The 7th International Symposium on Operations Research and Its Applications (ISORA'08)
Lijiang, China, October 31–Novemver 3, 2008

Coordinating Multi-Period Capacity Allocation and Order Scheduling via Optimization and Simulation

Shao-ju Lee[1] Ming-Hsuang Lee[2]

[1]Department of Business Administration, National Dong Hwa University, Hualien 97401, Taiwan
[2]Fu Sheng Industrial Co., Ltd. Tao-Yuan, Taiwan

Abstract This paper studies a multi-period production capacity allocation and order scheduling decision for manufacturing firms which seek to balance utilization, flexibility, stability and profitability. We consider a firm which must manage both make-to-stock and make-to-order decisions and design a coordination system to link the tactical capacity allocation with the operational oeder scheduling problems. The model consists of a simulation module and an optimization module. The former captures the allocation percentage, the MTS replenishment rules, and adjustment allowances, and the latter selects and schedules the stream of MTO orders. Through the study, the dynamic interactions between the tactical choices and operational activities are explored. By varying the parameters of the system, operational characteristics are observed and analyzed. The study results demonstrate that the coordination approach is viable and provides a prototype for further research for this vital decision problem.

Keywords Hybrid production system; production capacity allocation; order scheduling

1 Introduction

Manufacturing firms of various industries often confront a common problem of allocating production capacity among Make-to-Stock (MTS) and Make-to-Order (MTO) items. For the MTS items, the strategy is aimed at ready replenishment with on-hand stock to satisfy customers with common demands, but is burdened with relatively larger amount of inventory and related costs. For the MTO items, the incentive lies in producing customized orders for added revenue, but must respond with high degree of flexibility and incur small lot-size costs. These two strategies are not mutually exclusive in many industries, and in particularly, the high-tech industries. For firms in the high-tech industries, due to long set-up time, certain proportion of production capacity must be pre-allocated to handle the common components or semi-finished products, while the remaining proportion of the capacity must be kept unencumbered to meet customized orders.

Many researchers have proposed different ways of dealing with each strategy (Ashayeri & Selen, 2001; Carr & Duenyas, 2000; Federgruen & Katalan, 1999; Kogan, Khmelnitsky, & Maimon, 1998; Soman, 2005; Soman, van Donk, & Gaalman, 2004; Tsubone, Ishikawa, & Yamamoto, 2002), but few have combined the two strategies and given a workable way of balancing the two (Cochran & Kim, 1998). The main focus of this research is to interactively address both the tactical MTS production planning issues and the operational MTO manufacturing scheduling tasks to achieve best capacity utilization and revenue maximization. To capture the stochastic nature of MTS demands and MTO order variability, a multi-period simulation and optimization model is designed. The tactical allocation problem is represented by the allocation percentage parameter, the demand forecasts, and various MTS replenishment rules. The operational scheduling decision is treated by solving an optimization problem to schedule the incoming MTO orders in a forward-rolling fashion. The system is constructed by linking together the ARENA, LINGO, and EXCEL software through VBA and implemented on a PC.

The entire model is then tested using synthesized data for a hypothetical high-tech firm, and several relevant indicators such as capacity utilization percentage, MTS inventory level, MTO order acceptance rate are verified for typical settings. Scenario analyses of the simulation-optimization results based on various parameter settings are studied. Preliminary conclusions show that the hybrid model can accommodate different demand distributions, allocation proportions, and flexible interchange rules to suit a variety of manufacturing firms. The simulations-optimization approach can provide firms with useful insight in production planning and scheduling.

Section 2 gives a brief literature review of related research and defines the scope and foundation for this research. Section 3 describes the structure of the simulation-optimization model and the linkage of various software modules. Section 4 presents some sample study results and preliminary findings. Finally, Section 5 concludes with some suggested research extensions.

