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Combined make-to-order and make-to-stock in a food production system

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SOM-theme A: Primary processes within firms

Abstract

The research into multi-product production/inventory control systems has mainly assumed one of the two strategies: Make-to-Order (MTO) or Make-to-Stock (MTS). In practice, however, many companies cater to an increasing variety of products with varying logistical demands (e.g. short due dates, specific products) and production characteristics (e.g. capacity usage, setup) to different market segments and so they are moving to more MTO-production. As a consequence they operate under a hybrid MTO-MTS strategy. Important issues arising out of such situations are, for example, which products should be manufactured to stock and which ones on order and, how to allocate capacity among various MTO-MTS products.

This paper presents the state-of-the-art literature review of the combined MTO-MTS production situations. A variety of production management issues in the context of food processing companies, where combined MTO-MTS production is quite common, are discussed in details. The authors propose a comprehensive hierarchical planning framework that covers the important production management decisions to serve as a starting point for evaluation and further research on the planning system for MTO-MTS situations.

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1. Introduction

A majority of the operations management research characterizes production system as either Make-To-Order (MTO) or Make-To-Stock (MTS). The MTO systems offer a high variety of customer-specific and typically, more expensive products. The production planning focus is on order execution and the performance measures are order focussed e.g. average response time, average order delay. The competitive priority is shorter delivery lead-time. Capacity planning, order acceptance/rejection, and attaining high due date adherence are the main operations issues. The MTS systems offer a low variety of producer-specified and typically, less expensive products. The focus is on anticipating the demand (forecasting), and planning to meet the demand. The competitive priority is higher fill rate. The main operations issues are inventory planning, lot size determination and demand forecasting. The performance measures are product focussed e.g. line item fill rate, average inventory levels. The available literature (e.g. Kingsman et al., 1996; Vollman et al., 1997; Silver et al., 1998) has widely addressed these issues in pure MTO and pure MTS production.

While there is a large body of literature on MTO and MTS production control, lesser and lesser production systems are either fully MTS or MTO in practice (Williams, 1984; Adan & Van der Wal, 1998). The combined MTO-MTS problem has been relatively neglected in literature and to the best of our knowledge only a handful of papers has been explicitly dealing with this combined problem. Further, these papers have been rather limited in exploring all issues relevant for combined MTO-MTS situations and little has been done in positioning the different contributions.

It is important to recognize that very different managerial actions than those required in pure MTO and pure MTS strategy are necessary in a combined MTO-MTS production situation because of the different strategy contexts in which the products are produced. We postulate that a mix of MTO and MTS products and their interaction with the limited shared capacity opens interesting possibilities as well as

problems for production planning. For example, on the one hand, MTS products might be manufactured to fill capacity in periods of low demand for MTO items but on the other hand, we do not yet fully understand these interactions to answer the questions such as how much inventory should be kept or how due dates should be set in the combined MTO-MTS production situation.

In our discussion, we mainly focus on the food processing industries, where combined MTO-MTS production is quite common. Food processing industries are part of very competitive supply chains and have to cater to an increasing number of products and SKUs of varying logistical demands like specific features, special packaging, short due dates. In addition, they differ from discrete parts industry not only on the basis of kind of products, but also on market characteristics, the production process, and the production control. For example, limited shelf life of products and presence of sequence dependent setup add another dimension to the combined MTO-MTS problem. Hence, combined MTO-MTS production in food processing industries is an interesting and relevant research subject.

The organization of the paper is as follows. In the next section we review the state-of-the-art in the area of combined MTO-MTS production research and bring out the variety of production planning decisions arising in such situations. In section 3, we look at the food processing characteristics and assess the existing MTO-MTS literature in the context of its applicability to the food processing industries in section 4. In Section 5, we present a comprehensive hierarchical planning framework covering the important decisions in the combined MTO-MTS situation. Conclusions and suggestions for future research are provided in section 6.

