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Supply Chain Resource Integration and Optimization in Mass Customization by the Fourth Party Logistics

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Abstract: A new problem about the supply chain resource integration and optimization in mass customization (MC) by the fourth party logistics (4PL) is analyzed in this study. On this basis, a dynamic and multi-objective optimization model and an algorithm are set up for the decision optimization of the supply chain resource integration in mass customization by 4PL. The optimization model and the algorithm can not only reflect the operating requirements for the special resource integration process in mass customization but also reflect the thought of solving the key contradiction in mass customization and give consideration to the characters of 4PL operation in the supply chain. The application feasibility of the model and algorithm are also pointed out in this study.

Key words: Supply chain resource integration, optimization, mass customization, the fourth party logistics

INTRODUCTION

How to deal with the contradiction between mass production effect and customized demand is the key problem on Mass Customization (MC) (Duray *et al*., 2000). With the development of supply chain management, we can probe a new way to solve this problem through the excellent character of supply chain resource integration, allocation and optimization. However, the supply chain resource integration in mass customization has special characters, mainly reflected in the random information of customer orders and the outstanding collaborative benefit and risk conflictions which will cause many complicated contradictions in supply chain operation (Yao, 2011; Yao, 2013). Therefore, how to settle these problems is most important in implementing mass customization.

In recent years, the successful operation of the fourth party logistics (4PL) has gradually demonstrated that it is an effective mode to integrate, allocate and optimize the complicated resources of supply chain reasonably, efficiently and flexibly (Yao, 2010). 4PL have great superiorities in coordinating different kinds of supply chain co-operators' benefits and risks in the operation. Therefore, 4PL is a better method to settle the problems of the random information of the customer orders and the outstanding collaborative benefit and risk conflictions in MC. It is an effective way to integrate different resources of the supply chain and allocate the MC tasks to the cooperators. At the same time, the effective implementation of this process needs mathematic optimization method.

However, there are not effective quantitative methods to guide the MC integration practices by 4PL. Especially there are lack of analyses on quantitative integration process about the supply chain resource in MC by 4PL up to now which will inevitably limit the superiorities of 4PL application in mass customization.

Based on our early relative achievements about the supply chain operation in MC and the supply chain resource integration in 4PL mode (Yao, 2010; Yao, 2011; Yao, 2013), this study set up a dynamic and multi-objective optimization mathematic model about the decision optimization on supply chain resource integration in mass customization by 4PL from the view of systemically balancing and quantifying.

In order to solve the optimization problem, this study also discusses the algorithm for the decision optimization of the supply chain resource integration in mass customization by 4PL. The optimization model and the algorithm can not only reflect the operating requirements for the special resource integration process in mass customization, but also reflect the thought of solving the key contradiction in mass customization (Yao, 2013) and give consideration to the collaborative benefits and risks in the supply chain.

ASSUMPTIONS

This study assumes that the total production stages for MC is K and let k (k = 1, 2, ..., K) denote the index of each stage. We use t as an independent time variable and use t_k denote the starting moment at the kth stage.

In the 4PL resource integration scheme, the core enterprise can select the suitable moment t_k to implement supply chain resource integration and MC task allocation.

Let N_k denote the total number of the cooperators (including the number of the core enterprise's production/working groups taking part in the related production) at the kth stage. In following analysis, we use 'nodes' instead of 'cooperators'. Let r (r = 1, 2, ..., N_k) denote the index of the node at the kth stage. Let (kr) denote the index of each node. All these nodes will join in the supply chain resource integration and MC task allocation process by 4PL.

Yao (2011) pointed out that the key problem of MC is to satisfy the different customized demands with the scale production efficiency. As for a manufacturing supply chain, it is to make the system's comprehensive profits maximum on the premise of rationally realizing the production efficiency to different orders. Obviously, these constitute a contradictory body. To relieve these dominant contradictions in the dynamic scheduling and to show the effects of the scope economy in MC, we put forward the idea of the time threshold based on the elementary classification of the stochastic orders. The main idea of the time threshold is that the core enterprise should put forward a time horizon to wait dynamically for other orders' coming by weighing all factors in the supply chain system when it has received any order in the scheduling. At the same time, to promote the customized service level maximally and realize the approximately full customization, we also given an idea of the secondary classification of orders based on the time threshold. The main contents of the secondary classification are as follows: Definition 1, the orders received by the enterprise during the time threshold whose parts will be made by the unique designing and machining technology are named Special Order (SO); Definition 2, the orders besides SO are named General Order (GO); Definition 3, the orders that should be given the highest priority to operate to fit the urgent delivery date of customer are named Rush Order (RO) which are not restricted by the time threshold.

