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

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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.
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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; HKTDC, 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

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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, 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, 2011a; Kumar et al., 2011; Li et al., 2011; Ma et al., 2011; Xu, 2011a, 2011b; 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 et al., 2011; Li and Warfield, 2011).

The subject of manufacturing supply chain design 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

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