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Intelligent model design of cluster supply chain with horizontal cooperation

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Abstract Intelligent model design of complex system becomes a key issue for organization responsiveness to uncertainties. In the real business world, the rule of competition between one firm verse another is replaced by a chain verse another chain, the cooperation is the same, where does it occur? At industrial cluster, there are a multiple of rivals or potential competitors for each member of value chain, industrial cluster location not only contains a couple of focal firms locating at the same tier, but includes the corresponding upstream and downstream firms as well, all of which concentrate on a close geographical site. For adopting to ever-changing market and sever competition, it is most likely to form multiple paralleled single supply chains for each focal firm of industrial cluster, these paralleled single supply chains compete and cooperate with each other. Recent researches regarding supply chain design mainly focus on a limited tier in single supply chain, which only take into account vertical cooperation and ignore the across-chain horizontal one. This paper, based on cluster supply chain, provides a novel framework and approach to design cluster supply chain without across-chain horizontal cooperation, then by introducing item allocation proportion of vertical and horizontal cooperation (α: $1-\alpha$), the cluster supply chain design with across-chain horizontal cooperation is developed, then presents a hybrid method to find solution, at last, computational study is presented to investigate values of decision variables and their influence on cluster supply chain design.

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Introduction

Intelligent ubiquitous IT policy and its industries services are attracted more attention with the need for increased agility and flexibility in the manufacturing industry (Fletcher et al. 2002). Therefore, some specific organizations, such as Four Party Logistics (4PL), emerge and offer firms relevant services for their quick response to ever-changing market. For instance, 4PL utilizes technologies to provide quick solution for company intelligent configuring model of supply chain system, help firm determine the number/location/inventory of upstream and downstream firms they need. In the real business world, the relationship among firms becomes more complex and uncertainty, the 4PL are playing and will play an important role in providing this kind of intelligent ubiquitous business model design, because the rule of competition between one firm Verse another is replaced by a chain verse another chain (Christopher 2005), the cooperation is the same, where does it occur? With the further development of industrial and specialization division, industrial cluster provide an environment to makeup multi-chains and promote their member cooperation between them in order to implement leagilty strategy for sharpening their edge of competitive advantages (Kaufman and Rousseeuw 1990; Punj and Stewart 1983). Moreover, ever-changing market demand also forces firms to adopt coordination policy from firm-wide cooperation to chain-wide cooperation, and even to across-chain cooperation so that firms can survive and thrive. On this basis, we refer to multiple of single supply chains located in industrial cluster as cluster supply chain. Design of cluster supply chain with across-chain horizontal cooperation, in this paper, refers to more than one focal enterprises not only design their own individual single chains, but design the interlinked parts (i.e. across-chain horizontal cooperative components) of the two single chains as well. Therefore, this paper focuses on how to design intelligent model of the cluster supply chain of this kind for two core firms by 4PL.

Recent researches regarding supply chain design mainly focus on a limited tier in single supply chain, which only take into account vertical cooperation and ignore the across-chain horizontal one. Although some literatures refer to their studies in the context of supply chain networks, and they looks like multi-chains, this 'networks' basically contain just one focal firm, this firm is dominant in whole supply chain and superior to other upstream and downstream firms. Due to fan-shaped structure at the end of both sides along chain, so the supply chain calls as chain networks firms (Chauhan et al. 2004; Vanderaeghen and Loos 2007), but the one focal firm, rather more than one, plays a leadership role in making decision regarding as facility location, production capacity, inventory policy, transportation mode and batch size etc, in this way, this kind of chain network is indeed a single supply chain rather than multi-chains system.

As we known, at industrial cluster, there are a multiple of rivals or potential competitors in the proximity for each member along supply chain. It means industrial cluster not only contains a couple of focal firms locating at the same tier, but includes the corresponding upstream and downstream firms as well, all of which concentrate on a close geographical site. Thus, it is most likely to form multiple paralleled single supply chains for each focal firm of industrial cluster, these paralleled single supply chains compete and cooperate with each other, that is to say that these single supply chains led by each individual focal firm have interrelated or intertwined each other less or more. However, if these multiple chains system with across-chain horizontal cooperation is a certain kind of artificial formation by forcing two or more than two independent paralleled single supply chains together, it means nonsense. In the real business environment, due to geographical proximity, the characteristics of similar and complementary production, related industries, flexible and specialized and trust features, members in industrial cluster not only vertically cooperate along their own single supply chain, but also different single supply chains horizontally cooperate each other by mean of across-chain model, which facilitates firms to adopt to change of market uncertain demand, reduce customer search cost, improve customer service level and expand market share of the whole industrial cluster area. (Beaudry and Breschi 2003; Pandit et al. 2002). It is proofed by broad investigation or case studies conducted home and abroad, they found that industrial cluster offer a natural and inherent platform for designing or forming the multiple single-supply-chain system with across-chain horizontal cooperation, take examples of IT industrial cluster in Dongguan city of Guangdong Province of China and Garment industrial cluster in Humen Town in Guangdong Province of China (Yang and Feng 2002; Qi 2008).

In this paper, based on cluster supply chain, we provide a novel framework and approach to design of cluster supply chain with across-chain horizontal cooperation. The remaining parts of the paper are organized as follows. Section "Literature review" give a brief explanation of cluster supply chain. The cluster supply chain design problem is formulated and discussed in section "Problem presentation". Comprehensive explanation of the proposal GA approach is given in section "Model algorithm" followed by discussion of computational experiments in section "Illustration examples". Finally, concluding remarks are outlined in section "Conclusion and future research".

Literature review

Industrial cluster and supply chain

With the development of new organizational paradigm and globalization, industrial cluster not only is main source of national competition from a state perspective, but also is becoming one of major competitive weapons for individual firm. Industrial agglomeration firstly originates form Marshall's 'industrial district' (1920) and Weber's 'classic district' (1929), then followed by Hoover (1948), who further explored and illustrated agglomeration economy. Alex (1997) urged that firms within industrial cluster link forward and backward through innovation chain and product chain to sharpen the competitive edges, Rolelandt and Hertog (1998) denoted that in order to share new complementary technologies, obtain gains from shared specialized assets, speed up learning process, reduce transaction cost, overcome market barriers and diffuse innovative risk, so inter-dependant stakeholders such as firms, knowledge-producers, brokers, contractors and customers link together and weave value-added network, this value-added network is just 'cluster'.

Furthermore, Porter (1998) pointed out that industrial cluster is a strong and sustainable competitive advantage network of interconnected companies and institutions in a particular value chain where encompass an array of linked industries and other entities important to competition and cooperation. Industrial cluster generally link forward downstream retailers and customers and backward upstream suppliers and manufacturers and R&D companies, at the same time the geographical proximity surrounded by relevant organizations such as professional training school, information centre and inspection and surveillance organization etc. When firms operate in one location, the repeated interactions among them boost competition, improve productivity, innovation and coordination, and build trust. Companies operating in a cluster can have the advantage of scale without dealing with the inflexibilities of vertical integration or formal linkages (DeWitt et al. 2006).

