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A Proposed Hierarchical Production Planning Structure for Combined MTS/MTO Environments

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Abstract: - From the viewpoint of the relationship between production release and order arrival, production system can be classified into make-to-stock (MTS), make-to-order (MTO), assemble-to-order (ATO), and engineer-to-order (ETO) systems. Production planning is a complicated task which requires cooperation among multiple functional units in an organization. Planning is the consequence of a hierarchy of decisions dealing with different issues in the manufacturing environment. A classical approach to handle this multi-level decision-making process is hierarchical production planning (HPP). There are only a handful of research papers that explicitly talk about the combined MTO/MTS situation and even there are fewer papers using HPP in these kinds of environments. In this paper we propose a hierarchical model in combined MTS/MTO environments, consists of four phases include: MTS/MTO products separation, acceptance/rejection of incoming MTO orders, HPP, and master production planning.

Key-words: - Hierarchical production planning, Combined MTS/MTO environments, Linear Programming.

1 Introduction

There are different kinds of classifications for manufacturing system. From the viewpoint of the relationship between production release and order arrival, production system can be classified into make-to-stock (MTS), make-to-order (MTO), assemble-to-order (ATO), and engineer-to-order (ETO). For a MTS system, finished or semi-finished products are produced to stock according to forecasts of the demands. In a MTO system, work releases are authorized only according to the external demand arrival. There are only a handful of research papers that explicitly talk about the combined MTO/MTS situation [1 and 2].

Production planning is a complicated task which requires cooperation among multiple functional units in an organization. Planning is the consequence of a hierarchy of decisions dealing with different issues in the manufacturing environment. A classical approach to handle this multi-level decision-making process is hierarchical production planning (HPP). A rigorous mathematical analysis of HPP is found in the pioneering work of Hax and Meal [3]. Theoretical work on the topic has followed by Bitran et al., [4] and Bitran and Hax [5]. Yan et al., [6] formulated the HPP problem of flexible automated workshops by a linear programming model with the overload penalty different from the underload penalty and with demand constraints. Tavakkoli-Moghaddam and Biyabani [7] proposed a special design of a genetic algorithm (GA) to work out an aggregate production planning (APP) in order to minimize production costs in a real-case study of a car industry.

2 Proposed HPP Model

In this paper, we propose a HPP structure for combined MTS/MTO environments in four phases as shown in Fig. 1. In the first phase of the model, we develop a method in order to separate MTS/MTO products based on HPP. The second level is about acceptance/rejection of MTO orders. Decision making, in this phase and the two other remaining phases is based on linear programming (LP).

The third phase involves aggregate decisions. The next level of the hierarchy is the product family planning level. Consistency among the production plans at lower phases is achieved by linking mechanisms existing between each subsystem. The solution of a higher phase subsystem represents a constraint to be imposed on the next phase subsystem.

