Production Planning Model and Algorithm of Dynamic Mass Customization System

Yu Wang[1]*, Fang Li[2], Jijun Yuan[2]

1. *International Business School*, Jinan University, Guangzhou,510632 China.;

2. *School of Information Science*, Guangdong University of Business Studies, Guangzhou, 510320,China

***Abstract* — Based on the position of a single CODP, the production planning of mass customization is divided into two stages, make-to-stock production before CODP and make-to-order production after CODP. However, in the case of multiple CODPS, production planning of mass customization can be much more complex. This paper presents a dynamic mass customization system, that is, a three-stage production planning model with multiple CODPS. The three stages include push planning, push-pull planning and pull planning. An optimization model for production planning is provided in the aspects of production capacity, inventory constraints and stochastic demand for simulation calculation. The optimization model emphasizes on the analysis of the production planning during the period when push and pull production coexists. Its production volume is considered as the combination of pull production part (customer demands) and push production part (predicted production volume). Moreover, its production planning scheme is the combination of two production schedules. Lastly, the feasibility of the proposed model is tested using the production planning of turbines.**

Keywords - dynamic mass customization; customer order decoupling point; production planning; simulation

I. INTRODUCTION

Mass Customization is a main production pattern of manufacturing enterprises in the 21st century. Mass customization (MC) enterprises should satisfy various needs of their customers. One of the key problems is how to make appropriate production plans according to customization requirements and respond to customers' needs without delay as well. Based on the position of a single CODP, the production planning of mass customization is divided into two stages, that is, push stage before CODP and pull stage after CODP. Studies show that the push stage can be implemented steadily according to the reasonable plans made previously under relatively stable environment. The implementation of pull stage depends on market requirements or order quantity. However, in real production systems of mass customization, there are always more than one CODP. For instance, Boeing Commercial Airplane Company has three CODPS. Multiple CODPS can improve the agility of supply chain by segmenting product value chain into a group of refined agile system. With the development of enterprises, single CODP supply chain can no longer meet the demand of MC enterprises. The correlation studies on CODP are generally summarized as follows. A single CODP in the production process is widely and thoroughly discussed. Bucklin (1965) connected a single CODP structure to the postponement strategy. The position of CODP corresponds to different manufacturing strategies: engineer-to-order (ETO); make-to-order (MTO); and assemble-to-order (ATO) (Hoekstra and Romme 1992, Browne et al. 1996, Higgins et al. 1996, Sackett et al. 1997, Mather 1999, Wortmann et al. 2011). Hill (1995) extended this by adding design-to-order and make-to-print. Upstream the CODP, the raw materials are processed according to forecast, while in the downstream, the raw materials are processed according to customer order. Therefore, the CODP coincides with the most important stock point, from where the customer order process starts (Jan Olhager 2010). Verdouw et al (2006) addressed four main underlying factors of CODP and proposed the demand-driven multi-CODP chain network model. He successfully illustrated the existence of multi-CODP in diary industries' chain network. Garcia-Dastugue and Lambert (2007) mentioned multi-CODP in the supply chain where time-based postponement was used. Sun et al. (2008) proposed that multi-CODP exist in sophisticate production. Wang (2008) established supply chain model based on multi-CODP in mass dynamic customization. Wang (2010) accomplished a series of corresponding studies on multiple CODPS. Philipet et al. (2011) proposed the CODPS' existence in MC supply chain and elaborated the dynamic feature of CODP. Arnab Banerjee et al. (2011) proposed the multi-CODP paradigm in global supply chain.

All these relative researches show that multiple CODPS in supply chain is not only acceptable but also necessary. However, many authors came up with

* *Corresponding author. Email: twygs@jnu.edu.cn*

Address:No.601 Huangpu Avenue West Road,

Guangzhou, China.P.C.510632

production questions for multiple CODPS from different perspectives such as definition, position, relation etc. But there are few studies explored production plans deeply for multiple CODPS of mass customization. In more advanced MC model, how to make appropriate production plans which can meet customization requirements with high supply rate is significant. After analyzing the existing problems of MC's production planning based on single CODP, this paper describes a multi-stage production planning model based on multiple CODPS. In addition, this paper builds and solves the optimization model of economic production lot in push-stage and push-pull integrated stage respectively. Finally, its feasibility is tested using the production planning of turbines.