The effectiveness of clusters can be better understood by examining the practices of supply chain management. Clusters can be thought of as geographic concentration of competing, networked supply chains. Clusters present opportunities for a firm to streamline and shorten its supply chain, as these sources exist in a concentrated area (DeWitt et al. 2006). Supply chain management integrates process and builds long-term relationships among firms involved in the flow of products and services from the source through to end-users. All firms in the supply chain can benefit through achieving lower costs, improved customer value and satisfaction, and greater competitive advantage (Mentzer et al. 2001). Compared with market transactions among dispersed and random buyers and sellers, the proximity of firms in clusters and the repeated exchanges between them fosters communication, coordination, innovation, interdependence and trust. (DeWitt et al. 2006).

In industrial cluster site, these interconnected groups of companies in close geographical proximity to one another are a big source of supply chain and business advantage (Wu et al. 2006). Supply chains can intertwine with any one company being a part of many supply chains. As an example, IBM is part of a network of supply chains, since it is a customer in one supply chain (for server components), a supplier in another (to CompUSA for laptops), a partner in another (with Linux for software), and a competitor to another chain (Apple for desktop PCs) (DeWitt et al. 2006). As a whole, an industrial cluster is essentially collection of many interrelated supply chains (or supply networks). These supply chains contain many levels of independent suppliers and manufacturers with different suppliers possibly serving the same manufacturers, and different manufacturers ordering from the same supplier. These many-to-one, one-to-many, or many-to-many relationships are also possible between the manufactures and customers (Wu et al. 2006). These multi-chains are what we refer to cluster supply chains.

In comparison with the traditional single supply chain, cluster supply chain system contains a couple of paralleled single supply chains in the same region, not only do all enterprises in one single supply chain cooperate one another internally, but cooperation and coordination exist across different single supply chains externally as well. What is more, with the exception of firms in these single supply chains, there are a lot of small and medium-sized firms that are not in the chain but float around the same region for supporting and supplementing supply chains production and operation, as seen in Fig. 1.We take single chain in cluster supply chain system for example, some segments in the chain I including component fabrication, product assembly, which closely cooperate in single supply chain, usually play an important role in providing key and large quantity of component commonality to downstream firms. In some emergent cases, the single supply chain I be helped by other neighbor single supply chains in the same geographical location to replenish relevant items, even OEM (Original Equipment Manufacturer). On the basis of this, among cluster supply chain system exists many real time orders and colossal information feed-backed by market, the downstream segments closed to market can quickly respond to upstream parts for modifying component com-

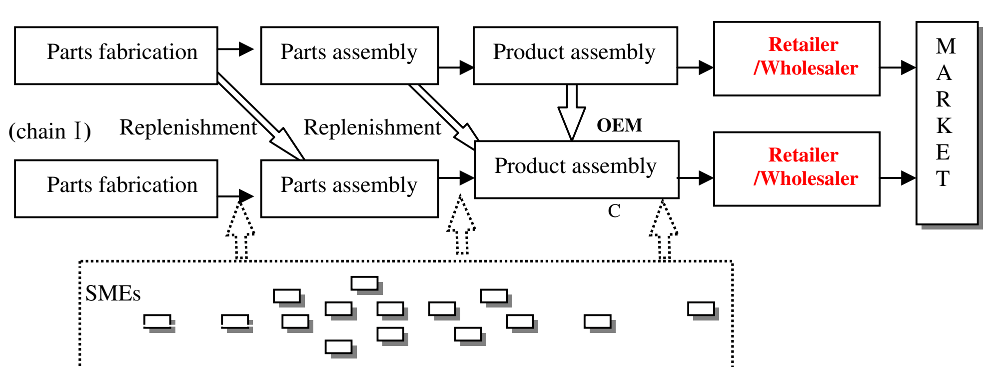

Fig. 1 Cluster supply chains

monality in order to turn them into tailored products, successful implementation of this efficient and low-cost modification contributes to those small and medium-sized firms, with the advantage of flexibility and specialization and sophistication, floating off single supply chains but embedding into cluster supply chain, provide supplementary items in a loose and uncertain way. Thus dissolving the contradiction between standard component commonality offered by single supply chain and personalized and customized stochastic demand required by market, this meets the requirements of MC to a large some degree, but can't be done well by traditional single supply chain I only.

Therefore, supports from those a lot of small and medium-sized firms and other single supply chains in the same geographical location maximize flexibility and minimize fragility of each individual single supply chain. In this way, enterprises in cluster supply chain system coordinate each other to support mutual competitive advantages.

Supply chain design

Design of cluster supply chain is an expansion of design from single supply chain design to multi-chains concurrent design. Studies regarding single supply chain design have presented fruitful and useful methodologies and results in different ways. Generally, there are two ways to design supply chain, one is qualitative approach, the other is quantitative one. The qualitative approach selects downstream and upstream firms by utilizing partner financial status, quality, performance histories, adoption to market and product change etc. (Wang et al. 2005; Matos and Afsrmanesh 2007), the quantitative by minimization of cost or maximization of profit of total of supply chain, which involved with facility capabilities, transportation routing and retailer/wholesaler specification (Chouinard et al. 2008). In particular, Chauhan et al. (2004) noted that supply chain design is to make decision regarding the location, number, capacity of each tier along supply chain, submarket allocation and suppliers of component, parts and materials and so on. Initially, supply chain design is regard as a supply chain facility location problem (FLP), and Bramel (2000) grouped FLP problem into three categories. One is PMP (P-Median Problem) model referred to that N retailers order from M warehouses and select P warehouses as the optimal solution, but this model is not involved with opening and fixed costs and considering each warehouse with infinite capacity. Two is CFLP (Capacitated Facility Location Problem) model that regarded number of warehouse as a variable, while taking into account opening and fixed costs and warehouse capacity (Jayaraman and Pirkul 2001). Combined with PMP and CFLP, Tragantalerngsak et al. (2000) studied FLP containing the firms at the first tier without capacity restriction and the second with restriction. Furthermore, Amiri (2006) gave more capacity options to specify number, location and capacity of producer and warehouse. Three is DSDP (Distribution System Design Problem) model that expanded to K product from a single product (Shen 2005).

The all above literatures regarding FLP explored supply chain design from strategy perspective. Due to tactical and operational factors (routing and inventory policy issues) also influencing supply chain design, Melkote (2001) added routing issue to FLP, and Chauhan et al. (2004) extended to three level of supply chain design with routing issue. From inventory perspective, Miranda and Garrido (2004) took economic order quantity and safety stock into account in supply chain design, particularly Shen and Qi (2007) considered both of routing and inventory policy issues in establishing supply chain design model. With the economic globalization, supply chain design is conducted from the global scale, and the factor 'supplier' has added to global supply chain configuration combined with considering tariff and non-tariff, exchange rate (Nagurney et al. 2003; Dasu and Torre 1997). Global supply chain design, for big companies such as DEC, HP and P&G, help them reduce direct cost and avoid trade barriers, but for small and medium-sized firms at industrial cluster, thanks to geography, culture and language difference, exchange rate fluctuation, legal and economic factors, the single supply chain design approach is not adoptable to SMEs designing their own multiple supply chains-cluster supply chains. Therefore, this paper, on basis of single supply chain, explores a novel approach to design cluster supply chains.

