the recipe is stocked, it is ordered in economic order quantities \( Q \); also, to protect against uncertainty a safety stock (SS) is held. In some cases it may be necessary to change these using order quantity modifiers on account of technological constraints like shelf life, minimum batch size etc. These can be easily brought in but are ignored in this chapter.

- It costs \( C_{MTS} \) euros/unit to produce the recipe for stock; it costs \( C_{MTO} \) when it is on order; the two costs are established by assuming that in MTO case the expected order size is \( D/N \) units, and in the MTS case it is \( Q \) units. In some cases, it may be possible to combine MTO orders into one production order but here we will assume that it is not done because of the large product variety and shorter lead time requirements. The combining of orders may lead to long and varying lead times.

- Stock is carried at a charge of \( r \) euros per unit per year.

- Service level is high enough so as to make the backorder cost negligible.

If we produce the recipe on the MTO basis, the average total processing time, \( TPT_{MTO} \), for each order is:

\[
TPT_{MTO} = S + \frac{D}{N \times P} \tag{3.1}
\]

\( C_{MTO} \), the cost per unit is then given by:

\[
C_{MTO} = \frac{TPT_{MTO}}{D/N} PC \tag{3.2}
\]

The total cost is the sum of ordering cost and the cost of the recipe itself. It can be given by:

\[
TC_{MTO} = N \times A + D \times C_{MTO} \tag{3.3}
\]
When the product is stocked, the average total processing time, $TPT_{MTS}$, for each batch is:

$$TPT_{MTS} = S + \frac{Q}{P}$$  \hspace{1cm} (3.4)

$C_{MTS}$, the cost per unit is then given by:

$$C_{MTS} = \frac{TPT_{MTS}}{Q}$$  \hspace{1cm} (3.5)

The expected annual cost $TC_{MTS}$ is:

$$TC_{MTS} = \frac{D}{Q} A + \left[ \frac{Q}{2} + (SS) \right] r + D \times C_{MTS} + C_{syst}$$  \hspace{1cm} (3.6)

where $C_{syst}$, euros/year, is the system cost (the recipe’s share) of having the item stocked. It is also possible to exclude this, since it can be incorporated in the inventory holding cost rate $r$.

The decision rule be applied is: if $TC_{MTO} < TC_{MTS}$ the recipe is classified as make-to-order; otherwise it is a MTS recipe.

Note that in order to compute the total cost we need the estimates of all the parameters involved. Most of them are already available in the recipe master and the order book. The required safety stock can also be taken from historical records, if the recipe was previously stocked; if not, an approximation can be used in the following form:

$$(SS) = k \sqrt{\frac{lD}{12}}$$  \hspace{1cm} (3.7)

where $k$ is the safety factor, and $l$ is the lead time, in months. This approximation is used for high variability recipes in RDV analysis, and assumes that demand during the lead time $l$ follows Poisson distribution; after all, this assumption is not that bad when we recall that these are the slow-moving items. For fast moving items i.e. low variability recipes, normally distributed demand approximation is used.

Figure 3.5 shows a screenshot of the output of the economic considerations.

### 3.3.4 Capacity constraints

Once we follow the sequential procedure described above—service considerations, demand analysis, cost considerations— we get an initial solution to the MTO/MTS partition. However, so far we have considered the recipes one by
one and have neglected their interactions with the capacity. We are not yet sure whether we have sufficient capacity to follow the MTO/MTS partition obtained so far. To do this, a rough-cut capacity check (i.e. ignoring congestion effects like machine interference) is performed. It is checked whether we have sufficient capacity to produce the initial MTO/MTS partition solution. This can be accomplished using the following expressions.

