Study on Supply Chain Optimization Scheduling of Networked Manufacturing

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Abstract: Supply chain scheduling is the very heartbeat of all supply chain systems. Optimization of the supply chain scheduling can help increase agility while reduce the running cost of corporations. Complying with its structure, supply chain of the networked manufacturing has the characteristics of distributed, multi plants and multi stages. In this paper, a thorough research was first done on the decision making problem of supply chain scheduling under networked manufacturing, a mathematical model was built. Based on these studies, an improved artificial fish-swarm algorithm was put forward to solve the supply chain optimization scheduling, which proposes a competition based mechanism to allocate computational resource for artificial fish with better vitality. Simulations were done to verify the algorithm, and it was proved to be very effective by artificial fish-swarm algorithm in the supply chain scheduling under networked manufacturing

Key-Words: Networked Manufacturing, Supply Chain, Scheduling, Artificial Fish-Swarm Algorithm, Optimization

1 Introduction

Supply chain scheduling is an effective way to synchronize the material flow between supplier and customers [1]. Under network manufacturing, as soon as corporations get the market opportunity, to enhance its competitive power, survive and develop through the fierce competition, corporations should effectively make use of facilities, knowledge, manpower and other resources according their different locations [2]. Evaluate the potential partner under different geographic constraints, select the corporation which satisfies the criteria and form networked corporation alliance, coordinate the scheduling, such that to achieve fast market response and enhance the agility.

The ultimate task of network manufacturing is decided by market, and transferred from the downstream of supply chain to upstream. As the coordinator of corporation alliance, the company wins the market opportunity would cooperate with its partners to complete the task of raw material supplying, components manufacturing, parts assembling, integration, distribution, delivering and some other manufacturing steps (which are included in the macro definition of manufacturing), so as to produce products with higher quality but lower cost in a shorter time. From the evaluation of potential candidates, choose corporations which meet the basic requirements of technology, product quality, reputation, logistic and etc. Many researches have been done this area. Paper [3] discussed the reliability problem of corporate alliance under network manufacturing, followed by considerations on the criteria of choosing partner both qualitatively and quantitatively. it builds up a foundation for the task scheduling of partner corporations.

After having decided the partnering corporation of supply chain, the scheduling of supply chain becomes the first important issue. By proper scheduling of supply chain, predominance complementation and prompt manufacturing can be realized effectively. A lot of researches have been focusing on the supply chain scheduling of large scale manufacturing, electronic business and resource restriction, while methods like simulated anneal and inheritance algorithm were used for the calculation [4, 5]. In this paper, according to the requirement of network manufacturing, the modified artificial fish-swarm algorithm is used to find out the most economic and prompt corporation partner from many candidates. The selected candidates will then form supply chain, perform task scheduling, make use of the network manufacturing environment and achieve the overall optimization of supply chain.

2 Decision Making Issue in Supply Chain Scheduling

There are many factors which can possibly affect the evaluation of partnering corporation, such as agility, technology, manufacturing cost, product quality, reputation, equipment and facilities, adaptive capacity, geographical issue and so on. Judging the above factors, several candidates can be chosen for individual part of the supply chain.

Candidates then need to perform task scheduling. The ones which win the task will form the supply chain and proceed to operation. During this process, majority of traditional manufacturing use localized scheduling method which passes from the later stage to previous stage. This kind of scheduling is relatively simple and guarantees the optimization of local area. On the other hand, the environment of network manufacturing provides the possibility to realize overall resource coordination, scheduling and optimization, such that coordinator corporate can choose partner or perform task scheduling regardless of the different manufacturing stages. All these will result in a much longer supply chain of task scheduling than normal supply chain.

Meanwhile, the environment of network manufacturing has decided the characteristics of supply chain: wide distribution, excessive factories, multiple stage and etc, it exhibits a nested and non-linear physical structure, and this will makes the scheduling problem more complicated than normal condition [6].

Under network manufacturing, all candidates locate in different places and possess different manufacturing capacity and cost. Hence, it is necessary to find the most economic partnering corporation as well as the most reasonable scheduling. For different market opportunities, coordinator of corporation alliance would choose the most suitable partners from candidates and allocate tasks, such that to meet the market requirements most probably. Hence, the supply chain scheduling under network manufacturing is a breakthrough of the localized optimization under traditional manufacturing environment. It guarantees the realization of final market opportunities, and optimizes overall interest in a most effective way.

