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Abstract: Considering the background of cloud manufacturing and cluster supply chain, we build the basic model to assign the orders priority within each capacity. Then, considering the inter-chain horizontal cooperation, the extended model is proposed to parallel allocation of cross-chain orders as the orders exceeding one single-chain's capacity. Lagrange algorithm is implemented, and the simulation analysis shown that the opportunity cost of rejected orders factor and cross-chain orders manufacturing cost factor have significant impacts on orders' allocation decision, and there is a critical point in the combinations of those two factors. Through combinations, the cluster supply chain can make the acceptance decisions policy and production schedules of priority orders and cross-chain orders, so that customers' satisfaction and the cluster supply chain's total profits achieve the best situations.

Keywords: cluster supply chain,; order decision; cross-chain order; cloud manufacturing ;Lagrange algorithm

1. INTRODUCTION

1.1 Background

With the EC development of C2B (customers to business) mode, MTO firms usually organize and coordinate the operations with orders-driven, and use the way of flexible specialization to deal with various production processes for the orders with multi frequency, small batch and personalized products. Because the main driver in MTO operations is customer orders, it is vital to coordinate operations and sales functions for effective use of available resources by managing the demand placed on the system[1] (Mehmet and Sridharan, 2005). Therefore, When making the order decisions, they usually use the way of work overtime or subcontracting, which on the contrary leads to higher operation costs.

Through specialization and cooperation with each other, MTO firms often gather in a particular area and form the industry clusters, based on which a kind of network with multi supply chains comes into being as we called cluster supply chain[2] (CSC)(Li, 2006). Under cloud manufacturing, the MTO firms in CSC can collaborate between supply chains, for example, the firms in different supply chain manages allocate inventory and collaborative purchase[3,4](Liu, 2011,2013). Similarly, the firms in different supply chain (is also called single supply chain) can also process the customer orders together, namely the problem is how to make the order decision in multi supply chains.

1.2 Problem description

A cluster supply chain is composed by a number of single supply chains, and each single supply chain contains MTO firms, sellers, and customers. The customer orders are collected by sellers and sent to MTO firms from the downstream to upstream of a single supply chain, then a job shop in a MTO firm with a set of customer orders is considered. The decision to make is which customer orders to accept and how to schedule it in order to maximize the profit and to fulfill the accepted orders by the due date, as well as how to process the rejected orders in order to maximize customer satisfaction and to allocate the rejected orders in multiple supply chains.

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Both decisions should be made simultaneously, otherwise an order may be accepted but the available residual capacity may not permit on-time delivery.

Each customer order has a set of operations to be processed with linear precedence constraint and deterministic processing times, a fixed due-date, and a known sales price. Tardy deliveries are not allowed. There are multiple resource types; each resource type has one or more machines. Job recirculation is allowed (i.e. the jobs can visit the same resource more than once). The objective considered is to maximize the operational profit over a planning horizon considering only the sales price and the manufacturing costs by accepting a subset of customer orders. The planning horizon is discredited into time buckets of equal length know as time periods. Without loss of generality, each time period is assumed as one day. Furthermore each day is divided into two shifts namely regular time and overtime. Overtime is typically expensive. The decision of accepting or rejecting the orders is done at the beginning of the day.

2. LITERATURE REVIEW

About order decisions, the order acceptance, lead-time or due date quotation, pricing and capacity planning are closely related. In the absence of differential pricing, RM becomes a capacity allocation and order acceptance problem.

Slotnick and Morton[5](2007) model a manufacturing facility that considers a pool of orders, and chooses for processing a subset that results in the highest profit. In addition to the problem characteristics in Slotnick and Morton[6] (2009) they consider customer weight. The objective is to maximize profit, which is the sum of per-job revenues minus total weighted tardiness. They propose two approaches: separation of sequencing and job acceptance decisions, utilizing a property of the problem that is exploited to good advantage in the analogous problem with weighted lateness and a joint consideration of sequencing and acceptance, using relaxation. They state that the joint approach is far superior to the first. Yano[7] (2010) research the order decisions by minimizing the expected total inventory holding costs and delay costs with the order delivery lead time as decision variable. Mehmet[8] (2010) studied order decisions and orders of the production planning problems under the income management; So and Song[9] (2010) considered short-term decision-making factors such as price, delivery time and capacity expansion level to make order decisions; Ebben[10] (2012) and Reitman[11] (2013) proposed order decision problems when the customer demand is sensitive of the price and delivery time. Weng[12] (2015) discussed the order production planning from the point of view of to maximize the expected income.

