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Optimization of Manufacturing Supply Chain under Across-chain Competition

[1]Shidi Miao, [2]Sisi Ding and [3]Chunxian Teng
[1]School of Software, Harbin University of Science and Technology, Harbin, 150040, China
[2]Library of Harbin Institute of Technology, Harbin, 150001, China
[3]The System Engineering Research Institute, Harbin University of Science and Technology, Harbin, 150080, China

Abstract: In this research, the development trend of supply chain under across-chain competition nowadays in manufacturing industry is summarized. The research of across-chain competition are more focused on competition equilibrium analysis, contract and information structure, the design problem of supply chain structure under the background of across-chain competition has certain research space. According to design principle and design method of supply chain structure, this research utilizes variational inequalities and spatial price equilibrium theory to give the equilibrium condition of supply chain competition and demand market. On this basis, this research constructs optimal model of supply chain, which is dominance structure under the background of supply chain competition. The model covers the maximum of profits and market share, the environmental protection optimum and so on. Thus it can depict the structure design of supply chain more all-sidedly. Finally, it shows the Euler method built to solve the optimal model and shows the effectiveness of this model through corresponding numerical example.

Key words: Supply chain competition, structure optimization, variational inequalities, equilibrium condition, Euler method

INTRODUCTION

With increasing penetration of global economy and wide spread of information, communication technology, at present competition form of business has been greatly diversified and complicated, but one point can be sure that the competition of supply chain has replaced the competition among companies and it has become main form of competition. Aimed the same divided markets, there are often many supply chains which are competing, for example in market of cell phones such as Nokia, Motorola, Samsung and so on, in market of cars such as Hyundai, Ford, Volkswagen, Toyota, General and so on. The competition means and forms among them are various, for example price competition, quality competition, service competition and advertising competition and so on. The goal they pursue perhaps is different but all of them will pursue profits and maximum of market share so that they can obtain better achievement and effect and competition superiority. Christopher (2000) once pointed out in the past many years competition form had transformed past competition among enterprise into more complicated competition of supply chain. O'Connor (1997), manager in a consulting company in America also offered similar view "the only way to survive is to compete total supply chain to total supply chain" . In research about equilibrium analysis of supply chain competition structure, with demand uncertainty and risk aversion retailer supposed, Xiao and Yang (2008) carried on research about the competition of price and service of two supply chains composed of single supplier and single retailer. Anderson and Bao (2010) expanded the equilibrium model of competition structure of supply chain to the competition among N supply chains. In research about contract and information structure under the background of across-chain competition, Zhang and Zhao (2010) studied information sharing of sale history for two horizontal competition supply chain. With the suppose of autoregressive time-series process for demand, their research showed that demand history of competition opponent may help retailer to make more accurate demand forecast and make the achievement of supplier improved. In optimizing research of supply chain structure design, Wan and Shu (2007) utilized fuzzy sets theory and configuration model to depict supply chain of new products, his article broke traditional supply chain structure based on enterprise nodes, whereas it looked on supply chain as collection of modules and every module finished one or several functions. The aim of his article was to determine the

Corresponding Author: Shidi Miao, School of Software, Harbin University of Science and Technology, Harbin, 150040, China

tactics of inventory and function of every module so that it could reach minimum cost and maximum service level. Klibi *et al.* (2010) considered that network design of supply chain including many strategic decisions, such as production arrangement, the distributor's quantity, position, production capacity, task and the choice for supplier, distributor and 3PL and so on. His article pointed out a fine design of supply chain demand and made an evaluation for future demand cost, income, forecast of service level and design effect and the design of robustness also was necessary considering the increasing uncertainty. Nagurney (2009) for the first time utilized theory of variational inequalities to solve M and A and reorganization among whole chain and studied quantitatively the problem of M and A among supply chain focusing on optimal system. Nagurney (2010a-c), Nagurney *et al.* (2010) utilized variational inequalities to construct the design of supply chain network and reorganization model, whose production capacity and product flow were optimal at purpose of minimum cost. On this basis, Nagurney and Woolley (2010) developed a series of researches of supply chain reorganization.