2 Literature Review and Problem Definition

In this section we will briefly discuss several research which are most relevant to the present study. First, Ashayeri and Selen (2001) focused on the optimzation of orders under a hybrid production environment, considering both the production and marketing sides. Orders are accepted based on the production capacity and the cost and revenue of candidate MTO orders. It uses the modified EOQ model to issue the MTS production, and mixed integer pramming model for the MTO order selection decision. The study experimented with the data from a Dutch dye manufacturing firm. Next, Tsubobe, Ishikawa, and Yamamoto (2002) use simulation to study the issue of reserved capacity for MTS and its impact. Demand for MTS was assumed to be Normal distribution and MTO demand was assumed to be Poisson. MTS production follows a fixed process and constant time requirement per unit, and MTO orders have raried time requirements. Through two experiments, their study observed the interactions of various variables, and for given conditions, optimized the best allocation proportion using Stochastic Approximation method. But the allocation proportion could not be dynamically adjusted. Finally, Soman, van Donk, and Gaalman (2004) consider the food industry as their study target. They provide a conceptual framework of Hierarchical Production Planning. The first hierarchy decides which product should be treated as MTS or MTO. The second hierarchy decides whether to accept an MTO order and then the third hierarchy engages in production scheduling and control. Other related research includes Kogan et al (1998), Federgruen and Katalan (1999), Carr and Duenyas (2000), and Youssef et al (2004).

This research considers a multi-period (e.g., n=14) two-level model as follows. At the tactical level, the planning model is projected out throughout the n periods based on the MTS forecasts and a pre-designated MTS/MTO allocation proportion. This yields the base MTS production requirements for the n periods. At the operational level, the incoming MTO orders for the current period are selected and scheduled (into the future periods) through the optimization model. The operational model basically ahheres to the capacity excluding the pre-allocated MTS portion, and fits in the MTO orders within the capacity limits and the due dates. The model assumes a higher priority for MTS production, and considers MTO orders a bonus. But whenever MTS safety stock is sufficient, the model also allows a certain degree of MTS capacity conversion to MTO.

The n-period optimization model is a mixed integer program in which the current period must decide which new orders to accept (and what capacity to commit for up to n periods) to maximize the total future MTO profit. Variables for the MIP model are: binary order acceptance variables, fractions of each accepted MTO order produced per period during preferred due date and before acceptable due date. The constraints include: all committed MTO demands being met by acceptable due dates, MTO capacity limits and MTS capacity limits per period for all periods The objective function for the total net profit over the n periods, and for: the sum of all MTO order (revnue– production cost - delay cost – holding cost – cost of converting MTS to MTO usage)

3 Simulation Model Assumptions, Parameters and Hypotheses

3.1 Model Assumptions

For specificity, this research makes the following assumptions concerning the simulation.

1. The setting for subject firm is multiple-product production with joint capacity.

2. The MTS product is a common item or upstream component for the MTO orders; its production time is assumed constant. The MTO orders are customized products with varied attributes and unit production time.

3. Capacity is assumed to be available production time/day Production capacity is assumed to be 100%, to be shared by all MTS and MTO production activities.

4. The simulation model has a weekly planning module with an arrgregate timeframe of 20 weeks. This module translates the given weekly MTS forecasts into daily forecasts to be used by the daily operations module.

5. Each day production time is allocated to the MTS production based on the current beginning inventory, the target inventory level (safety stock + forecast amount), if needed This MTS production time allocation must honor the prior MTO orders that had been pre-scheduled and production time pre-designated

6. Upon determining the daily production time utilization (MTS production + previously committed MTS production time), the remaining time is reserved for new MTO orders production.

7. Each day an “actual” MTS demand is generated, and is satisfied using stock from daily inventory and production

8. The daily operations module deals with the MTO requests. All MTO order requests received per day are evaluated together based on order due dates, available MTO production time for the operations module horizon.

9. MTO orders are scheduled into production (all or partially) by preferred due date, and/or completely fulfilled by the specified acceptable due date, with penalty charges for the delay.