In the existing literature, order decisions involves only a single MTO firms in the same supply chain.

3. PROBLEM DEFINITION

3.1 Mathematical formulation

The notation used in the formulation is presented below.

Sets and parameter

The symbols and meanings of the set and the parameters are shown in Table I.

Table 1. The meaning of set and parameters

set	symbol meaning	parameter	symbol meaning
$\{r \in R\}$	production equipment	RTL_{its}	length of shift time in SC_i
$\{t \in T\}$	time periods	MC_{irs}	production capacity of r within the time interval t in shift time s
$s \in S = \{1,2\}$	shift time,1 is regular time (RT), and 2 is overtime (OT).	MT_{ijor}	use equipment r to complete the production operation o *of* order j
		LT_{ij}	lead time of order j *in* SC_i

set	symbol meaning	parameter	symbol meaning
$\{j \in J\} = \{1,2,3\}$	orders / products (1 orders only 1 products)	P_{ij}	sales price (market price) of order *j* in SC_i
$\{o \in O_j\}$	production operations	MCT_{irs}	the cost of using equipment *r* in the shift time *s* in SC_i
$i \in I = \{1,2\}$	the single supply chain *i*	α_{ij}	the opportunity cost weight factor for rejected order *j*, $0 \le \alpha_{ij} \le 1$

Decision variable

PT_{ijorts} = hours of operation *o* of order *j* processed on resource *r* in shift time *s* of period *t*;

$$PP_{ijorts} = \begin{cases} 1, \text{if operation } o \text{ of order } j \text{ processed on equipment } r \text{ in shift time } s \text{ of time period } t; \\ 0, \text{otherwise}; \end{cases}$$

$$PA_{ij} = \begin{cases} 1, \text{if order } j \text{ accepted}; \\ 0, \text{otherwise}. \end{cases}$$

3.2 Decision model for single supply chain order (basic model)

Generally, when the customer orders arrive to the MTO firms in CSC, considering of production capabilities, and opportunity cost of rejection orders, the manager accept one part of orders (directed orders) and reject another orders (rejected orders) to pursue their own profit maximization. In the process of order decisions, the resources allocated within the single supply chain, and there is no cooperation between supply chains.

The mathematical formulation proposed for the basic model is presented below.

$$MaxmizeZ = \sum_{i\in I}\left(\sum_{j\in J} P_{ij}PA_{ij} - \sum_{j\in J}\sum_{o\in O_j}\sum_{r\in R}\sum_{t\in T}\sum_{s\in S} MCT_{irs}PT_{ijorts}\right) - \sum_{i\in I}\sum_{j\in J}\alpha_{ij}(1-PA_{ij})P_{ij} \quad (1)$$

Subject to

$$\sum_{j\in J}\sum_{o\in O_j} PT_{ijorts} \le MC_{irs}, \forall i\in I, r\in R, t\in T, s\in S \quad (2)$$

$$\sum_{s\in S}\sum_{t\in T} PT_{ijorts} = MT_{ijor}PA_{ij}, \forall i\in I, j\in J, o\in O, r\in R \quad (3)$$

$$\sum_{o\in O_j}\sum_{r\in R} PT_{ijorts} \le RTL_{its}, \forall i\in I, j\in J, t\in T, s\in S \quad (4)$$

$$PT_{ijorts} \ge \tau PP_{ijorts}, \forall i\in I, j\in J, o\in O_j, r\in R, t\in T, s\in S \quad (5)$$

$$\tau PP_{ijorts} \le PT_{ijorts} \le MT_{ijor}PP_{ijorts}, \forall i\in I, j\in J, o\in O_j, r\in R, t\in T, s\in S \quad (6)$$

$$\sum_{r\in R} tPP_{ijorts} \le LT_{ij}PA_{ij}, \forall i\in I, j\in J, t\in T, s\in S \quad (7)$$