Analyzing present situation of research above, nowadays the research of across-chain competition are more focused on competition equilibrium analysis, contract and information structure, the design problem of supply chain structure under the background of across-chain competition has certain research space. Zhang (2006) and other scholars utilized variational inequalities theory to depict the equilibrium problem of supply chain competition, but their researches haven't concern the design problem of supply chain structure under the across-chain competition background of multi-criteria and random demand. At present the research of structure design of supply chain more focused on single chain, the structure design under the background of across-chain competition still leave some to be consummated. Nagurney (2010b) utilized nonlinear programming and variational inequalities to study the design of supply chain structure but didn't consider the influence of across-chain competition. On this basis this article constructs optimization model of supply chain structure under the background of across-chain competition and through corresponding numerical example, it proves the effectiveness of the model.

HYPOTHESIS OF MODEL

Among model of supply chain competition, every node enterprise on the supply chain delivers the final products to consumption market through purchase of raw materials, production, sale and other activities. The competitiveness of supply chain is embodied from purchase, production, distribution and sale. To depict more clearly competition of network of this kind, this article utilizes the market chains offered from references as supply chain to participate mainly of market competition.

Market Chain is a structure of chain pattern which delivers the final products to the final consumption market, which are engaged in business activities coordinated with one another. These business includes raw material obtainment of appointed products, production, assembly, distribution, sale and so on.

According to the definition of market chain, supply chain can be looked on as a series of market chains. Supply chains can be considered abstractedly as network structure composed of a series of sets of nodes and links. The node represents the enterprise on supply chain and the link represents a series of activities concerned with the node enterprise, such as production, sale and so on. Let $G_i = [N_i, L_i]$; $i = 1,2,..., I$ denote the supply chain G_i composed of the set N_i of nodes and the set L_i of links. Let $G = [N, L] = \cup_{i=1,...,I} [N_i, L_i]$ denote the network of supply chain composed of all competing supply chain. Every manufacturer has several production factories and the distributors locate the downstream of the factories. The retailers are the terminal of the whole supply chain and they are responsible for selling products to market. The links connecting manufacturers and their production factories represent the production activity. The links connecting production factories and distributors, the links connecting distributors and retailers represent transportation activity. The links connecting retailers and markets represent sale activity. Let S_{ij} denote all the sets of potential market chain between (i, j), let S_j denote all the sets of potential market chain which points to the demand market j, let S denote all the sets of potential market chain.

Let X_s, $s \in S$ and x_a, $\forall \alpha \in L$ be respectively market link s and the nonnegative production flow on Link α and the link flow is the sum of the flow of their participation in the market chain, that is:

$$x_a = \sum_{s \in S} \delta_{as} X_s, \forall a \in L, \quad \delta_{as} = \begin{cases} 1, \text{if} & a \in s \\ 0, \text{if} & a \notin s \end{cases} \tag{1}$$

Every link has some capacity constraints. Let $u_a \geq 0$ denote the nonnegative capacity constraint on Link a. The capacity on every link can be represented by the production flow's upper limit on this link. So the inequality constraints can be expressed as:

$$0 \leq x_a \leq u_a, \forall \alpha \in L \tag{2}$$

The cost on the link is related to the production flow which flows over this link, that is, $C_a = C_a(X_a)$, $\forall \alpha \in L$. Generally, one link is allowed to participate the operation on multiple market chains. Therefore, it will be involved on the distribution of the cost of link. In this article, we distribute the cost of the link on every market chain in proportion. That is, $\forall \alpha \in L$, the cost C_{as} (X_a) on the market chains, which is distributed through the cost C_a (x_a) on link a can be expressed as:

$$C_{as}(x_a) = \frac{C_a(x_a)}{x_a}\delta_{as}X_s,\ \delta_{as} = \begin{cases}1, \text{if } a \in s \\ 0, \text{if } a \notin s\end{cases} \tag{3}$$