Problem presentation

Considering cluster supply chain with two single chains, assume that each individual single chain consists of one supplier, one manufacturer and one retailer, and produce the similar or the same products among the two single chains. Meanwhile we do not take into account that the two single supply chain exist direct competition at the echelon of supplier, manufacturer and retailer. The process of design cluster supply chains is presented as follows. First, select, specify and optimize the firms of three echelons of each individual single supply chain from candidate firms (i.e. vertical design of cluster supply chain). Then, on basis of this, we consider across-chain horizontal design of cluster supply chain through introducing 0–1 variables in order to specify whether it exists horizontal transaction between the two single supply chains. Therefore, cluster supply chains design need solving the several problem: (1) for certain product, if there is an across-chain replenishment relationship between supplier at one chain and manufacturer at the other chain, or manufacturer at one chain and retailer at the other chain; (2) determine supplier's item and batch; (3) determine transportation routing and transportation batch between suppliers and manufacturers; (4) determine manufacturer's production batch; (5) determine transportation routing and transportation batch between manufacturers and retailers.

Model formulation

The following notation is used in the formulation of the model.

j	Index set of single supply chains, $j \in \{1, 2, \}$
i	Index set of products available to manufacturer at single supply chains, $i \in \{1, 2, \cdots, I\}$.
direct_c_{ji}	Transportation cost of delivery per unit of product i from supplier to manufacturer at single supply chain j.
c_j	Maximum transportation capacity level for supplier shipping product i to manufacturer at single supply chain j.
direct_f_{ji}	Fixed cost of per unit of product i for opening and operating among supplier and manufacturer at single supply chain j.
m_{ji}	Manufacturing cost of per unit of product i at single supply chain j.
cap$_{ji}$	Consumption production capacity for manufacturer producing one unit of product i at single supply chain j.
M_j	Maximum production capacity level of manufacturer at single supply chain j.
direct_p_{ji}	Transportation cost of delivery per unit of product i from manufacturer to retailer at single supply chain j.
p_j	Maximum transportation capacity level of manufacturer at single supply chain j.
direct_g_{ji}	Fixed cost of per unit of product i for opening and operating among manufacturer and retailer at single supply chain j.
h_{ji}	Warehouse capacity needed for retailer stocking one unit of product i at single supply chain j.
INV_j	Maximum warehouse capacity level of retailer at single supply chain j.
d_i	Total market demand for product i.
x_{ji}	Transportation volume of shipping product i from supplier at single supply chain j to manufacturer at single supply chain j or other single supply chain.
y_{ji}	Transportation volume of shipping product i from manufacturer at single supply chain j to retailer at single supply chain j or other single supply chain.
u_{ji}	Binary variable for supplier at single supply chain j providing product i to manufacturer at the same single chain ($u_{ji} = 1$, if supplier at single supply chain j provide product i to manufacturer at the same single chain and 0 otherwise).
z_{ji}	Binary variable for manufacturer at single supply chain j providing product i to retailer at the same single chain ($u_{ji} = 1$, if manufacturer at single supply chain j provide product i to retailer at the same single chain and 0 otherwise).

Model without across-chain horizontal cooperation

The cluster supply chain without across-chain horizontal cooperation is that the two single supply chains, existed at the same industrial cluster location, have no relationship and cooperation apart from sharing with the same market, it means the two single supply chains among cluster supply chains system produce the similar or equal products, and only compete each other. In this way, this cluster supply chain system can be shown as Fig. 2.

For each individual single supply chain among cluster supply chain system, it total cost can be presented as

$$\min \mathrm{TC}_j = \sum_i^I \text{direct\_}c_{ji} \cdot x_{ji} + \sum_i^I \text{direct\_}f_{ji} \cdot u_{ji} + \sum_i^I m_{ji} x_{ji} + \sum_i^I \text{direct\_}p_{ji} \cdot y_{ji} + \sum_i^I \text{direct\_}g_{ji} \cdot z_{ji} \tag{1}$$

Assumed that certain industrial cluster area exists two single supply chains without across-chain cooperation, the total cost of the two single supply chains is given by the follow as.

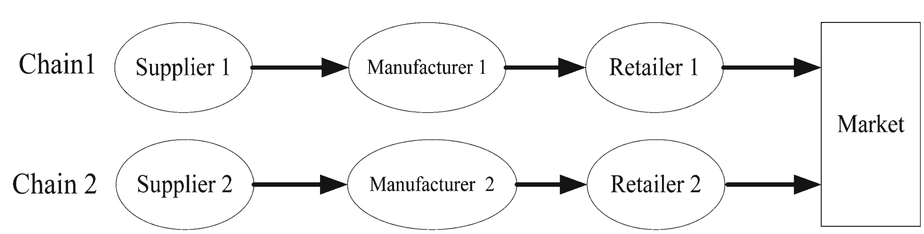

Fig. 2 Cluster supply chain system without across-chain horizontal cooperation

$$\min \mathrm{TC} = \sum_{j}^{2}\sum_{i}^{I} \mathrm{direct\_}c_{ji} \cdot x_{ji} + \sum_{j}^{2}\sum_{i}^{I} m_{ji}x_{ji} + \sum_{j}^{2}\sum_{i}^{I} \mathrm{direct\_}p_{ji} \cdot y_{ji} + \sum_{j}^{2}\sum_{i}^{I} \mathrm{direct\_}f_{ji} \cdot u_{ji} + \sum_{j}^{2}\sum_{i}^{I} \mathrm{direct\_}g_{ji} \cdot z_{ji} \quad (2)$$

Subject to:

$$\sum_{i}^{I} x_{ji} \le c_j, \quad \forall j = 1, 2 \quad (3)$$

$$\sum_{i}^{I} \mathrm{cap}_{ji} \cdot x_{ji} \le M_j, \quad \forall j = 1, 2 \quad (4)$$

$$\sum_{i}^{I} y_{ji} \le P_j, \quad \forall j = 1, 2 \quad (5)$$

$$\sum_{i}^{I} h_{ji} \cdot y_{ji} \le INV_j, \quad \forall j = 1, 2 \quad (6)$$

$$x_{ji} \cdot u_{ji} \ge y_{ji}, \quad \forall i, j \quad (7)$$

$$\sum_{j}^{j} y_{ji} \cdot z_{ji} = d_i, \quad \forall j = 1, 2 \quad (8)$$

$$x_{ji} \ge 0, y_{ji} \ge 0, \quad \forall i, j \quad (9)$$

$$u_{ji} \in \{0, 1\}, z_{ji} \in \{0, 1\}, \quad \forall i, j \quad (10)$$

The model minimizes total costs (2) made of: the costs of shipments from supplier to manufacturer for each individual single supply chains, the costs of production of manufacturer for each individual single supply chains, the costs of shipment from manufacturer to retailer for each individual single supply chains, the fixed costs occurred between supplier and manufacturer for each individual single supply chains, the fixed costs occurred between manufacturer and retailer for each individual single supply chains. Constraint sets (3)–(6) represent the capacity of transportation, production and warehouse, respectively. Constraint set (7) ensures that the total volume that suppliers ship do not exceed manufacturer demands. Constraint set (8) guarantees that the total market demand must be satisfied by manufacturer production. Constraint set (9) enforces the non-negativity restrictions on the corresponding decision variables and Constraint set (10) enforces the integrality restrictions on the binary variables.