2. Literature review

There are only a handful of research papers that explicitly talk about the combined MTO-MTS situation. In this section, we review the work of Williams (1984), Bemelmans (1986), Li (1992), Carr et al., (1993), Federgruen & Katalan (1994,

1999), Adan & Van der Wal (1998), Arreola-Risa & DeCroix (1998), Nguyen (1998), Carr & Duenyas (2000) and Rajagopalan (2002), which yield important insights for the combined MTO-MTS situation. Table 1 provides an overview of the literature in terms of subjects addressed; demand, production & process structure considered; performance criteria used; and the solution approach.

One of the first studies on combined MTO-MTS production system is due to Williams (1984). This research deals with many questions raised by MTO products - which products should be stocked? What special business (MTO) should be accepted? How should one choose the batch sizes for MTS? The waiting time for the availability of the capacity for the individual products is estimated using approximation to M/G/m queue. Bemelmans (1986) considers fast-movers and slow-movers products (with batch-size equal to one) and present the situation as a capacitated single-machine, multi-product-planning problem. He describes a concept of capacity oriented inventory - uncertainty in the demand of a certain product can be covered by the inventory of another product, whose demand is larger or less uncertain. This idea might be further extended to having (extra) inventory for MTS to have more capacity available for MTO.

To have an exact and tractable analysis, Carr et al., (1993) assume that no setups times and costs are incurred. The MTO/MTS decision is based on the ABC classification. A production strategy labelled as "No *B/C* policy", wherein the *B* and *C* category items are produced on order and *A* category items are MTS, is followed. They model the system as M/D/1 queue and provide the estimates of the number of orders in the queue, average-waiting times in the system. They show that the "No *B/C* policy" incurs less cost than pure MTS strategy, especially under high traffic intensity. Adan et al*.,* (1998) also present a similar model with an extension to two-stage production. They consider the production system as Markov process with states defined by the number of MTO orders in queue and MTS inventory on hand and derive expressions for mean number of orders in the queue and mean production lead-time.

Table 1: Overview of literature on combined MTO/MTS production situation

Paper	Subjects addressed	Demand-Product-Process structure	Performance criteria	Solution approach
Williams (1984)	• MTO/MTS partitioning • Lot sizes for MTS product	• Stochastic demand, Multi product, multi (identical) machines • Non-preemptive priority for MTO items over MTS items	• Minimizing sum of inventory holding costs, stock out costs and setup costs	• Approximations of M/G/m queues
Bemelmans (1986)	• Decomposition of items into Slow and fast movers • Conditions for product and capacity oriented approaches	• Stochastic demand • Single-machine, multi-product, multi-period capacitated problem • Batch sizes equal to 1	• Minimizing sum of inventory holding costs, stock out costs	• Queuing theory and Math Programming
Li (1992)	• Impact of customer behaviour and market on MTO/MTS partitioning	• Stochastic demand, Single product • Price, quality, delivery lead time variations • The firm may not get all the orders	• Profit maximization	• Stochastic optimization with infinite time horizon
Carr et al. (1993)	• Exact expressions for cost of a strategy for an example of MTO/MTS situation	• Unit demand with stochastic arrival • ABC like classification for MTO/MTS decision, No setups	• Minimizing sum of inventory holding cost, stock out costs	• 2 priority class M/D/1 queue, Pre-emptive resume between priority class and FCFS within a class
Federgruen & Katalan (1994, 1999)	• Production sequencing & base stock levels • Comparison of priority rules	• Stochastic demand • Cyclic schedule and base-stock policy	• Minimizing sum of inventory holding, stock out & setup costs	• Results of M/G/1 queues with vacations used
Adan & Van der Wal (1998)	• Effect of combining MTO & MTS on the production lead time in single & two stage production	• Stochastic demand, two types of product • No backordering for MTS product • No setup times	• Mean no. of orders in the queue and mean production lead-time	• Markov process with states defined by number of MTO orders in the queue and MTS inventory on hand
Arreola-Risa & DeCroix (1998)	• MTO/MTS partitioning	• Stochastic demand and manufacturing times, Single stage multi product system • Base stock policy, FCFS scheduling • Backordering costs	• Minimizing sum of inventory holding costs, stock out costs	• M/G/1 queue results
Nguyen (1998)	• Estimation of fill rate & average inventory level	• Unit demands with Stochastic arrivals • Lost sales case, No setup time • No due dates for MTO customers	• Line item fill rate and average inventory levels for MTS items	• Mixed queuing network, Use of the heavy traffic limit theorem.
Carr & Duenyas (2000)	• Joint admission control and sequencing problem	• Single machine, two types of product • No backordering, No setup times, Pre-emption allowed, MTO orders can be rejected	• Profit maximization	• Markov decision process for 2-class M/M/1 queue.
Van Donk (2001)	• Locating Customer Order Decoupling point	• Limited intermediate storage between two stages of food production system	• Service levels and cost trade-off	• Case study • Application of CODP concept
Rajagopalan (2002)	• MTO/MTS partitioning • Deciding Reorder point and replenishment quantity	• (Q, r) inventory policy for MTS products • No sequence dependent setups • Minimum service level constraints for product	• Minimizing sum of inventory holding costs, stock out costs and setup costs	• Non-linear integer program with service level constraints, Heuristic procedures