$$\sum_{s'\in S}\sum_{t'=1}^{t-1} PT^{*}{}_{ij(o-1)rt's'} + \sum_{s'=1}^{s} PT^{**}{}_{ij(o-1)rts'} \ge MT_{ij(o-1)r}\sum_{r'\in R} PP_{ijor}, \forall i\in I, j\in J, o\in O_j, r\in R, t\in T, s\in S \quad (8)$$

$$\sum_{s\in S}\sum_{t'=1}^{t} PT_{ij(o-1)rt's} \ge MT_{ij(o-1)r}\sum_{r'\in R} PP_{ijor'|S|t}, \forall i\in I, j\in J, o\in O_j, r\in R, t\in T \quad (9)$$

$$PT_{ijorts} \ge 0, PP_{ijorts} \in \{0,1\}, PA_{ij} \in \{0,1\}, \forall i\in I, j\in J, o\in O_j, r\in R, t\in T, s\in S \quad (10)$$

Objective (1) is formulated to maximize the total profit of CSC, and consisted of two parts: the first term is the total sales revenue minas the production cost, and the second term is the opportunity cost of refused orders. α_{ij} is the weight factor of the opportunity cost, in the short term, the order's opportunity cost is not more than the order's sale revenue, namely $0 \le \alpha_{ij} \le 1$。

Constraint set (2) ensures that the production capacity of equipment *r* of shift time *s* in time period *t* is not violated. Constraint set (3) ensures that adequate production equipments are allocated to process operation *o* of order *j*. The total hours allocated to process an operation should be equal to its processing time. Constraint set (4) ensures that each operation of an order is processed for no more than RTL_{its} hours in each shift time during each time period. Constraint set (5) and (6) set the PP_{ijorts} decision variables to either 1 or 0. It takes a value of 1 when $PT_{ijorts} > 0$, indicating that operation *o* of order *j* is scheduled for processing on equipment *r* of shift time *s* in time period *t*; otherwise it takes a value of 0. The PP_{ijorts} variables are used to ensure the precedence relationship. The parameter s in constraint (5) indicates that whenever an operation is processed on an equipment it should be processed for at least *s* units of time. Constraint set (7) ensures that when an order is accepted, the completion time of the last operation of that order does not exceed the order due date. Constraint set (8) ensures that operation *o* of order *j* can be processed in period *t* during regular hours only after completing operation (*o*-1). Constraint set (9) ensures that operation *o* of order *j* can be processed in period *t* during overtime only after completing operation (*o*-1). Constraint sets (10) impose the non-negativity restrictions and binary restrictions on the decision variables.

3.3 Decision model for multiple supply chain orders (extended model)

Considering of the collaboration between supply chains, the rejected orders in single supply chain will be accepted temporarily as the reserved orders. Then those orders enter into the next supply chain and be made order decisions again, the process of orders decisions for multiple supply chain.

The mathematical formulation proposed for the extended model is presented below.

$$MaxmizeZ' = \begin{bmatrix} \sum_{i\in I}\left(\sum_{j\in J} P_{ij}PA_{ij} - \sum_{j\in J}\sum_{o\in O_j}\sum_{r\in R}\sum_{t\in T}\sum_{s\in S} MCT_{irs}PT_{ijorts}\right) \\ +\sum_{i\in I}\left(\sum_{j\in J} P_j PA'_{ij} - \sum_{j\in J}\sum_{o\in O_j}\sum_{r\in R}\sum_{t\in T}\sum_{s\in S} \beta_{ij} MCT_{irs}PT'_{ijorts}\right) \\ -\sum_{i\in I}\sum_{j\in J}\alpha_{ij}(1-PA_{ij}-PA'_{ij})P_{ij} \end{bmatrix} \tag{13}$$