10. The simulation and optimization modules iterates with a rolling horizon of 2 weeks, and 14 days, respectively. Thus each action taken affects the resource availability, inventory status, and revenue for the future periods.

11. Supply of raw material, pricing, quantity discount, or out-sourcing are not considered.

3.2 Simulation Parameters

1. Daily MTS demands are assumed to be normally distributed, randomly generated.

2. Number of daily MTO orders is uniformly distributed ($1 \sim 6$), each order is a randomly generated normal variate with different production cost, preferred due data and acceptable due date.

3. Each simulation run assumes a production capacity allocation proportion α (0.0$\sim$1.0) for MTS, so 1-α is the gross upper bound of capacity pre-allocation for MTO.

Hypotheses

Based on previous studies on MTS/MTO coordination (Ball, Chen, & Zhao, 2003; Cochran & Kim, 1998; Ertay, 1998; Federgruen & Katalan, 1999; Kogan et al., 1998; Schragenheim, 2002; Youssef et al., 2004), we have made the following general hypotheses concerning the simulation study:

1. H1: Under the same MTS allocation proportion α, MTO order selection by optimization will be better than the FIFO selection.

2. H2: When MTS or MTO demand variability increases, the system will become more volatile in terms of inventory level and capacity utilization.

3. H3: MTS long-term demands and α jointly determine the actual MTS capacity utilization percentage. A lower value of α will yield more remaining capacity for MTO orders

4 Simulation Results

Simulation using synthesized data of a hypothetical high-tech firm has been performed for three categories of scenarios. Due to space limitations of this abbreviated paper, only sample graphs from the simulation study are shown. The results of the study are described in this section.

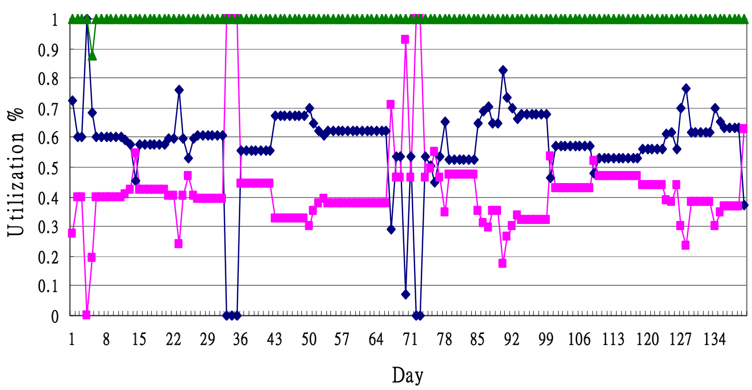
The first category is the base-case simulation run which yields the baseline statistics as a reference point. The value of α is set at 0.7 based on operational experience. It is observed that accepting MTO orders using MIP optimization is better than the FIFO rule, so H1 is established.

The second category of simulation runs change (increase one or both) the MTS and MTO demand variances, and thus observe a much more volatile system behavior in terms of capacity utilizations and MTS inventory levels. The up-and-down pattern is much more frequent than that of the base-case. This observation verifies H2. Graph 1 shows a sample of the capacity utilization variations, the bottom dotted line represents the MTO %, the middle line the MTS % and the top line the total capacity utilization percentage. Graph 2 shows the volatile pattern of the MTS inventory level, as compared to that of the base-case.