The question whether a particular product will follow a MTO or MTS strategy is the discussion focus in Li (1992), Arreola-Lisa & DeCroix (1998) and Van Donk (2001). Li 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. Arreola-Lisa & DeCroix (1998) provide optimality conditions for the MTO/MTS partitioning in a multiproduct, single machine case with FCFS scheduling rule. They study the effect of manufacturing time diversity on MTO/MTS decision for backorder-cost cases of dollar per unit and dollar per unit per time. Their result shows an extent to which reducing manufacturing-time randomness leads to MTO production. Van Donk (2001) describes the application of 'Customer Order Decoupling Point' (CODP) concept in a case of food processing company.

Federgruen et al., (1994, 1999) address a variety of strategic questions - the number and types of products that should be manufactured to stock or to order, the effects of adding low volume specialized items to a given product line on the stock system. They present a class of cyclic base stock policy for which a variety of cost and performance measures can be evaluated by the suggested analytical methods for the polling model. They develop cost curves for different priority rules under different circumstances, which can be used to calculate a marginal break-even price at each of additional utilization due to addition of MTO items.

Nguyen (1998) models the combined MTO-MTS situation as a mixed queuing network. She uses the heavy traffic limit theorem in developing the procedure for finding estimates of fill rates and average inventory levels. Unlike Williams, Rajgopalan (2002) allows low demand items to follow the MTS strategy. He provides a heuristic procedure to solve a non-linear, integer programming formulation of the problem that determines the MTO/MTS partition and the batch sizes for the MTS items.

Joint order acceptance/rejection and sequencing problem is discussed in Carr et al., (2000). They consider a 2-class (MTO and MTS) M/M/1 queue with no backordering

6

for MTS product and provide a structure of optimal admission control and sequencing policies in terms of production threshold curve and acceptance threshold curves that are functions of MTS inventory level and MTO queue size.

MTO-MTS issues in the literature

It is clear from the literature that there are diverse issues that need to be addressed in the combined MTO-MTS production. The question whether a particular product will be made to stock or made to order is the principle issue in designing and managing the production planning & control function. This *MTO versus MTS decision* is more strategically oriented and is complicated due to various factors involved. The solution needs to consider the trade-offs between product-process characteristics and the demands from the market. Another main decision is to find a suitable *production and inventory policy.* The main issue here is finding a balance between the possibilities of buffering (in time and quantity) the uncertainty of orders by deciding suitable due dates and/or by finding suitable levels of stocks of MTS product. Thus, these are the decisions regarding capacity allocation, order acceptance, lot sizes and inventory policy. Then there are *operational scheduling and control decisions*, which deal with issues like production sequencing.

In the next sections, we understand the food processing industry characteristics and assess the above literature in the context of it.