Subject to constraints (2)-(12), and

$$\sum_{j\in J}\sum_{o\in O_j} PT_{ijorts} + \sum_{j\in J}\sum_{o\in O_j} PT'_{ijorts} \le MC_{irts}, \forall i\in I, r\in R, t\in T, s\in S \tag{14}$$

$$\sum_{s\in S}\sum_{t\in T} PT_{ijorts} + \sum_{s\in S}\sum_{t\in T} PT'_{ijorts} = MT_{ijor}\left(PA_{ij} + PA'_{ij}\right), \forall i\in I, j\in J, o\in O, r\in R \tag{15}$$

$$\sum_{o\in O_j}\sum_{r\in R} PT_{ijorts} + \sum_{o\in O_j}\sum_{r\in R} PT'_{ijorts} \le RTL_{its}, \forall i\in I, j\in J, t\in T, s\in S \tag{16}$$

$$\sum_{r\in R} tPP'_{ijorts} \le LT_{ij}PA'_{ij}, \forall i\in I, j\in J, t\in T, s\in S \tag{17}$$

$$PT'_{ijorts} \ge 0, PP'_{ijorts} \in \{0,1\}, PA'_{ij} \in \{0,1\}, \forall i\in I, j\in J, o\in O_j, r\in R, t \tag{18}$$

$$PP_{ijorts} \in \{0,1\}, \forall i\in I, j\in J, o\in O_j, r\in R, t\in T \tag{19}$$

$$PA_{ij} + PA'_{ij} \le 1, \forall i\in I, j\in \tag{20}$$

Objective (13) consists of three parts: the first part is the profits of directed orders; the second part is the profits of cross-chain orders; the last part is the opportunity cost of rejected orders. β_{ij} is the production cost factor of cross-chain orders, obviously, $\beta_{ij} \geq 1$. when $\beta_{ij} = 1$, there is a high level of cooperation between supply chains, and cross-chain production cost is equivalent to the sigle supply chain. On the contrary, if $\beta_{ij} \rightarrow +\infty$, which shows the collaboration level between supply chains is very low, and then the orders processed in another supply chain need more time to coordinate people and equipments, so the production cost is very high. β_{ij} ensures the accepted orders processing sequence, first is directed orders, followed by cross-chain orders, which comply with the actual operation norms in CSC. Moreover, we add three decision variables PT'_{ijorts}, PP'_{ijorts} ,and PA'_{ij}. PT'_{ijorts} is the time of operation *o* of cross-chain order *j* processed on resource *r* in shift time *s* of period *t*; PP'_{ijorts} is 1 if operation *o* of order *j* processed on equipment *r* in shift time *s* of time period *t*, otherwise is 0; PA'_{ij} is 1 if cross-chain order j accepted, otherwise is 0.

Constraint set (14) ensures the production capacities meet with the directed orders and cross-chain orders; Constraint set (15) ensures the equipments are enough for processing operation *o* of order *j*, and total hours allocated to process an operation should be equal to MT_{ijor}; Constraint set (16) ensures that each operation of the directed orders and cross-chain orders is processed for no more than RTL_{its} hours in each shift time during each time period; Constraint set (17) ensures that when a cross-chain order is accepted, the completion time of the last operation of that order does not exceed the leading time LT_{ij}; Constraint set (18)-(20) is the same as constraint set(10)-(12), but constraint set (20) ensures the order is accepted by the SC_i to be unique.

4. ALGORITHM DESIGN

The extended model are all a mixed integer nonlinear programming problem (MINLP). To solve this problem, an effective method is calculating lower bounds, and using upper and lower bounds to evaluate the algorithm[13,14]. Lagrange Relaxation is an effective method for solving the lower bound. Because Lagrange relaxation is relatively simple and has good properties, it can not only be used to evaluate the effect of the algorithm, but also improve the efficiency of the algorithm. The basic principle of Lagrange algorithm using Lagrange multiplier to relax the difficult constraints in the original problem, so it is relatively easy to solve Lagrange's problem, and through calculate the Lagrange dual problem and gradually approaching to obtain the optimal solution of the original problem.

A better lower bound for the Lagrange relaxation problem also should be similar to the optimal solution of the IP problem. With such logic, Lagrange heuristic algorithm is generated. A Lagrange heuristic algorithm mainly includes two parts: the first part is a Lagrange sub gradient optimization, but the result maybe not the necessarily feasible solution, so the second part is making the feasible solution based on the first part.