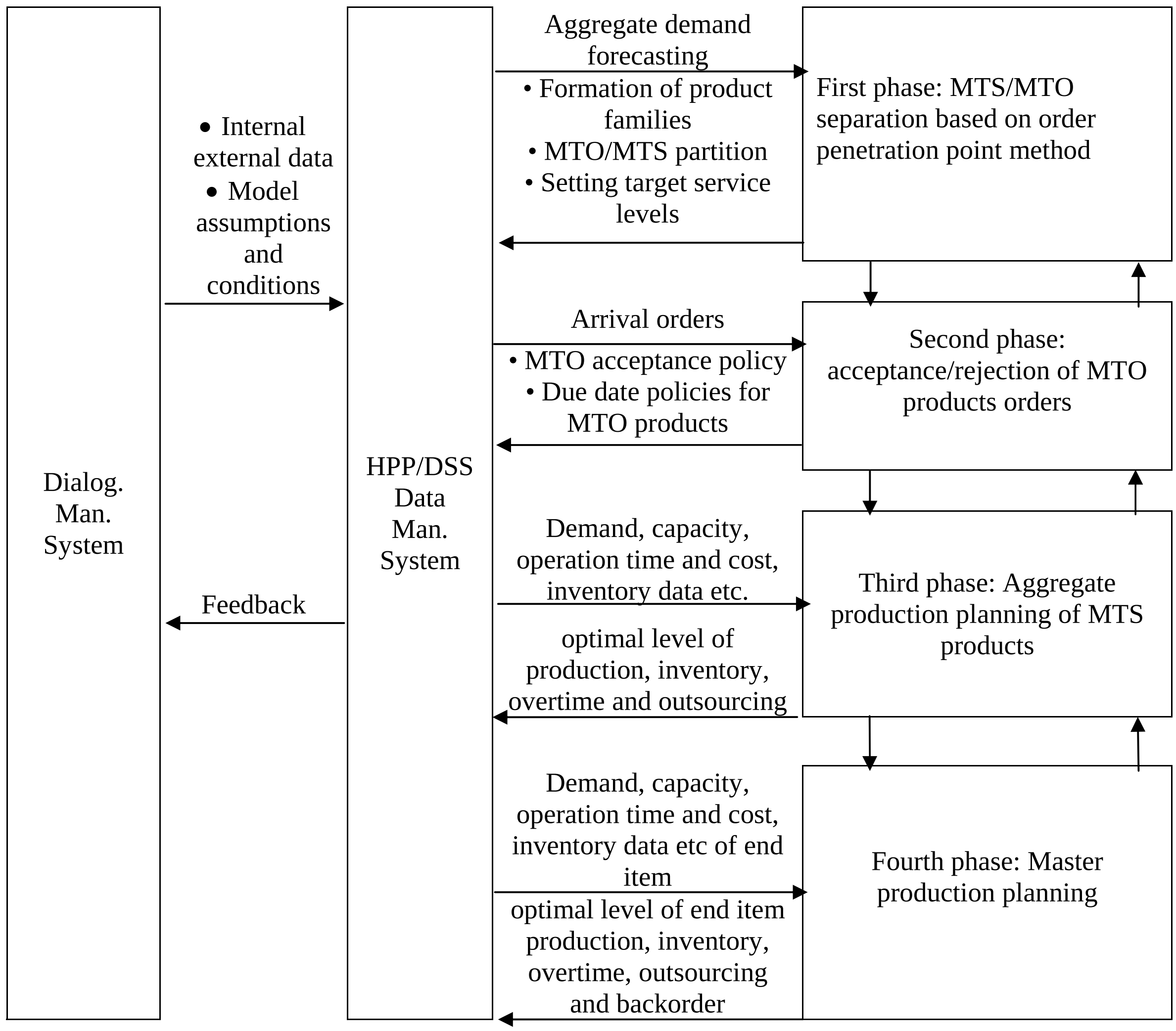

Fig. 1. The proposed HPP structure in combined MTS/MTO environments

3 First phase: MTS/MTO Separation Based on Order Penetration Point Method

In the first phase of the model, we separate MTS and MTO products. The HPP is traditionally defined as the point in the manufacturing value chain for a product, where the product is linked to a specific customer order. Different manufacturing situations such as MTS, ATO, MTO, and ETO all relate to different positions of the HPP. Thereby, the HPP divides the manufacturing stages that are forecast-driven from those that are customer-order-driven. There are so many factors affecting on the HPP position. We divided the most important factors into three categories, related to market, product, and production characteristic.

3.1 Market-Related Factors

Delivery lead-time requirements set by the market restricts. *Product demand volatility* indicates to what extent it is possible or reasonable to make products to order or to stock. Low volatility means that the item can be forecast-driven. *Product volume* is related to demand volatility in that the relative volatility is lower for high-volume items, can be measured by the coefficient of variation. *Product range and product customization requirements*; A broad product range and a wide set of customization required by the customer would be impossible to provide on a MTS basis. A narrow range and predetermined customer choices make it possible to move towards ATO or even MTS. *Customer order size and frequency* are indicators of volume and the repetitive nature of demand. Large customer order sizes are typically associated with high demand volumes. High frequency leads to repetitive demand making forecasting easier. For products with highly *seasonal demand*, it may be uneconomical for the manufacturing firm to respond to all demand when it occurs. Consequently, the firm may choose to manufacture some products to stock in periods with low demand in anticipation of peak demand. Thereby, production is leveled and plant utilization increases. Thus, a product may shift between MTS and MTO/ATO depending upon the season.