Let p_{ij} denote the retail price of production i in market j, it depends on the demand from the market d_{ij}, that is:

$$p_{ij} = p_{ij}(d_{ij}), \forall i, j \tag{4}$$

THE CRITERION OF MARKET SHARE MAXIMUM AND ENVIRONMENTAL PROTECTION OPTIMUM

Market share has become an important factor for enterprise obtaining more profits. In general, the enterprises who have more market share can obtain more profits than the ones who have less. Buzzell *et al*. (1975) made research about the relation between the market share and performance. According to their research, there is positive correlation between the market share and rate of return on investment. They analyzed the reason why high market share was profitable and cited some reasons such as the effect of scale economy and market competitive forces. Whereafter, they pointed out the relative degree between market share and return on investment using PIMS(Profit impact of market strategies) database. Particularly when market share increased, enterprise would obtain more marginal cost with reducing of purchase cost and sale cost, accordingly enterprise would make higher product quality and more bargaining power. This article gives market share certain weight to join optimization model of supply chain as a content of decision. If the weight is greater than 1, it is represented that the leader on supply chain thinks more about market share. If the weight is less than 1, it is represented that the leader on supply chain considers the maximum of market share on the base of the maximum of profits. Every supply chain will maximize quantity supplied in order to occupy more market share and more competition advantage. The goal of maximum quantity supplied can be expressed as:

$$\max \sum_{j=1}^{J} X_{S_{ij}} \tag{5}$$

Let e_a denote the carbon emission on link a, it may be considered as the carbon emission in the course of production or in the course of transportation. In a word, it is directly proportional to the product flow on the link ***a***. e_a is the function of x. The decision principle is the minimum carbon emission. That is:

$$\text{Min } e_a(x_a) \tag{6}$$

The quantity of carbon emission above may be transformed into corresponding economic indicator by enduing with weights.

THE ESTABLISH OF OPTIMAL MODEL

Equilibrium condition of supply chain competition: Synthesizing the quantity model above, the optimal model of supply chain is represented. The effectiveness of supply chain i is the synthetic function of its revenue, carbon emission and quantity supplied. The goal of total supply chain is the set of model described above. It can be called effectiveness maximum when carbon emission and quantity supplied are minimum and the profits are maximum. The effectiveness function can be expressed as:

$$U_i(X) = \sum_{j=1}^{J}[\rho_{ij}(d_{ij})\sum_{s\in S_{ij}} X_s - \sum_{a\in L_i}[C_a(x_a) + \alpha_a e_a(x_a)] + \beta_{ij}X_{S_{ij}}] \tag{7}$$
$$\text{s.t. } 0 \le x_a \le u_a, \forall a \in L_i$$

where, α_a denotes the payment of carbon emission of every unit product on link a, which reflects paying close attention to environment protection. B_{ij} depicts non-negative weight of market share of maximum supply chain G_i in market j.

According to references, the Equilibrium solution of Non-cooperative Nash competition between supply chains needs to satisfy as follows:

$$U(X^*_{S_i}, X^*_{S_{-i}}) \ge U(X_{S_i}, X^*_{S_{-i}}) \tag{8}$$

where, $S_{-i},...,S_{i-1},S_{i-1},...,S_1$, it is showed that the competition Equilibrium will achieve when no supply chain may raise its effectiveness unilaterally.

Supposing that effectiveness function $U_i(X)$ is continuously differentiable function about variable X, let λ_a be the Lagrange multiplier related to constraint (2). Therefore, the Equilibrium solution of Non-cooperative Nash competition is X^*_s if and only if it can satisfy with the variational inequalities as follows:

$$\sum_{i=1}^{I}\left\langle \nabla_{X_s} U_i(X^*_s)^T, X_s - X^*_s \right\rangle \le 0, \quad \forall s \in S \tag{9}$$

where, <.,> denotes the transvection in Euclidean space, Δ_{xs} U_i (X_s) represents the gradient of X_S about U_i (X_S).

