A bi-objective model for supply chain design of dispersed manufacturing in China

Abraham Zhang, Hao Luo, George Q. Huang


Abstract

Dispersed manufacturing achieves the greatest cumulative competitive advantage by dissecting a supply chain and assigning each process to an optimal location. Dispersed manufacturing has been an integral part of global manufacturing in China. This paper presents a bi-objective model for the supply chain design of dispersed manufacturing in the context of rising business operating costs in coastal China. It considers essential trade-offs between supply chain cost and lead time to determine optimal facility locations of manufacturing steps. The model is applied to a representative case to illustrate the cost benefits of dispersed manufacturing as opposed to performing all manufacturing steps of a product at a single facility location. It provides explanations in several factors that have benefited manufacturing growth in China, and offers insights in the emerging global manufacturing trends.

Keywords: Supply chain management; Supply chain strategy; Dispersed manufacturing; Manufacturing network; China; Integer programming

1. Introduction

Manufacturing activities have become more spatially fragmented in the past few decades (Ferdows, 1997; Lee and Lau, 1999; Ronald et al., 2005; Christopher et al., 2011). Manufacturers nowadays do not necessarily perform all manufacturing steps of a product at a single facility location. Instead, they often ship semi-finished products to a different location for further processing or sales (Fawcett, 1992; Ferdows, 1997; Feng and Wu, 2009). The rapid advancement of information technologies, especially the wide adoption of e-business platforms and enterprise information systems (Li, 2011b), has been a key enabler behind the trend. It allows facilities at distant locations to coordinate product design and development (Fritzsche et al., 2012; Li and Liu, 2012; Liu and Wang, 2012; Ren et al., 2012), and production activities (Tan et al., 2010; Wang and Xu, 2012) efficiently at an affordable cost.

This paper defines dispersed manufacturing as the practice of dissecting the manufacturing process into multiple stages, and assigning them to geographically dispersed locations to achieve a competitive edge (Magretta and Fung, 1998). Dispersed manufacturing exploits comparative advantages of multiple locations, however, dramatically increases the complexity in supply chain design. According to the seminal work of Fisher (1997), a typical challenge of supply chain design is the management of trade-offs between efficiency and responsiveness, which are measured by cost and lead time respectively. Locating labor-intensive manufacturing steps in proximity to cheap labor is able to lower production costs, but lengthens the supply chain and increases logistics costs. Global manufacturers need to define business priorities, design their supply chains, and review facility location decisions when there are major changes in global and regional business environments (Skinner, 1996).

Dispersed manufacturing has been an integral part of global manufacturing in China. It has allowed the country to participate in global supply chains to realize its labor cost advantage and skill competence. Dispersed manufacturing is what is behind the boom in intra-Asia trade as China rises as the “Factory of the
World” (Magretta and Fung, 1998). Tens of thousands of global manufacturers in China import raw materials and semi-finished products from Asian countries, perform labor-intensive assembly operations, and then export end-products to developed countries (GPRD Business Council, 2007). As the traditional gateway to China, Hong Kong has played a pivotal role to support manufacturing growth in China, especially in the southern regions. Hong Kong traders typically obtain overseas orders and organize manufacturing in a dispersed network of factories in the Pearl River Delta (PRD) region (Fung et al., 2008; HKDTC, 2008). A great example is Li & Fung (Hamid and Lee, 2006), which dissects the supply chain to assign a manufacturing step to an optimal location. Li & Fung synchronizes a network of thousands of factories around the globe, to minimize total costs and shorten order lead times (Magretta and Fung, 1998; Hagel, 2002). Its business model has attracted high profile retailers including The GAP, Target Corp. and Marks & Spencers Plc. In 2010, giant retailer Wal-Mart also signed a multi-billion dollar deal to source through Li & Fung and expected “significant” savings across its supply chain (Cheng, 2010; Talley and O’Keeffe, 2010).

Inspired by Li & Fung’s success (Magretta and Fung, 1998; Joanna, 1999; Hagel, 2002), several studies advocated dispersed manufacturing from a strategic viewpoint (Chung et al., 2004; Hamid and Lee, 2006). However, quantitative studies on dispersed manufacturing have been scare. In recent years, new trends have emerged as some global manufacturing activities are moving away from coastal China because of rising production costs and the hike in oil prices (Trunick, 2008; Kumar et al., 2009; Zhang and Huang, 2010; Zhang et al., 2012). However, they assumed that all manufacturing steps of a product are performed at a single facility location, although dispersed manufacturing has been a business reality in China. There is an urgent need to perform quantitative studies in the supply chain design of dispersed manufacturing in China in light of the emerging global manufacturing trends.

In a broader scope of supply chain design, many mathematical models have been built to aid manufacturing facility location decisions. A recent review of these models can be found in Melo et al. (2009). However, there are considerable challenges to adapt these models for Chinese manufacturing due to very different business environments, for example, North American Free Trade Agreement (NAFTA) (Wilhelm et al., 2005; Robinson and Bookbinder, 2007). The Chinese manufacturing and its business environment are unique in many ways. Many Chinese factories are export oriented and their major markets are faraway developed countries (GPRD Business Council, 2007). Their supply chain costs are sensitive to oil price fluctuations due to a long transport distance. In terms of business environment, China is still far from being a free market. The Chinese central government controls the exchange rate of its currency renminbi (RMB), which is very influential on the cost competitiveness of Chinese manufacturers. It offers export value-added tax (VAT) rebates by product types to encourage certain industries. Geographically, China has a large continent and there are significant cost disparities between its coastal and inland regions. To mitigate rising cost pressure in coastal regions, Chinese manufacturers has the alternative of relocating to inland regions besides the option of moving overseas.

This paper aims to narrow the research gap by developing a bi-objective model for the supply chain design of dispersed manufacturing in China. The work is inspired by a supply chain optimization project that Li & Fung implemented for a major US client. The client achieved substantial cost savings by switching to a dispersed manufacturing network. The bi-objective model captures the distinctive attribute of dispersed manufacturing by defining multiple production stages. It considers essential trade-offs between supply chain cost and lead time (Fisher, 1997) to determine optimal facility locations of manufacturing steps. The measurement of supply chain lead time is particularly relevant to dispersed manufacturing as it may consume considerable transport lead times if manufacturing facilities are far from each other or at different countries. The model is tailored for the unique Chinese manufacturing environment and it includes parameters such as currency exchange rate and export VAT rate. The model application with a representative case illustrates the cost benefits of dispersed manufacturing as opposed to performing all manufacturing steps of a product at a single facility location. It provides explanations in several factors that have benefited manufacturing growth in China in the past few decades. It also offers managerial insights on the future developments of global manufacturing trends.

