Decision Analysis of Supply Chain Resource Integration and Optimization in Mass Customization by the Fourth Party Logistics*

Jianming Yao
School of Business, Renmin University of China,
Beijing, 100872, China

And

Zhenzhen Zhao
School of Business, Renmin University of China,
Beijing, 100872, China

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 paper. 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 validated is also pointed out in this paper.

Keywords: Decision Analysis, Supply Chain Resource Integration, Optimization, Mass Customization, Fourth Party Logistics.

1. INTRODUCTION

How to deal with the contradiction between mass production effect and customized demand is the key problem on mass customization (MC) [1]. 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 [2, 3]. 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 [4]. Especially, 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 customer orders and the outstanding collaborative benefit and risk conflictions in MC and the effective way is to integrate the different resources of the supply chain and allocate the MC tasks to them. The implementation of this process needs mathemathic optimization method.

However, there are no effective quantitative methods to guide the integration practices and 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, see Reference [2-4], this paper 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 the supply chain.

In order to solve the optimization problem, this paper also set up an 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 [2] and give consideration to the collaborative benefits and risks in the supply chain.

2. ASSUMPTIONS

We assume that the total production stages for MC is $K$ and let $k$ ($k = 1, 2, \ldots, K$) denote the index of each stage. We use $t_k$ as an independent time variable and use $t_k$ denote the starting moment at the $k$th stage.

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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 \( N_0 \) 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 \( k \)th stage. In following analysis, we use ‘nodes’ instead of ‘cooperators’. Let \( r \) (\( r = 1, 2, \ldots, N_j \)) denote the index of the node at the \( k \)th 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.

Reference [3] pointed out that the key problem of MC to solve is to satisfy the different customized demands with the scale production efficiency. As for 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 scheduling and to show the effects of the scope economy in MC, different orders. Obviously, these constitute a contradictory threshold. The main contents of the secondary classification are to make the system’s comprehensive profits maximum on the General Order (GO); Definition 3, the orders that should be followed: Definition 1, the orders received by the enterprise is to satisfy the different customized demands with the scale production efficiency in the supply chain scheduling in MC, which can be corresponding to the classification of RO; on the other hand, it contains completely the realization of the production quality demand of \( (hij) \) to \( (kr) \) and also contains the customized delivery date of products, 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. Here, we will introduce the 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 \( N_0 \) 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 \( h \) (\( h = 1, 2, \ldots, G \)) denote the index of each production category.

Let \( M_g \) (\( g = 1, 2, \ldots, G \)) denote the total number of the order categories divided by the order classification described above in the \( h \)th production category at moment \( t_k \) and let \( i \) (\( i = 1, 2, \ldots, M_g \)) denote the index of each order category. Let \( N_m \) (\( m = 1, 2, \ldots, M_g \)) denote the number of the total orders in the \( i \)th order category at moment \( t_k \) and let \( j \) (\( j = 1, 2, \ldots, N_m \)) 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 \( T_{dk,hij} \) denote the delivery date; let \( T_{exp,k+hij} \) and \( C_{exp,k+hij} \) denote respectively the production time and cost (not including the extra inventory time and cost), the extra inventory time and cost; let \( T_{exp,k+hij} \) and \( C_{exp,k+hij} \) denote the expected production time and cost determined by the core enterprise; let \( C_{C,k+hij} \) denote the extra inventory cost per unit time and define \( C_{C,k+hij} = T_{exp,k+hij} \cdot C_{C,k+hij} \). Let \( T_{exp,k+hij} \) 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 \( A_{ap,k+hij} \) and \( Q_{ap,k+hij} \) denote respectively the spare production capacity demand and the production quality demand of \( (hij) \) to the \( k \)th stage. Let \( A_{ap,k+hij} \) denote the spare production capacity supply of \( (kr) \) to \( (hij) \). Let \( Q_{ap,k+hij} \) denote the production quality supply of \( (kr) \) to \( (hij) \). At the same time, let \( t_{k+hij} \) denote the profit preference of \( (kr) \) to \( (hij) \), let \( U_{dk,hij} \) and \( U_{min,k+hij} \) denote respectively the profit preference satisfaction degree of \( (kr) \) and its minimum, let \( U_{SC} \) denote the overall satisfaction profit of the supply chain system and let \( \phi_k(t_k) \) (\( 0 < \phi_k(t_k) \leq 1 \)) denote the contribution factor of \( (kr) \) to \( U_{SC} \) (when all the nodes achieve their maximum satisfaction profit and all \( \phi_k(t_k) = 1 \), \( U_{SC} \) will be maximum ideally). Assume that the financial compensation is needed when the delivery date exceed the due date by accidents. So, let \( \beta \) denote the delayed delivery tolerance parameter and let \( \phi_{max} \) denote the maximum of \( \beta \) which will be jointly determined by the core enterprise and other cooperators. Assume that if \( (hij) \) is operated at \( (kr) \), then \( \phi_{k+hij}(t_k)=1 \), otherwise \( \phi_{k+hij}(t_k)=0 \).