The Equilibrium solution of supply chain in this article can be represented the solution of $(X_s^*,\lambda_a^*)\in R_+^{n_s}\times R_+^{n_a}$, when $\forall(X_s,\lambda_a)\in R_+^{n_s}\times R_+^{n_a}$, we have the followings:

$$\begin{aligned}&\sum_{i=1}^{I}\sum_{j=1}^{J}[\sum_{a\in L_i}[\frac{\partial C_a(x_a^*)}{\partial X_{S_{ij}}}\frac{\delta_{as}X^*_{S_{ij}}}{x_a^*}+(C_a(x_a^*)+\alpha_a e(x_a^*))\\&\frac{\delta_{as}(x_a^*-\delta_{as}X^*_{S_{ij}})}{(x_a^*)^2}]+\alpha_a\frac{\partial e(x_a^*)}{\partial X_{S_{ij}}}-\rho_{ij}(d_{ij})\\&-\frac{\partial\rho_{ij}(d_{ij})}{\partial X_{S_{ij}}}\sum_{s\in S_{ij}}X_s-\beta_{ij}+\lambda_a^*]\times[X_{S_{ij}}-X^*_{S_{ij}}]\\&+[u_a-x_a^*]\times[\lambda_a-\lambda_a^*]\geq 0\end{aligned}\tag{10}$$

Equilibrium model of demand: Here we utilize spatial price equilibrium theory to depict equilibrium condition of demand market. Samuelson (1952) and Takayama and Judge (1964) proved firstly that the price and the production flow which satisfied typical spatial price equilibrium theory could be transformed into extremum solving problems and mathematical programming problems. This kind of development on theory has not only help qualitative research about equilibrium problem, but also created conditions for efficient algorithm and expanded the range of application about this theory. Since then spatial price equilibrium theory will be widely used on agriculture, market of energy resource, ore economy, finance and so on.

We can solve supply price, demand price and production flow according to spatial price equilibrium theory. Equilibrium condition is that if there is transaction between supply and demand, market price is equal to supply price adding cost, if market price is lower than supply price adding cost, there will not be transaction between supply and demand. The equilibrium condition of random economy can be represented as the equilibrium condition of dealing between market chain and consumers. The demand quantity of market chain S_{ij} on market j can be given by:

$$d_j(\rho_{ij}^*)\begin{cases}\leq\sum_{i=1}^{I}\sum_{s\in S_{ij}}X_s^*, & \text{if}\rho_{ij}^*=0\\ =\sum_{i=1}^{I}\sum_{s\in S_{ij}}X_s^*, & \text{if}\rho_{ij}^*>0\end{cases}\tag{11}$$

The equilibrium condition above can be represented as variational inequalities given by:

$$\sum_{j=1}^{J}[\sum_{i=1}^{I}\sum_{s\in S_{ij}}X_s^*-d_j(\rho_{ij}^*)]\times[\rho_{ij}-\rho_{ij}^*]\geq 0\tag{12}$$

When competition equilibrium condition is achieved between supply chain and supply chain, both supply chain and demand market should satisfy variational inequalities(10), (12). According to the definition by Nagurney *et al.* (2002), we can draw following theorem depicting equilibrium condition of supply chain competition.