3 Task Scheduling Model

A supply chain is made up of raw material supply, manufacture, integration, storage, shipping, distribution and some other stages. Assuming at a certain manufacturing stage i (i=1, 2, … , n), r_j partnering candidates have passed the preliminary evaluation and waiting for task scheduling now. Let P_{ij} denotes the jth candidate in current stage, which having a physical location at (x_{ij}, y_{ij}). At stage i+1, assuming a kth candidate $P_{i+1,k}$, and $D_{(i,j),(i+1,k)}$ denotes the distance between P_{ij} and $P_{i+1,k}$. Let C_{ij} represent the unit manufacturing cost of candidate P_{ij}, and it can be simply divided into fixed cost C_{ij1} (including environment, processing, management and etc, which are direct manufacturing cost that unrelated to the next target of supplying) and variable cost C_{ij2} (transportation cost which is related to the location of supplying target). Let the unit distance transportation cost in manufacturing stage i is U_i, unit distance transportation time is T_0. As a result, now both transportation time $T_{(i,j),(i+1,k)}$ and transportation cost are proportional to transportation distance, while unit manufacturing time and capacity of unit manufacturing period of company P_{ij} are inverse proportional, namely, $1/W_{ij}$. Assuming the whole supply chain starts from supplying of raw material, and end with several distributor of the coordinating corporation. When $i=1$, the current stage will be raw material supplying stage; if $i=n$, current stage will be distribution stage. In the distribution stage, the sale target need to meet Y_{nk} delivery time within a certain period for any distributor of the coordinating corporation is M_{nk}. Driven by the demand and passed back to candidate corporations, the supplying demand which meet Y_{ij} delivery time is M_{ij}. Considering that whole supply chain is driven by the demand, we can build up following scheduling model:

$$\begin{cases} \min C = \sum_{i=1}^{n-1}\sum_{j=1}^{r_i} C_{ij1}M_{ij} + \sum_{i=1}^{n-1}\left(U_i \sum_{j=1}^{r_i}\sum_{k=1}^{r_{i+1}} M_{ij}D_{(i,j),(i+1,k)}\right) \\ \min T = \sum_{i=1}^{n-1}\sum_{j=1}^{r_i} M_{ij}\left(1/W_{ij} + U_i \sum_{j=1}^{r_i}\sum_{k=1}^{r_{i+1}} D_{(i,j),(i+1,k)}\right) \end{cases} \quad (1)$$

S.T.

$$\sum_{j=1}^{r_i} M_{ij} \le \sum_{j=1}^{r_i} Y_{ij}W_{ij} \quad (2)$$

$$W_{ij} \le W_{ij}^{\max} \quad (3)$$

$$\sum_{j=1}^{m_i} M_{ij} = \sum_{j=1}^{m_{i-1}} M_{i-1,j} \quad (4)$$

$$D_{(i,j),(i+1,k)} = \sqrt{(x_{i+1,k}-x_{ij})^2 + (y_{i+1,k}-y_{ij})^2} \quad (5)$$

$$M_{ij} \ge 0, W_{ij} \ge 0 \quad (6)$$

Equation (2) suggests that the summation of throughput should equal or greater than the demand of all distributors while equation (3) suggests that the throughput of each factory should not exceed its maximum capability. Equation (4) shows the total output from stage should equal to the demand of next stage. Equation (5) defines the distance between any two factories in two consecutive stages. Equation (6) defines boundary condition of the defined model.

In real manufacturing process, different departments of a corporation (especially coordinating corporation) could be involved in the production of several stage in the supply chain. However, this will only change the symbolic meaning of specific symbols in the model rather than affecting the scheduling procedure. Hence, the target of supply chain scheduling is to minimize the total cost from production and transportation, as well as minimize the total time taken by production and transportation. This is problem involves optimization of several targets, while it is hard to optimize all the targets at the same time using only one scheduling plan. Considering the task scheduling process in real manufacture, there are some preference of time and cost. For this reason, we will introduce preference weighting factor *α, β* (the sum of weighting factors is 1) to build up the following task scheduling objective function:

$$\min f(x)=\alpha\sum_{i=1}^{n-1}\sum_{j=1}^{r_i}C_{ij1}M_{ij}+\alpha\sum_{i=1}^{n-1}\left(U_i\sum_{j=1}^{r_i}\sum_{k=1}^{r_{i+1}}M_{ij}D_{(i,j),(i+1,k)}\right)$$
$$+\beta\sum_{i=1}^{n-1}\sum_{j=1}^{r_i}M_{ij}(1/W_{ij}+\sum_{j=1}^{r_i}\sum_{k=1}^{r_{i+1}}T_{(i,j),(i+1,k)}D_{(i,j),(i+1,k)}) \quad (7)$$

In the above equation, when *α*=0, *β*=1, task scheduling is based on minimizing total time. When *β*=0, *α*=1, task scheduling is based on the minimization of total cost (maximization of total profit).

4 Solution of Task Scheduling

For the supply chain task scheduling model under network manufacturing environment, the solution is a NP-complete problem. Thus, in this paper, an improved artificial fish-swarm algorithm is proposed to solve this complicated problem.