The rest of this paper is organized as follows. Section 2 reviews relevant literature. Section 3 develops a bi-objective model. Section 4 applies the model for a case study. Section 5 presents results and analysis. Section 6 discusses findings and managerial implications. Section 7 concludes the research.
2. Literature review

Dispersed manufacturing, multi-plant manufacturing, and manufacturing network all involve multiple manufacturing facilities and need advanced information technologies to support process integration (Li et al., 2012; Tao et al., 2012). However, they are of key distinctions. Dispersed manufacturing and multi-plant manufacturing are a manufacturing practice or strategy (Schmenner, 1982), while manufacturing network is referred to as a network of manufacturing facilities (Boone et al., 1996). To be more specific, dispersed manufacturing is the type of process-focused multi-plant manufacturing whose facilities are geographically dispersed. Although they all involve a manufacturing network, dispersed manufacturing is different from product-focused multi-plant manufacturing, or process-focused multi-plant manufacturing whose facilities are at a same location (Hayes and Schmenner, 1978). Our work on the supply chain design of dispersed manufacturing in China is relevant to three research streams: supply chain strategy, manufacturing supply chain design, and global manufacturing trends in China. We review most relevant literature in all these research streams, and then draw conclusions on research gaps.

The first research stream deals with supply chain strategy. Fisher (1997) proposed the supply chain strategy of physical efficiency for functional products with predictable demand, and market responsiveness for innovative products with unpredictable demand. The optimal trade-off between supply chain efficiency and responsiveness is largely dependent on product and demand characteristics. Fisher’s (1997) typology has been widely accepted in the industry and has also been supported by a number of academic studies (Lowson, 2001; Lowson, 2002; Warburton and Stratton, 2002; Lovell et al., 2005; Chopra and Meindl, 2007; Collin et al., 2009). It is thus safe to conclude that both cost and lead time management are of strategic importance to supply chain performance (Fisher, 1997; Mason-Jones and Towill, 1999; Coyle et al., 2009; Whicker et al., 2009).

The second research stream is concerned with manufacturing supply chain design. From a manufacturing strategy perspective, Shi and Gregory (1998) presented a map for international manufacturing network configurations. The map categorized different levels of geographic dispersion of manufacturing operations. Rudberg and Olhager (2003) proposed a typology for manufacturing network design including four basic network configurations. Miltenburg (2009) further explored manufacturing strategy objects and linkages between objects for a company’s international manufacturing network. His study affirmed the proposition of previous studies that manufacturing network design is crucial for a firm’s global competitiveness (Shi and Gregory, 1998; Rudberg and Olhager, 2003). From the viewpoint of enterprise information systems, it is also recognized that supply chain design and collaboration are very important to manufacturers’ market and financial performance (Li, 2006; Kumar et al., 2011; Li, 2011a; Li, Ford et al., 2011; Ma et al., 2011; Xu, 2011b; Xu, 2011a; Zdravkovic et al., 2011; Sepehri, 2012). As manufacturing supply chains have become more spatially dispersed, manufacturers are now more vulnerable to supply chain disruptions and quality issues (Li, Su et al., 2011; Li and Warfield, 2011).

The subject of manufacturing supply chain design and has also attracted wide attention in the operations research/management science community. A large number of mathematical models have been developed for various facility location and supply chain design problems. Mixed integer programming (MIP) techniques have been used most often (Wilhelm et al., 2005; Melo et al., 2009). A review of relevant models can be found in the work of Beamon (1998), Meixell and Gargyeya (2005), Melo, et al. (2009), and Lee and Wilhelm (2010).

Most supply chain design models measured profit or cost alone. It has been found that optimal manufacturing network design is influenced by many cost parameters. They include labor costs (Robinson and Bookbinder, 2007), transportation costs (Cohen and Moon, 1990; Kulkarni et al., 2005; Feng and Wu, 2009), exchange rates (Mohamed, 1999; Vidal and Goetschalckx, 2000; Bhutta et al., 2003; Wilhelm et al., 2005), government investment incentives (Wilhelm et al., 2005; Feng and Wu, 2009), tariffs (Bhutta et al., 2003; Chakravarty, 2005), etc.

Only few models incorporated the measurement of lead time apart from profit or cost. Arntzen et al. (1995) built a bi-objective model to measure both cost and lead time. Its implementation achieved savings of over $100 million at Digital Equipment Corporation. Li and O’Brien (1999) developed an integrated model for supply chain partner selection. The model considered four criteria: profit, lead time performance, delivery promptness and waste elimination. Cakravastia, et al. (2002) developed a two-stage model for the supplier selection process in designing a supply chain network. The model evaluated two performance criteria: price and delivery lead time.

Most supply chain design models did not consider the possible geographical dispersion of manufacturing activities (Hammami et al., 2008). Among the few exceptions, a model built by Vila, et al. (2006) was for the lumber industry. A model presented by Thanh, et al. (2008) considered the manufacturing of semi-finished products, however, its focus was mainly on the dynamic facility location issues. A model developed by Hammami, et al.
(2009) was for a French automotive company. It is not clear how these models can be adapted for labor-intensive product sectors in China.

The third research stream is pertaining to the emerging manufacturing trends in China. Relevant studies (Kumar and Kopitzke, 2008; Kumar et al., 2009; Zhang and Huang, 2010; Zhang et al., 2012) focused on cost factors alone. Kumar and Kopitzke (2008) compared the total cost of outsourcing in China and Mexico, and maintaining domestic production in the US. They pointed out that exchange rate fluctuations could pose significant risks to outsourcing in China. Kumar, et al. (2009) identified that recent business environment changes in China made it less cost competitive. However, switching to alternative low cost countries is challenged with finding capable suppliers. Zhang and Huang (2010), and Zhang, et al. (2012) suggested that labor-intensive manufacturing activities in coastal China may move to alternative lower-cost locations. These studies have timely identified that critical changes are happening for global manufacturing in China. However, they assumed that all manufacturing steps of a product are performed at a single facility location.

The review above reveals two research gaps. First, very few supply chain design models have incorporated the measurement of lead time, which is of strategic importance to supply chain performance. Most existing models only considered costs or profits. Second, studies on the recent trends of global manufacturing in China assumed that all manufacturing steps of a product are performed in a single facility, even though manufacturing activities have become more spatially fragmented in the past several decades (Ferdows, 1997; Lee and Lau, 1999; Ronald et al., 2005; Christopher et al., 2011).