Theorem 2-1: Equilibrium condition of optimized model for supply chain structure design under supply chain competition can be represented as followings variational inequalities problem: Solve $(X_s^*,\lambda_a^*,\rho^*)\in R_+^{n_s}\times R_+^{n_a}\times R_+^{IJ}$ to take any (X_s, λ_a, p) $\in$ $R^{ns}_+\times R^{na}_+\times R^{IJ}_+$ to satisfy as followings:

$$\begin{aligned}&\sum_{i=1}^{I}\sum_{j=1}^{J}[\sum_{a\in L_i}[\frac{\partial C_a(x_a^*)}{\partial X_{S_{ij}}}\frac{\delta_{as}X^*_{S_{ij}}}{x_a^*}+(C_a(x_a^*)+\alpha_a e(x_a^*))\\&\frac{\delta_{as}(x_a^*-\delta_{as}X^*_{S_{ij}})}{(x_a^*)^2}]+\alpha_a\frac{\partial e(x_a^*)}{\partial X_{S_{ij}}}-\rho_{ij}(d_{ij})\\&-\frac{\partial\rho_{ij}(d_{ij})}{\partial X_{S_{ij}}}\sum_{s\in S_{ij}}X_s-\beta_{ij}+\lambda_a^*]\times[X_{S_{ij}}-X^*_{S_{ij}}]\\&+\sum_{j=1}^{J}[\sum_{i=1}^{I}\sum_{s\in S_{ij}}X_s^*-d_j(\rho_{ij}^*)]\times[\rho_{ij}-\rho_{ij}^*]\\&+\sum_{a\in L}[u_a-x_a^*]\times[\lambda_a-\lambda_a^*]\geq 0\end{aligned}\tag{13}$$

The variational inequalities above can be transformed into standard form. Solve $X^*\in K$ to take any $X\in K$ to satisfy as following:

$$\langle F(X^*)T, X-X^*\rangle\geq 0\tag{14}$$

Where K is denoted closed convex set, F(X) is denoted continuous function between K and R^n. Actually, let $K = R^{ns}_+\times R^{na}_+\times R^{IJ}_+$ and $F(X) = [F_1(X), F_2(X), F_3(X)]$:

$$\begin{aligned}&F_1(X)=\sum_{i=1}^{I}\sum_{j=1}^{J}[\sum_{a\in L_i}[\frac{\partial C_a(x_a^*)}{\partial X_{S_{ij}}}\frac{\delta_{as}X^*_{S_{ij}}}{x_a^*}+(C_a(x_a^*)+\alpha_a e(x_a^*))\\&\frac{\delta_{as}(x_a^*-\delta_{as}X^*_{S_{ij}})}{(x_a^*)^2}]+\alpha_a\frac{\partial e(x_a^*)}{\partial X_{S_{ij}}}\\&-\rho_{ij}(d_{ij})-\frac{\partial\rho_{ij}(d_{ij})}{\partial X_{S_{ij}}}\sum_{s\in S_{ij}}X_s-\beta_{ij}+\lambda_a^*]\\&F_2(X)=\sum_{j=1}^{J}[\sum_{i=1}^{I}\sum_{s\in S_{ij}}X_s^*-d_j(\rho_{ij}^*)]\\&F_3(X)=\sum_{a\in L}[u_a-x_a^*]\end{aligned}\tag{15}$$

Then Variational inequalities (13) can be represented standard form.

ALGORITHM AND NUMERICAL ANALYSIS

According to Nagurney (2010c), we represent the algorithm of variational inequalities called Euler method. This method can be used to solve variational inequalities problem accurately. Specially, The iterator τ in Euler method can be represented as following:

$$X^{\tau+1} = P_K(X^\tau - \alpha_\tau F(X^\tau)) \qquad (16)$$

where, P_K denotes the projection in feasible region k, F denotes the function in variational inequalities. Solving $X^* \in K$ can get as following:

$$\langle F(X^*)^T, X - X^* \rangle \geq 0, \qquad \forall X \in K \qquad (17)$$

According to Dupuis and Nagurney (1993), in order to ensure astringency of Euler method in the course of general iteration, the list $\{\alpha_\tau\}$ needs to satisfy:

$$\sum_{\tau=0}^{\infty} \alpha_\tau = \infty, \alpha_\tau > 0$$

and if $\tau \to \infty$, $\alpha_\tau \to 0$.