The annual capacity, $X_{MTS}$, required by the recipe if it is produced to stock is simply the average total processing time of the batch multiplied by the number of batches per year. It is given by:

$$X_{MTS} = TPT_{MTS} \times \frac{D}{Q} \quad (3.8)$$

The annual capacity, $X_{MTO}$, required by the recipe if it is produced on order is simply the average total processing time of orders multiplied by the number of orders. It is given by:

$$X_{MTO} = TPT_{MTO} \times N \quad (3.9)$$

The total capacity needed for the given MTO-MTS partition is then given by the expression:

$$\sum X_{MTO} \times y + X_{MTS} \times z \quad \text{where } y, z = 0 \text{ or } 1 \quad (3.10)$$

Figure 3.5: Output report: Economic considerations
where,
\[ y = 1 \text{ if a product is produced on MTO basis; 0 otherwise; } \]
\[ z = 1 \text{ if a product is produced on MTS basis; 0 otherwise; } \]
\[ y + z = 1 \text{ if the product is offered; 0 otherwise. } \]

In case it is observed that there is a shortage of capacity, i.e. the capacity obtained using the expression (3.10) is less than the available capacity, an iterative procedure is followed to modify the existing MTO/MTS partition. The procedure starts by changing the category of that recipe where increase in total costs (by moving it from MTO to MTS category or vice versa) is minimal. After each iteration a capacity check is done again for checking the feasibility of the partition. The procedure terminates when a feasible partition is found or when all items have been checked. In the later case, it is clear that the company has capacity shortage. Then, the company may choose not to offer some recipes with low volume, low variability. Low volume, high variability recipes can be offered on MTO basis, if they have high contribution margins.

Alternatively, it is also possible to use the following formulation for the rough-cut capacity planning instead of the iterative procedure (with feasibility checks) described above.

\[
\begin{align*}
\min & \quad \sum (TC_{MTO_i} \times y_i + TC_{MTO_i} \times z_i) \\
\text{s.t.} & \quad \sum (X_{MTO_i} \times y_i + X_{MTS_i} \times z_i) \leq X \\
& \quad y_i + z_i = 1 \\
& \quad y_i, z_i = 0 \text{ or } 1
\end{align*}
\]

This integer(binary) linear programming model chooses \( y_i \) and \( z_i \) (decision variables) in such a way that the total cost is minimised while the capacity constraint is satisfied. The model is solved using the SOLVER available in Microsoft Excel. Few \( y_i \) and \( z_i \) values will have to be preset using the outcome of the earlier steps, e.g. for a certain recipe, the service requirements may force \( z_i = 1 \), i.e. product has to be produced on MTS basis irrespective of the cost.

There are various output reports available from the decision aid. The most important report suggests the MTO/MTS partition for each recipe along with the justification of the decision. The justification comes from service level requirements, demand analysis, and cost considerations discussed in this section.
3.4 Conclusion

In this chapter, a simple and easy to understand tool for the MTO or MTS decision is presented. This decision, though strategically oriented and complex, influences the production planning and control function of any company. Such decisions are generally taken once every 6 months or a year. The tool presented gives a unified treatment of various trade-offs and considerations that go into taking the decision. There are no data or investment requirements on the part of the company to make use of this tool. The familiar interface of Microsoft Access/Excel makes the use of the tool even more attractive. Here, we must state that this tool has not been fully implemented in a real-life setting but the initial feedback is satisfactory.

It is felt that that the decision aid presented in this chapter is the first ever attempt at developing a ready-made tool for MTO/MTS decision in food processing industries. There are obviously certain limitations with the presented approach. The tool considers only service delivery time requirements, demand variability, and cost considerations. The tool looks at only the two extremes MTO and MTS. It ignores ATO. However, ATO situations are very rare in food processing industry given the fact that the intermediate products are mostly volatile. The logical extension of the aid presented in this chapter should include other factors that impact the MTO-MTS decision. Shelf life, for example, can be easily brought in cost considerations. The cost model used in this paper while useful has certain drawbacks: we used deterministic approach with constant demand, and infinite capacity assumptions as in classical independent lot size formula (although the capacity constraints were brought in later). Future models should aim at considering multiple products for determining lot sizes and MTO versus MTS option simultaneously. Another unanswered question is about selection of basic unit (recipe or SKU) for doing the analysis similar to one presented in this chapter. In-depth demand analysis; and commonality indices for SKUs and recipes should help in this regard.