3. OPTIMIZATION MODE

We set up a 0-1 programming model as follows.

The optimization objective functions are

\[
\min_{\text{max PROFID profit}} Z_k = \sum_{k=1}^{N_k} \sum_{r=1}^{R_k} \sum_{h=1}^{G} \sum_{j=1}^{N_m} \left[ (C_{C,k+hij}(t_j) + T_{exp,k+hij}(t_j) C_{C,k+hij}(t_j)) \right]
\]
In the model, Constraint (5) describes the spare production that all orders received during the time threshold must go through all the production stages. Constraint (8) assures that each production stage of the same customized product at different stages will continue smoothly. Constraint (7) assures the capacity demand relations 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 (9) assures that the supply chain’s collaborative operation characters and complexities in the supply chain resource integration and task allocation in MC compared with the micro-level of the solution operation in order to realize the application of our alleviation ideas.

\[ \min Z_2 = \sum_{r=1}^{N_r} (T_{\text{sup},kr}(t_k) - T_{\text{ex},kr}(t_j)) \delta_{kr,hj}(t_k) + \beta \]  

\[ \min Z_3 = \sum_{r=1}^{N_r} (T_{\text{ex},kr}(t_j)) \delta_{kr,hj}(t_k) \]  

\[ \max Z_4 = U_{\text{st}}(t) = \sum_{k=1}^{K} \sum_{r=1}^{R} \sum_{j=1}^{J} \phi_{kr}(t_j)U_{kr}(t_k) \]  

subject to

\[ \sum_{k=1}^{K} \sum_{r=1}^{R} \sum_{j=1}^{J} A_{\text{dem},kj}(t_k) \leq \sum_{k=1}^{K} \sum_{r=1}^{R} A_{\text{sup},kr}(t_k) \]  

\[ T_{\text{D,kr}}(t_k) \leq \sum_{j=1}^{J} (T_{\text{ex},kr}(t_j)) \delta_{kr,hj}(t_k) \]  

\[ \leq (1 + \beta)T_{\text{D,kr}}(t_k) \]  

\[ \left[ T_{\text{sup},kr}(t_k) - (T_{\text{ex},kr}(t_j) + T_{\text{ext,kr}}(t_k)) \right] \leq T_{\text{D,kr}}(t_k) \]  

\[ \sum_{r=1}^{R} \sum_{j=1}^{J} \delta_{kr,hj}(t_k) = N_o \]  

\[ \delta_{kr,hj}(t_k) = 1 \]  

\[ U_{kr}(t_j) \geq U_{\text{min,kr}}(t_k) \]  

\[ Q_{kr,hj} \geq Q_{\text{sta,kr}} \]  

Where \( 0 \leq \beta \leq \beta_{\text{max}} < 1; k = 1, \ldots, K; r = 1, \ldots, R; h = 1, \ldots, H; i = 1, \ldots, M_i; j = 1, \ldots, N_m. \)

In the model, Constraint (5) describes the spare production capacity demand relations. Constraint (6) reflects the delivery constraints of the customized production. Constraint (7) assures that each production stage of the same customized product at different stages will continue smoothly. Constraint (8) assures that all orders received during the time threshold must go through all the production stages. The orders whose tasks may not participate in some stages in practice, we make them through the virtual stages to replace. Constraint (9) assures that each task will be completed by its corresponding cooperators and there will not be any duplicated production to one task.

Constraint (10) assures that the supply chain’s collaborative operation characters and complexities in the supply chain resource integration and task allocation. Otherwise, they may not accept the resource integration and task allocation. Constraint (11) assures the quality demand of MC.

4. 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. In addition, the smaller the value of \( \beta \), 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, the same as analyzing the profit preference, the decision result will be determined by the profit situation of the subjective and objective collaborative production.

Equation (4) addresses optimizing the supply chain’s overall profit on the premise that every cooperator can achieve its own satisfaction level.

These four objective functions influence and restrict each other. The ultimate objective of the model is to reflect the levels of alleviating the dominant contradictions. It also illustrate that the supply chain resource integration and task allocation in MC by 4PL is a typical multi-objective optimization problem. In alleviating two dominant contradictions, we must consider a comprehensive optimization solution for these multiple objectives at the same time. Therefore, we choose four aspects including the customized production cost, the production time, the scale production effect and the production capacity congestion as the optimizing goals which are closely related to the micro-level of the solution operation in order to realize the application of our alleviation ideas.