Model with across-chain horizontal cooperation

In comparison with the aforementioned model, model of cluster supply chain design with across-chain horizontal cooperation is that the cluster supply chains not only exists inter-chain vertical cooperation between upstream and downstream firms along each individual single supply chain, but also across-chain horizontal cooperation as well. This kind of across-chain horizontal cooperation occurred among the two single supply chains, which avoid being out of stock or overstock so as to turn to help from the extra supply channel or emergency order channel, while the regular supply and order channel via vertical co-operational supply pipeline unable do well. For the two single supply chains located at industrial cluster, so the two single chains are characterized by production similarity, which leads to two single supply chains substitute their products with each other, the model with two single chains is showed in Fig. 3.

Let cross_c_{ji} be the transportation price of supplier at the single supply chain j send product $i$to manufacturer at another single supply chain by the way of across-chain shipment, and cross_p_{ji} be the production price of manufacturer at the single supply chain j produce product i to retailer at another single supply chain by the way of across-chain model, and cross_f_{ji} be the fixed cost of supplier at the single supply chain j provide product i to manufacturer at another single supply chain by the way of across-chain model, and cross_g_{ji} be the fixed cost of manufacturer at the single supply chain j provide product i to retailer at another single supply chain by the way of across-chain model.

α is a proportion of a firm allocating its supply items between vertical (α) and horizontal cooperation pipeline ($1 - \alpha$), in this way, α also means weighted parameter of vertical cooperation, it represents that a firm at industrial cluster pre-plan to provide the proportion α of items to downstream firm with which vertically cooperate while the parameter ($1 - \alpha$) implies that the firm provide the other firm of single supply chain proximity to it through extra emergency channel (horizontal cooperation) in order to

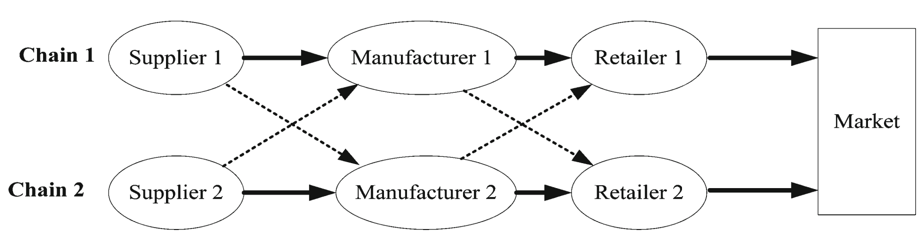

Fig. 3 Cluster supply chain system with across-chain horizontal cooperation

avoid overstock. For instance, the retailer 1 has two options to cooperate with upstream firms, one is manufacturer 1 via regular supply pipeline, two is manufacture 2 through the other single supply pipeline close to the single supply chain in anticipation of reducing inventory, and the manufacturer 1 is given weight α while the other manufacturer $1-\alpha$. The value of α is affected by three factors: stock level, order level from vertical channel and demand of horizontal cooperation. Not loss of generality, considering that the across-chain horizontal cooperation between the two single supply chains is mutual and symmetrical, assumed each individual firm at all tiers operate and cooperate with the parameters α and $1-\alpha$ vertically and horizontally.

In addition, two new decision variables v_{ji} and w_{ji} are introduced, where v_{ji} is a binary variable of supplier at single supply chain j providing product i to manufacturer at the other single chain through across-chain model ($v_{ji}=1$ if supplier at single supply chain j serving product i to manufacturer at the other single chain through across-chain model and 0 otherwise), and w_{ji} is a binary variable of manufacturer at single supply chain j providing product i to retailer at the other single chain through across-chain model ($w_{ji}=1$ if manufacturer at single supply chain j serving product i to retailer at the other single chain through across-chain model and 0 otherwise), the other variables aforementioned remain intact, so the cost for the single supply chain j with across-chain cooperation is represented as follows.

$$
\begin{aligned}
\min \mathrm{TC}_j = & \sum_{i^I} \alpha \cdot x_{ji} \cdot \mathrm{direct\_}c_{ji} \\
& + \sum_{i^I} (1-\alpha) \cdot x_{ji} \cdot \mathrm{cross\_}c_{ji} \\
& + \sum_{i}^{I} m_{ji} x_{ji} + \sum_{i}^{I} \alpha \cdot y_{ji} \cdot \mathrm{direct\_}p_{ji} \\
& + \sum_{i}^{I} (1-\alpha) \cdot y_{ji} \cdot \mathrm{cross\_}p_{ji} \\
& + \sum_{i}^{I} \mathrm{direct\_}f_{ji} \cdot u_{ji} + \sum_{i}^{I} \mathrm{cross\_}f_{ji} \cdot v_{ji} \\
& + \sum_{i}^{I} \mathrm{direct\_}g_{ji} \cdot z_{ji} + \sum_{i}^{I} \mathrm{cross\_}g_{ji} \cdot w_{ji}
\end{aligned} \tag{11}
$$

Thus the total cost of cluster supply chain design with across-chain horizontal cooperation can be formulated

$$
\begin{aligned}
\min \mathrm{TC} = & \sum_{j}^{2} \sum_{i}^{I} \alpha \cdot x_{ji} \cdot \mathrm{direct\_}c_{ji} \\
& + \sum_{j}^{2} \sum_{i}^{I} (1-\alpha) \cdot x_{ji} \cdot \mathrm{cross\_}c_{ji} \\
& + \sum_{j}^{2} \sum_{i}^{I} m_{ji} x_{ji} \\
& + \sum_{j}^{2} \sum_{i}^{I} \alpha \cdot y_{ji} \cdot \mathrm{direct\_}p_{ji} \\
& + \sum_{j}^{2} \sum_{i}^{I} (1-\alpha) \cdot y_{ji} \cdot \mathrm{cross\_}p_{ji} \\
& + \sum_{j}^{2} \sum_{i}^{I} \mathrm{direct\_}f_{ji} \cdot u_{ji} \\
& + \sum_{j}^{2} \sum_{i}^{I} \mathrm{cross\_}f_{ji} \cdot v_{ji} \\
& + \sum_{j}^{2} \sum_{i}^{I} \mathrm{direct\_}g_{ji} \cdot z_{ji} \\
& + \sum_{j}^{2} \sum_{i}^{I} \mathrm{cross\_}g_{ji} \cdot w_{ji}
\end{aligned} \tag{12}
$$