3.2 Product-Related Factors

The *customization opportunities* that the producer provides in the product design in anticipation of the customization requirements. If the customization offered is wide and enters the product at early production stages, an MTO policy is necessary, whereas if customization enters at a very late production stage ATO may be more appropriate. The breadth and depth of the *product structure* indicates the product complexity. A deep product structure may well correspond to long cumulative production lead times.

3.3 Production-Related Factors

The *production lead time* is a major factor to consider with respect to the delivery lead-time requirements set by the market. The number of *planning points* in a manufacturing process restricts the number of potential HPP positions. A planning point is a manufacturing resource or a set of manufacturing resources such as a work centre or a work cell that can be regarded as one entity from a production and capacity planning point of view. The *flexibility* of the production process, e.g. through short set-up times, is a prerequisite for producing to order.

The position of the *bottleneck* of the production process relative that of the HPP is interesting. From a resource optimization point of view, it is proposed to have the bottleneck upstream the HPP, so the bottleneck does not have to deal with volatile demand and a variety of different products. With respect to the just-in-time principle of elimination of waste, it would be best to have the bottleneck downstream the HPP so that the bottleneck only needs to work on products for which the firm has customer orders. A bottleneck can be a candidate for the HPP, especially if it is an expensive resource performing significant activities in the production process of the product. Resources with *sequence-dependent set-up times* are best positioned upstream the HPP. Such resources can easily turn into bottlenecks without proper sequencing.

4 Second Phase: Acceptance/Rejection of MTO Products Orders

We used the backward method proposed by Kingsman and Hendry [8] to calculate the operation completion date (OCD), earliest release date (ERD), and latest release date (LRD):

$$OCD_{n,i} = DD_i$$
$$OCD_{n-1,i} = OCD_{n,i} - TWK_{n,i} - W_p$$
$$OCD_{n-2,i} = OCD_{n-1,i} - TWK_{n-1,i} - W_p$$
....
$$OCD_{1,i} = OCD_{2,i} - TWK_{2,i} - W_p$$
$$LRD_i = OCD_{1,i} - TWK_{1,i} - W_p$$
$$ERD_i = LRD_i - pool\,delay$$

Parameters:

- n number of sources.
- DD_i due date for job *i*.
- $OCD_{r,i}$ operation completion date for operation *r* of job *i*.
- LRD_i latest release date of job *i*; if job releases after this time the DD will not be achieved.
- ERD_i earliest release date of job *i*.
- W_p waiting time per operation for a job.
- TWK_{ij} total work content for operation *r* of job *i*.
- $pool\,delay$ maximum order work content that are accepted but not release.

$$\min \sum_i MZ_i + NU_i \quad (1)$$
$$MAD_i \le ERD_i + MZi \quad , \forall j \quad (2)$$
$$\sum_i TWK_{ij} \le \sum_{t=1}^{12} C_{jt} + NU_i \quad , \forall j \quad (3)$$
$$V_i = Z_i + U_i \quad , \forall j \quad (4)$$
$$TWK_{ij}, C_{jt}, MAD, ERD \ge 0 \quad U_i, Z_i = 0 \text{ or } 1$$

Parameters:

- C_{jt} available source *j* in period *t* for MTO products consisting of over time and regular time workforce.
- MAD_i material arrival date needed for job *i*.
- M, N large numbers used to ensure the effects of binary variables.

In the above model, the objective function (1) minimizes the sum of two large numbers in respect

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to binary variables. Constraint (2) checks the needed material for job *i*. Constraint (3) is related to capacity needed for job *i*. Constraint (4) is the sum of two binary variables; if this is equal to zero then we accept the order if it is more than zero then we reject the order. Of course, there are some solutions in order to accept the order when the sum of them is more than zero. If Z_i is equal to one then MAD is greater than LRD so we can use following solutions in order to accept the order: *ERD<MAD<LRD*: In this situation, the priority of the order can be changed. Following alternatives can be done in order to keep the feasibility of DD:

- Changing the OCD values: keeping the feasibility of DD the value of MAD-ERD should be distributed over OCD values in order to achieve equal MAD and ERD (MAD=ERD). The new OCD values are derived from following equation:

$$OCD' = OCD - \frac{MAD - ERD}{n}$$

- In order to have equal MAD and ERD, the value of W_p can be decreased.
- The order can be delivered tardy.