II. PRODUCTION PLANNING MODEL WITH MULTIPLE CODPS OF MASS CUSTOMIZATION SYSTEM

The term of production planning mode of MC based on multiple CODPS is proposed in order to make up for the shortage of traditional production planning mode of MC (production planning mode of a single CODP). Some scholars analyze the customization demands deeply from the view of optimizing production operation, and they suggest setting multiple CODPS in MC supply chain. In the same production system, different customization attribute combinations correspond to different CODPS so as to set different delivery date for customization clients. Unlike postponement strategy, the proposed idea makes customers choose production customization as early as possible so as to meet the depth of customization. Then try to move the production CODP of a large number of components to clients so that these customized products can be produced in mass production mode as much as possible. Lastly, the personalization is realized. Therefore, customers with special customization requirements have to pay more and wait longer, while others pay less and wait shorter. Because business activities are driven by customers' needs, production planning, and control activities, the greatest challenge of multiple CODPS production model is production planning and control model. Therefore, we have to put forward a new production planning and control model which adapts to the multiple CODPS production model.

The CODP positioning plays an important role in market-oriented strategy and production planning of supply chain. Under the single CODP condition, the upstream planning of CODP separation is based on forecast, while the downstream planning is based on make-to-order. It is a two-stage production. As shown in Fig.1, the production chain of mass customization is linear chain structure and the production planning model of a single CODP can be described. The 1,2,...i...j...n in Fig.1 and 2 represent nodes and manufacturing points in supply chain. The dashed line represents the CODP location.

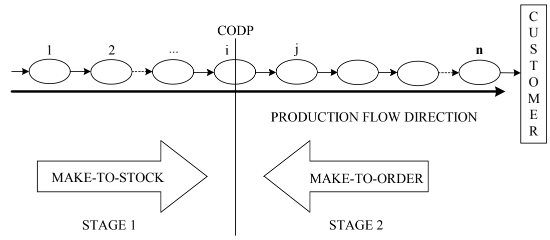

Fig.1 Two-Stage Production Model Of a Single CODP

The production model of a single CODP has two stages: push-production before CODP and pull-production after CODP. There is a buffer stock on CODP. But in the production model of multiple CODPS, there are more than one CODP. At some nodes of supply chain, the production mode can be push-production sometimes and pull-production at other times. In practice, the switch and implementation of production modes are realized by production planning and instruction. In fact the producers who are guided by planning and instruction can not exactly understand the current production mode of products. The optimization of the switch among CODPs embodies the formulation and control of planning or instruction, that is, the design and control of production planning and the remedial measure when plan fails. Pull-production mode can formulate production planning based on the order requests (time and amount), production capacity and BOM charts. So once a client makes an order, a precise production plan can be formed with strict time requirement. Yet push-production mode makes production planning according to the forecast, so different customization combinations need to be forecasted and the predictive value of standardization modules in push-production mode can be acquired by the comparison and decomposition of BOM chart. The production planning of every node is formulated basing on inventory management policy. In the supply chain of multiple CODPS, the operation planning of certain nodes may be the combination of these two kinds. Thus, the production planning of MC is much more complex when there are multiple CODPS. Taking all these features into consideration, the multi-stage production planning model with multiple CODPS is illustrated in Fig. 2.

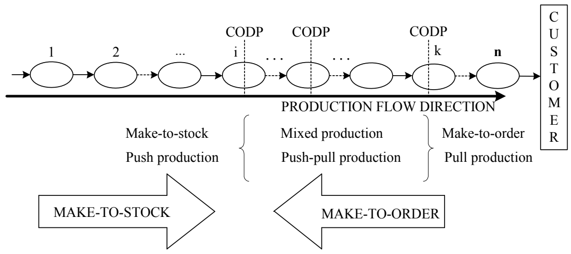

Fig.2 Multi-Stage Production Planning Model of Multiple CODPs

As shown in Fig. 2, the production planning of multiple CODPS can be divided into three stages according to the combination of customization attributes. The delivery time of CODP which is nearest to customers is the shortest. The delivery time of CODP which is farthest from customers is the longest. Therefore, the schedule of production planning splits into three stages as well. The stage before CODP which is farthest from customers is in push-production mode. In this stage production forecast is done by MPS. The most commonly used prediction method of enterprises, such as statistical analysis, considers the demands as continuous uniform distributed in order to formulate the semi-finished products processing plan, or sometimes considers the demands as normal distributed in order to solve reproduction points problem. The stage after CODP which is nearest to customers is in pull-production mode. In this stage the production activities are arranged according to orders. The production mode between above two stages is push-pull. Its production planning is the sum of push and pull. The major difference between multiple CODPs and a single CODP is the push-pull production planning in the middle stage of supply chain.