Subject to: (3)–(6),

$$\alpha x_{1i} \cdot u_{1i} + (1-\alpha) \cdot x_{2i} \cdot v_{2i} \geq y_{1i} \quad \forall i \tag{13}$$

$$\alpha \cdot x_{2i} \cdot u_{2i} + (1-\alpha) \cdot x_{1i} \cdot v_{1i} \geq y_{2i}, \quad \forall i, \tag{14}$$

$$\sum_{j}^{2} \alpha \cdot y_{ji} \cdot z_{ji} + \sum_{j}^{2} (1-\alpha) \cdot y_{ji} \cdot w_{ji} = d_i \quad \forall i = 1, 2, ..., I \tag{15}$$

$$\sum_{i}^{I} u_{ji} \geq 1 \quad \forall j = 1, 2 \tag{16}$$

$$\sum_{i}^{I} z_{ji} \geq 1, \quad \forall j = 1, 2 \tag{17}$$

$$x_{ji} \geq 0, \quad \forall i, j \tag{18}$$

$$y_{ji} \geq 0, \quad \forall i, j \tag{19}$$

$$u_{ji} \in \{0, 1\}, \quad \forall i, j \tag{20}$$

$$v_{ji} \in \{0, 1\}, \quad \forall i, j \tag{21}$$

$$z_{ji} \in \{0, 1\}, \quad \forall i, j \tag{22}$$

$$w_{ji} \in \{0, 1\}, \quad \forall i, j \tag{23}$$

The total costs (12) equally made of: the costs of shipments from supplier to manufacturer with vertical and horizontal cooperation, the costs of production of manufacturer for each individual single supply chains, the costs of shipment from manufacturer to retailer with vertical and horizontal cooperation, the fixed costs occurred between supplier and manufacturer with vertical and horizontal cooperation, the fixed costs occurred between manufacturer and retailer with vertical and horizontal cooperation. Constraint set (13) guarantees that the orders from all manufacturer should be satisfied by the supplier at the first single supply chain, and constrain set (14) ensures that orders from all manufacturer should be satisfied by the supplier at the second single supply chain. Constraint set (15) represents market demand restriction. Constraint sets (16) and (17) ensure existence of vertical and horizontal cooperation among cluster supply chain respectively. Constraint set (18–23) enforces the non-negativity and integrality restrictions on the corresponding variables.

Model algorithm

The objective for this model is the minimization of system-wide overall cost that could be broken down into fixed investment cost, variable operating cost, vertical fixed shipping cost, horizontal fixed shipping cost, vertical variable shipping cost, horizontal variable shipping cost, in-process inventory cost etc. The model with mixed non-linear program (MNILP) can be computed by Lagrange algorithm or other comprehensive algorithms (Daniel and Rajendran 2005), but these methods are inefficient due to more variables and constraints existing in one model. For decisions are made on a set of qualitative variables, a genetic algorithm is applied to qualitative policy variables, a mixed integer programming solves the approximate model for given policy variables resulted from the genetic algorithm, and simulation is used to calculate the optimal solution of cluster supply chain.

The procedure for the approach consists of the following steps:

Step 1. Initialization: Create an initial random population of Ns alternatives. Each alternative is represented by a chromosome in the term of GA terminology, which identifies cluster supply chain characterized by values of qualitative decision variables (The representation of alternative in term of chromosome is described in the following part).

Step 2. Determine fitness values of all new chromosomes by evaluating performance measures of cluster supply chain they represent. Given the fixed set of values of qualitative decision variables, we determine the optimal values of quantitative decision variables in a constructed MIP model. Finally, a simulation model is generated for cluster supply chain configuration given that the values of quantitative decision variables, and the values of qualitative decision variables provided by GA in order to obtain the overall cost and the customer service level. In this way, we obtained Pareto-optimal solutions for cluster supply chain design problem, otherwise continue forward step 3.

Step 3. Selection: Create a mating pool applying selection operator.

Step 4. Crossover: Create new offspring by applying the crossover operator on individuals in the mating pool.

Step 5. Mutation: Create new offspring by applying the mutation.

Step 6. Iteration: Repeat step 2 until the objective criteria are satisfied.

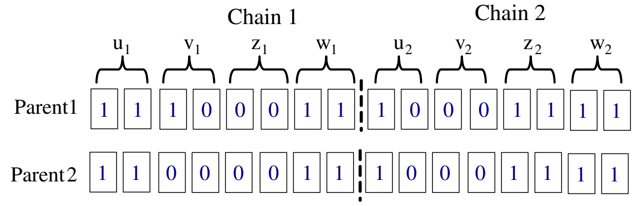

Fig. 4 Chromosome representation

Chromosome representation

Each chromosome represents a potential optimal solution. A chromosome is composed of genes. Each gene contains a parameter (the binary variable, represented by b_i). Parameters associated with cluster supply chain occupy a segment of genes as shown in Fig. 4. A gene in a segment represents the value of one quantitative decision variable, for instance, delivering some products between two companies, which imply the supply-order relation in one chain or across chains for different products/parts taking place at that stage.

Operators

Fitness value

The fitness value defines the relative strength of a chromosome. It evaluates the chromosome structure and returns a positive value. The larger the value is, the stronger the chromosome. A strong chromosome means that it is more desirable. The fitness value is guided by an equation. This equation may formulate the total cost of the system, and is considered by most researchers. Some researchers formulate the equation to optimize the total lead times to increase the service level. In supply chain management, it is crucial to consider the customer service level, meanwhile the costs should be considered as well. In a situation such as supply chain cooperation, equal distribution of benefits should never be neglected. This approach for calculating the fitness value will have the representations including the total cost of the system,

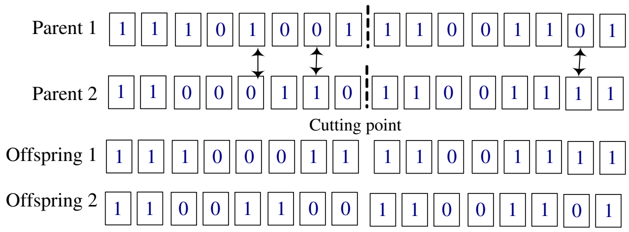

Fig. 5 Illustration of crossover operator

total delivery day utilized, and the equality on manufacturer's utilization ratio.

Selection operator

The selection operator implements the idea of the 'survival of fittest'. It is the process of selecting chromosomes from the pool to be the parent chromosomes for the next crossover process. This selection process is basically arbitrary. Every chromosome may have a probability to be chosen. However, the stronger the chromosome is, the better the chance that it will be selected. This mimics the idea of only the strong surviving, while the weaker will be eliminated. Indeed, every chromosome can appear more than once in the mating pool as the parent chromosome. The number of chromosomes selected is equal to the pool size initially defined.

Crossover operator

For this hypothetical model, it adapts the multi-points crossover method. Because of the length of the chromosome in this problem size, a two-point crossover is adapted, which is 20% of the genes undergoing crossover. This low percentage of crossover allows the chromosome to replace its weaker genes gradually, and prevents the offspring chromosomes changing too rapidly from parent chromosomes. The crossover operation is illustrated in Fig. 5.

Mutation operation

In this paper, the mutation of chromosomes will occur only when a pair of chromosomes with an identical genes structure is selected to crossover. Both of them will mutate instead of crossover. Similar to crossover, the number of mutated genes is two, which is 20%. The mutation operation is illustrated in Fig. 6

Monitor operator

The idea of Elitist strategy is to bring the best chromosomes from the previous stage to the present stage without changing the gene structure (Dejong 1975). This ensures the best chromosomes can survive. Onwubolu and Kumalo (2001) proposed an 'Isbest strategy', which ensures the best chromosomes in the present stage are pushed into the next stage (Onwubolu and Muting 2001). Meanwhile, the best chromosomes are preserved, preventing loss of best chromosomes. In this paper, the function of a monitor operator serves to monitor the performance of the evolution of the pool. After each evolution, the strongest chromosomes in the present stage will be identified and recorded. These strongest chromosomes will be compared with the overall strongest chromosomes evaluated so far from the beginning. If these new chromosomes are weaker than those overall strongest chromosomes, the overall strongest chromosomes will be inserted back into the mating pool for the crossover or mutation processes. This allows the strongest chromosomes to survive and have another chance to become stronger. The number of insertions is set equal to the rounded off integer of pool size divided by ten-approximately 10% of the chromosomes in the pool will be replaced. With this low percentage, the strongest chromosomes can prevent domination in the mating pool. When the number of strongest chromosomes is larger than the number of calculated insertions, the number of insertions will be set equal to the number of strongest chromosomes. Again, this ensures the survival of all the strongest chromosomes. The insertion will be spread out evenly, i.e. each insertion will be separated by a space that is equal to the number of insertions calculated.