MAD> LRD: in this situation Material Arrival Date is even later than latest released date LRD). The following alternatives are possible in order to keep the DD feasible:

- OCD changing: keeping the feasibility of DD the value of MAD-ERD should be distributed over OCD values in order to have equal MAD and ERD (MAD=ERD). The new OCD value is derived from following equation:

$$OCD' = OCD - \frac{MAD - ERD}{n}$$

- In order to have equal MAD and LRD, the value of W_p can be decreased.
- The order can be rejected or delivered tardy.

If U_i is equal to one then there is no sufficient capacity for job i in source *j* so we can use following solutions in order to accept the order: the capacity of system can be increased in order to accept order, the order can be delivered tardy, if order acceptance needs high capacity and workload then it can be rejected.

5 Third Phase: APP of MTS Products

APP is performed under managerial constraints that reflect an organization policy in regard to manpower adjustments, the holding of inventory, and outsourcing to other organizations. The APP attempts to minimize costs given a set of aggregate production. The APP model described in this article uses a mixed-integer linear programming (LP) formulation to determine the aggregate policies for the rate of production, inventory, regular and overtime workforce, and workforce smoothing activities. The parameters and indices are as follows:

Parameters:

D_{it} demand (in units) for product family *i* in aggregate period *t*.

c_{it} unit (variable) production cost of product family *i* in aggregate period *t;*

CAP_{jt} capacity of source *j* in aggregate period *t* for MTS products.

CO_t overtime cost per labor hour.

p_u maximum percentage allowed for working less than regular time work force.

PS_{it} maximum outsourcing level (in labor hours) of product family *i* in aggregate period *t*.

CW_j regular time workforce cost per labor hour;

C_{ft} firing cost per labor hour.

$\beta_{t,t-1}$ maximum percentage of difference in production level allowed for two subsequent periods.

a_{ij} average usage rage of source *j* for producing product family *i* in aggregate period *t*.

h_{it} unit inventory carrying cost of product family *i* in aggregate period *t*.

cs_{it} unit outsourcing cost of product family *i* in aggregate period *t*.

SS_{it} safety stock of product family *i* in aggregate planning *t*.

C_{ht} hiring cost per labor hour.

Variables:

I_{it} inventory level (in units) of product family *i* in aggregate period *t*.

X_{it} production level (in units) of product family *i* in aggregate period *t*.

W_{jt} regular time workforce level (in labor hours) of source *j* in aggregate period *t*.

F_t firing (in labor hours) in aggregate period *t*.

SS_{it} outsourcing level (in labor hours) of product family i in aggregate period *t*.

O_{jt} overtime (in labor hours) of source *j* in aggregate period *t*.

H_t hiring (in labor hours) in aggregate period *t*.

Y_t total level of production families in aggregate period *t*.

Z_t variable introduced to smooth the level of production in subsequent periods.

$$\min Z = \sum_{i=1}^{n}\sum_{t=1}^{4} h_{it} * I_{it} + \sum_{j=1}^{J}\sum_{t=1}^{4} [CO_t * O_{jt} + CW_t * W_{jt}] + \sum_{i=1}^{n}\sum_{t=1}^{4} C_{it} * X_{it} + \sum_{i=1}^{n}\sum_{t=1}^{4} cs_{it} * S_{it} + \sum_{t=1}^{4} [C_{ht} * H_t + C_{ft} * F_t] \quad (5)$$

s.t.

$$I_{i,t-1} + X_{it} + S_{it} - I_{it} = D_{it} \quad , \ \forall i,\ t \quad (6)$$

$$\sum_{i\in j} a_{ij} X_{it} < CAP_{jt} + O_{jt} \quad , \quad \forall i, j, t \quad (7)$$

$$\sum_{i\in j} a_{ij} X_{it} > (1 - p_u) \times CAP_{jt} \quad , \ \forall i, t \quad (8)$$