Equilibrium model of supply chain competition in this article can be represented as iterated algorithm:

$$\begin{aligned}
X_{S_{ij}}^{\tau+1} &= \max\{0, X_{S_{ij}}^\tau + \alpha_\tau(\rho_{ij}(d_{ij}) + \frac{\partial \rho_{ij}(d_{ij})}{\partial X_{S_{ij}}} \sum_{s \in S_{ij}} X_s^\tau \\
&- \alpha_a \frac{\partial e(x_a^\tau)}{\partial X_{S_{ij}}}) - \beta_{ij} + \lambda_a^\tau - \sum_{a \in L_i} [\frac{\partial C_a(x_a^\tau)}{\partial X_{S_{ij}}} \frac{\delta_{as} X_{S_{ij}}^\tau}{x_a^\tau} \\
&- [C_a(x_a^\tau) + \alpha_a e(x_a^\tau)] \frac{\delta_{as}(x_a^\tau - \delta_{as} X_{S_{ij}}^\tau)}{(x_a^\tau)^2}]\} \\
\rho_{ij}^{\tau+1} &= \max\{0, \rho_{ij}^\tau + \alpha_\tau(\sum_{i=1}^{I} \sum_{s \in S_{ij}} X_s^\tau - d_j(\rho_{ij}^\tau))\} \\
\lambda_a^{\tau+1} &= \max\{0, \alpha_\tau(u_a^\tau - x_a^\tau)\}
\end{aligned} \qquad (18)$$

And then we will solve the numerical example using the algorithm mentioned above to prove the validity of model. Node 1 and node 2 separately show leading enterprise on two supply chain in Fig. 1. The nodes under them are production factories. The nodes under production factories are retailers and they separately sell products to market M_1 and market M_2.

According to the definition of market chain, there are ten market chains in this example and there are five potential market chains in supply chain 1, they are given by:

$$S_{111} = \{a_1^1, a_4^1, a_9^1\},$$
$$S_{112} = \{a_1^1, a_5^1, a_{10}^1\},$$
$$S_{113} = \{a_2^1, a_6^1, a_9^1\},$$
$$S_{114} = \{a_2^1, a_7^1, a_{10}^1\},$$
$$S_{121} = \{a_3^1, a_8^1, a_{11}^1\}$$

There are also five potential market chains in supply chain 2, they are given by:

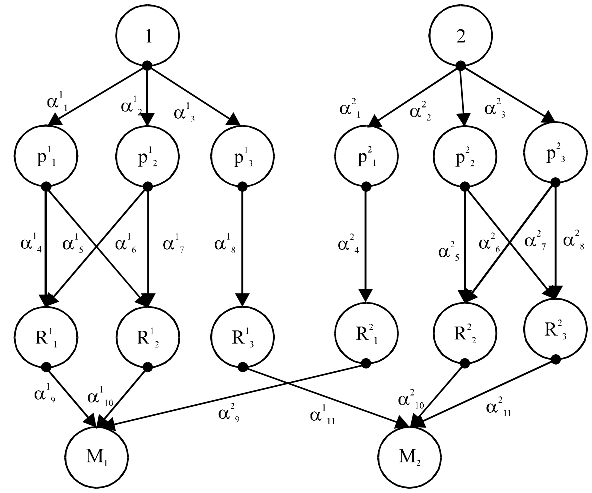

Fig. 1: Primitive structure of supply chain network

Table 1: Link cost of the first supply chain

Link	Cost
Production link	$C_{a_1^1} = 17X_{a_1^1}, C_{a_2^1} = 10X_{a_2^1}, C_{a_3^1} = 12X_{a_3^1}$
Transportation link	$C_{a_4^1} = 5X_{a_4^1}, C_{a_5^1} = 3X_{a_5^1}, C_{a_6^1} = 2.5X_{a_6^1}, C_{a_7^1} = 2.4X_{a_7^1}, C_{a_8^1} = 3X_{a_8^1}$
Sale link	$C_{a_9^1} = X_{a_9^1}, C_{a_{10}^1} = X_{a_{10}^1}, C_{a_{11}^1} = 1.5X_{a_{11}^1}$