We can see that, on one hand, the idea of the secondary order classification contains completely the customized qualities of products, which can be reflected by the physical characters of products and be corresponding to the classification of GO and SO and also contains the customized delivery date of products which can be corresponding to the classification of RO; on the other hand, it contains completely the realization of the production efficiency in the supply chain scheduling in MC which can be reflected by the complexity of the production process, be corresponding to the classification of GO and SO and can be reflected by the same time production lot corresponding to the definition of the time threshold. So, to plan and optimize the supply chain resource integration and MC task allocation based on the order classification by the time threshold is a good idea to satisfy the different demands of the customer with the higher production efficiency. This is the key way to relieve the first dominant contradiction.

The existence of the rush orders and special orders may make it more complicated and difficult to handle the supply chain resource integration and MC task allocation. But as a real meaning customized system, to greatly satisfy the customer demands is necessary. And only on this base can the excellent service brand be set up gradually and can the supply chain cooperative relationships develop and last greatly and long. At the same time, to reduce the rush orders and the special orders gradually will be the objective for the enterprises to get by reform and process reorganization. In this study, we will also introduce the above idea of the time threshold and the order classification into the supply chain resource integration and MC task allocation process to determine the decision optimization adjustment moment.

For the order information, let N_O denote the total number of the orders received by the core enterprise during the time threshold T_0. Let G denote the number of the production categories divided by the starting stages of the different sub-tasks of the orders at moment t_k and let h (h = 1, 2, ..., G) denote the index of each production category.

Let M_g (g = 1, 2, ..., G) denote the total number of the order categories divided by the order classification described above in the hth production category at moment t_k and let i (i = 1, 2, ..., M_g) denote the index of each order category. Let N_m (m = 1, 2, ..., M_g) denote the number of the total orders in the ith order category at moment t_k and let j (j = 1, 2, ..., N_m) denote the index of each order. Finally, let (hij) denote the index of each order after the above division.

When the tasks of (hij) are produced by (kr), we assume the relations as follows: Let $T_{D.hij}$ denote the delivery date; let $T_{kr.hij}(t_k)$, $C_{T.kr.hij}(t_k)$, $T_{ext.kr.hij}(t_k)$ and $C_{ext.kr.hij}(t_k)$ denote respectively the production time and cost (not including the extra inventory time and cost), the extra inventory time and cost; let $T_{exp.kr.hij}(t_k)$ and $C_{exp.kr.hij}(t_k)$ denote the expected production time and cost determined by the core enterprise; let $C_{\text{Äô}.kr.hij}(t_k)$ denote the extra inventory cost per unit time and define $C_{ext.kr.hij}(t_k) = T_{ext.kr.hij}(t_k)\ C_{\text{Äô}.kr.hij}(t_k)$. Let $T_{\text{Ä}.k+1,r.hij}(t_k)$ denote the acceptable absolute value of the difference between the actual production time and the expected production time for (kr) producing the tasks of (hij) when it is operated at stage (k+1, r).

To set the constraints, let $A_{dem.k.hij}(t_k)$ and $Q_{sta.k.hij}$ denote respectively the spare production capacity demand and the production quality demand of (hij) to the kth stage. Let $A_{sup.kr.hij}(t_k)$ denote the spare production capacity supply of (kr) to (hij). Let $Q_{kr.hij}$ denote the production quality supply of (kr) to (hij). At the same time, let $\eth_{kr.hij}(t_k)$ denote the profit preference of (kr) to (hij), let $U_{kr}(t_k)$ and $U_{min.kr}(t_k)$ denote respectively the profit preference satisfaction degree of (kr) and its minimum, let $U_{SC\text{-}4PL}(t_k)$ denote the overall satisfaction profit of the supply chain system controlled by 4PL and let $\phi_{kr}(t_k)$ $(0 = \phi_{kr}(t_k) = 1)$ denote the contribution factor of (kr) to $U_{SC\text{-}4PL}(t_k)$ (when all the nodes achieve their maximum satisfaction profit and all $\phi_{kr}(t_k)$ equal 1, $U_{SC\text{-}4PL}(t_k)$ will be maximum ideally). Assume that the financial compensation is needed when the delivery date exceed the due date by accidents. So, let λ denote the delayed delivery tolerance parameter and let λ_{max} denote the maximum of λ which will be jointly determined by the core enterprise and other cooperators. Assume that if (hij) is operated at (kr), then $\omega_{kr.hij}(t_k) = 1$, otherwise $\omega_{kr.hij}(t_k) = 0$.