3. A bi-objective model

This section presents a bi-objective model for the supply chain design of dispersed manufacturing in China. The bi-objective model incorporates major business environment variables that have been affecting labor-intensive global manufacturers in China in recent years. These factors include currency exchange rate, production cost, transportation cost, and export VAT rate. We consider a geographically dispersed manufacturing network as depicted in Figure 1 (Li and O'Brien, 1999; Meixell and Gargeya, 2005; Zhang and Huang, 2012). The model formulation assumes that the manufacturing process is broken into three production stages: component manufacturing, subassembly manufacturing, and end-product manufacturing. However, it can be easily extended to more production stages by following the example of Hammami, et al. (2009). Each type of component, subassembly and end-product may be manufactured at a different facility using raw materials or semi-finished products. There are multiple candidate locations for each facility.

The model does not consider capacity constraints and is based on the single-product case (Melachrinoudis and Min, 2000). It is assumed that demand, production and transportation lead times (LTs) are deterministic and they are measured by days. Model notations, formulation and resolution (Melachrinoudis and Min, 2000; Bhutta et al., 2003; Ting and Cho, 2008; Zhang and Huang, 2012) are presented in the following subsections.

![Figure 1](image_url). A geographically dispersed manufacturing network
### 3.1. Notations

Sets and indices:

- $M$: Set of markets, indexed by $m$
- $C$: Set of components, indexed by $c$
- $S$: Set of subassemblies, indexed by $s$
- $L$: Set of production locations, indexed by $l, l'$ and $l''$.

Parameters:

- $D_m$: Annual demand of the end-product at market $m$
- $SE_s$: Units of subassembly $s$ required for one end-product
- $CS_{cs}$: Units of component $c$ required for one subassembly $s$
- $e_l$: Exchange rate to the USD from the currency used at location $l$
- $VAT_l$: Realized VAT rate at location $l$
- $RMC_{cl}$: Raw material cost for component $c$ at location $l$
- $ITC_{cl}, ITT_{cl}$: Inbound transportation cost and LT for component $c$ at location $l$
- $CTC_{cl}, CTT_{cl}, CTD_{cl}$: Cost, LT and tariff to transport component $c$ from location $l$ to $l'$. Note that $l$ and $l'$ may or may not refer to a same location. If locations $l$ and $l'$ are at different countries, transportation cost and LT are often much greater than domestic transport and import/export tariffs may be levied by customs
- $STC_{sl}, STT_{sl}, STD_{sl}$: Cost, LT and tariff to transport subassembly $s$ from location $l$ to $l'$. Note that subassembly imports/exports may or may not be subject to customs tariffs
- $ETC_{lm}, ETT_{lm}, ETD_{lm}$: Cost, LT and tariff to transport the end-product from location $l$ to market $m$. Note that major markets of developed countries import most labor-intensive products from low cost countries and levy import tariffs.
- $CPC_{cl}, SPC_{sl}, EPC_{l}$: Variable production cost of component $c$, subassembly $s$ and the end-product at location $l$. The cost is measured by local currency. It is calculated by per product unit. It includes both labor and non-labor related costs but excludes raw material cost.
- $FCC_{cl}, FSC_{sl}, FEC_{l}$: Fixed cost to produce component $c$, subassembly $s$, and the end-product at location $l$. The cost is incurred as long as a facility is in operation regardless of its production volume. It covers expenses for business license, essential information systems infrastructures, etc.
- $CPT_{cl}, SPT_{sl}, EPT_{l}$: Production LT of component $c$, subassembly $s$ and the end-product at location $l$. It varies by locations depending on the availability of skilled workers and supporting services. Well-established industrial clusters have advantages to enable a short production LT.
- $IR_{l}, IC_{c}, IS_{s}, IE$: Annual inventory holding cost of component $c$ raw materials, component $c$, subassembly $s$, and the end-product in transportation pipeline
- $\lambda$: A sufficiently large constant.

Variables:

- $\pi_{cl}, \pi_{sl}, \pi_{l''}$: Production status of component $c$, subassembly $s$ and the end-product at location $l$ (1 if in operation; 0 otherwise)
$CPQ_{cl}, SPQ_{dl'}$ Quantity of component $c$ and subassembly $s$ produced at location $l$ for location $l'$

$EPQ_{lm}$ End-product production quantity at location $l$ transported to market $m$.

### 3.2. Model formulation

**Objective functions**

Minimize: 

$$
\sum_{i \in C} \sum_{l \in L} \sum_{d \in D} CPQ_{cl} RMC_{cl} + \sum_{i \in C} \sum_{l \in L} \sum_{d \in D} CTC_{cl} + \sum_{s \in S} \sum_{l \in L} \sum_{d \in D} SPQ_{dl's} SPC_{dl's} + \sum_{m \in M} EPC_{cl} EPQ_{lm} (1 + VAT_f) + \sum_{i \in C} \sum_{l \in L} \sum_{d \in D} CPQ_{cl} ITC_{cl} + \sum_{s \in S} \sum_{l \in L} \sum_{d \in D} SPT_{dl's} SPQ_{dl's} + \sum_{m \in M} (ETC_{cl} + EDT_{lm}) EPQ_{lm}$$

$$+ \sum_{i \in C} \sum_{l \in L} \sum_{d \in D} CTT_{cl} ITC_{cl} + \sum_{s \in S} \sum_{l \in L} \sum_{d \in D} STT_{dl's} IS_{dl's}$$

$$+ \sum_{m \in M} EPQ_{lm} EPP_{lm} (1) / 360$$

(1)

Minimize:

$$\sum_{l \in L} \sum_{c \in C} \sum_{l \in L} \sum_{d \in D} CPT_{cl} CPQ_{cl} + \sum_{s \in S} \sum_{l \in L} \sum_{d \in D} SPT_{dl's} SPQ_{dl's} + \sum_{m \in M} EPT_{l} EPQ_{lm}$$

$$+ \sum_{l \in L} \sum_{c \in C} \sum_{l \in L} \sum_{d \in D} CTT_{cl} CPQ_{cl} + \sum_{s \in S} \sum_{l \in L} \sum_{d \in D} STT_{dl's} SPQ_{dl's} + \sum_{m \in M} ETT_{lm} EPQ_{lm}$$

(2)