Based on Figure 2, the following text illustrates how to calculate the production volume of the working point at each stage. In Figure 3, the dashed line represents the processing of push mode, while the solid line represents the processing of pull mode. For each working point, production mode determines how it arranges the production plan. In Stage I and Stage III, the working points only conduct a single mode of production: push production in Stage I and pull production in Stage III. In Stage II, the push production and pull production mode coexists in the working points j+1 to k. There are n CODPs in total in this processing flow, each of them corresponds to a product mix and is distributed among working points where the corresponding semi-finished products are kept.

For each working point in Stage II, the combination of push- and pull-mode production is adopted. Thus we can decompose the production into pull production part and push production part according to the CODPs. Take the working point m2 for example, in Figure 3, we can see that the vertical line L through m2 intersects with the horizontal lines through CODPs. For CODP 1, line L intersects the solid line across CODP 1, representing that the processing corresponding to CODP 1 at working point m2 is pull production and the production volume is determined by actual order amount for PM 1. It is similar for CODP 2 to M-1. As for CODP M, Line L intersects with the dashed part of the line across CODP M. Therefore the processing of the corresponding PM M at working point m2 is push production and the production volume depends on the prediction of demand of PM M. This case also suits CODP M to n.

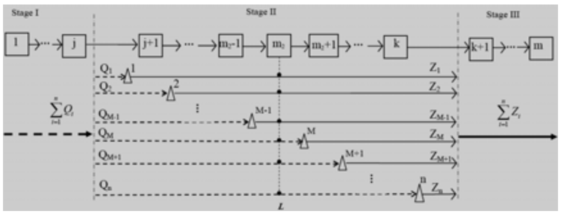

Fig. The Production Planning Model of Decomposing CODPs

The following text analyzes the production planning of different working points in Stage I and Stage II. For the working points in Stage I, the production volume is the total predicted amount of all product mixes. For the working points in Stage II, the volume will be fully discussed. While for Stage III of pull production, the volume is the overall volume required by customer for all product mixes, which won't be discussed in this paper.

III. PUSH PRODUCTION PLANNING OPTIMIZATION ALGORITHM AND MODEL

Based on the preceding analysis, in the whole production process, there will be a certain amount of semi-finished products in the exact place where CODP is. The following text will discuss how to arrange push mode production and inventory strategy of semi-finished products, in order to gain economic benefit of large-scale production. Inventory cost, production start-up cost, production cost and shortage cost will be taken into consideration. For stochastic demand, set up objective function on the target of minimum total cost, then establish constraint functions for production and inventory capacity according to customized products demand, at last figure out the optimal production quantities of semi-finished products.

A. Assumptions

Assumption1: assume that customized products in the supply chain go through all *n* processing (nodes), and the production capacity of each node is limited.

Assumption2: assume that the amount of customized products is proportional to the amount of required semi-finished products, and the production of semi-finished products is driven by the demand of a certain class of customized products; assume the intervals of order arrival times of semi- finished products are mutually independent and have the same distribution, subjecting to negative exponential distribution of parameterλ, and the distribution function *F(Δt)* is:

$$F(\Delta t) = 1 - e^{-\lambda \Delta t}$$

λ is the average arrival rate of orders.

Assume that each order demand of the corresponding semi-finished products is mutually independent and has the same distribution, approximately subjects to $N(\alpha, \sigma^2)$, and the distribution function is:

$$G(D) = \frac{1}{\sqrt{2\pi}\sigma} \int_{\infty}^{D} e^{\frac{(y \ \alpha)^2}{2\sigma^2}} dy$$

$$-\infty < y < +\infty$$

In real production system, demand *D* is not an arbitrary value between(-∞,+∞), generally $D \in [D_{min}, D_{max}]$. This limit will be handled in the simulation process.