3. Food production system characteristics

Some recent empirical studies (Van Dam, 1995;Van Donk, 2001) show that the combination of MTO and MTS is quite common in food processing industries. Several reasons exist why the combined MTO-MTS grows in significance in food processing industry. Van Donk (2001) mentions that food-processing companies have to deal with an increase in logistical demands from their customers. Firstly, being part of very competitive supply chains, food-processing companies cater to an increasing number of products and SKUs with client specific features, special packaging *etc* to increase or maintain the market share. Secondly, retailers and wholesalers expect

7

small deliveries within short and dependable time window. At the same time, they do not accept two subsequent deliveries with the same 'best before' date, even if they will sell the product well before that date. This means that customers prefer a MTO policy with short response time. Thirdly, consumer behaviour is more erratic (Meulenberg et al., 1998). This requires logistic and production systems to respond quickly to changing customer behaviour. As a consequence of this product/SKU proliferation and shorter production cycles, manufacturers are forced to shift a part of their production system from MTS to MTO and are operating under a hybrid MTO-MTS strategy. Producing a very large number of products on pure MTO basis is not viable because of large number of setups that are required and pure MTS is also ruled out because of unpredictable demand and the perishable nature of the products.

As a first step in developing a production planning and control framework for combined MTO-MTS production food processing industry, we investigate the production characteristics and a variety of issues that need to be addressed by the management. These are in addition to increased logistical demands of the market as described in the previous paragraph. The discussion is largely motivated by the food processing industry case studies conducted by the authors and other researchers at the University of Groningen (Ten Kate 1994, Van Dam 1995, Van Donk et al., 1996; Van Wezel et al., 1996; Van Dam et al., 1998; Van Donk, 2001; Van Wezel, 2001).

A typical food processing process is illustrated in Figure 1. Two stages can be distinguished: a processing stage during which the products are manufactured, and the packaging stage in which they are packaged.
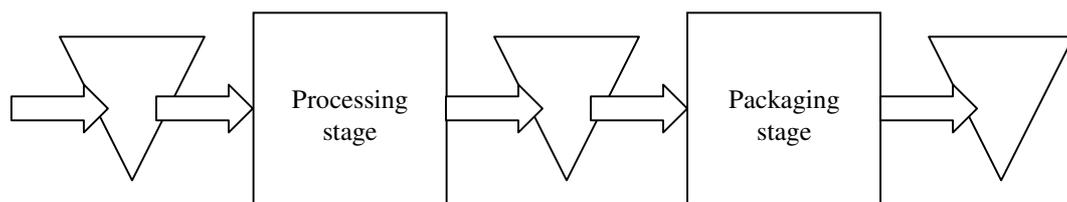

Figure 1: A typical food processing process

8

The following characteristics, compiled from the above-mentioned literature, are found in case of food processing industries:

1. Plant characteristics
    a. Expensive capacity with flow shop oriented design because of conventional small product variety and high volumes.
    b. Extensive sequence dependent setup and cleaning times between different product types.

2. Product characteristics
    a. Variation in supply and quality of raw material
    b. Limited shelf life for raw materials, semi-finished and finished products.
    c. Volume or weight as the unit of measure unlike the discrete manufacturing.

3. Production process characteristics
    a. Processes having variable yield and processing time.
    b. A divergent flow structure - a product can be packaged into many SKU sizes.
    c. Multiple recipes for a product.
    d. Packaging stage labour intensive whereas the processing stage is not.
    e. Production rate mainly determined by the capacity.

In most of the cases, a subset of these characteristics is present. Each of these factors has to be taken into account for developing a production planning and control framework. For example, high setups and an orientation to use capacity as much as possible, leads to longer production runs and finished good inventory. In many cases, the intermediate stock point as depicted can only store temporarily, due to the instability and perishability of the products or because of limited capacity and hence, the 'postponement strategies' suggested by the latest literature (Van Hoek, 2001) are not fully applicable in many food processing industries. Also, unlike discrete industries, capital and capacity intensity of the equipment makes use of dedicated lines for some products and hence, the simplified planning rather unlikely.