**Constraints:**

$$\sum_{l \in L} EPQ_{lm} = D_m \quad m \in M$$

(3)

$$\sum_{l \in L} SPQ_{dl'} = S_i \sum_{m \in M} EPQ_{lm} \quad s \in S, \ l' \in L$$

(4)

$$\sum_{l \in L} CPQ_{cl} = \sum_{s \in S} \sum_{l \in L} SPQ_{dl's} \quad c \in C, \ l \in L$$

(5)

$$\sum_{l \in L} CPQ_{cl} \leq \pi_{cl} \lambda$$

(6)

$$\sum_{l \in L} SPQ_{dl'} \leq \pi_{l'} \lambda$$

(7)

$$\sum_{m \in M} EPQ_{lm} \leq \pi_{l'} \lambda$$

(8)

$$\pi_{cl}, \pi_{l'}, \pi_{l'} \in \{0, 1\}$$

(9)

$CPQ_{cl}, SPQ_{dl'}, EPQ_{lm}$ are integers

(10)

Objective (1) is to minimize total supply chain costs measured by the USD. The first term calculates raw material costs for component production. The second term represents fixed operating costs of manufacturing facilities that are in operation. The third term refers to variable production costs and VAT costs for component manufacturing, subassembly manufacturing and end-product manufacturing. The fourth term calculates inbound transportation costs of raw materials. The fifth term represents component transportation costs and possible import/export tariff costs. Similarly, the sixth and seventh terms refer to transportation and tariff costs for subassemblies and end-products respectively. The eighth term sums up costs of holding raw material, component, subassembly and end-product inventories in transportation pipelines. One year is approximated as 360 days.
Objective (2) is to minimize weighted activity days and it is obtained by summarizing the multiplication of quantity and LT in days for production and transportation activities (Arntzen et al., 1995). The first term refers to production activities including component manufacturing, subassembly manufacturing and end-product manufacturing. The second term represents inbound raw material transportation activities. The third term is for component transportation activities. Similarly, the fourth and fifth terms are for subassembly and end-product transportation activities.

Equation (3) ensures that market demand is met. Equation (4) sets the flow balance for subassemblies produced and used for the production of end-products. Similarly, equation (5) maintains the flow balance for components produced and used for the production of subassemblies. Constraints (6)–(8) set the production status as one if there are components, subassemblies or end-products produced at a candidate location. Constraints (9) and (10) define the characteristics of variables.

### 3.3. Model resolution

The bi-objective model presented above is non-deterministic polynomial-time hard (NP-hard) due to the existence of integer variables (Lodi, 2010). However, the model is relatively easy to solve as all constraints are linear. The computational complexity of the model is mainly determined by the number of integer variables. Let a set name followed by a symbol “$\circ$” denotes the size of the set, it is easy to calculate the number of integer variables of the model as $(C^o + S^o)L^o^2 + (C^o + S^o + M^o + 1)L^o$. The branch-and-cut algorithm, which integrates the branch-and-bound and the cutting plane algorithms, can efficiently solve problem instances with a few thousands or even tens of thousands of integer variables (Hillier and Lieberman, 2005). The branch-and-cut algorithm recursively divides the original problem into sub-problems which correspond to nodes of an enumeration tree. Let $Q^s$ and LP($Q^s$) denote a node and the linear relaxation of the sub-problem associated with the node. The generic procedures of the branch-and-cut algorithm are as follows (Appa et al., 2004):

- **Preprocess $Q^s$;**
- if ($Q^s$ remains feasible)
  - **Repeat**
    - Solve LP($Q^s$) if it is feasible and its optimal solution is fractional
    - Identify valid inequalities violated by the fractional solution;
    - Add the violated inequalities to LP($Q^s$);
  - **until** (LP($Q^s$) is infeasible) or (an integer solution is found) or (no inequalities are added)
  - if (LP($Q^s$) is still feasible and no integer solution has been found)
    - Apply the branch-and-bound algorithm to partition $Q^s$ into two sub-problems;
  - else prune $Q^s$;
- **Return**;

We use the weighting method (Arntzen et al., 1995; Melachrinoudis and Min, 2000) to convert the two objectives into a single objective. Positive weights $\omega_1$ and $\omega_2$ ($\omega_1 + \omega_2 = 1$) are assigned to the two objectives and they reflect decision makers’ subjective preference with regard to the importance of the objectives (Canbolat et al., 2007; Ting and Cho, 2008). However, notice that objective (1) measures cost while objective (2) measures lead time, weights may not be meaningful unless the two objectives are re-scaled properly (Ravindran et al., 2010). Thus, utilizing the optimization results obtained from the base case scenario, we re-scale the two objective functions to the same order of magnitude by using 10 raised to an appropriate power (Steuer, 1989; Melachrinoudis and Min, 2000). We then resolve the model through the branch-and-cut algorithm embedded in commercial solver ILOG CPLEX 11.2.0.

Table 1 presents the computational results on a computer with Intel® Dual-core 1.5G processor and 2G RAM. The average CPU running time is acceptable for all problem instances. The computational performance is comparable with similar models reported in the literature (Melachrinoudis and Min, 2000; Dahel, 2003; Thanh et al., 2008).
### Table 1. Computational results

<table>
<thead>
<tr>
<th>Markets</th>
<th>Subassemblies</th>
<th>Components</th>
<th>Locations</th>
<th>Constraints</th>
<th>Integer variables</th>
<th>Average CPU time (s)</th>
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<td>5</td>
<td>10</td>
<td>20</td>
<td>630</td>
<td>6520</td>
<td>153.5</td>
</tr>
</tbody>
</table>

### 4. Model application

#### 4.1. Case description

This section applies the model for a case study. The characteristics of manufacturing operations are adapted from Zhao’s (2006) case study of a leading footwear manufacturer in the PRD. The model application considers a family of low-end labor-intensive footwear products. A unit of end-product (E) is formed by one unit of upper subassembly (S1) and one unit of sole subassembly (S2). A subassembly S1 and S2 is made from one set of upper components (C1) and one set of sole components (C2) respectively. The product family has three product types differentiated by demand characteristics: unseasonal, seasonal and fashionable footwear (Zhang and Huang, 2012).

As mentioned in Section 3, this study is a part of a larger research project about global manufacturing in China. The research project has considered three major markets of developed countries, namely North America, Europe and Japan. It evaluated 10 alternative low cost manufacturing locations in Asia, Africa, America and Europe. We have observed similar facility location patterns for different markets and several categories of candidate locations. To simplify the presentation of data and modelling results, this analysis is based on the single market of the US. Besides the PRD, the case analysis considers another three alternative locations: inland China (Inland), Vietnam and Mexico. The PRD represents coastal China. Inland represents lower-cost areas of China. Vietnam represents lower-cost Asian countries. Mexico represents low cost locations near major markets.