Assumption3: the production lead time L is independent and has the same distribution. The time of processing a unit of semi-finished product is *a*, so the mean time of processing *Q* units semi-finished products is *aQ*. Because the length of lead time is influenced by various factors and there will be a certain degree of fluctuation, assume it subject to $N(\beta\ ,\ \varphi^2)$, and $L \in [L_{\min}, L_{\max}]$, $\beta=aQ$. Its distribution function is:

$$G(D) = \frac{1}{\sqrt{2\pi}\sigma}\int_{\infty}^{D} e^{\frac{(y\ \alpha)^2}{2\sigma^2}}\,dy$$
$$-\infty < y < +\infty$$

Assumption4: Inventory shortage is allowed. The delay cost caused by shortage is part of shortage cost.

Assumption 5: the *(s, S)* inventory strategy is applied, in which the safety stock *s* can be set according to the actual situation. The replenishment at reproduction point is carried out at the beginning of each cycle. Inventory strategy parameters *s* and *S* are integer times of a specified inventory resolution.

Assumption6: there is a production start-up cost in each production cycle of semi-finished products. Semi products are used to produce customized products, so production set up cost of semi-finished products is counted as production cost of customized products.

Assumption7: The inventory cost of semi products is included in the total cost. The total cost TC of customized products includes production cost QC, inventory cost SC, shortage cost HC, and production start-up cost K. The production cost QC includes raw material cost and processing cost. Transportation cost is negligible.

B. Modeling

In a single CODP push production plan, assume there are *i* kinds of customized products, and such products have time penalty α_i of deferred production. The total cost model of the *i* kinds of semi-finished product is

$$\min\{\sum_{i\in I}\sum_{t\in T}(\mu_i Q_{it}+X_{it}\delta_i)+\sum_{t\in T}S_{it}h_i+\max\{0,\alpha_i*\sum_{k=1}^{k_t}\sum_{w=1}^{w_t}\{(\xi_{ikw}D_{ikw}-Q_{it}-S_{T-1})*(t_{i-finish}+l_i-t_{i-\text{deliver}})\}+K_i\}$$

$$\begin{cases}\rho_i Q_{it} + X_{it}\tau_i \le \widetilde{F} \\ s \le S_{it} = S_{i(T-1)} + Q_{it} - \sum_{k=1}^{k_t}\sum_{w=1}^{w_t}\xi_{ikw}D_{ikw}\end{cases} \quad \textbf{(2)}$$

$\sum_{i\in I}\sum_{t\in T}(\mu_i Q_{it} + X_{it}\delta_i)$ is the production cost of *i* kinds of semi-finished products;

$\sum_{t\in T} S_{it}h_i$ is the inventory cost of *i* kinds of semi-finished products;

$\max\{0,\alpha_i * \sum_{k=1}^{k_t}\sum_{w=1}^{w_t}\{(\xi_{ikw}D_{ikw} - Q_{it} - S_{T-1})*(t_{i-finish} + l_i - t_{i-\text{deliver}})\}$ is the shortage cost of *i* kinds of semi-finished products; K_i is the order processing and production preparation cost of *i* kinds of customized products. $\rho_i Q_{it} + X_{it}\tau_i \le \widetilde{F}$ is production capacity constraint;

$s \le S_{it} = S_{i(T-1)} + Q_{it} - \sum_{k=1}^{k_t}\sum_{w=1}^{w_t}\xi_{ikw}D_{ikw}$ is inventory constraint. The variables in the model are shown in table1:

TABLE 1. THE EXPLANATION OF THE VARIABLES

T is planning cycle,and *t* is planning period, $t \in [0,T]$.	D_{ikw} : In cycle *T*, for the *i* kinds of semi-finished products, the amount of *w* customized products on the *k* demand.
μ_i : the unit production cost of *i* kinds of semi-finished products.	$S_{i(T-1)}$:*T-1* period, inventory surplus of *i* kinds of semi-finished products.
Q_{it} :, the production amount of *i* kinds of semi-finished products in *t* period.	$t_{i\ finsh}$: the production completion period of *i* kinds of semi-finished products.
X_{it} :, whether the *i* kinds of semi-finished products can be put into production in *t* period, $X_{it} = 1$ when positive, $X_{it} = 0$ otherwise.	l_i : production lead time of *i* kinds of semi-finished products.
δ_i : other constant expenses of *i* kinds of semi-finished products.	$t_{i-\text{deliver}}$: delivery time of *i* kinds of semi-finished products.
S_{it} : inventory amount of *i* kinds of semi-finished products in *t* period .	K_i : order processing and production preparation cost of *i* kinds of semi-finished products.
h_i : unit inventory cost of *i* kinds of semi-finished products.	ρ_i : unit capacity (time) of the production of *i* kinds of semi-finished products.
α_i : unit time penalty of deferred production of *i* kinds of semi-finished products.	τ_i : constant expense capacity of *i* kinds of semi-finished products.
ξ_{ikw} : In cycle *T*, for *i* kinds of semi-finished products, the coefficient of half amount of *w* customized products on the *k* demand.	$\widetilde{F}$: a total production capacity on cycle *T*

Optimal batch production Q_{it} will be discussed on two cases:

***Case 1**:* no shortage case. $Q_{it} \geq \sum_{k=1}^{k_t}\sum_{w=1}^{w_t}\xi_{ikw}D_{ikw} - S_{i(T-1)}$, namely, (1) expression does not include $\max\{0, \alpha_i * \sum_{k=1}^{k_t}\sum_{w=1}^{w_t}\{(\xi_{ikw}D_{ikw} - Q_{it} - S_{T-1}) * (t_{i-finish} + l_i - t_{i-\text{deliver}})\}$, and second constraint $S_{it} = S_{i(T-1)} + Q_{it} - \sum_{k=1}^{k_t}\sum_{w=1}^{w_t}\xi_{ikw}D_{ikw}$ on expression (2) is substituted into (1) to form expression (3)

$$\min\{(\mu_i + h_i) * Q_{it} + X_{it}\delta_i + S_{i(T-1)} * h_i - h_i * \sum_{k=1}^{k_t}\sum_{w=1}^{w_t}\xi_{ikw}D_{ikw} + K_i\}$$

(3)

(3) shows that the smaller Q_{it} is, the better the result is, the bigger $\sum_{k=1}^{k_t}\sum_{w=1}^{w_t}\xi_{ikw}D_{ikw}$ is, the better the result is. Therefore, in no shortage case, $Q_{it} = \sum_{k=1}^{k_t}\sum_{w=1}^{w_t}\xi_{ikw}D_{ikw} - S_{i(T-1)}$, the minimum total cost is $\min TC = \mu_i * Q_{it} + X_{it}\delta_i + K_i$.

***Case 2**:* shortage case. $S_{it} = 0$, then

$$\min\{\mu_i Q_{it} + X_{it}\delta_i + \alpha_i * [\sum_{k=1}^{k_t}\sum_{w=1}^{w_t}(\xi_{ikw}D_{ikw} - Q_{it} - S_{T-1}) * (t_{i-finish} + l_i - t_{i-\text{deliver}})] + K_i\}$$

$$= \min\{[\mu_i - \alpha_i * (t_{i-finish} + l_i - t_{i-\text{deliver}})] * Q_{it} + X_{it}\delta_i + \alpha_i * [\sum_{k=1}^{k_t}\sum_{w=1}^{w_t}(\xi_{ikw}D_{ikw} - S_{T-1})] * (t_{i-finish} + l_i - t_{i-\text{deliver}}) + K_i\} \quad (4)$$

Because of shortage, $\sum_{k=1}^{k_t}\sum_{w=1}^{w_t}\xi_{ikw}D_{ikw} > Q_{it} + S_{i(T-1)}$.
Then it can be split into two situations: unit production cost is not less than, or less than punishment cost coefficient. The optimal batch production in these two situations is:

$$\begin{cases} \mu_i < \alpha_i * (t_{i-finish} + l_i - t_{i-\text{deliver}}) & Q_{it} = \dfrac{\widetilde{F} - X_{it}\tau_i}{l_i} \\ \mu_i \geq \alpha_i * (t_{i-finish} + l_i - t_{i-\text{deliver}}) & Q_{it} = Q_{\min} \end{cases} \quad (5)$$

In this model, the demands are continuous. Demands arrival times, demands amount and lead times are considered as random variables. For such a complex model, the research operation of achiving the optimal production batch Q* is impractical. So we use computer simulation to solve the optimization model.