OPTIMIZATION MODLE

This study set up a 0-1 programming model as follows:

$$\begin{aligned}\min Z_1 = \sum_{k=1}^{K}\sum_{r=1}^{N_k}\sum_{h=1}^{G}\sum_{i=1}^{M_g}\sum_{j=1}^{N_m}\{[(C_{T.kr.hij}(t_k)\\ + T_{ext.kr.hij}(t_k)C_{\Delta\tau.kr.hij}(t_k))\\ + \pi_{kr.hij}(t_k)T_{kr.hij}(t_k)]\omega_{kr.hij}(t_k)\}\end{aligned} \quad (1)$$

$$\min Z_2 = \left|\begin{aligned}&T_{exp.kr.hij}(t_k) -\\ &(T_{kr.hij}(t_k) + T_{ext.kr.hij}(t_k))\end{aligned}\right| + \lambda \quad (2)$$

$$\min Z_3 = \left|\sum_{j=1}^{N_m}\pi_{kr.hij}(t_k) - N_m\right| \quad (3)$$

$$\max Z_4 = U_{kr}(t_k) - U_{min.kr}(t_k) \quad (4)$$

$$\max Z_5 = U_{SC-4PL}(t_k) = \sum_{k=1}^{K}\sum_{r=1}^{N_k}\phi_{kr}(t_k)U_{kr}(t_k) \quad (5)$$

Subject to:

$$\sum_{h=1}^{G}\sum_{i=1}^{M_g}\sum_{j=1}^{N_m}A_{dem.k.hij}(t_k) \le \sum_{r=1}^{N_k}A_{sup.kr.hij}(t_k) \quad (6)$$

$$\begin{aligned}T_{D.hij}(t) \le \sum_{k=1}^{K}\sum_{r=1}^{N_k}(T_{kr.hij}(t_k) +\\ T_{ext.kr.hij}(t_k))\omega_{kr.hij}(t_k) \le (1+\lambda)T_{D.hij}(t)\end{aligned} \quad (7)$$

$$\begin{aligned}\left|T_{exp.kr.hij}(t_k) - (T_{kr.hij}(t_k) + T_{ext.kr.hij}(t_k))\right|\\ \le T_{\Delta.k+1,r.hij}(t_k)\end{aligned} \quad (8)$$

$$\sum_{r=1}^{N_k}\sum_{h=1}^{G}\sum_{i=1}^{M_g}\sum_{j=1}^{N_m}\omega_{kr.hij}(t_k) = N_O \quad (9)$$

$$\sum_{r=1}^{N_k}\omega_{kr.hij}(t_k) = 1 \quad (10)$$

$$U_{kr}(t_k) \ge U_{min.kr}(t_k) \quad (11)$$

$$Q_{kr.hij} \ge Q_{sta.k.hij} \quad (12)$$

where, $k = 1,\dots K$; $r = 1,\dots, N_k$; $h = 1, \dots G$; $i = 1, \dots, M_g$; $j = 1, \dots, N_m$.

In the model, Constraint (6) describes the spare production capacity demand relations. Constraint (7) reflects the delivery constraints of the customized production. Constraint (8) assures that each production stage of the same customized product at different stages will continues smoothly. Constraint (9) assures that all orders received during the time threshold must go through all the production stages. For the orders whose tasks may not participate in some stages in practice, we make them through the virtual stages to replace. Constraint (10) assures that each task will be completed by its corresponding cooperators and there will not be any duplicated production to one task. Constraint (11) assures that the supply chain's collaborative relations are built on the satisfaction of the cooperators' profit preferences reaching their acceptable levels. Otherwise, they may not accept the resource integration and task allocation. Constraint (12) assures the quality demand of MC.