By simulating the food seeking, rear-ending and gathering behavior of real fish, an improved artificial fish-swarm algorithm has been gaining increased attentions these years. Starting from the basic behavior of each fish, the above algorithm reaches overall optimization during the local searching process. However, because the computing resource is evenly allocated to individuals, the fishes whose vitality is lower than the average would increase the optimization time tremendously [8-9]. We introduce a competition mechanism in this work, which provides more computing resources to fishes having stronger vitality and solve the scheduling model more effectively.

4.1 Artificial Fish-Swarm Algorithm

Assume *m* is manufacturing stage of corporation which has the most candidate corporations. There are total *n*+1 manufacturing stages in the supply chain, all the candidate corporation from the previous stage would share the contracts provided by the next stage. In fact, because it is impossible to further divide a single contract, it is possible that sometimes a partner corporation wins several contracts while some other corporations would win nothing in the supply chain scheduling and be weeded out during the competition. The contract sharing scheme is used as arithmetic variable code, for the candidate corporations whose manufacturing stage less than m, * will be used to substitute the missing stages, artificial fish *X*, $(x_{11}.x_{12},...,*;x_{21},...,*;...;x_{i1}.x_{i2},...,x_{im};...;x_{n1},...,*)$ is a set of variable coding. Define the distance between X_p and X_q to be d_{pq}, we have:

$$d_{pq}=\sum_{i=1}^{m}\mathrm{sgn}\left(\left|x_p(i)-x_q(i)\right|\right) \quad (8)$$

For artificial fish X_p, its *k*-distance neighborhood is :

$$N(X_p,k)=\left\{X_i\left|d_{pi}<k\right.\right\} \quad (9)$$

For a set of fish $\left\{X_1,X_2,...,X_l\right\}$, define X_c to be the center of this set of simulated fish:

$$X_c=\bigcup_{i=1}^{l}\bigcup_{\substack{j=1\\ j\neq i}}^{l}\left(X_i\cap X_j\right) \quad (10)$$

4.2 Behavior of individual fish

Assume a set of artificial fish $\left\{X_1,...X_u,...,X_v,...,X_l\right\}$, arbitrary individual fish X_u in this set is constrained by the behavior of food seeking, rear-ending, gathering as well as competition mechanism. Let *V* represent the field of vision of the artificial fish, S stands for the maximum step, δ stands for the density coefficient. According to the objective function built based on supply chain scheduling model, the greatest food concentration obtained during the moving of artificial fish would be our ultimate goal of optimization. Thus, according to equation (2), food concentration $F = 1/\min f(x)$ will be determined by equation (7). If the current status of X_u is X_u^i, then the next status X_u^{i+1} will be determined by following behaviors:

(1)Food seeking

$$\begin{cases} X_u^{i+1} = Rnd(N(X_u^i, S) \cap N(X_v^i, d_{uv} - S)) & (F_u < F_v) \\ X_u^{i+1} = Rnd(N(X_u^i, S)) & (F_u \geq F_v) \end{cases} \quad (11)$$

Looking at above equation, in the field of view *V* of artificial fish, the relative food concentration of X_u^i comparing with other artificial fish X_v^i will be *F*. if $F_u < F_v$, then X_u^i will move one step forward towards the direction of X_v^i within its *s*-neighborhood. Otherwise, X_u^i will randomly move one step within its *s*-neighborhood. Function $Rnd(S)$ represents a random value within the *s* boundary.

(2)Gathering

$$X_u^{i+1} = Rnd(N(X_u^i, S) \cap N(X_c^i, d_{uc} - S)) \quad (\frac{F_c}{n_f} < \delta F_u) \quad (12)$$

In the above equation, X_u^i search for buddy fishes in its field of vision. Let n_f represent the number of buddy fish, and a simulated fish X_c^i rests in the center of buddy fish. If $F_c / n_f > \delta.F_u$, X_u^i will move one step toward the center within s-neighborhood.

(3)Rear Ending

$$X_u^{i+1} = Rnd(N(X_u^i, S) \cap N(X_m^i, d_{um} - S)) \quad (F_m < \delta F_u) \quad (13)$$

Where, X_u^i search for buddy fishes in its field of vision. Let X_m^i is one of the buddy fishes with the biggest F . If $F_m > \delta.F_u$, X_u^i will move one step toward X_m^i within s-neighborhood.

4.3 Competition Mechanism

In order to achieve the overall optimization, we should use mark one particular fish as the pivot fish, X_b, to record down the extreme value of the optimized artificial fishes. After each step, compare each fish's F with the pivot fish's. If $F_u > F_b$, then $F_u \to F_b$,and $X_u \to X_b$. Hence, X_b is always the most optimized fish.