- Step 1. Initialization, determine the value of the parameters according to the actual situation, set initial value Lagrange multiplier $\lambda_i^k = 0$, *i*=1,2,3,*k*=0, $k \in T$.
- Step 2. For a given λ_i^k, calculate $z_{LR}(\lambda_i^k)$.
- Step 3. The feasible solution set of LR is composed of a finite number of integer points, and the pole is x^* (x is the all decision variables in the model). Then $z_{LR}(\lambda^*) = \max(ax^* + \lambda^* bx^*)$ (*a* and *b* are all parameters in the model). Set $I = \{t | z_{LR}(\lambda) = ax^t + \lambda^* bx^t\}$, for $t \in T$,calculate sub gradient $s^t = bx^t$ 。
- Step 4. Choose a sub-gradient s^k ($k \in T$) from step 3, if $s^k = 0$, λ_i^k is the optimal solution and the calculation will be stopped; otherwise, go to step 5.
- Step 5. Design equation $\lambda_i^{k+1} = \min\{\lambda_i^k + \theta_k, s^k, 0\}, k := k+1$, and $\sum_{k=1}^{\infty} \theta_k = \infty$, $\theta_k \rightarrow 0, k \rightarrow \infty$. Repeat Step 5.
- Step 6. Algorithm termination principle: the value of λ_i^k is no more than the given value in a specified number of steps, at this time the target value is not likely to change or change very little.

5. DECISION SUPPORT USING THE PROPOSED EXTENDED MODEL

The extended model proposed can help the operations manager/decision maker to determine which subset of incoming customer orders should be selected to maximize profits. It can be integrated into a decision support system to make day-to-day decisions so that the resources of the cluster supply chain are appropriately used. The extended model can be run at the beginning of each decision period, such that the operations manager can reserve capacity for already accepted orders and determine which new orders to accept. In situation where a particular order(s) have to be selected for strategic reasons, a corresponding subset of order(s) that will maximize the profits can also be determined. [15]

We present an example to illustrate how the user can utilize this model. Considering a cluster supply chain comprised of SC_1 and SC_2, the Table 2a shows the characteristics of SC_1 and SC_2. The cost of using each equipment in regular time (RT) and overtime (OT) are given in Table 2b. It is assumed that regular production time and overtime is 8 hours each. There are 5 customers orders, orders j_{11}, j_{12} and j_{13} is for SC_1, orders j_{21} and j_{22} is for SC_2. Table 3 shows the parameters of these orders. The MINLP model for the example problem is solved using the commercial solver Lingo 7.1.

The optimum profit of CSC is $925 (see the left part of Table 4a) when all of customer orders are accepted if SC_1 and SC_2 cooperate with each other (see the right part of Table 4b). However, the optimum profit of CSC will reduce to $770 (see the right part of Table 4a) with non-collaboration between SC_1 and SC_2 , for that the equipments of SC_1 is not adequate to process order j_{12} and the order is rejected (see the left part of Table 4b, PA_{12}=0).

Table 2a. Parameters of CSC

parameters	RTL_{its}	MC_{irs}
SC_1	8	32
SC_2	8	48

Table 2b. Parameters of CSC

parameters	MCT_{irs}		parameters	MCT_{irs}	
	RT cost	OT cost		RT cost	OT cost
R_{11}	40	60	R_{21}	40	60
R_{12}	20	30	R_{22}	20	30
R_{13}	30	45	R_{23}	30	45

Table 3. Parameters of orders

parameters	P_{ij}	LT_{ij}
O_{11}	750	3
O_{12}	900	3
O_{13}	1500	3
O_{21}	600	3
O_{22}	800	3

Table 4a. The total profits of SC_1, SC_2, and CSC

α \ β	1.0			1.1			1.2			1.3			1.4			1.5		
	CSC	SC_1	SC_2	CSC	SC_1	SC_2	CSC	SC_1	SC_2	CSC	SC_1	SC_2	CSC	SC_1	SC_2	CSC	SC_1	SC_2
0.0	925	570	355	845	570	275	765	570	195	770	570	200	770	570	200	770	570	200
0.1	925	570	355	845	570	275	675	485	190	670	470	200	670	470	200	670	470	200
0.2	925	570	355	845	570	275	675	485	190	670	470	200	670	470	200	670	470	200
0.3	925	570	355	845	570	275	760	570	190	700	500	200	700	500	200	700	500	200
0.4	925	570	355	845	570	275	760	570	190	700	500	200	700	500	200	700	500	200
0.5	925	570	355	845	570	275	760	570	190	700	500	200	700	500	200	700	500	200