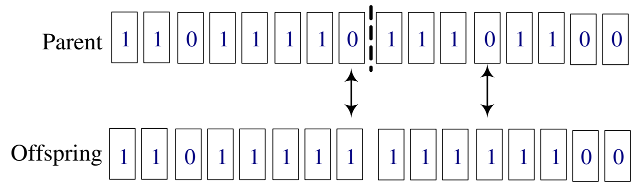

Fig. 6 Illustration of mutation operator

Illustration examples

The studied case refers to one of Chinese industrial clusters where there is cluster supply chain with the two single supply chains ($j = 2$), each individual single supply chain contains one supplier, one manufacturer and one retailer, the two single supply chains serve the same market with two products, the values is shown in Tables 1 and 2 through software Matlab, we computing the two above problems.

Impact of different value of α on cluster supply chains

As for the goal function (12), let the weighted parameter a endowed by different values ($1 \geq \alpha \geq 0$), and the step is 0.05, and compute values of decision variables and of the goal functions with different weighted parameters. It is found

Table 1 Data of parameters

Value of parameter		direct_c_{ji}		cross_c_{ji}		direct_f_{ji}		cross_f_{ji}		direct_p_{ji}		cross_p_{ji}		m_{ij}	
(a)															
Single chain		1	2	1	2	1	2	1	2	1	2	1	2	1	2
Product	1	10.5	10.0	11.5	11.0	120	110	130	120	10.0	10.5	11.0	12.0	32	31
	2	14.0	13.5	15.0	15.0	150	145	180	170	12.0	13.0	13.5	14.0	38	37
Value of parameter		cap$_{ji}$		h_{ji}		direct_g_{ji}		cross_g_{ji}		d_i					
(b)															
Single chain		1	2	1	2	1	2	1	2						
Product	1	1.5	1.5	1.0	1.0	90	95	110	115	350					
	2	3.0	3.0	3.0	2.5	140	150	160	160	380					
Value of parameter		M_j	c	p_j	INV$_j$										
(c)															
Single chain	1	1,100	360	360	1,080										
	2	1,200	380	375	1,150										

Table 2 Result of cluster supply chain design with and without across-chain horizontal cooperation

α	Time consumed (min)	Target value (TC)	Binary variables of across-chain horizontal cooperation								Connection lines (K)	Inventory		Ratio (TC/K)
			v				w					Product 1	Product 2	
			v_{11}	v_{12}	v_{21}	v_{22}	w_{11}	w_{12}	w_{21}	w_{22}				
0.50	2	45,337.50	1	0	0	1	1	1	1	1	12	10	0	3,778.125
0.55	3	45,431.95	0	1	1	1	1	1	1	1	14	9	0	3,245.139
0.60	2	45,174.20	0	1	1	1	1	1	1	1	14	5	0	3,226.729
0.65	4	44,968.82	0	1	1	1	1	1	1	1	14	1	0	3,212.059
0.70	2	44,785.85	0	1	1	1	1	1	1	1	14	0	0	3,198.989
0.75	2	44,740.00	0	1	1	1	1	1	1	1	14	1	0	3,195.714
0.80	2	44,605.60	0	1	1	1	1	1	1	1	14	0	0	3,186.114
0.85	3	44,597.35	0	1	1	0	1	1	1	1	13	1	4	3,430.565
0.90	3	44,364.85	1	0	0	1	1	1	1	1	12	3	0	3,697.071
0.95	5	44,409.00	1	0	0	1	1	1	1	1	13	1	1	3,416.077
1.00	1	43,112.50	0	0	0	0	0	0	0	0	6	0	0	7,185.417

that for $\alpha < 1 - \alpha$ (or $0.5 > \alpha > 0$), the cost of cluster supply chain design with across-chain cooperation is greatly higher than that without across-chain cooperation, and for $\alpha \geq 1-\alpha$, the situation is reverse, that is to say that the cluster supply chain design with across-chain horizontal cooperation incurred less cost. This change implies there exists close relationship between the total cost and weighted parameter α. Although the parameter α is effected by a couple of factors, such as inventory level, order quantity from downstream in regular channel, and demand quantity in horizontal emergency channel, the parameter α is playing the most important role in impacting the total cost. In other words, the allocation proportion of vertical and horizontal cooperation (α: $1 - \alpha$) is linked to its own cooperation cost incurred vertically and horizontally.

In real business world, vertical coordination along cluster supply chain is a long term and orientated-strategy, while horizontal cooperation is a temporary and short term contract. Due to that strategy is overall and long term relationship, thus the operation cost is relative low, while horizontal cooperation is extra and temporary one, the operative cost higher. Although α and $1 - \alpha$ is the item allocation proportion of vertical and horizontal cooperation in cluster supply chain, this proportion also can be refer as a adjusting param-

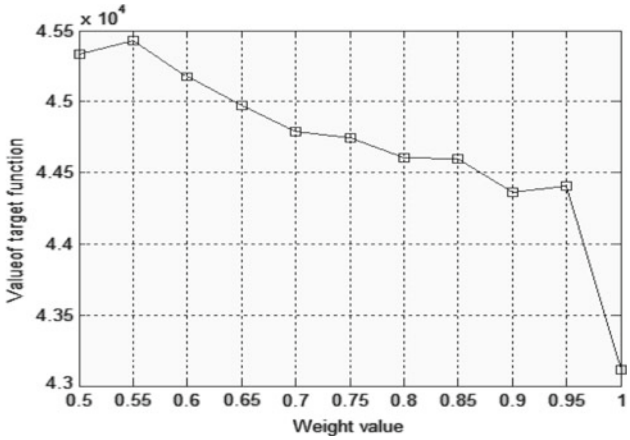

Fig. 7 Relationship between target function value and weighting value

eter trade off between vertical and horizontal cooperation cost. The vertical cooperation cost increase through giving higher value of weighted parameter α (i.e. $\alpha \geq 1 - \alpha$), on the other hand, it means reducing the horizontal cooperation cost, and promotes the across-chain horizontal cooperation of cluster supply chain, on the contrary, when $\alpha \leq 1 - \alpha$ $(0.5 > \alpha > 0)$, it amplifies the horizontal cooperation cost, which leads to disrupting coordination between one single chain and another one.

Furthermore, for when α belong to the area $\alpha \geq 1 - \alpha$ $(0.5 > \alpha > 0)$, it also implies that the vertical cooperation channel is a regular and long term strategic channel, while across-chain horizontal cooperation is temporary and supplementary channel, for the cost incurred in strategic channel is lower than that in temporary channel, it matches with real situation occurred in business world. In this way, the paper will put more emphasis on α belonging to the area $0.5 \leq \alpha \leq 0$ to explore the change of cluster supply chain design.

