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Collaborative Production Planning with Order Splitting In Cloud Manufacturing Platform

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Abstract**—**Cloud manufacturing platform collects customers' orders and manages distributed manufacturing resources to accomplish orders, then transports products to customers. This paper discusses collaborative production planning problem between multi-enterprises in the cloud-manufacturing platform. We have presented a collaborative production-planning model for integrating order splitting and production planning decisions. This model could give two decisions: (1) which orders should be split, and the fraction of each order processed at each enterprise. (2) In which periods the order processed at the enterprise. A genetic algorithm optimization-based approach is developed to address the problem. Finally, an improved genetic algorithm-based approach is developed to address the problem.

Keywords- collaborative production planning; order splitting; cloud manufacturing

I. INTRODUCTION

"Cloud manufacturing" is gradually becoming a new trend in the development of China's manufacturing industry. And Collaborative decision making of order splitting and production planning is an important research field in intelligent manufacturing.

In the case where the demand is known or predictable in each period, classic production planning problems are decision making of the production time of each order with the goal of minimize the sum of setup cost, production and inventory costs [1,2]. Due to the practical application needs, nearly a decade of production planning models have taken into account the production capacity, time windows and other constraints and decision-making goals are also extended from a single cost minimization to the largest profit, the shortest time to complete, the highest customer satisfaction and other multi-objective combination [3,4].

Order splitting emerges with the supplier selection decisions in the research of production planning problems. When studying production-planning issues, order splitting can decide which supplier to choose and the order splitting rate in the selected supplier during each production period. Basnet (2005) proposed a multi-period lot sizing problem by using the enumerative search algorithm to decide what products to order in what quantities with which suppliers in which period [5]. Z. Liao and J. Rittscher (2007), proposed a genetic algorithm to solve the multi-objective single item lot sizing problem and joint consideration of supplier selection, order splitting rate, procurement lot sizing, carrier selection [6]. H. Ding(2009) studied the production-distribution network design issues, including supply chain configuration and related decisions such as order splitting, transportation allocation and inventory control[7]. F. Ye(2011) raised the issue of parallel suppliers. They put forward the order splitting strategy and established a single-period bi-objective model, which minimize total cost and the deviation of production load rates between any two suppliers, respectively [8]. T. Pan (2014) established a joint optimization model for order splitting and production planning and pointed out that order splitting rate plays an important role in the formulation of production plan [9].

In summary, this paper establishes a collaborative production-planning model considering order splitting. The model provides two decisions. First, how the order is effectively split and allocated, and how it can take into account the production of the enterprise load balance and the entire platform revenue. Second, formulate collaborative production planning in consideration of production time window and production capacity constraints, meet the order's lead-time and make the sum of production costs and distribution costs minimal. The model combines the order splitting and production planning joint decision, which can improve the accuracy of the production plan, and more adapt to the requirements of intelligent manufacturing.

II. PROBLEM DESCRIPTION AND MATHEMATICAL MODEL

A. Problem description

The customers in the cloud-manufacturing platform submit orders to the platform for the production of a certain product, and there are many enterprises on the platform with the ability to produce the product. The customers' orders contain information such as product requirements and lead-time. After accepting the orders, the cloud platform according to a certain decomposition strategy decomposes the orders and assigns them to enterprises. Then the enterprises began to produce. In the delivery period, the enterprises complete the sub-order and deliver the product to the customers directly. The problem requires decision-making: (1) whether each order is split, how to split, and how much each enterprise produces? (2) After the enterprises receiving the sub orders, which were split, how does the enterprise to arrange the production time before the delivery time to complete the order.

