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A multi-echelon multi-product stochastic model to supply chain of small-and-medium enterprises in industrial clusters

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ABSTRACT

An Industrial Cluster (IC) is a set of similar and interrelated firms in a specific field situated in a geographic concentration to share joint resources. To date, the interrelations between ICs and Supply Chain Management (SCM) have been improperly mathematically studied, despite their inherent relationship. In this paper, a Supply-Demand Hub in Industrial Clusters (SDHIC) as a specific common provider of warehousing and logistics activities managed by a third-party logistics provider (3PL) is proposed to minimize the total cost of the considered supply chain. Activities of businesses in IC is modeled thorough a two-stage stochastic programming model followed by an acceleration techniques for the Benders decomposition. The numerical experiments comprising sensitivity analysis are conducted over a case study to show the attractiveness of the proposed model. Some managerial insights are presented based on the obtained results.

1. Introduction

The term Industrial Cluster (IC), also known as business cluster, i.e., linkage of interrelated, geographically adjacent companies operating together within the same commercial segment which enjoy unusual competitive success in their field, was introduced and popularized by Michael Porter in The Competitive Advantage of Nations (Porter, 1990). According to Porter (1998), comparative benefit is less related in modern economy, while competitive benefit is now more important. Porter (1998) also specified that the economic map of the world is conquered by ICs at the present time. Based on comparative advantages, there are several types of ICs including high-tech, historic know-how-based, factor endowment clusters, low-cost manufacturing clusters, etc. Among different ICs, the clusters with high technology such as Silicon Valley (Saxenian, 1994) are well adjusted to the knowledge economy and usually play a key role in this area as a research centers. The activities of companies within ICs rely on confident local specificities like accessibility of natural resources, centers of technological development, etc. (Pedro, Hélcio, & Márcio, 2011). Owing to the proximity of entities within an IC by geography and activities, cluster ingredients take pleasure in the economic advantages of their adjacency (Shakya, 2009). Firms working in an IC profit of scale without handling the inflexibilities of official links and vertical integration.

One of the main objectives of an IC like supply chain management (SCM) is to connection echelons of a SC for effective flow of information, material and finance. DeWitt, Giunipero, and Melton (2006) illustrated the connection between SCM and Porter's cluster theory, and showed indication of their possible joint positive influence on organization performance and competitiveness. The combination of these two concepts can efficiently enhance the competitive benefit of industries with the intention of improving regional economic competitiveness. In some countries like Italy, the USA, India and Germany, the growth of ICs plays a remarkable role in feeding the development of their productivity and honing their capabilities in order to compete effectually in the global zone (Antoldi, 2006; DeWitt et al., 2006). Today, the small-and-medium enterprises (SMEs) play a crucial and significant role specifically in the financial side of developing countries throughout the world. In fact, the SMEs are the key driving force for innovation, economic growth and employment opportunities, specifically in the economies of Asian Pacific area.

Since there are several reasons it might be problematic for SMEs to satisfy their customers' demands/requirements with high-quality and low price, it might be better economically to move some or all of their activities to a location with low utility costs, wages and taxes, owing to globalization and simplicity in communication and transportation. In recent years, the organizations would like to outsource their logistics activities to an expert firm like a third-party logistics providers (3PL) which are able to accomplish a range of tasks from warehousing, inventory management, transportation of inventories, handling, freight consolidation, inventory distribution, selecting transportation mode, information management, etc. (Kim, Yang, & Kim, 2008). One of the

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obstacles encountered by SMEs in the Malaysia, for example, is absence of external canals of distribution (Zain, Khalili, & Mokhtar, 2007). So, a desirable and skilled logistic activities like extending distribution canals (Gill & Allerheiligen, 1996), distribution planning (Waller, 1995) as well as delivery service (Kallio, Saarinen, Tinnilä, & Vepsäläinen, 2000) for enterprises is vital.

The lack of land to make warehouses in ICs is provoking together with the quick growth of manufacturing scales and land prices. Worries of gaining lands is one of the biggest obstacles in the extra growth of ICs (Chen, 2006). Consequently, finding appropriate approaches to enhance the land utilization within industrial clusters is vital. To deal with such a difficulty, the Supply-Demand Hub in Industrial Clusters (SDHIC) as a common special warehouse providing warehousing and logistics services is proposed in this research. The concept of SDHIC is taken from supply hub in industrial park (SHIP) (Qiu & Huang, 2013a) and the SHIP thought is inspired from 'supply hub' proposed by Barnes, Dai, Deng, Down, and Goh (2000). Barnes et al. (2000) discussed about the advantages and disadvantages of using supply hub. In this regard, Kayvanfar, Husseini, Karimi, Sajadieh, and Jun (2016) analyzed and described supply hub in industrial cluster as the basis form of SDHIC. Also, recently, Kayvanfar, Husseini, NengSheng, Karimi, and Sajadieh (in press) optimized the interactions of entities in IC using SDHIC in deterministic condition. They suggested three mathematical models by using (1) SDHIC, (2) supply hub and (3) without any hub (classic model). They then compared the proposed models to demonstrate the usefulness of employing SDHIC. Finally, they proposed some managerial insights based on conducted sensitivity analysis.