C. Simulation Solution Description

Step 1: generate simulated surplus inventory $S_{i(T-1)}$ on former cycle *T-1*.

a) Randomly generate production amount $Q_{i(T-1)}$ □$[Q_{\min}, Q_{\max}]$ on cycle *T-1*.

b) If it satisfies inequation $\rho_i Q_{it} + X_{it}\tau_i \leq \widetilde{F}$, continue, otherwise return a).

c) Call demand module of customized products, randomly generate $k'_{T-1} * w_{T-1}$ random variables $D_{ik_{T-1}w_{T-1}}$ (when demand is greater than k'_{T-1}, it will be out of stock). Then

$$S_{i(T\ \ 1)} = Q_{i(T\ \ 1)} \quad \sum_{k=1}^{k_t}\sum_{w=1}^{w_t}\xi_{ikw}D_{ikw}$$

Step 2: generate simulated state on cycle *T*.

a) make $j = 0$, $TC(j)$ infinity.

b) Randomly generate production amount Q_{iT} □$[Q_{\min}, Q_{\max}]$ on cycle *T*.

c) If it satisfies inequation $\rho_i Q_{it} + X_{it}\tau_i \leq \widetilde{F}$, continue, otherwise return b).

d) Call module of generating random variables to randomly generate production lead time at the end of cycle T.

e) Call module of generating random variables to randomly generate $k_T + 1 - k'_T$ random variables Δt_j which satisfy:

$$\sum_{j=k'_T}^{k_T+1}\Delta t_j > l_{(T)} \quad \sum_{j=k'_T}^{k_T}\Delta t_j \leqslant l_{(T)}$$

f) Call module of customized products demand to randomly generate $k_T - k'_T$ random variables $D_{ik_T w_T}$,

1)if $Q_{it} \geqslant \sum_{k=1}^{k_t}\sum_{w=1}^{w_t}\xi_{ikw}D_{ikw} \quad S_{i(T\ \ 1)}$

When

$$Q_{it} = \sum_{k=1}^{k_t}\sum_{w=1}^{w_t}\xi_{ikw}D_{ikw} \quad S_{i(T\ \ 1)}$$

the minimum total cost is $TC = \mu_i * Q_{it} + X_{it}\delta_i + K_i$

$Q_{it} = \dfrac{\widetilde{F} - Xi_i\tau_i}{l_i}$ Otherwise execute 2)

2) If $\mu_i < \alpha_i * (t_{i-finish} + l_i - t_{i-\text{deliver}})$ and ,
the total cost is minimum.
Otherwise, when $Q_{it} = Q_{\min}$
the total cost is minimum.

D. Push-pull Production Planning Model with multiple CODPS

CODP *i*(*i*=1,2,…,n) corresponds to product mix *i* (PM *i*). The working points upstream CODP conduct push production, with predicted demand amount.

Through the preceding economic lot production model, the optimal production batch is Q^* and the optimal production cycle is T^*. Therefore, assume the production volume of semi-finished products for PM i by the working points upstream the CODP i is:

$$P_{m_1} = \sum_{i=1}^{n} Q_{it}$$

The working points downstream CODP i conduct pull production. At CODP i, the common semi-finished products of PM i are stored. When the order for any product of PM i arrives, the working points downstream the CODP continue processing. Therefore during cycle T, the production volume depends on the actual demand, denoted by Z_{it}.

It is obvious that the relative position of working points in Stage II and CODPs is different from each other. Thus, the total production volumes of working points are the combination of the pull production volumes and the push production volumes, but each of them is various.

From the above analysis, during cycle T the production volume of working points 1 to j is $\sum_{i=1}^{n} Q_i$, and that of working points k+1 to n is $\sum_{i=1}^{n} Z_i$. For working points in Stage II, taking the working points j+1 for example, since it is behind CODP 1 and ahead of CODP 2 to n, its production volume should be the combination of pull production volume of PM 1 and push production volumes of PM 2 to n, that is $Z_1 + \sum_{i=2}^{n} Q_i$.