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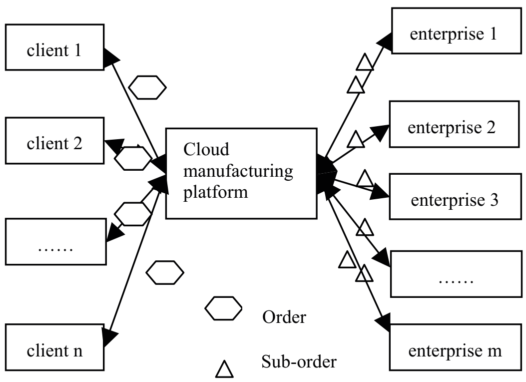

Figure 1. Order splitting under cloud platform

Model hypothesis: (1) Cloud manufacturing platform without inventory; (2)An enterprise cannot complete the production within the planning cycle; (3)For sub-orders under cloud platform after decomposition, enterprise produce all products; (4) If the order is selected for production, it can only be produced at a certain time; (5) Do not consider the enterprise outsourcing production.

The representation of the set and parameters in the model:

TABLE I. SETS AND PARAMETERS

N	Set of orders, indexed by n
M	Set of enterprises, indexed by m
K	Set of sub-orders, indexed by k
C	Set of clients, indexed by c
T	The number of time periods, indexed by t
E_{mt}	The production capacity of the enterprise m at period t
E_m^{max}	The greatest capacity of enterprise m in all time periods
W_n	The demand of order n
e_{nc}	1, If order n is the order for client c，0, otherwise
q_{nk}	Demand quantity of item k in order n
$[a_n, b_n]$	Delivery window of order n
D_{mc}	The distance between the enterprise m and the client c
g_k	The unit shipping cost per kilometer of item k
p_{mk}	Unit production costs of enterprise m product order item k
s_{mk}	The setup cost of item k at enterprise m
ΔU_{max}	The maximal allocation difference between the two enterprises
F_{max}	The maximal number of enterprise that process an order
F_{lb}	The minimum order splitting ratio

TABLE II. DECISION VARIABLES

V_{mn}	Order splitting ratio, i.e., the fraction of order n processed at enterprise m
Y_{mn}	1,if order n is assigned to enterprise m; 0,otherwise
X_{mnkt}	The production quantity of item k of order n processed at enterprise m at period t
Y_{mnkt}	1,if item k in order n is processed at enterprise m at period t;0, otherwise

B. Mathematical model

The goal of the model is to minimize the total cost (f). The total cost includes the cost of production (f1) and transportation costs (f2).

$$f_1 = \sum_{t=1}^{T}\sum_{m=1}^{M}\sum_{k=1}^{K}\left(p_{mk}\sum_{n=1}^{N}X_{mnkt} + s_{mk}\sum_{n=1}^{N}Y_{mnkt}\right) \quad (1)$$

$$f_2 = \sum_{m=1}^{M}\sum_{n=1}^{N}\left(\sum_{c=1}^{C}e_{nc}d_{mc}\right)\left(\sum_{k=1}^{K}g_k q_{nk}\right) \quad (2)$$

The objective function is:

$$\mathrm{Min} f = (f_1 + f_2) \quad (3)$$

Restrictions:

$$\sum_{n=1}^{N}\sum_{k=1}^{K}X_{mnkt} \le E_{mt}, \forall m \in M, t = 1,2 \ldots\ldots T \quad (4)$$

$$\sum_{t=1}^{b_n}X_{mnkt} = W_n V_{mn}, \quad \forall m \in M, n \in N, k = (n-1)*M+1 \quad (5)$$