The base case scenario represents the business condition in mid-2008 before the unfolding of the global financial crisis in the late part of the year. At that time, global manufacturers in the PRD faced unprecedented cost pressure. Trends of relocating labor-intensive manufacturing activities away from coastal China started to develop because of Chinese currency RMB appreciation, rising labor cost, increased oil prices and reduced export VAT rebates (Rubin and Tal, 2008; Kumar et al., 2009; Zhang and Huang, 2010; Zhang et al., 2012).

As mentioned previously, the bi-objective model is inspired by a supply chain optimization project that Li & Fung implemented for a major US client. Actual project data cannot be disclosed due to confidentiality reasons. However, we are able to resemble the practice of dispersed manufacturing using reasonable data presented in the following subsection.

#### 4.2. Assumptions and data

We assume that unseasonal, seasonal and fashionable footwear products all have an annual demand of 1,200,000 units in the US market. We assign weights 1.0, 0.8 and 0.6 respectively to their cost objectives. All transportation modes use 40FT full containers. Each shipment transports 6,400 units of finished products or their equivalent volume. Transportation costs vary linearly with oil prices. The correlation factor between transportation costs and oil price is 55.8% in relation to the base oil price of $140 per barrel (Rubin and Tal, 2008).

The exchange rate from the RMB to the USD is 0.143 at the base case scenario. Note that the Chinese government has been controlling the RMB exchange rate. Before July 2005, China had fixed the RMB to the USD exchange rate at 0.121 for more than ten years when its economy expanded rapidly. Facing pressure from other governments (Kumar et al., 2009), China had allowed the RMB to appreciate by about 20% until the global financial crisis started in September 2008. After that, the pace of the RMB appreciation slowed down and the currency only gained another 10% by the end of 2011 (SAFE, 2012).
Table 2 presents data on supply chain costs and LTs. Most raw materials are sourced internationally and thus there are minimal differences in raw material costs across candidate locations. The production of C1, C2, S1, S2 and E accounts for 15%, 10%, 45%, 15% and 15% of total labor cost respectively. Similarly, production non-labor cost allocation factors are 15%, 35%, 20%, 15% and 15%. A 5% mark-up on top of production labor and non-labor costs is given to manufacturers to account for their profit margins. The two candidate locations in China have higher labor costs than Vietnam. Minimum wages in China have been increasing by about 10% each year since mid-2000s (HKTDC, 2011).

Production LTs are shorter in China, especially in its coastal region, because of well-established industrial clusters and highly productive Chinese workers (HKTDC, 2010; The Economist, 2012). Industrial practitioners acknowledge that Chinese workers are more skillful and productive than their counterparts in other low cost countries. In the 1980s and the 1990s, many global manufacturing activities moved to China to take advantage of its cheap labor and favourable industrial policies (Zhang et al., 2012). As a result, a large pool of migrant workers have gained experiences and become very proficient with labor-intensive manufacturing activities. At the same time, many industrial clusters, or so-called specialized towns, have been established in coastal China. They spur higher labor productivity, lower input cost, and significantly reduce production LTs because required materials, equipments and services are readily available (HKTDC, 2010).

China has much better transport infrastructures than most other low cost countries. In particular, ports and highways are well developed in coastal China and they support efficient logistics services. This helps reduce transportation costs and LTs for manufacturing activities in China. The very large volume of import/export cargoes also creates economies of scale to lower ocean freight costs in and out of China (Zhang et al., 2012).

Realized VAT rate in China is 6% at the base case scenario because the full VAT rate is 17% and exports enjoy a rebate of 11%. The Chinese government used to give full VAT rebates to promote exports. Since mid-2000s, it started to reduce export VAT rebates for labor-intensive products in an attempt to upgrade and transform its manufacturing industries (HKTDC, 2007).

<table>
<thead>
<tr>
<th>Table 2. Supply chain costs and LTs</th>
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<tbody>
<tr>
<td>PRD</td>
</tr>
<tr>
<td>Fixed annual operating cost/location</td>
</tr>
<tr>
<td>Raw material cost/C1 unit</td>
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<tr>
<td>Inbound transportation cost/C1 unit</td>
</tr>
<tr>
<td>Raw material cost/C2 unit</td>
</tr>
<tr>
<td>Inbound transportation cost/C2 unit</td>
</tr>
<tr>
<td>Total production labor cost/unit</td>
</tr>
<tr>
<td>Total production non-labor cost/unit</td>
</tr>
<tr>
<td>Inbound transportation LT for C1, C2 (days)</td>
</tr>
<tr>
<td>Production LT for C1, S1, S2, E (days)</td>
</tr>
<tr>
<td>Production LT for C2 (days)</td>
</tr>
<tr>
<td>End-product transportation cost/unit</td>
</tr>
<tr>
<td>End-product transportation LT (days)</td>
</tr>
<tr>
<td>Realized VAT rate</td>
</tr>
</tbody>
</table>

Table 3 gives unit transportation costs and LTs for C1 and S1. Data in the lower triangle part are for transportation costs, while those in the upper triangle part are for transportation LTs. In comparison with C1 and S1, transportation costs of C2 and S2 are three times higher because they are more freight-intensive. Transportation LTs between facilities at a same location are zero days. Tariff rates are 20% for products imported into North America.
Table 3. Transportation costs and LTs for C1 and S1

<table>
<thead>
<tr>
<th>LT (days)</th>
<th>Cost</th>
<th>PRD</th>
<th>Inland</th>
<th>Vietnam</th>
<th>Mexico</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRD</td>
<td>$0.014</td>
<td>1</td>
<td>10</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Inland</td>
<td>$0.028</td>
<td>$0.014</td>
<td>12</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Vietnam</td>
<td>$0.085</td>
<td>$0.099</td>
<td>$0.017</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>$0.141</td>
<td>$0.155</td>
<td>$0.155</td>
<td>$0.014</td>
<td></td>
</tr>
</tbody>
</table>

Besides the case study of Zhao (2006), we acquired supplemental data from the industry. Major data sources were Hong Kong Trade Development Council (HKTDC), ProMexico, Werner International, GHK (Hong Kong) Ltd., Shenzhen Container Trailer Association and four logistics companies. We conducted data validation and the supply chain cost structure is on par with the industrial average. Specifically, total production cost comprises of about 50% raw material costs, 20-30% labor costs and 20-30% non-labor costs for the labor-intensive footwear (Lowder, 1999; HKTDC, 2007). Ocean shipping costs are in the range of 0.5-8% and 5-18% of product value respectively for intra-Asia and cross-continental trade (Fung et al., 2008; Zhang and Huang, 2012). Air shipping is not considered because involved products are of low value.