The analyzed result shows at Fig. 7 for $\alpha \geq 1 - \alpha$ $(0.5 \leq \alpha \leq 1)$ except of $\alpha = 1$. According to the result, while values of α belong to the area (0.55–0.85), the values of all decision variables and target functions have not greatly changed. However, the values of target functions have tendency of decrease with the increase in α (Fig. 7). There are two special cases of $\alpha = 0.5$ and $\alpha = 1$, the former case tries to equally balance possibility between horizontal and vertical collaboration, but the cost is maximum among all alternatives, and the amount of unsold product also remain highest level, thus leading to resource wastes; while the latter case is extreme one in which there is not any across-chain cooperation between a single chain and the other single chain among cluster supply chain, the corresponding cost is 43112.5, less than the costs incurred for any parameters α, this does not prove that the alternative is best one, the reason is that, in this setting or scenario, cluster supply chain completely replies on the vertical collaboration along single chain without the horizontal cooperation across the two single chains, if some uncertainties occur, it is most likely to encounter the risk of failure to fulfill order from the end customers due to lack of other extra and emergency replenishment sources.

On basis of described above, when values of α belong to the area (0.55–0.85), it implies that the more value of parameters α, the more the cluster supply chain has tendency to cooperate vertically rather than horizontally, because the total cost decrease with the increase in parameters α, that means that the higher value of parameters α will reduce chance of across-chain horizontal cooperation and trigger more risk that cluster supply chain will encounter.

In order to select one optimal alternative regard as parameter α, we, based on the above analyzed, count the overall number (K) of connection lines both along single supply chains and across two single chains for different values of parameter α. It needless to say that the higher value of K implies that cluster supply chains have more sources or channels or pipelines to replenish items to firms in regular and emergency need, thus reduce the risk that cluster supply chain usually face in an uncertain and competitive environment. Then the total costs with respective to different values of parameter α are divided by the corresponding values of K, i.e. *TC/K*, in this way, we utilize this ratio (*TC/K*) to select the best alternative and the corresponding value of parameter α.

In general, the evaluation rule is that the best alternative is one with the lowest value of *TC/K*, vice verse. Through computing (Table 2), it is obvious that when $\alpha = 0.8$ the value of *TC/K* (3186.114) is lowest, so the alternative with $\alpha = 0.8$ is the best one, then followed by $\alpha = 0.75$ and 0.70 (their values of *TC/K* are 3195.714 and 3198.989, respectively). The result illustrates that for higher value of α, across-chain horizontal cooperation play an important role in cluster supply chain design. On the other hand, too high and too low value of α are not suitable for this situation, for instance, when $\alpha = 0.95$ and 0.90, or $\alpha = 0.65$ and 0.60, the values of α do not remain relative smaller.

Impact of other corresponding costs on cluster supply chain design

According to above analyzed, the value of *TC/K* is the lowest when $\alpha = 0.8$. In the context of that $\alpha = 0.8$, we observe what effects will take place in cluster supply chain design, when some corresponding parameters change their values (Tables 3, 4, 5, 6).

First, we analyze impact of the changes of supplier/manufacturer per unit shipping fixed/variable cost on total of cost the model (12), which can reflect the extent of horizontal and vertical cooperation in cluster supply chain design. The Figs. 8 and 9 show the total cost is more sensitive to the changes of supplier/manufacturer per unit vertical/horizon-

Table 3 Impact of change of cluster supply chain supplier shipping fixed/variable costs on total cost for $\alpha = 0.8$

Change of shipping cost (%)	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	
ΔTC (%)	0.79	1.58	2.37	3.16	3.95	4.74	5.53	6.32	7.11	7.90	Δdirect_c_{ji}
	0.21	0.43	0.64	0.86	1.07	1.28	1.50	1.71	1.93	2.14	Δcross_c_{ji}
	0.07	0.11	0.16	0.20	0.25	0.29	0.34	0.39	0.43	0.48	Δdirect_f_{ji}
	0.03	0.08	0.14	0.19	0.24	0.29	0.35	0.40	0.45	0.50	Δcross_f_{ji}

Table 4 Impact of change of cluster supply chain manufacturer shipping fixed/variable costs on total cost for $\alpha = 0.8$

Change of shipping cost (%)	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	
ΔTC (%)	0.76	1.54	2.27	3.00	3.74	4.46	5.25	5.97	6.71	7.49	Δdirect_p_{ji}
	0.21	0.43	0.65	0.86	1.07	1.27	1.48	1.69	1.91	2.10	Δcross_p_{ji}
	0.07	0.13	0.18	0.24	0.29	0.34	0.40	0.45	0.50	0.56	Δdirect_g_{ji}
	0.09	0.15	0.21	0.27	0.33	0.39	0.45	0.51	0.57	0.63	Δcross_g_{ji}

Table 5 Impact of change of cluster supply vertical/horizontal shipping fixed/variable costs on total cost for $\alpha = 0.8$

Change of shipping cost (%)	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	
ΔTC (%)	1.55	3.12	4.64	6.16	7.69	9.20	10.78	12.29	13.82	15.38	Vertical shipping variable cost
	0.42	0.86	1.29	1.71	2.14	2.55	2.98	3.40	3.83	4.24	Horizontal shipping variable cost
	0.12	0.22	0.32	0.42	0.52	0.62	0.71	0.81	0.91	1.01	Vertical shipping fixed cost
	0.12	0.23	0.34	0.46	0.57	0.68	0.80	0.91	1.03	1.14	Horizontal shipping fixed cost

Table 6 Impact of change of horizontal cost on connection lines when $\alpha = 0.85$

cross_c_{ji}	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
Connection lines (K)	13	13	13	13	13	13	13	12	12	12
direct_c_{ji}	5	10%	15%	20%	25%	30%	35%	40%	45%	50%
Connection lines (K)	13	14	14	14	14	14	14	14	12	14
cross_p_{ji}	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
Connection lines (K)	13	13	13	13	13	13	13	13	13	13
direct_p_{ji}	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
Connection lines (K)	14	12	13	13	13	13	13	13	13	13

tal shipping variable costs, particularly for vertical shipping variable cost, on the other thing, there is no effects on the total cost for the changes of supplier/manufacturer per unit vertical/horizontal shipping fixed costs, for instance, when supplier/manufacturer per unit vertical/horizontal shipping fixed costs increase by 50% respectively, the corresponding total costs only increase by 0.48 and 0.50 (or 0.56 and 0.63%) respectively. Figure 10 shows that when overall transportation fixed/variable costs in cluster supply chains increase by each 5%, there is the same result of total cost of the model (12) occurred as the above sensitive analysis. So, the per unit horizontal/vertical shipping variable costs should give a priority in design cluster supply chains, especially for per unit vertical shipping variable cost. And the changes of corresponding fixed costs have less effect on cluster supply chain configuration.