Obviously, any SC comprising several business entities has a high degree of uncertainty due to its real world characteristics and such uncertainty is the main reason that affects the coordination and configuration of SC. Stochastic programming is a well-known modeling framework for optimization problems dealing with uncertainty, especially for the real-world optimization problems. The two-stage stochastic program with recourse is mentioned as a general-purpose method to deal with uncertainty in the model parameters.

Despite displaying such a significance, one can scarcely discover quantitative modeling approaches in the literature on the integration of ICs and SCM as well as connections of businesses within an IC, up to now, especially in uncertain situations. In other words, the optimization of ICs' activities is insufficiently surveyed up to now and in this research an endeavor is made to cover such an important gap in real-world condition. In this research, we study the two-stage stochastic programming problems with integer and binary first-stage and continuous second-stage decision variables with the aim of minimizing the logistics costs, i.e., transportation and ordering costs, and the expected future logistics costs comprising inventory holding and shortage costs (backorder and lost sales). The considered uncertainties in this study comprise "demand of customers", "production capacity of manufacturers" and "supply capacity of suppliers" in each period which altogether lead to system uncertainty.

The rest of the paper is organized as follows. Section 2 reviews the related literature. Section 3 explains the details of SDHIC. Section 4 describes the considered two-stage stochastic problem including assumptions, the proposed mathematical model. A solution applying Benders decomposition (BD) algorithm and acceleration techniques is presented in Section 5. Section 6 illustrates the experimental outcomes in terms of a case study. Finally, Section 7 states conclusions and future works.

2. Literature review

Porter (1998) summarized that clusters largely have impact on competition and make competitive benefits in three ways: (1) by growing the efficiency of organizations based in the IC; (2) by driving the direction and innovation pace that reinforces the growth of future productivity; (3) by motivating the creation of new companies, which reinforces and expands the cluster, creating a positive response. Kuah (2002) discussed about clusters' advantageous for SMEs in detail including costs and benefits analysis of locating in an IC from two different perspectives: demand side and supply side. Bayraktar et al. (2010) compared the relationship of SCM and information system (IS) practices of SMEs working in food products and beverages in Turkey and Bulgaria. The analysis of Bulgarian SMEs determined that they put more importance on managing most of the SCM activities so as to improve their efficiency. Yusuf et al. (2014) considered the competitiveness, agility and performance of IC members over non-members in the oil and gas SC. Their results showed that ICs improve and enable higher levels of agile practices. Giannoccaro (2015) studied the relevancy of learning and adaptation in SC positioned in ICs, with the goal of determining the best adaptive SC. He carried out this research owing to growing attention which the design of adaptive SCs has been receiving in recent years. Banasik, Kanellopoulos, Claassen, Bloemhof-Ruwaard, and van der Vorst (2017) studied the results of closing loops in a SC of mushroom cluster and proposed a multi-objective model so as to establish trade-off between environmental and economic factors and investigate alternative recycling skills in a quantitative manner.

Shah and Goh (2006) suggested structured hierarchical model for the inventory management based on the supply hub to help in achieving balance between different entities involved in a chain. Several other researchers (Li, Ma, Guo, & Zuo, 2008; Li et al., 2009; Wang, Zhu, & Yang, 2010) demonstrated the advantages of using the supply hub. Trappey, Trappey, Lin, Liu, and Lee (2007) proposed an integrated business and logistics hub (IBLH) model integrating information flows and material flows with the goal of shortening SC processes and inventory costs. Li, Zhang, and Jin (2013) studied two-stage SC optimization coordination and applied queuing theory as well as basic inventory strategy. They also used supply-hub operation mode for assembly manufacturing companies in their study. Qiu and Huang (2013b) investigated that how manufacturers and SHIP cooperate to optimize their logistics activity such as making decision for replenishment. They then proposed a bi-level model to address the mentioned problem. Qiu, Luo, Xu, Zhong, and Huang (2015) presented an Internet-of-Things (IoT) enabled supply hub in industrial park or SHIP for boosting the effectiveness of sharing physical belongings besides presented services. Qiu and Huang (2016) studied about the interactive decision making problem between SHIP and its member companies for sharing of transportation services. They used a bi-level approach to model their problem. Their consequences demonstrated that SHIP's advantage does not continuously increase with the capacity of vehicles. Kayvanfar, Husseini, Karimi, and Sajadieh (2017) investigated supply chain of SMEs in an IC using SDHIC in terms of bi-objective mathematical model in deterministic condition to minimize total cost of this supply chain. The multi-objective version of intelligent water drops algorithm (MOIWD) was developed to solve this model. Moreover, they employed two other multi-objective meta-heuristic algorithms, named non-dominated ranking genetic algorithm (NRGA) and reference-point based non-dominated sorting genetic algorithm III (NSGA-III). The comparative results revealed that MOIWD dominated NRGA and NSGAIII in terms of both convergence and diversification criteria.

Stochastic problems have been developed in extensive applications. Alonso-Ayuso, Escudero, Garín, Ortuño, and Pérez (2003) presented a two-stage stochastic model for handling the uncertainty in supply chain with the aim of specifying the plant size, production topology, selection of products, product designation among factories and finally vendor selection for purchasing raw materials. Lodree, Jang, and Klein (2004) studied minimizing customer response time in a two-stage stochastic area with uncertainty in demand with the goal of minimizing related costs to production, shortage and inventory holding. Santoso, Ahmed, Goetschalckx, and Shapiro (2005) presented a stochastic approach including solution procedure to solve supply chain network design