5. Results and analysis

5.1. Base case results

Table 4 shows optimal supply chain design of dispersed manufacturing in the base case scenario. The measurements of unit supply chain cost and supply chain lead time correspond to the two objectives of the bi-objective model. To be specific, unit supply chain cost is obtained from the division of total yearly cost by demand volume. Supply chain lead time is calculated as the sum of longest lead time at each supply chain echelon, assuming raw materials and semi-finished products are ordered based on actual demand and there are no delays in order processing. Mexico is not selected as a manufacturing location in the base case scenario. It is thus not included in the presentation of results.

For unseasonal footwear with weight 1.0 for costs, Vietnam is the optimal manufacturing location for labor-intensive component C1 and subassembly S1. Inland China is the best fit for freight-intensive component C2, subassembly S2 and end-product E. This is because Vietnam has a decisive advantage in labor cost, while inland China strikes a good balance between low labor cost and logistics cost. The unit supply chain cost is $7.60 and supply chain lead time is 96 days.

Table 4. Optimal supply chain design of dispersed manufacturing in the base case scenario

<table>
<thead>
<tr>
<th></th>
<th>(\omega_l=1.0) (unseasonal footwear)</th>
<th>(\omega_l=0.8) (seasonal footwear)</th>
<th>(\omega_l=0.6) (fashionable footwear)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PRD</td>
<td>Inland</td>
<td>Vietnam</td>
</tr>
<tr>
<td>C1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>C2</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>S1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>S2</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>E</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Unit supply chain cost</td>
<td>$7.60</td>
<td>$7.94</td>
<td>$8.06</td>
</tr>
<tr>
<td>Supply chain lead time (days)</td>
<td>96</td>
<td>53</td>
<td>49</td>
</tr>
</tbody>
</table>
clustering and a developed logistics infrastructure. Splitting manufacturing activities between the PRD and inland China serves best the required trade-off between supply chain efficiency and responsiveness. The unit supply chain cost is $7.94 and supply chain lead time is 53 days.

For fashionable footwear with the lowest weight 0.6 for costs, the PRD is the optimal location for all manufacturing steps to meet the high demand in supply chain responsiveness. The unit supply chain cost is $8.06 and supply chain lead time is 49 days.

5.2. Cost benefits of dispersed manufacturing

We can understand the cost benefits of dispersed manufacturing by comparing the results in Tables 4 and 5. Table 5 presents optimal supply chain design of non-dispersed manufacturing. The results are obtained by running the bi-objective model with the following two additional constraints (11) and (12). These two constraints impose the condition that component and subassembly manufacturing must be at a same location as end-product manufacturing. Note that it is valid to compare supply chain cost of dispersed and non-dispersed manufacturing only when they fulfill the same required level of supply chain responsiveness. This is ensured by assigning the same weight \( \omega_1 \) to dispersed and non-dispersed manufacturing for a same product type. Consequently, supply chain responsiveness, as measured by \( \omega_2 = 1 - \omega_1 \), is set at the same level.

\[
\pi_i = \pi''_i \quad c \in C, \ l \in L \\
\pi''_i = \pi'''_i \quad s \in S, \ l \in L
\]  

(11) (12)

For unseasonal footwear, dispersed manufacturing reduces unit supply chain cost from $7.66 to $7.60, although it increases supply chain lead time from 60 days to 96 days. The cost saving is resulted from relocating the production of most labor-intensive subassembly S1 from inland China to Vietnam. The cost saving in this case is only marginal, however, it will become more substantial if we consider lower-cost alternative locations such as Bangladesh and Cambodia (Jassin - O’ Rourke Group. LCC, 2008).

Table 5. Optimal supply chain design of non-dispersed manufacturing in the base case scenario

<table>
<thead>
<tr>
<th>( \omega_1 = 1.0 ) (unseasonal footwear)</th>
<th>( \omega_1 = 0.8 ) (seasonal footwear)</th>
<th>( \omega_1 = 0.6 ) (fashionable footwear)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRD</td>
<td>Inland</td>
<td>Vietnam</td>
</tr>
<tr>
<td>C1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>C2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>S1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>S2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>E</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Unit supply chain cost</td>
<td>$7.66</td>
<td>$8.06</td>
</tr>
<tr>
<td>Order lead time (days)</td>
<td>60</td>
<td>49</td>
</tr>
</tbody>
</table>

For seasonal footwear, dispersed manufacturing reduces unit supply chain cost from $8.06 to $7.94. This represents a 1.5% reduction in the supply chain cost. Such a cost saving is very attractive to supply chain managers as labor-intensive products usually have very low profit margins. Supply chain lead time increases from 49 days to 53 days. The difference is only four days and is less likely to be a concern for seasonal products.

For fashionable footwear, the bi-objective model suggests the same supply chain design for dispersed and non-dispersed manufacturing. Locating all manufacturing steps at a single location minimizes manufacturing lead time, and thus is preferred for fashionable products that have short product life cycles. The result also demonstrates that the bi-objective model has the capacity of suggesting non-dispersed manufacturing if it happens to be optimal.

5.3. Sensitivity analysis

Table 6 presents the results of sensitivity analysis in business environment changes. The second column includes nine scenarios of different business environment changes. Optimal manufacturing locations are given in the third to
fifth column. Production stages (C1, C2, S1, S2, E) assigned to a manufacturing location are given in a bracket. If multiple locations are involved, a plus (“+”) symbol is inserted between locations.