Table 4b. The orders decision with the maximization profits of CSC

Supply chain order decision($\beta_{ij} \to +\infty$, non-collaboration in SC_1 and SC_2)								Cross-chain order decision($1 \le \beta_{ij} \le +\infty$, collaboration in SC_1 and SC_2)							
	j	O_{ij}	R_{ij}	PT_{ijorts} RT	OT	MT_{ijor}	PA_{ij}		j	O_{ij}	R_{ij}	PT_{ijorts} RT	OT	MT_{ijor}	PA_{ij}
SC_1	j_{11}	1	11	10	0	3	1	SC_1	j_{11}	1	11	10	0	3	1
		2	13	0	8					2	13	0	8		
	j_{12}	1	11	0	0	4	0		j_{13}	1	11	6	4	3	1
		2	12	6	0					2	12	4	4		
		3	12	10	2					3	11	12	0		
	j_{13}	1	11	6	4	3	1	SC_2	j_{21}	1	22	8	0	2	1
		2	12	4	4					2	23	6	0		
		3	11	12	0				j_{22}	1	21	8	0	3	1
SC_2	j_{21}	1	22	8	0	2	1			2	23	8	0		
		2	23	6	0					3	22	6	0		
	j_{22}	1	21	8	0	3	1		j_{12}	1	21	0	6	3	1
		2	23	8	0					2	21	8	0		
		3	22	6	0					3	22	8	2		

According to Table 4b, the operation managers can make order decisions by designing the combination value of α and β. (α =0.3, β =1.3) is the critical value: α =0.3 is the critical state of orders rejection rate, and β =1.3 is the critical state of cooperation level between multiple supply chains. At this time, the customer satisfaction and the total profits of CSC are in equilibrium state (i.e. average customer service quality level and average profit rate level in an industry). The managers can take the following strategies to make order decisions.

- To obtain the better brand awareness, customer experience or user evaluation, the managers can set the higher critical value of α (α >0.3, i.e. the opportunity cost of rejection orders is very high) , so as to reduce the directed orders rejection rate as possible. At the same time, the critical value of β is set higher than 1.3, which means a high price of cooperation for cross-chain orders, so as to no longer accept cross-chain orders and ensure the directed orders have enough production capacities. If the directed orders exceed its production capacity and need another supply chain to process the insufficient part, the critical value of β is set lower than 1.3, which attract cooperators to accepted cross-chain orders with lower collaboration costs.
- To obtain good profitability, satisfaction of financial statements or optimal profits for shareholders, in a word, to pursuit for the maximum of output and input, the managers will set lower critical value of α (α <0.3, i.e. reject those unprofitable orders). At the same time, to achieve the maximum profits with sufficient orders (short term), the managers will set a higher β (β >1.3) to not accept cross-chain orders; to avoid idle resource for less orders (long-term), the managers will set the lower β (β <1.3) to attract cross-chain orders.
- To obtain better profits in the short term, and form long-term brand effect, the managers can combine above two strategies, and make orders decision based on critical value of (α , β).Specifically, the managers can use the strategies in Table 5 to make flexible orders decisions.

6. CONCLUSIONS

The order decision in C2B mode, considering the three dimensions of customer satisfaction, enterprise resources and supply chain collaboration, we establish a decision model for cross-chain orders based on collaborations in supply chains. The numerical calculation and result analysis shows that the cross-chain order decisions is more flexible than the non-cross-chain's case. At the same time, the order rejection opportunity cost factor α and cross-chain order production cost factor β have an affect on order decisions. through designing the value combination of (α , β), the managers can make appropriate order accepted decisions and production plans, which make the customer satisfaction and total profit of cluster supply chain to reach the optimal value.

Around this research area, the next step we will consider of limit the order's completion time, that is, the order decisions in cluster supply chain with delivery time.

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