Based on the economic lot model of semi-finished products, the followings present a general model of production volume calculation of the working points in multi-CODP MC production system.

(1) Denote the node in Stage I (including node 1 to j) as m_1 (m_1 =1,2,…,j), thus

$$P_{m_1} = \sum_{i=1}^{n} Q_{it}$$

P_{m_1} is the productive task of m_1.

(2) Denote the node in Stage III (including node k+1 to m) as m_3(m_3=k+1,…,m), thus

$$P_{m_3} = Z_1 + Z_2 + ... + Z_n$$

P_{m_3} is the productive task of m_3. Z_i is the actual demand for customized product i.

(3) Denote the node in Stage II (including node j+1 to k) as m_2 (m_2=j+1,…,k) and assume m_2 is positioned just before CODP M, thus

$$P_{m_2} = \sum_{i=k+1}^{k} Q_{it} + \sum_{j=k}^{n} Z_{it}$$

P_{m_2} is the production task of m_2.

IV. APPLICATION EXAMPLE

Steam turbine is a kind of technology-intensive product with high reliability requirement. Its structure is very complex and its main components are required to have high precision and be resistant to high-temperature and impact. Each steam turbine has nearly 5000 parts. Steam turbines embody the design principle of combination products: decompose it into a variety of standard modules, just like building a house with blocks. According to customers' individual needs, limited number of standard modules can be combined to produce different customized products. Currently, there are hundreds of steam turbine type models. Steam turbine plants mainly consist of five workshops: the diaphragm workshop, the cylinder plant, the rotor assembling shop, the tank shop and the final assembly shop. The supply chain of more turbine production processing is simplified into Fig.4 in which four CODPS are designed.

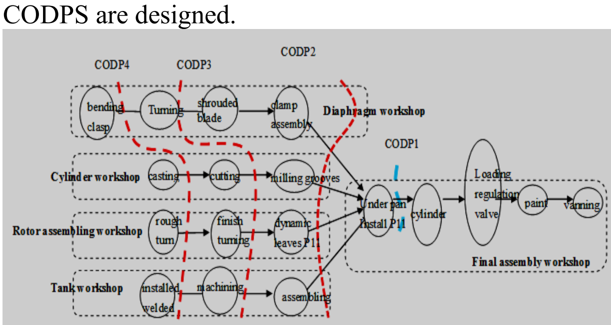

Fig.4 Multi-CODPS Mass Customization Production System of Turbine Machine

The turbine's production chain (Fig. 4) is abstracted into the following linear process. Since every node from node 1 to node 8 contains multiple processing sites, for example node 1 is the abstraction of bending clasp, casting, rough turn and installed welded. Node names are simplified by numbers in Fig. 5. Set CODPS at node 3,4,6,7 .

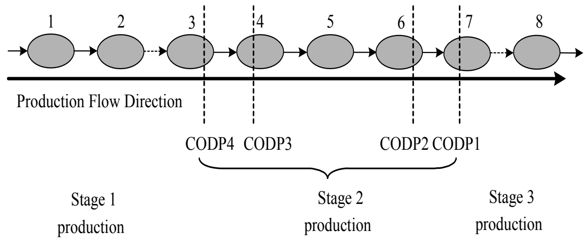

Fig.5 Abstract Liner Diagram of Turbines Production

Related parameters' information of the semi-finished products in one month are shown in table 2.

TABLE 2. RELATIVE PARAMETER TABLE OF PRODUCTION AND INVENTORY OF SEMI-FINISHED PRODUCTS

i	μ_i (Yuan)	δ_i (Yuan)	h_i (Yuan)	ρ_i	τ_i	α_i	ξ_{ikw}	K_i (Part)	$\widetilde{F}$
1	100	50	1	18	20	5	1	1000	6000
2	120	60	1.5	6	10	5	1	2000	7000
3	140	40	1	12	15	5	1	1500	8000
4	160	55	2	11	20	5	1	1500	9000

According to the data in Table 2, production task of each stage node in a certain period is calculated individually.