$$O_{jt} \le over\_time_{jt} \quad , \quad \forall j, t \quad (9)$$

$$S_{it} \le PS_{it} \quad , \ \forall i, t \quad (10)$$

$$I_{it} \ge SS_{it} \quad , \ \forall i, t \quad (11)$$

$$Y_t - Y_{t-1} \le \beta \times Z_t \quad , \quad t = 2, ..., T-1 \quad (12a)$$

$$Y_t - Y_{t-1} \ge \beta \times Z_t \quad , \ t = 2, ..., T-1 \quad (12b)$$

$$Y_t \le Z_t \quad , \quad \forall t \quad (12c)$$

$$Y_{t-1} \le Z_t \quad , \quad \forall t \quad (12d)$$

$$Y_t = \sum_{i=1}^{n} X_{i,t} \quad , \quad \forall t \quad (12e)$$

$$\sum_{j=1}^{J} [W_{jt} - W_{j(t-1)}] - H_t + F_t = 0 \quad , \quad \forall t \quad (13)$$

$$O_{jt} \ge 0; \quad X_{it}, I_{it} \ge 0, \text{integer} \ , \ Z_t, Y_t \ge 0$$

The objective function (5) minimizes the some of production, inventory, hiring and firing of workforce, overtime, outsourcing costs. M is the penalty to smooth production in the subsequent periods, as the value of M increases the production level in the subsequent periods would be smoother. Constraint (6) is the basic inventory identity relationship for each product family. Constraints (7) and (8) are related to the minimum and maximum capacity levels. Constraint (9) is the maximum level of the overtime available and Constraint (10) is maximum level of outsourcing. Constraint (11) is minimum level of inventory related to safety stock. Constraints (12) smoothes level of production. And constraint (13) balances the regular time manpower during sub sequential periods.

6 Fourth Phase: Master Production Planning

In the this section, we used another mixed-integer programming (MIP) formulation for MPS in order to determine the optimal level of end items of product families during periods.

Parameters:

$I_{it'}$ planned inventory level (in units) of product family *i* in aggregate period *t*.

$X_{it'}$ planned production level (in units) of product family *i* in aggregate period *t*.

$O_{jt'}$ planned overtime (in labor hours) of source *j* in aggregate period *t*.

D_{ikt} demand (in units) of end item *k* of product family *i* in period *t*.

C_{ik} unit (variable) production cost of end item *k* of product family *i* in period *t*.

h_{ik} unit inventory carrying cost of end item *k* of product family *i* in period *t*.

CAP_{jt} capacity of source *j* in aggregate period *t* for MTS products.

CO_{jt} overtime cost per labor hour of source *j* in period *t*.

a_{ikj} average usage rage of source *j* for producing of end item *k* of product family *i* in period *t*.

C_{zi} penalty cost for deviation from aggregate production planning.

CB_{ik} backorder cost per unit for end item *k* in family *i*.

Variables:

X_{ikt} production quantity (in units) of end product *k* of product family *i* in period *t*.

I_{ikt} Inventory (in units) of end item *k* of product family *i* in period *t*.

S_{ikt} inventory (in units) of end item *k* of product family *i* in period *t*.

O_{jt} overtime (in labor hours) of source *j* in monthly period *t*.

B_{ikt} backorder (in units) of end item *k* of product family *i* in period *t*.

$$\min Z = \sum_{t=1}^{T}\sum_{i=1}^{n}\sum_{k\in i}\begin{pmatrix} h_{ik}\times I_{ikt} + C_{ik}\times X_{ikt} \\ +CS_{ikt}\times S_{ikt} + CB_{ik}\times B_{ikt}\end{pmatrix}$$

$$+\sum_{t=1}^{T}\sum_{j=1}^{J} CO_{jt}\times O_{jt} + \sum_{i=1}^{n} C_{zi}\times Z_i \qquad (14)$$

s.t.