4. MTO-MTS in food processing industry

Having understood the food processing industry characteristics, we now turn to the various planning decisions involved in a combined MTO-MTS production situation. For the discussion that follows, we assume that no intermediate storage is possible and consider a combined MTO-MTS food production system as single equipment. This equipment can be considered as the bottleneck facility out of the processing and packaging stages. The demand is uncertain. For MTO items, no finished goods inventory is maintained. Each order for a MTO product has an agreed upon due date linked to it. The firm aims to deliver the product by this date. The MTS orders are fulfilled from the stock. All products have limited shelf life. A sequence dependent setup time is incurred, when there is changeover from production of one product to another. The presence of the sequence dependent setup-times makes formation of product families attractive. The changeover times between products of the same family are relatively less and hence can provide some extra processing time, especially useful in the high utilisation situation under which we are operating. We are interested in deciding the production -inventory strategies in such situations. The performance of the manufacturing system will be judged by the capacity utilization, order focussed measures for the MTO product and product-focussed measures for the MTS items.

While the production structure as presented above seems relatively simple, the complexity of the production planning decisions that have to be taken for the combined MTO-MTS system is large. In the following sub-sections, we discuss the main decisions under three categories as identified in section 2.

4.1 MTO versus MTS decision

Many papers (Williams, 1984; Carr et al., 1993) suggest the use of simplistic rules, e.g. ABC classification or its variants, to tackle the important issue of MTO/MTS. The high volume items are produced to stock and low volume items are produced to order. However these approaches only consider demand characteristics and totally

ignore the production and market characteristics, like manufacturing time, response time *etc* and food processing characteristics like setup times and perishability.

The 'customer order decoupling point' (CODP) concept (Hoekstra & Romme, 1992) suggests a qualitative way to solve this MTO/MTS question. 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 (for elaboration and application of CODP concept in food industry see Van Donk, 2001). 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. The CODP concept suggests that the typical MTO candidates are - a) Products contributing little or irregular work load to the manufacturing system e.g. export orders and tenders, b) Items with low setup times, c) Items with high holding cost, d) Customized products, e) Highly perishable products. Though this seems logical, it is felt that this is based on only single product-by-product analysis and may not hold true when a group of products and their interactions with capacity are considered. We submit that these interaction effects between MTO and MTS are the most intriguing, but least researched and understood issues within this field.

4.2 Production and inventory policy decisions

Here, we are interested in the various issues revolving around the capacity co-ordination, given the firm MTO orders and anticipated demand for the MTS items. The aim is to allocate the capacity among different products for maximizing the expected profit while attaining the desired minimum service levels in terms of due date performance for MTO product and line item fill rate for MTS items. This calls for adopting suitable and tailored production and inventory strategies.

The important questions are - How to do capacity allocation among MTO and MTS product? Should we adopt a fixed cyclic sequencing strategy or a dynamic

11

sequencing? As mentioned earlier, the control of setup times is a major concern in the food processing industry and hence products are grouped in families and a cyclic production policy is generally followed. What should be the length of the production cycle? What should be number of runs per family per production cycle? What should be the run length for each family? What should be the run length for MTS items within a family run? What are the acceptance/ rejection criteria for MTO orders? How to set due dates for the MTO orders? How much safety stock and cycle stock should be maintained for MTS items?

Here, it is also required to have an understanding of the effect of adding MTO items or moving MTS items to MTO in the product portfolio. MTO production of some of the items means reduction in the inventory of these items but there may be an increase in the inventory of the MTS items to achieve the equivalent service levels. This can be explained with the help of results from Karmarkar et al., (1985) and Bemelmans (1986). No inventory for MTO items means an increase in the number of setups and hence the machine utilization. This finally increases the production lead-time. This can only be reduced by increasing the cycle stock and safety stock of the MTS items. Thus there is a complex trade-off between decreasing inventory of some items and increasing the cycle and safety stock of others items.

The limited shelf life of the food products is also an important consideration. It can pose limits on the safety stock levels and cycle length for the products.