In addition, in the process of sensitive analysis of variable and fixed costs of cluster supply chain, it is also found that, when $\alpha = 0.85$, changes of cost usually lead to 13 or 14 connection lines along single supply chain or across the two single chains, but 12 lines in few situations (Table 2). When $\alpha = 0.82$ usually for 14 connection lines, $\alpha = 0.86$ for 13 lines, for other values of parameter α there is the same situation occurred as the total connection lines in cluster supply chains generally remain a certain number with a low fluctuation. From this respective, it implies that no matter vertical and horizontal costs vary at the constant α the connection lines in cluster supply chains remain unchanged. In other

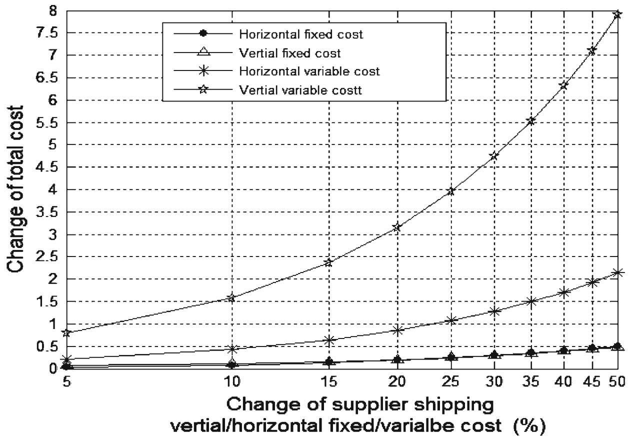

Fig. 8 Relationship between supplier shipping cost and total cost for $\alpha = 0.8$

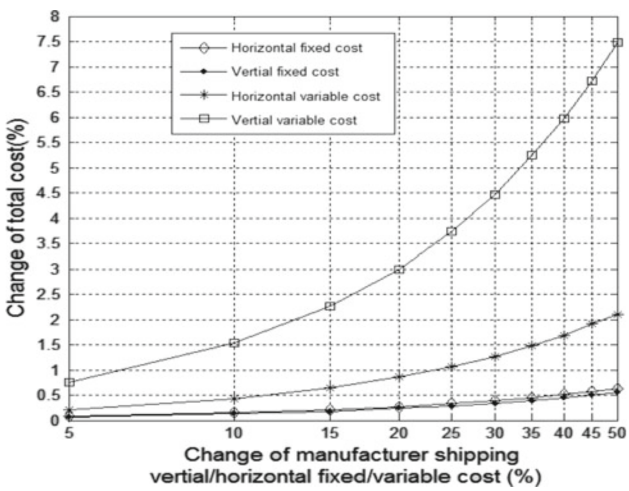

Fig. 9 Relationship between manufacturer shipping cost and total cost $\alpha = 0.8$

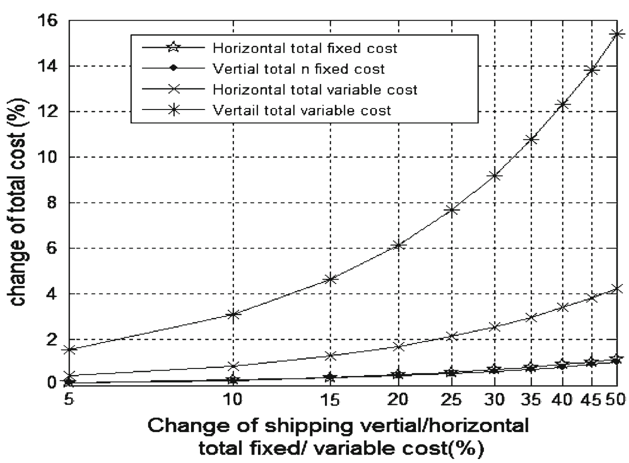

Fig. 10 Relationship between shipping cost and total cost $\alpha = 0.8$

words, for the certain value of α, variable costs have not direct relationship with cooperative lines in cluster supply chains, but it is obviously affected by values of parameter α. And parameter α is determined by both cost and decision maker's philosophy.

Conclusion and future research

We have presented a novel framework for intelligent model design cluster supply chain in which there are a multiple of rivals or potential competitors in the proximity for each member along supply chain. It means industrial cluster not only contains a couple of focal firms locating at the same tier, but includes the corresponding upstream and downstream firms as well, all of which concentrate on a close geographical site. Thus, it is most likely to form multiple paralleled single supply chains for each focal firm of industrial cluster, these paralleled single supply chains compete and cooperate with each other, that is to say that these single supply chains led by each individual focal firm have interrelated or intertwined each other less or more. Due to geographical proximity, the characteristics of similar and complementary production, related industries, flexible and specialized and trust features, members in industrial cluster not only vertically cooperate along their own single supply chain, but also different single supply chains horizontally cooperate each other by mean of across-chain model, which facilitates firms to adopt to change of market uncertain demand, reduce customer search cost, improve customer service level and expand market share of the whole industrial cluster area. Recent researches regarding supply chain design mainly focus on a limited tier in single supply chain, which only take into account vertical cooperation and ignore the across-chain horizontal one. This paper, based on industrial cluster, established cluster supply chain design models without across-chain horizontal cooperation, then by introducing item allocation proportion of vertical and horizontal cooperation (α: $1 - \alpha$), the model with across-chain horizontal cooperation is also developed. Considering more variables and constraints existing in one model (MIP), a genetic algorithm is applied to qualitative policy variables, then a mixed integer programming solves the approximate model for given policy variables resulted from the genetic algorithm, and simulation is used to calculate the optimal solution of cluster supply chain.

Through a case computation, it is found that higher value of weighted parameter α (i.e. $\alpha \geq 1-\alpha$) enables reducing the horizontal cooperation cost, and promotes the across-chain horizontal cooperation of cluster supply chain, on the contrary, when $\alpha \leq 1 - \alpha$ ($0.5 > \alpha > 0$) amplifies the horizontal cooperation cost, which leads to disrupting coordination between one single chain and another one. Furthermore, for when α belong to the area $\alpha \geq 1 - \alpha(0.5 \leq \alpha \leq 1)$ also implies that the vertical cooperation channel is a regular and long term strategic channel, while across-chain horizontal cooperation is temporary and supplementary channel, for the cost incurred in strategic channel is lower than that in temporary channel, it matches with real situation occurred in business world. We put more emphasis on α belonging to the area $0.5 \leq \alpha \leq 1$ to explore the change of cluster supply chain design. When values of α belong to the area (0.55–0.85), the more value of parameters α, the more the cluster supply chain has tendency to cooperate vertically rather than horizontally. In order to select one optimal alternative regard as parameter α, we use *TC/K* to determine, through computing finds when $\alpha = 0.8$ the value of *TC/K* (3186.114) is lowest, so the alternative with $\alpha = 0.8$ is the best one. In addition, the per unit horizontal/vertical shipping variable costs should give a priority in design cluster supply chains, especially for per unit vertical shipping variable cost. And the changes of corresponding fixed costs have less effect on cluster supply chain design.

This work reveals some promising areas where one could place more efforts in the future. More sophisticated aspects in cluster supply chain management may be added into the model. For example, the item allocation proportion of vertical and horizontal cooperation may vary in tier of cluster supply chains instead of just only one. Cluster supply chains has many stakeholders involved and usually has more than one objective, thus multiple objectives could be applied into this framework.

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