$$\sum_{m=1}^{M}V_{mn} = 1, \forall n \in N \quad (6)$$

$$F_{lb}Y_{mn} \le V_{mn} \le Y_{mn}, \forall m \in M, n \in N \quad (7)$$

$$\sum_{m=1}^{M}Y_{mn} \le F_{max}, \forall n \in N \quad (8)$$

$$U_m - U_{m'} \le \Delta U_{max}, \forall m, m' \in M \quad (9)$$

$$E_m^{max} < W_n, \forall m \in M, n \in N \quad (10)$$

$$\sum_{n=1}^{N}W_n \le \sum_{t=1}^{T}\sum_{m=1}^{M}E_{mt} \quad (11)$$

Constraint (4) is capacity constraints. It indicates that at any time of each enterprise, the sum of the production orders of each sub-order does not exceed the maximum capacity of the time period; Constraint (5) is time window constraint. Any business order for sub-orders must be completed before the latest delivery time; Constraints of (6) (7) (8) are order-splitting constraint. Constraints (6) indicate that the sum of the total decomposition rate of an order must be 1; Constraints (7) is the range of the order-splitting ratio; Constraints (8) indicate that for an order, the maximal number of enterprises that can process one order; Constraints (9) is utilization constraint. It indicates that the difference between the utilization rates between the two firms does not exceed the given value (ΔU_{max}). The utilization rate refers to: the sum of the demand for all orders assigned by an enterprise and the ratio of the capacity in the planned period. Constraints (10) indicate that if the demand for any order is greater than the capacity of the entire planned period of any enterprise, the order must be split. Constraints (11) indicate that the total amount of all orders in a planned cycle must be less than the sum of capacity for each period, thus ensuring that all orders can be completed within the planning cycle.

III. Solving Strategy and Algorithm Design

A. Coding scheme

In this model, K represents the set of sub orders , and K=M*N. So by the number of sub-order k, you can find the corresponding order number n and the allocation of enterprise number m and achieve dimensionality.

$$m = \begin{cases} M, & \text{if } (k\%M == 0) \\ k\%M, & \text{if } (k\%M \neq 0) \end{cases};$$

$$n = \begin{cases} k/M, & \text{If } (k\%M == 0) \\ k/M + 1, & \text{if } (k\%M \neq 0) \end{cases}$$

Decision variable dimensionality reduction:

$$v_k = V_{mn}, \quad k = 1,2,\cdots K$$

v_k, it indicates the allocation rate of order n = k / 3 + 1 For enterprise k%M or indicates the distribution law of order n = k/3 assigned to firm M.

$$y_k = \sum_{t=1}^{T} t\,Y_{mnkt}, \quad k = 1,2,\cdots K$$

y_k, it represents the item k in the production period of the enterprise during the period of k%M.

$$L_r = \{v_{r1}, v_{r2}, \cdots, v_{rK}; y_{r1}, y_{r2}, \cdots, y_{rK}\}$$

B. Genetic Algorithm

1) Crossover and mutation strategy

Crossover is the primary method of generating new individuals; it determines the global search capability of genetic algorithms. In order to ensure that the offspring do not violate the order decomposition rate of the relevant constraints (6), (7), (8), here use the sub-parallel and parallel cross strategy. While exchanging the sub-segments of the first part of the parent chromosome and the second parts of the same gene are interchangeable.

The role of mutation is to enhance individual diversity; it determines the local search capability of the genetic algorithm. In order to ensure that the offspring do not violate the order decomposition rate of the relevant constraints (6), (7), (8), here use the sub-parallel and parallel mutation strategy. While exchanging the sub-segments of the first part of the parent chromosome and the second parts of the same gene are interchangeable.

2) Fitness function

The fitness of chromosomes was evaluated by normalized calibration technique. Let F_{max} and F_{min} be the maximum target value and the minimum target value of the current population respectively, α is a positive real number that is limited to the (0, 1) interval, then the adaptive function of the algorithm is $F_i = \frac{F_{max} - f_i + \alpha}{F_{max} - F_{min} + \alpha}$.

3) Selection strategy

The population of the extended population is composed of the parent and the offspring, and the population is selected by using the roulette wheel method to select the population size of a chromosome to form a new population.

IV. Calculation experiment and result analysis

The algorithm used in this paper is JAVA programming and run tests on Intel Q7CPU and 4G memory.

A. The generation of data sets

Due to the randomness of the data on the cloud-manufacturing platform, the random parameter set is generated as follows.