4.3 Operational decisions

There are certain operational issues that firms need to answer on a regular basis. The first question is at the interface of the sales and production functions. The order acceptance/rejection decision has to be based on the characteristics of the already accepted orders and possibility of generating feasible schedule, which includes the new order. The second question is related to the operational scheduling and

sequencing. The firms need to define the scheduling rules for variety of situations that may arise answering the question - which product to produce next?

Applicability of MTO-MTS literature in food processing industry

It is felt that the field of MTO-MTS research is still in its infant stages. Though the literature dealing with combined MTO-MTS situation, as discussed in the section 2, helps in better understanding of the different issues involved, they do have limited applicability in the food processing industry.

The MTO-MTS literature is mainly characterised by queuing theory applications with strict limitations and pre-requisites. The assumption of equal cost structure for all products is unlikely to hold given the large number of SKUs to be produced. The assumptions of batch sizes of one, no-setups, pre-emptive resume production policy are also unrealistic owing to the fact that there are large and sequence dependent setups present in the food processing industry. Moreover, the stress on costs as the only performance measure is also not conforming to the way the decisions are taken in practice. Due-date performance might be more important, especially in the short term.

The very important decision of partitioning products in either MTO or MTS is in most of the literature taken on the basis of volume only and it is assumed that the MTO-products do have a low volume. In food processing this is not always the case. Due to tenders, export orders and promotional activities (special packaging size, add-ins etc.) MTO might also apply to large orders. Another important issue in the partitioning is the existence of product families that might affect the MTO/MTS decision for the product based on the production cycle of their family. Also, the shelf-life of the products ("best-before" date) which limits the possibilities of use of built-up inventories to fulfil the customer orders and limited intermediate storage possibilities are also not dealt within the literature.

We argue that the available literature is limited not only in its applicability for real-life situations but also in explaining the fundamental interactions between two types of orders competing for a shared capacity and the use of time (due dates) and quantity buffers (inventory).

5. Hierarchical planning framework

It is obvious that all the issues raised in the previous section cannot be handled simultaneously. The whole problem is very complex and analytically intractable because of presence of sequence dependent setup and the congestion effects. A hierarchical decision-making is a reasonable approach to solve the issues involved. In this section, we present a generalised hierarchical planning framework that extends the underlying principles discussed in the well-known hierarchical production planning literature from MIT (viz. Hax & Meal, 1975, Bitran et al., 1977). The essential idea of having such a hierarchical approach is the partition of global problem into smaller manageable component sub-problems. These sub-problems are either to be solved sequentially, such that, the solution of a sub-problem poses constraints on the subsequent sub-problem - each level solves its own problem and performance feedback is given to the higher level - or solved simultaneously in a co-ordinated way.

The above-mentioned literature on hierarchical production planning (and other as reviewed by McKay et al., 1995) attempts to solve a "static" problem without discussing the dynamic events happening in the manufacturing system. Also, it does not answer some of the key questions like - How many levels are appropriate? Which decisions to take at which level of the hierarchy? Although the answers to these will depend on the organization or the case being studied, no attempts have been made to tackle these important questions. Only general guidelines are provided - Which decision to take at which level is dependent on the time horizon for the decision and level of aggregation. Higher levels are concerned about product groups and larger time horizon while lower levels deal with individual orders/product and shorter time horizon.

An alternative stream of hierarchical planning literature (Schneeweiss, 1995), addresses the dynamic nature of decision making in some way but the two key questions about the number of decision levels and which decisions are to be taken at which level, remain unanswered.

We follow Gershwin's concept (1989) of 'frequency separation' in coming up with the hierarchy and answering the two questions above. Gershwin considers scheduling problems in the dynamic manufacturing system with machine failures, repairs, setups, demand changes, etc., and he proposes a hierarchical structure based on the frequency of occurrences of different types of events. This framework is based on the assumption that events tend to occur in a discrete spectrum, which defines the hierarchical levels. The levels of the hierarchy correspond to classes of events that have distinct frequencies of occurrence. The more frequent activities are the lower level activities and the less frequent ones are at the higher level. Table 2 shows typical dynamic events/activities and their frequency of occurrence.