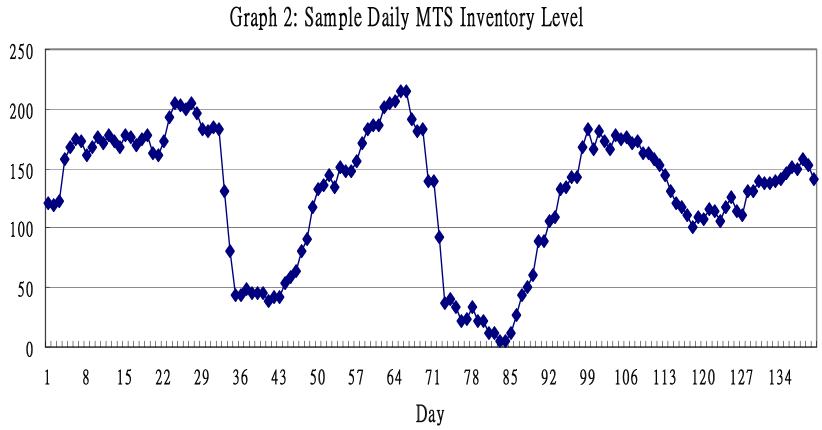
The third category of simulation runs varies the α value to examine its effect on system stability. General observations are that when α is reduced (0.7, 0.6, ..., 0.4), MTS utilization percentage remains stable due to demands, but the production capacity for MTO is increased. This leads to more gainful orders being accepted and higher average MTO profit. But with lower α value, the average MTS inventory is lowered and its standard deviation is increased. These phenomena agree with H3.

Since the in previous three categories of simulation runs MTO orders are generated daily, the cumulative orders often fully utilize the the production capacity utilization. The system could only accommodate about one quarter of the MTO orders. The fourth category of simulation runs varies the order arrival frequencies and the number of orders to observe the effect on capacity utilization. Results show that while MTS utilization remains stable reflecting the MTS demand, MTO utilization percentages varies with the order magnitudes. This seems to suggest that accepting smaller-sized orders has the advantage of freeing up MTO capacity more frequently and allowing more opportunity for future orders. Graph 3 shows the utilization percentages for the MTO, MTS and total capacities. It can be seen that with less frequent MTO orders, the system has many occasions of non-full days. Graph 4 shows a more stable MTS inventory level owing to less frequent MTO orders competing for the same capacity.

Graph 1: Sample Daily MTS %, MTO % and Total %

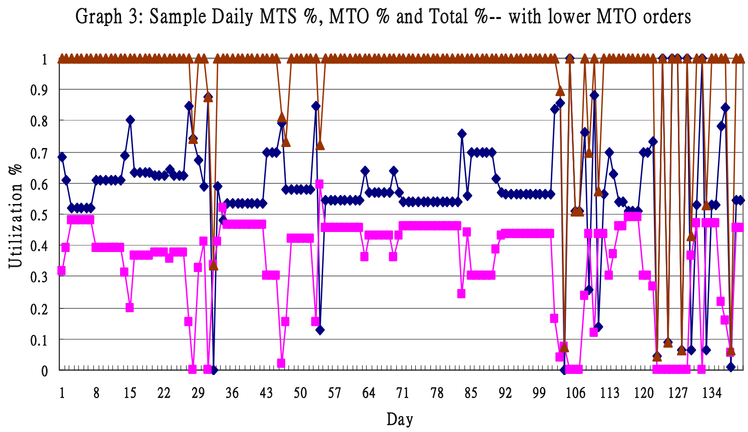


Other factors considered include the MTS safety stock level which controls whether MTO orders can "borrow" from excess MTS capacity, and the maximum MTS inventory level which caps MTS from utilizing excess MTO capacity.



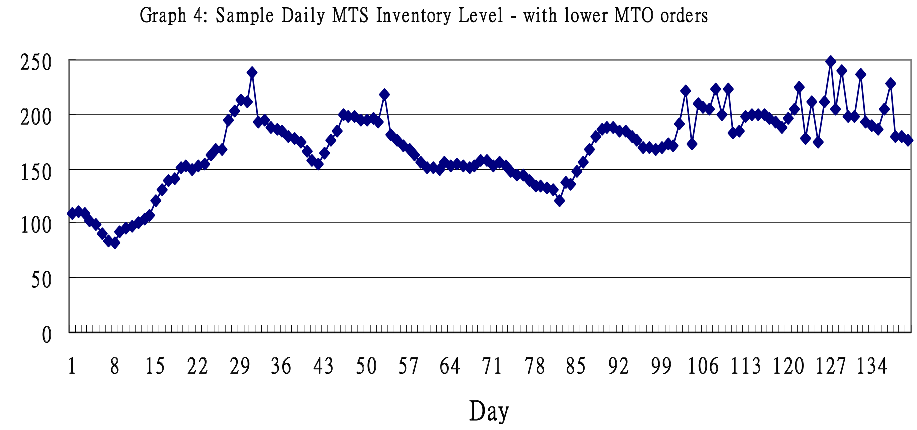
5 Conclusions and Suggested Further Research