(1) Use node 2 as an example on Stage 1. Push production is used on this stage, which means the production planning is based on the forecast demand of semi-finished products. So the production task on node 2 is the sum of optimal production batch of each semi-finished product,that is

$$P_2 = \sum_{i=1}^{4} Q_{it}$$

According to the model in 3.2.2 and simulation process in 2.2.3, the calculation process of Q_{it} is as follows:

First, simulate surplus $S_{i(T-1)}$ of 4 kinds of customized products in the last cycle according to step one of the simulation.They are 200 pieces, 160 pieces, 220 pieces and 320 pieces.

Second, gain random total demand of 4 kinds of customized products on a certain lead time according to step two of the simulation, They are

$$D_1 = \sum_{k=1}^{k_t}\sum_{w=1}^{w_t} \xi_{1kw} D_{1kw} = 420,$$

$$D_2 = \sum_{k=1}^{k_t}\sum_{w=1}^{w_t} \xi_{2kw} D_{2kw} = 990,$$

$$D_3 = \sum_{k=1}^{k_t}\sum_{w=1}^{w_t} \xi_{3kw} D_{3kw} = 610,$$

$$D_4 = \sum_{k=1}^{k_t}\sum_{w=1}^{w_t} \xi_{4kw} D_{4kw} = 850.$$

For the capacity constraints, maximum production batches of customized products of class 1,4 are

$Q_{1t-\max} = \dfrac{\widetilde{F} - Xi_1\tau_1}{\rho_1} = 333$,

$Q_{4t-\max} = \dfrac{\widetilde{F} - Xi_4\tau_4}{\rho_4} = 816$,which are respectively less than demand $D_1 = \sum_{k=1}^{k_t}\sum_{w=1}^{w_t} \xi_{1kw} D_{1kw} = 420$ and $D_4 = \sum_{k=1}^{k_t}\sum_{w=1}^{w_t} \xi_{4kw} D_{4kw} = 850$. So the optimal production batch of customized products of class 1,4 should be $Q_{1t} = 333$, $Q_{4t} = 816$.

Maximum production batches of customized products of class 2,3 are

$Q_{2t-\max} = \dfrac{\widetilde{F} - Xi_2\tau_2}{\rho_2} = 1165$,

$Q_{3t-\max} = \dfrac{\widetilde{F} - Xi_3\tau_3}{\rho_3} = 665$,which are respectively greater than demand. So the optimal production batch of customized products of class 2,3 are $Q_{2t} = 990$, $Q_{3t} = 610$ .In summary,

$$P_2 = \sum_{i=1}^{4} Q_{it} = 333+816+990+610= 2749$$

(2) Use node 8 as an example in Stage 2. Pull production is used in this stage, which means the production is based on customers' demand. So the production task on node 8 is the sum of demand amount of 4 customized products.

$$P_8 = \sum_{i=1}^{4} D_{it} = 420 + 990 + 610 + 850 = 2870$$

(3) Use node 5 as an example on Stage 3. Push and pull production is combined in this stage. So the production task on node 5 is the sum of customers' demand amount on node 3, 4 and forecast optimal production batch on node 6,7. In summary,

$$P_5 = \sum_{i=6}^{7} Q_{ti} + \sum_{i=3}^{4} D_{it} = 333+990+610+850=2783$$

With the example of turbines' production planning, the feasibility of multi-CODP multi-stage production planning model is proved. Therefore, in real world applications, this model can be used to calculate the production tasks of push stage and push-pull combined stage of multi-CODP to make a better arrangement of production.

V. CONCLUSION

Firstly, this paper analyzes two-stage production planning based on single CODP, and sets up a multi-stage production planning model based on multiple CODPS of mass customization. Secondly, the paper divides production planning in supply chain with multiple CODPS into three stages: push production planning before CODP based on forecast; push-pull production planning based on forecast and order; pull production planning after CODP based on make-to-order. According to the three-stage model, optimization models of push and push-pull production planning are established and tested using an example of steam turbines. The operating mechanism of production planning based on multi-CODP of MC can be guaranteed.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

ACKNOWLEDGEMENTS

The paper is supported by the project of National Natural Science Foundation, China (No.71302153;71272084); the project of China Postdoctoral Science Foundation (No. 2014T70838);the project of Natural Sciences of Guangdong Province, China (No. 2014A030313608).

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