Table 2: Typical dynamic events/ activities and their frequency

Operation (production)	High
Order arrival	High
Equipment setup	High
Equipment cleanup	High
Product Transport/ storage	High
Production sequencing	High
Machine breakdown/ maintenance	High, Medium
Order acceptance and due date determination	High, medium
Manpower allocation	High, medium, low
Due date changes	Medium
Lot size determination	Medium
Rush order arrival	Medium, low
Production cycle determination	Medium, Low

Forecast changes	Low
Market changes	Low
Capacity addition/ depletion	Very Low
MTO-MTS determination	Very low
Grouping of items into families	Very Low

Figure 2 provides an overview of the generalised hierarchy of decisions involved in the dynamic, combined MTO-MTS production situations. There are three levels of decisions in the hierarchy. The decisions related to high frequency events, from the table 2, are at the lowest level, the medium frequency decisions relate to the second level of hierarchy whereas the decisions related to less frequent events reside at the top level of the hierarchy. In the following paragraphs, we describe these decision levels in more detail.

At the first level, there are decisions that relate to determining which products to manufacture to order and which products to manufacture to stock. The determination of product families and setting the target service levels for these families is also done at this level. This MTO/MTS decision level uses the similarities in product, process and market characteristics of the product to form product families. The information needed for locating the decoupling point (Van Donk, 2001) will be used to decide on MTO/MTS partitioning. Based on the expected sales volume and revenues for these products, the target service levels are set in terms of line item fill rate for MTS products and response time for MTO products. Feedback on realized line item fill rate and response time in previous periods is also used as an important input. The planning horizon is a few months up to a year and this decision is taken periodically without too much operational details.

We call the second level as capacity co-ordination. At this level the demand and capacity is balanced. On the basis of orders on-hand and the forecast for customer orders, the available capacities and stocks, realized efficiency in previous periods, and
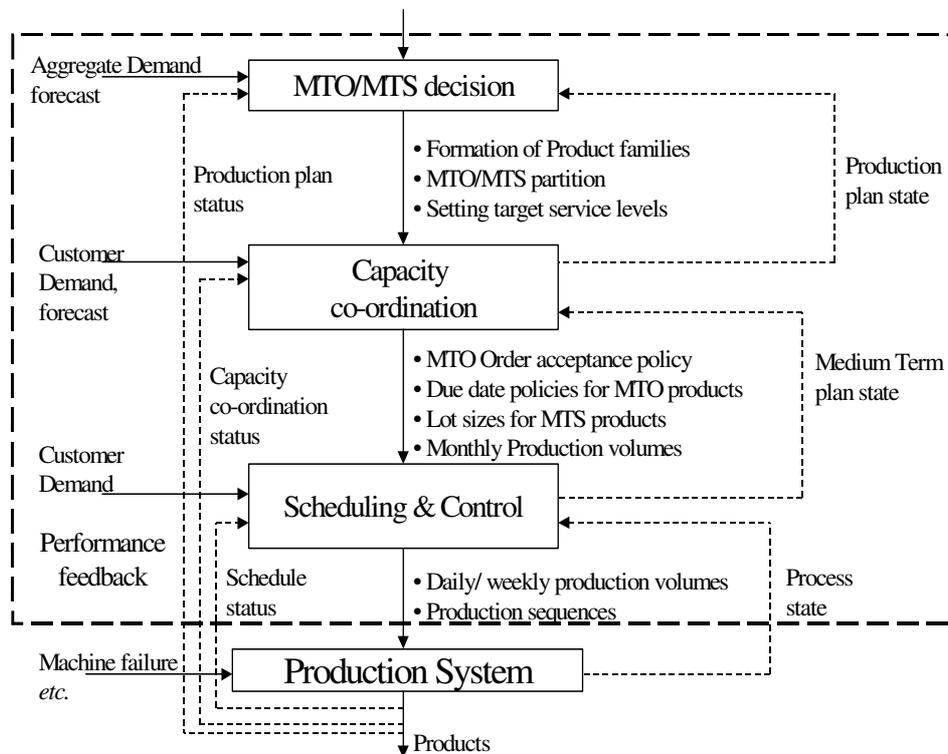
Figure 2 Hierarchical approach to MTO-MTS problem