Table 2: Link cost of the second supply chain

Link	Cost
Production link	$C_{a_1^2} = 10X_{a_1^2}, C_{a_2^2} = 20X_{a_2^2}, C_{a_3^2} = 11X_{a_3^2}$
Transportation link	$C_{a_4^2} = 3X_{a_4^2}, C_{a_5^2} = 2X_{a_5^2}, C_{a_6^2} = 3X_{a_6^2}, C_{a_7^2} = 2.5X_{a_7^2}, C_{a_8^2} = 2.6X_{a_8^2}$
Sale link	$C_{a_9^2} = 2.5X_{a_9^2}, C_{a_{10}^2} = 1.5X_{a_{10}^2}, C_{a_{11}^2} = 1.6X_{a_{11}^2}$

$$S_{211} = \{a_1^2, a_4^2, a_9^2\},$$
$$S_{221} = \{a_2^2, a_5^2, a_{10}^2\},$$
$$S_{222} = \{a_2^2, a_6^2, a_{11}^2\},$$
$$S_{223} = \{a_3^2, a_7^2, a_{10}^2\},$$
$$S_{224} = \{a_3^2, a_8^2, a_{11}^2\}$$

where, S_{ijr} denotes market chain r which have pointed to market j in supply chain i. The link cost of two supply chains is given as Table 1 and 2.

Supposing that carbon emission of production link, transportation link, sale link of two supply chains are the same, they are separately $2X_a$, X_a and $0.4X_a$. Let $\alpha_a = 1$ and $B_{ij} = 1$, suppose the demand function as followings:

$$d_j = 45 - p_j, j = 1,2.$$

The results are shown as Table 3.

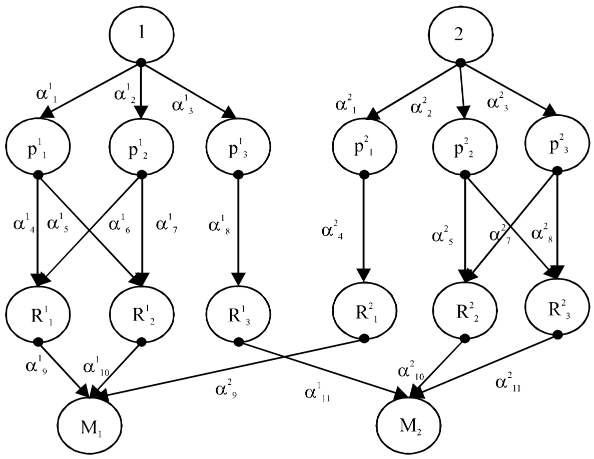

Fig. 2: Optimal structure of supply chain network

Table 3: Optimal M-chain flow

Supply chain 1	S_{111}	S_{112}	S_{113}	S_{114}	S_{121}
Flow	0.1521	0.2513	0.8681	0.8785	0.7233
Supply chain 2	S_{211}	S_{221}	S_{222}	S_{223}	S_{224}
Flow	0.7815	0.0883	0	0.8112	0.8234

Table 3 shows that the second market chain flow supplied products by supply chain 2 for market M2 is zero, which means market chain S_{222} in supply chain 2 will be driven away from the market. The final structure of supply chain is shown as Fig. 2.

CONCLUSION

According to design principle and design step of supply chain structure, this article utilizes variational inequalities and spatial price equilibrium theory to give the equilibrium condition of supply chain competition and demand market. On this basis, this article constructs optimal model of supply chain, which is dominance structure under the background of supply chain competition. The model covers the maximum of profits and market share, the minimum of carbon emission and so on. Thus It can depict the structure design of supply chain more all-sidedly. At last, it shows the Euler method built to solve the optimal model and shows the effectiveness of this model through corresponding numerical example.

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