For unseasonal footwear, inland China is most cost competitive to host all manufacturing steps in scenario (1), in which RMB exchange rate is reversed to its historical low level before China allowed RMB to appreciate since July 2005. Vietnam is the optimal location to host all manufacturing activities in scenarios (2) and (3). It suggests that Vietnam will gain a decisive cost advantage over China if the trend of RMB appreciation continues. Scenario (4) represents the labor cost condition in the PRD before it climbed rapidly since mid-2000s. The result is consistent with the fact that the trend of relocating labor-intensive manufacturing from the PRD did not appear until mid-2000s (Trunick, 2008; Kumar et al., 2009; Zhang and Huang, 2010; Zhang et al., 2012). The result comparison of scenarios (4) and (5) demonstrates that labor cost is influential on the attractiveness of the PRD to retain a portion of stages in scenario (1), in scenarios (1) and (2). Only in scenarios (6) and (7) simulate a very low-level and a very high-level oil price respectively. The results show that Vietnam remains as optimal manufacturing location for C1 and S1 which are not freight-intensive. However, Mexico becomes most favoured to produce relatively freight-intensive C2, S2 and E. This result affirms the idea of sourcing freight-intensive products near markets at high oil prices (Goel et al., 2008; Rubin and Tal, 2008). The results in scenarios (8) and (9) suggest VAT rebates as another factor that affects manufacturing location decisions in China, although it is not as influential as labor cost or RMB exchange rate. It affirms that favourable VAT policies in China have helped the nation to attract manufacturing activities (Kumar et al., 2009).

Table 6. Sensitivity analysis results

<table>
<thead>
<tr>
<th>Scenario No.</th>
<th>Business environment change</th>
<th>$\omega_i$=1.0 (unseasonal footwear)</th>
<th>$\omega_i$=0.8 (seasonal footwear)</th>
<th>$\omega_i$=0.6 (fashionable footwear)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RMB depreciates by 15%</td>
<td>Inland (C1, C2, S1, S2, E)</td>
<td>PRD (C1, C2, S1, S2, E)</td>
<td>PRD (C1, C2, S1, S2, E)</td>
</tr>
<tr>
<td>2</td>
<td>RMB appreciates by 15%</td>
<td>Vietnam (C1, C2, S1, S2, E)</td>
<td>PRD (C1) + Inland (C2, S1, S2, E)</td>
<td>PRD (C1, C2, S1, S2, E)</td>
</tr>
<tr>
<td>3</td>
<td>RMB appreciates by 30%</td>
<td>Vietnam (C1, C2, S1, S2, E)</td>
<td>Inland (C1, C2, S1, S2, E)</td>
<td>PRD (C1, C2, S2, E) + Inland (S1)</td>
</tr>
<tr>
<td>4</td>
<td>DLC in PRD decreases by 30%</td>
<td>PRD (C1, S2, E) + Inland (C2)</td>
<td>PRD (C1, C2, S1, S2, E)</td>
<td>PRD (C1, C2, S1, S2, E)</td>
</tr>
<tr>
<td>5</td>
<td>DLC in PRD increases by 30%</td>
<td>Inland (C2, S2, E) + Vietnam (S1)</td>
<td>PRD (C1, C2, S1, S2, E)</td>
<td>PRD (C1, C2, S2, E) + Inland (S1)</td>
</tr>
<tr>
<td>6</td>
<td>Oil price $40/barrel</td>
<td>Inland (C2, S2, E) + Vietnam (C1, S1)</td>
<td>PRD (C1, C2, S2, E) + Inland (S1)</td>
<td>PRD (C1, C2, S1, S2, E)</td>
</tr>
<tr>
<td>7</td>
<td>Oil price $240/barrel</td>
<td>Vietnam (C1, S1) + Mexico (C2, S2, E)</td>
<td>PRD (C1, C2, S2, E) + Inland (S1)</td>
<td>PRD (C1, C2, S1, S2, E)</td>
</tr>
<tr>
<td>8</td>
<td>Full VAT rebate in China</td>
<td>Inland (C1, C2, S1, S2, E)</td>
<td>PRD (C1, C2, S2, E) + Inland (S1)</td>
<td>PRD (C1, C2, S1, S2, E)</td>
</tr>
<tr>
<td>9</td>
<td>Zero VAT rebate in China</td>
<td>Inland (C2, S2, E) + Vietnam (C1, S1)</td>
<td>PRD (C1, C2, S1, S2, E)</td>
<td>PRD (C1, C2, S1, S2, E)</td>
</tr>
</tbody>
</table>

For seasonal footwear, all production stages should be located in either inland China or the PRD. Vietnam is not selected in any scenario because it is not ready as China to facilitate a responsive supply chain. The labor cost advantage of Vietnam is largely offset by its weakness in logistics and lack of strong and complete industrial supply chains (HKTDC, 2010). In almost all scenarios except scenarios (1) and (4), inland China is the optimal manufacturing location of S1 because of its lower labor cost than the PRD.

For fashionable footwear, all production stages should be located in the PRD in most scenarios. Only in scenarios (3) and (5), both inland China and the PRD should be involved because of the greater cost disparities. Ideally, Mexico should be more responsive than Asian locations to serve the US market. Several product sectors, for example, automobiles and auto parts, have developed successful export businesses. However, Mexico is much less established for commodity-level purchased products like footwear (Gantz, 1999; Kumar et al., 2009). In contrast, the PRD has become the world’s largest manufacturing base of a variety of commodity-level purchased products. Industrial clustering offers non-cost advantages to make it a choice location of fashion items (HKTDC, 2010).
The above sensitivity analysis demonstrates that optimal supply chain design is not always obvious for dispersed manufacturing. Supply chain strategies have primary influence on optimal facility location decisions. Production cost parameters have significant impacts on optimal manufacturing location decisions of labor-intensive products that employ an efficient supply chain strategy. However, production and transportation LT parameters are more important to time-sensitive products that pursue a responsive supply chain strategy. Coastal China and Asian lower-cost countries have distinctive advantages to support a responsive and a cost-efficient supply chain respectively, while inland China strikes a good balance between the two. Furthermore, supply chain re-engineering may be required every few years due to ever-changing business environments (Christopher et al., 2011). This proves the value of the bi-objective model as an advanced analytical tool for the supply chain design of dispersed manufacturing.

6. Discussion

Previous studies of Chinese manufacturers suggested that their competitiveness were derived from marketing and human resource competencies (Li, 2000), manufacturing control (Li, 2005), favourable foreign exchange rate, cheap labor (Adams et al., 2006), and supply chain collaboration (Li, 2012). This research sheds new light to offer explanations why China’s manufacturing sector has been growing fast in the past three decades. It also suggests future trends of manufacturing growth in China in a changing business environment.

Dispersed manufacturing is a widely adopted practice that has facilitated rapid manufacturing growth in China. A key enabler of the practice is the rapid advancement of information technologies in the past few decades. Dispersed manufacturing allows a supply chain to take advantage of comparative advantages of multiple locations. As illustrated in the case study, these comparative advantages may be derived from low labor cost, a developed transportation infrastructure and industrial clustering. Optimal supply chain design of dispersed manufacturing is highly sensitive to business environment changes. It is thus necessary to re-evaluate the supply chain design of dispersed manufacturing when they are major changes in regional and global business environments.