$$I_{ik(t-1)} - I_{ikt} + X_{ikt} + S_{ikt} + B_{ikt} - B_{ik(t-1)} = D_{ikt} \quad , \ \forall i,k,t \qquad (15)$$

$$\sum_{i=1}^{n}\sum_{k\in i}\sum_{t=1}^{T} a_{ikj}\times X_{ikj} \le CAP_{jt} + O_{jt} \quad , \ \forall j,t \qquad (16)$$

$$\sum_{t\in t'} O_{jt} = O_{jt'} \quad , \ \forall j \qquad (17a)$$

$$\sum_{t\in t'} W_{jt} = W_{jt'} \quad , \ \forall j \qquad (17b)$$

$$\sum_{k\in i}\sum_{t\in t'} X_{ikt} + U_{1i} - V_{1i} = X_{it'} \quad , \ \forall i \qquad (18)$$

$$Z_{1i} \ge U_{1i} \quad , \ \forall i \qquad (19)$$

$$\sum_{i=1}^{6}\sum_{k\in i}\sum_{t\in t'} I_{ikt} + U_{2l} - V_{2l} = I_{it'} \quad , \ \forall i,k,t \qquad (20)$$

$$Z_{2i} \ge U_{2i} \quad , \ \forall i \qquad (21)$$

$$Z_{2i} \ge V_{21} \quad , \ \forall i \qquad (22)$$

$$\sum_{i=1}^{6}\sum_{k\in i}\sum_{t\in t'} S_{ikt} + U_{2l} - V_{2l} = S_{it'} \quad , \ \forall i,k,t \qquad (23)$$

$$Z_{3i} \ge U_{3i} \quad , \ \forall i \qquad (24)$$

$$Z_{3i} \ge V_{31} \quad , \ \forall i \qquad (25)$$

$$O_{jt} \ge 0; \ X_{ikt}, I_{ikt} \ge 0 \text{ and integer}, \ \forall i,k,t$$

The objective function (14) is to minimize the sum of production, inventory, overtime, and outsourcing costs in the master production planning period. The aggregate decisions from the previous phase appear as right-hand side values for a series of multiple goal constraints in the linear programming model. Constraint (15) is the basic inventory identity relationship for each end item of product family. Constraint (16) is the upper bound limit for end items according to capacity and overtime. Constraints (17a) and (17b) are limits for overtime and regular time manpower (according to APP). Constraints (18) to (25) are related to harmonization and integration of the fourth and third phases.

7 Conclusion

We have proposed a hierarchical production planning structure for combined MTS/MTO environments in four phases. In the first phase of the model, we have developed a method in order to MTS/MTO products separation based on order penetration point. The second level is about acceptance/rejection of MTO orders. The third phase involves aggregate decisions. The next level is the product family planning level. The aggregate production plan for the product type is disaggregated into more detailed product family plans which are in turn partitioned into production plans for end items. Further research from this study may follow several directions. One path may be to make an empirical study of manufacturing organizations, comparing the effectiveness of their current production planning with the theoretical policy resulting from this model. Another direction may be a complete discussion about MTS/MTO products separation.

References:

[1] V. Nguyen, A multi class hybrid production center in heavy traffic, *Operations research*, Vol. 46, No. 3, 1998, pp. 513–525.

[2] S. Rajagopalan, Make-to-order or make-to-stock: Model and application, *Management Science*, Vol. 48, No. 2, 2002, pp. 241-256.

[3] A.C. Hax, and H.C. Meal, Hierarchical integration of production planning and scheduling. In M. A. Geisler (Ed.), Studies in *management sciences*, Vol. I, Logistics. New York: Elsevier, 1975, pp. 53–69.

[4] G.R. Bitran, E.A. Haas and A.C. Hax, Hierarchical production planning: A single state system, *Operations Research*, Vol. 29, No. 4, 1981, pp. 717-743.

[5] G.R. Bitran, and A.C. Hax, Desegregation and resource allocation using convex knapsack problems with bounded variables, *Management Science*, Vol. 27, 1981, pp. 431-441.

[6] H.-S. Yan, X.-D. Zhang and M. Jiang, Hierarchical production planning with demand constraints, *Computers and Industrial Engineering*, Vol. 46, No. 3, 2004, pp. 533-551.

[7] R. Tavakkoli-Moghaddam and H. Biyabani, The use of genetic algorithms for aggregate production planning, *Proceedings of the 4th Int. Symposium on Intelligent Manufacturing Systems*, Sakarya, Turkey, September 6-8, 2004, pp. 683-692.

[8] B. Kingsman and L. Hendry, The relative contributions of input and output controls on the performance of a workload control system in make-to-order companies, *Production and planning control*, Vol. 13, No. 7, 2002, pp. 579-590.