5. 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 programming 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 paper, we use an improved ant optimization algorithm to solve the optimization problem, for it has more advantages [5] has been widely used in combination optimizations, dynamic routing and scheduling problems [6]. Certainly, there is possibility to develop other algorithm to solve the problems in this paper, 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. So, it is difficult to comprehensively deal with the problems in this paper by fish swarm algorithm.

However, as shown in the former text, there are much more new operating 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. In order to make the algorithm rational and suitable, we must develop the general ant algorithm.

Suppose that a supply chain network at the moment of resource integration and task allocation adjustment is composed of the source node, object node and cooperator nodes. The stage division of the network will be determined dynamically by the practical production circumstance of the several orders at the moment \( t_0 \).

In the running of algorithm, ants will move from the source node to the object node through the network and die then. As the ants can’t return, the pheromone [5] of different roads will be determined intelligently by the different cooperators’ production parameters. The structure of the algorithm is as follows.

First, we consider the structure of the ants and the forbidden nodes. To realize the algorithm we adopt the special method to make ants. That is: we make two-step division to the ant production classification. Each order class is corresponding to the different production parameters. The structure of the algorithm is as follows:

**ALGORITHM STEPS**

1. **Step 1**: The core enterprise determine the resource integration and task allocation adjustment moment.
2. **Step 2**: When the algorithm begins, we judge the order classification according to the description and set up the ant resource integration and task allocation adjustment moment.
classification, then determine the allowable fields for them.

**STEP 3.** Set the expected production delivery date \( T_s \), set the production cost of all kinds of MC production class corresponding with the different kinds of ant class \( A_i \) at different production stages. Determine the relations between \( T_s \) and the remained pheromone of all kinds of ants by the way of sampling and analyzing the present data.

**STEP 4.** Determine the expected satisfaction level of every optimization index such as the production cost and delivery date according to the historical experience and the data on-the-spot.

**STEP 5.** Set and adjust the value of \( \alpha, \beta, \gamma \) and \( \xi \).

**STEP 6.** Generate ant batch \( t \) (in the beginning, \( t=1 \)) at source node and there are kinds of ant class in every batch. Let the number of the ants in every class be \( x \) times as much as the number of the corresponding kinds of orders \( (3<x<10) \). Make the ants move to the object node and die when they arrive. Update the pheromone at every node according to the rule and then let \( t=t+1 \).

**STEP 7.** Account the ant number passing every node in every batch. Make the judgment of whether the ant number of selecting every node has become stable. We can judge the stable state by comparing the number of the ants selecting one node in this batch with the former batch to see if there is no obvious change, or by observing the number of the ants that always changes in a small scope during the recent several batches.

Then, we give the assignment of MC tasks to different cooperators according to the number of the ants distributed at the different nodes, calculate the optimizing level of all kinds of indexes and judge if they have reached the satisfaction level. If yes, we can stop the algorithm and turn to step 8, otherwise turn to step 6.

**STEP 8.** Output the algorithm result and make the resource integration and task allocation implementation according to it.

Here, we should also pay attention to several issues.

Firstly, if the move of the ants can’t reach the stable state even they have passed all batches, we should adjust the values of all kinds of parameters to a larger range, which means we should turn to step 5.

Secondly, if every index can’t reach the satisfaction level even if the algorithm has run in a long time, we should revise the expected satisfaction level, which means we should turn to step 4.

Finally, when the algorithm reaches the stable state, the problems of production congestion at some nodes are disappeared, and even if the quantities of the attraction pheromone at these nodes are larger, the ant current through these nodes will not increase. It is owed to the role of the exclusion probability.

**7. 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.

**8. CONCLUSIONS**

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

The model and algorithm set up in this paper 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 production process but also merge the solution methods of several important relations into the integration optimization process.

The quantitative method of the resource integration optimization in MC by 4PL in this paper 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; easily balance the relationships among multi-objectives of integration from the angle of subjective and objective system strategy; easily solve the special problems (such as the congestion problem) in the actual operational level. In addition, the model and algorithm are also transition bridges from the integration optimization theories and methods to the practice.

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 attention to the complicacy of the dominant factors. Especially in different production or service industries, it is most important to grasp this principle. Meanwhile, it need more depth analysis about the complex relations among various factors to guide the integration practice of 4PL with better integration strategy and to exploit more advantages in integrating supply chain resources in MC by 4PL.

**9. REFERENCES**