TABLE III. PARAMETERS FOR GENERATING THE EXPERIMENTAL DATA

D_{mc}	U[100,200]	The distance between the enterprise m and the customer c
g_k	U [0.1,0.2]	Shipping costs per kilometer of item k
p_{mk}	U [30,40]	Unit production costs of enterprise m production order item k
s_{mk}	U [2000,3000]	Production preparation costs of enterprise m production order item k
E_{mt}	U[10000,20000]	The production capacity of the enterprise m at time t
W_n	U [8000,16000]	Demand of order n

B. The sensitivity analysis of the parameters

- Figure 2(a)(on the left side) is the convergence graph of target value using the standard genetic algorithm. The figure shows the comparisons of mutation rate at different values with the crossover rate equals 0.95.When the mutation rate equals 0.01, the curve converges progressively, but when the mutation rate increase, the curve will lead to premature and fall into local optimum.
- Figure 2(a)(on the right side) shows the convergence graph of object value using the genetic algorithm of improved crossover operator, which is changed from original unit crossover into multi-segment crossover. It is found that using the improved crossover operator, a higher convergence rate is obtained, but the optimal target value is not improved significantly. At the same time, through comparing, it is confirmed that when the crossover rate equals 0.95, the target value is optimal.
- Figure 2(b)(on the right side) shows the result of the genetic algorithm of improved mutation operator with a given crossover rate of 0.95. It is found that the improved mutation operator has the best ability to find the optimal target value when the mutation rate equals 0.1.
- Figure 2(b) (on the left side) shows the four graphs of improved both crossover operator and mutation operator, only improved crossover operator, only improved mutation operator and the standard genetic algorithm. It is found that the ability to find the optimal target value of improved both crossover operator and mutation operator is better than the other three algorithms. So it proves the improved genetic algorithm in the paper is more suitable to solve the problem than the standard genetic algorithm.

V. CONCLUSIONS

This paper discusses collaborative production planning problem between multi-enterprises in the cloud manufacturing platform. We present a collaborative production planning model for integrated order splitting and production planning decisions. This model can give two decisions: (1) which orders should be split, and the fraction of each order processed at each plant. (2) In which periods the order processed at the plant. A genetic algorithm optimization-based approach is developed to address the problem. Finally, an improved genetic algorithm-based approach is developed to address the problem.

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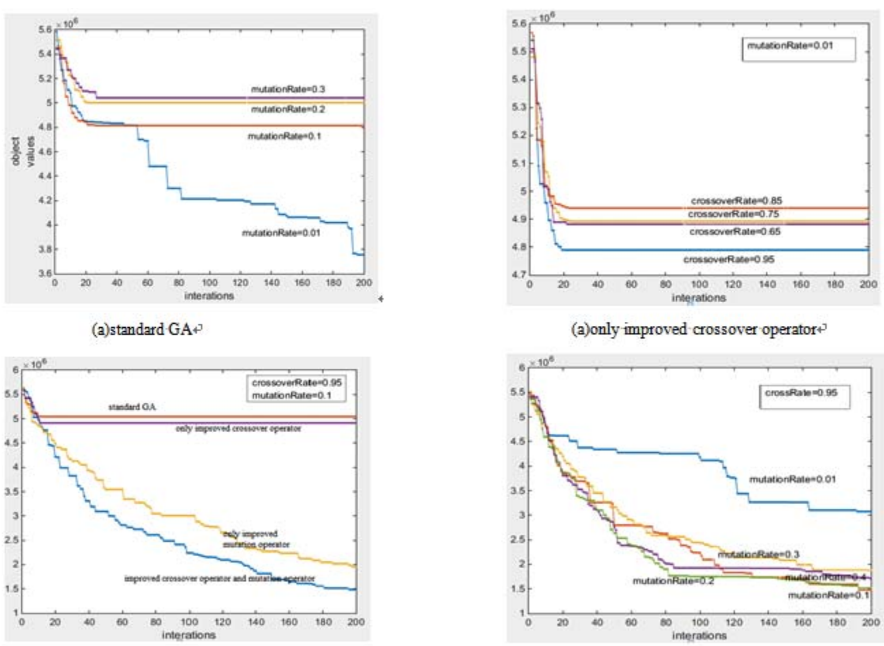

(a)standard GA

(a)only improved crossover operator

(b) both im proved crossover and mutation operator

(b)only improved mutation operator

Figure 2. Convergence graph of target value