the feedback regarding the realization of plans, the decisions are made at this level concerning the allocation of production orders for both MTO and MTS product to planning periods. This level specifies the target inventory levels for MTS product in each planning period and sets policies for order acceptance and due dates setting for the MTO orders. Production run length and production cycle length for each family and/or product is also specified. Another decision at this level is purchasing special packing materials with long lead-time. The time horizon is typically a few weeks to a month.

17

At the third level, there are scheduling and control decisions. The production orders are sequenced and scheduled. The sequence should be so as to meet the inventory and due date targets set at the upper levels while minimizing the total setup and cleaning time. The exact starting and ending time of production order is determined. The rescheduling because of unforeseen reasons is also done at this level. The time horizon for this level is typically from a day to a week and is worked out with as much detail as is needed. A regular feedback on due date performance and line item fill rate is given to the top levels.

Comments

It may be noted that duration of activities also needs to be considered while deciding the hierarchy. For example, in food process industry the setup and cleaning times are quite high. Although setups are frequent and must, their impact has to be considered at the capacity co-ordination level as well. Also, the rush orders from the strategic customers though less frequent, may still have to be handled at the lower levels of hierarchy.

The conceptual framework suggested in this section is a first attempt to structure the production planning decisions in a combined MTO-MTS production situation. Though it is just another way of looking at the decision-making and a generic but not an in-depth prescription for structuring the specific levels for all the MTO-MTS situations, it can be used as a starting point for designing or redesigning the planning and scheduling hierarchy structure for a particular situation. However, several other important points need to be addressed on a case-by-case basis: when is decision level activated, when the decisions are deferred in view of the dynamic events in Table 2.

6. Conclusions

This paper investigated a number of issues with respect to the combined MTO-MTS situation in food processing industries. While a number of papers are present with

respect to combined MTO-MTS production, the specific food processing industries have hardly been dealt with in literature. We argued that this is certainly needed. From our description of food processing industries a number of specific characteristics can be derived that are of special relevance for this combined situation: high capacity utilisation, sequence dependent set-ups and limited shelf live. We reviewed the literature on MTO-MTS and concluded that some useful ideas are present. However, the majority of contributions do not address those specific characteristics of food processing. Moreover, most contributions are highly mathematical oriented and have some rather restricted assumptions.

This paper introduces a general framework to decide on the main problems in managing a combined MTO-MTS system in food processing. The framework combines a three level decision model with contributions from MTO-MTS literature. We conclude that the framework is a valuable contribution to both the description of the MTO-MTS production situation and possibly to the managerial decision-making in organisations.

Future research

Firstly, further refinement of the hierarchical framework is needed. Each of the levels in the hierarchy contains a specific decision for combined MTO-MTS situation. Quantitative decision aids are to be developed in the context of the hierarchy. It is clear from the discussion in this paper that the interaction effects between MTO-MTS orders and shared capacity are captivating, but yet not understood well. The presence of setups, and due dates for MTO products make queuing models less tractable analytically. Simulation studies might be helpful to study the MTO/MTS decision and the interactions between the products and the capacity under varying demand patterns, setup times and processing times. Secondly, in food processing industry stability and maintainability of the production cycle are the main performance measures rather than cost measures at the scheduling and control level. How to achieve stable schedules in dynamic, combined MTO/MTS is an open question.

Finally, we think that the scientific community could benefit from more empirical studies. It would be interesting to know how planners deal with the combined MTO-MTS situations in practice and compare with the hierarchical framework suggested in this paper. An investigation of the demand-product-process characteristics that led to particular choices made for the decision structures in practice is also appealing.

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