MEANING OF OPTIMIZATION

Equation 1 addresses optimizing the production cost of MC and its outstanding feature is the introduction of the profit preference factor. Equation 2 addresses optimizing the punctual deliveries of the customized products. From system opinion, when the actual production time is closer to its expected value, the deliveries to the customers can be better guaranteed. At the same time, the smaller the value of λ, the higher the level of the punctual delivery service is. Equation 3 addresses optimizing the scale production. The value of Z_3 is smaller the better. Because the division of N_m is based on the order classification ideas discussed above and the direct aim of the ideas is to alleviate the key contradiction in MC, which is also the goal of Equation 3. When the spare production capacity of (kr) is greater than

N_m needed, the tasks of N_m can be completed by one or more cooperators at the same stage. Obviously, the scale production effect of the former is higher than latter. But, from the angle of cooperator's profit preference, the decision result will be determined by the profit situation of the subjective and objective collaborative process. Equation 4 addresses optimizing every cooperator's profit on the premise that every cooperator can achieve its own satisfaction level. Equation 5 addresses optimizing the supply chain's overall profit by 4PL integration idea.

The above five objective functions influence and restrict each other. It illustrate that the supply chain resource integration and task allocation in MC by 4PL is a typical multi-objective optimization problem. In optimization, 4PL must consider a comprehensive optimization solution for these multiple objectives at the same time. Therefore, this study choose four aspects including the customized production cost, the production time, the scale production effect and the production capacity congestion as the optimizing goals.

OPTIMIZATION ALGORITHM

The above 0-1 programming model is a typical NP-hard problem. Currently, there are not very effective solution methods for linear 0-1 problem, such as the knapsack problem. Especially, when the optimization objective is nonlinear, the solving difficulty is even greater. In general, the genetic algorithm and bionic approach are the primary methods to solve such problems.

In this study, we use an improved ant optimization algorithm to solve the problem, for it has more advantages (Bonabeau *et al.*, 2000) and has been widely used in combination optimizations, dynamic routing and scheduling problems (Bautista and Pereira, 2005). Certainly, there is possibility to develop other algorithm to solve the problems in this study, but till now, ant algorithm is the best one. For example, fish swarm algorithm is another bionic method, but it is more complex, need long time computation and is difficult to balance the parameter relations among much more points to be sought in the optimization network although it has more advantages in global search. Meanwhile, a major problem is that it is difficult to bring multi-attribute optimization objectives in solving the multi-objective optimization. However, for there are much more new characters and complexities in the supply chain resource integration and task allocation in MC compared with the general operation problems such as JSS and FSS. To make the algorithm rational and suitable, we develop the general ant algorithm in this study and it is omitted here.

VALIDATE RESULT

We validate the reasonability and feasibility of the above model and ant algorithm in the optimization decision of the supply chain resources integration in MC by 4PL through a case study and simulation. It is omitted here.

CONCLUSION

This study explores a quantitative method about the supply chain resource integration in MC by 4PL and presents an integration optimization and MC task allocation model to reflect the mechanism of quantification. Obviously, there are many and complex factors which play a decisive role in decision optimization and it is need to give more deep and detailed analyses to the operational characters and rules.

The model and algorithm in this study are based on the integration quantitative theories and methods in 4PL mode. They not only reflect the complicated characteristics of the supply chain resource integration in MC process but also merge the solution methods of several important relations into the integration optimization.

The quantitative method in this study can reflect the complex diversity of the supply chain resources to be integrated in 4PL, can reflect the different resource demands for different MC customer and can reflect the resource integration demands for supply chain system and every resource individual. It can clearly describe the complex relationships between the subject and object in the supply chain resource integration in MC and easily balance the relationships among multi-objectives of integration from the angle of subjective and objective system strategy.

The integration mode of the supply chain resource in MC by 4PL belongs to the frontier of supply chain management field. In future study, we should give more depth analysis about the complex relations among various factors to guide the integration practice of 4PL with better strategy and to exploit more advantages in integrating supply chain resources in MC by 4PL.

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