Some artificial fishes have greater vitality, so they can easily achieve the overall optimization. At the same time, there are also some fishes blindly searches around some individual extreme points. In the conventional way of solving this problem, every fish share resources equally. Therefore, a competition mechanism should be applied to improve the artificial fish algorithm such that it can allocate more computing resource to fishes with stronger vitality and help to achieve the overall optimization much faster. Define the power of any artificial fish as X_u:

$$R_u^{i+1} = F_u^{i+1} / F_b^{i+1} + F_u^{i+1} / F_u^i \quad (14)$$

According to the formula above, if $R_u^{i+1} \geq \sum_{j=1}^{l} R_j^{i+1} / 2$, then the resources X_u can get is calculated by the following steps:

Step 1: Initialize some variables, and list down the restrictions. *N*- number of fishes, *V*- the field of vision, δ - density coefficient, *F*- food concentration formula.

Step 2: Randomly generate a pool of artificial fishes. There is no restriction on the initial state of the fish, so even the invalid state will be acceptable.

Step 3: Check whether it satisfies the exit condition. If so, go to step 8, otherwise go to step 4.

Step 4: Calculate the power of every single fish and allocate the resource to each fish by the competition mechanism.

Step 5: Allow the fishes start optimization process by different principles such as tail-chasing, gathering and hunting.

Step 6: After each optimization action, compare the food concentration of every fish with the pivot fish. If $F_u > F_b$, then $F_u \to F_b$,and $X_u \to X_b$

Step 8: Record down the new status of the fishes and go back to step 3.

Step 9: Output the optimization result. End.

5 Experiment and Discussion

Taking a networked manufacturing company in aluminum industry as a concrete example, there was one time that the owner company had a market chance at several locations. It had the requirement for product delivery deadline. After preliminary investigation, it required to form a supply chain that including 4 phases, namely raw material (A), aluminum smelting (B), processing (C), distribution and sales (D). Each phase had 5 different selections by various companies. Let's say we know every company's coordinate is (*x,y*), fixed cost is C_1, productivity per month is *W*, unit interval transportation cost between 2 adjacent phase is *U*, the demand of each distributor is *M*, unit price is *A*, and delivery deadline is *Y*, and the unit interval transportation time is T_0 =0.00025 months. We initialize all the variables and set up a process table (refer to table 1).

Table 1. The parameters of supply chain

Firm		1	2	3	4	5
A	x	15	731	556	135	235
	y	86	198	768	821	467
	C_1	12	9	15	14	10
	W	23	35	45	50	20
B	x	881	561	765	235	710
	y	246	101	34	456	18
	C_1	21	18	22	20	16
	W	55	30	15	45	35
C	x	369	103	38	258	717
	y	428	754	196	986	136
	C_1	28	30	27	36	30
	W	45	32	28	50	17
D	x	781	235	93	756	565
	y	96	886	128	333	310
	M	60	90	80	45	70
	A	800	650	730	915	865
	Y	7	8	12	9	13

Note: A-B: U_1 =0.001, B-C: U_2 =0.0013, C-D: U_3 =0.0012.

Let N=15, V= 6 S= 4 and δ is negligible, we use the improved artificial fish algorithm to solve this problem. Set α , β are representing supply-chain scheduling median duration and cost effectiveness. Different values of them may result in different scheduling models. Balance the trade off and avoid any subjective decision, we take α =0.7, β =0.3, i.e. the scheduling takes longer time but more cost effective. Run a program in Visual C++ 6.0 repeatedly for 150 times, and finally get the maximum food concentration is F=1/14415.32.

By the above calculation, we can filter out those companies that have very high cost but low efficient production lines, or are far away from the rest though they might pass the quality assurance test.

Referring to table 2, the gross profit of all companies involved in this scheduling model is up to US$246044.36, the total time spent is 29.55 days. More importantly, it definitely meets the delivery deadline and volume.

Table 2. Scheduling Result

No.	A	B	C	D
1	0	0	160 (P_{D2} , P_{D5})	60
2	160 (P_{B5})	125 (P_{C3})	60 (P_{D1})	90
3	0	0	125 (P_{D3} , P_{D4})	80
4	185 (P_{B2} , P_{B4})	60 (P_{C2})	0	45
5	0	160 (P_{C1})	0	70

5 Conclusion

The integrated resources environment of networked manufacturing enables the overall optimization scheduling of supply chain. By discussing a real market problem, this report describes how to use the improved artificial fish-swarm algorithm to schedule the tasks for potential business partners and filter out those companies that have high cost but low efficient production lines, so that the supply chain of networked manufacturing can be optimized in all aspects.

The improved artificial fish-swarm algorithm applies a competition mechanism that allocating more resources to more powerful fishes. By conducting a test, we can verify the correctness and effectiveness of selecting the business partners and scheduling the tasks.

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