Manufacturers faced with turbulent economic environment, fierce competition and low profit margin must plan wisely and execute precisely to maintain competitive position. Previous research on hybrid mode production planning either address the optimization of MTO orders without explicitly consider its effect on the over-all system cost, or study the effect of MTS/MTO allocation proportion without allowing dynamic adjustment.



This research integrates both factors and utilizes a simulation-optimization approach to take advantage of both tools. Since various demand distributions and inventory rules can be implemented readily in this model, it is hoped that manufacturers of many industries wrestle with the decision between MTS and MTO allocation will find this research useful. The prototype model is built on a PC with Intel Pentium Mobile processor of 1.6GHz, 1GB RAM. The simulation time for 5 iterations of 140 periods is about 15 minutes, making this a viable operations tool.

Further research can be extended to experiment with various demand distributions, order frequency and size distributions, MTS/MTO interchange rules, production lot size,



set-up cost, over-time capacity, and incorporating more flexible heuristic scheduling rules . Another research direction would be the simulation of different life cycles for different products.

References

[1] J. Ashayeri and W.J. Selen. Order selection optimization in hybrid make-to-order and make-to-stock markets. *The Journal of the Operational Research Society,* 52(10), 1098 2001

[2] M.O. Ball C.-Y. Chen, and Z.-Y. Zhao. *Material compatibility constraints for make-to-order production planning* (Vol. 31): Elsevier Science, 2003

[3] S. Carr, and I. Duenyas. Optimal admission control and sequencing in a make-to-stock/make-to-order production system. *Operations Research,* 48(5), 709, 2000

[4] J. K. Cochran and S.S. Kim. Optimum junction point location and inventory levels in serial hybrid push/pull production systems. *International Journal of Production Research,* 36(4), 1141-1155, 1998

[5] T. Ertay Simulation approach in comparison of a pull system in a cell production system with a push system in a conventional production system according to flexible cost: a case study. *International Journal of Production Economics,* 56-57, 145-155 1998.

[6] A. Federgruen and Z Katalan. The Impact of Adding a Make-to-Order Item to a Make-to-Stock Production System. *Management Science,* 45(7), 980 1999.

[7] K. Kogan, E. Khmelnitsky and O. Maimon. Balancing facilities in aggregate production planning: make-to-order and make-to-stock environments. *International Journal of Production Research,* 36(9), 1998

[8] E.M. Schragenheim. *Make-to-stock under drum-buffer-rope and buffer management Methodology.* Paper presented at the APICS-The Educational Society for Resource Management, America, 2002

[9] C.A. Soman. *Make-to-order and make-to-stock in food processing industries.* University of Groningen, 2005

[10] C.A. Soman, D.P. van Donk and G Gaalman. Combined make-to-order and make-to-stock in a food production system. *International Journal of Production Economics,* 90(2), 223-235, 2004

[11] H.Tsubone, Y. Ishikawa and H. Yamamoto. Production planning system for a combination of make-to-stock and make-to-order products. *International Journal of Production Research,* 40(18), 4835, 2002

[12] K.H.Youssef, C.Van Delft and Y. Dallery. Efficient Scheduling Rules in a Combined Make-to-Stock and Make-to-Order Manufacturing System. *Annals of Operations Research,* 126(1-4), 103-134, 2004