Trade-offs between supply chain efficiency and responsiveness affect the supply chain design of dispersed manufacturing. Dispersed manufacturing can be very effective to facilitate low cost production by locating labor-intensive manufacturing steps at low cost regions. However, it also lengthens the supply chain due to the geographical dispersion of involved facilities. For products that have highly unpredictable demands and require short order lead times, it is preferable to organize manufacturing at one location that has well established industrial clusters and efficient logistics services.

Dispersed manufacturing has allowed China to participate in global supply chains to realize its labor cost advantage and rise as the “Factory of the World”. Besides low labor cost, favourable Chinese currency policies have also contributed to the exponential manufacturing growth in China. As demonstrated in sensitivity analysis, RMB exchange rate is very influential on manufacturing location decisions. Before China allowed RMB to appreciate in July 2005, a favourable RMB exchange rate pegged to the USD had granted manufacturers in China a considerable cost advantage. Although not as influential as RMB exchange rate, export VAT rebate is another policy factor that has benefited manufacturing growth in China.

In recent years, there are emerging trends of relocating global manufacturing activities away from coastal China because of its rapidly rising business operating costs. However, it does not mean that manufacturing growth in China will stop or slow down. It is true that a portion of manufacturing activities have moved to lower-cost Asian countries, as reflected in the “China plus one” strategy (Trunick, 2008). However, such a relocation decision is only valid for labor-intensive products that have a stable demand and compete mainly on cost. From the viewpoint of supply chain strategy, most manufacturers nowadays pursue both supply chain efficiency and responsiveness (Selldin and Olha, 2007; Sonia and Damien, 2010). The cost disparities between inland and coastal China creates an advantage to organize dispersed manufacturing within China. Supply chain responsiveness can be largely preserved by performing less labor-intensive manufacturing steps in coastal China to take advantage of its industrial clusters and efficient logistics services. Labor-intensive manufacturing steps can move to inland China to reduce total production costs substantially, and it only causes marginal increases in logistics costs and lead times.

China’s manufacturing sector is likely to continue to expand although the growth pattern may change. Inland China has great potentials to become the new engine of manufacturing growth, while coastal China is upgrading itself towards the manufacturing of high-value and time-sensitive products. In fact, the emerging trends can be observed in Li & Fung’s recent move to shift its sourcing focus from coastal to inland China. The sourcing giant is optimistic about the continual manufacturing growth in China because of its scale and fairly established
transportation infrastructure (Kwok, 2010). Another example is the relocation of some iPhone® and iPad® manufacturing activities away from coastal China in and around the year 2011. Apple Ltd. and its contract manufacturer Foxconn chose inland Chinese cities instead of lower-cost Asian countries. Industrial clustering and fairly developed transport infrastructure in China played a key part to retain the production of iPhone® and iPad® as they are innovative products and demand a responsive supply chain.

In summary, patterns and reasons of manufacturing growth in China have been changing. Low labor cost, favourable Chinese currency policies and VAT policies had played a pivotal role to support manufacturing growth in China before mid-2000s. Over the years, China has established strong industrial clusters in many product sectors and has greatly improved its transport infrastructures. It has also nurtured a large pool of workers who are highly productive and proficient with labor-intensive manufacturing activities. As a result, China’s manufacturing sector is no longer as dependent on low cost factors as it was. The wide practice of dispersed manufacturing allows Chinese manufacturers to take advantage of the cost disparities of inland and coastal China. Inland China is emerging as the new engine of manufacturing growth in China. Coastal China is still a choice location for the manufacturing of time-sensitive products because of industrial clustering and efficient logistics services.

7. Conclusions

This paper deals with supply chain design of dispersed manufacturing in China under changing business environments. Dispersed manufacturing dissects the supply chain to assign each process to an optimal location to achieve the greatest cumulative competitive advantage. It has been an integral part of global manufacturing in China as the nation rises as the “Factory of the World”. Supply chain design of dispersed manufacturing is a challenging task, because it needs to consider essential trade-offs between supply chain efficiency and responsiveness. Optimal supply chain design also needs to be reviewed when there are major changes in global and regional business environments. This paper presents a bi-objective model for the supply chain design of dispersed manufacturing. It incorporates major business environment variables that have been impacting the landscape of global manufacturing in China in recent years. The bi-objective model is then applied for a case study to illustrate the benefits of dispersed manufacturing. It provides explanations of business environment variables that have benefited manufacturing growth in China. It also offers managerial insights on the emerging global manufacturing trends.

This paper makes several key contributions. First, it studies the supply chain design of global manufacturing in China in the context of dispersed manufacturing. Existing studies on manufacturing in China assumed all manufacturing steps of a product are performed at a single facility location. Second, it develops a bi-objective model for the supply chain design of dispersed manufacturing. Both supply chain cost and lead time are considered for the optimal location decisions of three production stages, namely component manufacturing, subassembly manufacturing and end-product manufacturing. Third, the bi-objective model is applied for a case study of manufacturing in coastal China amid rising business operating costs. The model application shows that supply chain strategies have primary influence on optimal facility location decisions. Fourth, the modeling results illustrate the cost benefits of dispersed manufacturing, and suggest significant impacts of business environment variables. Besides low labor cost, favorable Chinese currency policies and VAT policies have helped China to grow its manufacturing industries in the past few decades. Last but not least, it offers insights on the emerging global manufacturing trends in China. As business operating costs rise rapidly in coastal China, labor-intensive manufacturing steps are likely to move away, but time-sensitive production may stay because of its efficient logistics services and industrial clustering. It strikes a good balance between supply chain efficiency and responsiveness to relocate labor-intensive manufacturing steps to inland China and retain other manufacturing steps in coastal China.

The work presented in this paper is probably first of its kind in the area of supply chain design of dispersed manufacturing in China. It will be beneficial to conduct further experimentations for different product sectors and extend the bi-objective model for a multiple-product case. Capacity constraints could also be added. In addition, the model could be extended to incorporate stochastic elements to consider risk factors that exist in global supply chains.

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References


HKTDC, 2007. Cost escalation and trends for export price increase - a look at the rising production costs in the PRD. Hong Kong: Hong Kong Trade Development Council.

HKTDC, 2008. The changing business model of trading companies in Hong Kong. Hong Kong: Hong Kong Trade Development Council.


