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Bi-objective intelligent water drops algorithm to a practical multi-echelon supply chain optimization problem

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ABSTRACT

Industrial Clusters (ICs) are defined as geographically adjacent interconnected companies working together within the same commercial section which enjoy unusual competitive success in their field. The relationships between Supply Chain Management (SCM) and ICs have been imperfectly mathematically investigated, in spite of their intrinsic correlation. To bridge this gap, a bi-objective multi-echelon supply-distribution model is firstly proposed in this paper to optimize collaborations of different echelons. The considered problem is then solved using a recently introduced metaheuristic algorithm, the intelligent water drops (IWD) algorithm in terms of a multi-objective approach. The IWD is then compared with two well-known algorithms, reference-point based non-dominated sorting genetic algorithm (NSGA-III) and non-dominated ranking genetic algorithm (NRGA). The two considered objectives are 1) minimizing the total incurred logistics costs, and 2) maximizing the service level of customers. The small-and-medium sized enterprises (SMEs) positioned in IC as manufacturers profit from using a 3PL-managed supply-demand hub in industrial cluster (SDHIC) as a public provider of warehousing and logistics services. The validity of the proposed approach is illustrated through experimental results including comprehensive statistical analysis on the three used measurement metrics.

1. Introduction

Porter [1] proposed that the economic map of the world is nowadays dominated by clusters, or linkage of interconnected, geographically adjacent businesses operating together within the same commercial segment which enjoy unusual competitive success in their field. The activities of entities within industrial clusters (IC) depend on certain local specificities such as availability of natural resources etc. [2]. Cluster ingredients profit from the economic advantages of several location-specific externalities and synergies, because of the closeness of organizations located in an IC [3]. One of the main objectives of an IC like supply chain management (SCM) is to join stages of a supply chain for effective flow of information, material and finance. Working enterprises, specifically small-and-medium enterprises (SMEs) in a cluster, they yield of scale without dealing with the inflexibilities of vertical integration or formal connections. 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 [4–7]. The SMEs have played and still play an essential and central role in the economics of developing countries all around the globe. 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. Within an IC, the firms could be supported SCM through integrating processes and making long-term relationships among cluster enterprises involved in the flow of services and products from the beginning to the end-users [8]. Information systems and trust in relationships within an IC help to decrease the transaction costs of the supply chain and boost the competitiveness of SMEs within the cluster.

In recent decades, organizations prefer to outsource their logistics activities to an expert firm like a third-party logistics provider (3PL). The 3PLs can accomplish a range of tasks from warehousing, inventory management, transportation of inventories, handling, freight consolidation, inventory distribution, selecting transportation mode, international transport management, border management, information management, etc. [9]. For instance, one

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of the problems faced by SMEs in Malaysia is lack of foreign channels of distribution [10], but having a good and capable logistic activity such as developing channel distribution [11], distribution planning [12] and delivery process [13] for enterprises is vital. In developing countries, many SMEs have insufficient data about channels of marketing and therefore fail to establish marketing networks. Zain et al. [10] conducted a research in which 97 SMEs were selected in Malaysia and the main problems of these SMEs were investigated. Their conclusion showed that "lack of foreign channels of distribution" is one of the five main problems faced by SMEs in Malaysia. To handle the above-mentioned difficulties, the SMEs outsource their logistics activities through a 3PL which mitigates the risk and financial burden.

The shortage of land resources for building warehouses in ICs together with the quick growth of production scales and land prices is provoking. Concerns of land acquisition have been regarded as one of the greatest obstacles in the further growth of industrial clusters [14]. Therefore, finding proper approaches to boost the land utilization within ICs is vital. To deal with such a problem, the Supply-Demand Hub in Industrial Clusters (SDHIC) as a public warehouse providing warehousing and logistics services is proposed in this research, where its concept is inspired from supply hub in industrial park (SHIP) [15]. The SHIP is concept extended from supply hub, which is adopted by many electronic manufacturers to overcome the shrinking of production life cycles and to attain cost reduction as well as higher-quality responsiveness.

Some of the advantage of using SDHIC are: 1) it leads to Just-in-Time (JIT) procurement, owing to regular deliveries to the SMEs and trivial distance between SDHIC and SMEs/manufacturers; 2) land utilization via integrating the warehouses of manufacturers and diminishing demand variances (storage capacity of pooling effect); 3) risk pooling and mitigation for SMEs (demand fluctuations have effects on the required storage space, but by applying SDHIC, the SMEs should pay for the hired holding space and associated services they use; 4) information sharing both vertically, between entities of different echelons such as SMEs and the suppliers, and horizontally, between any two enterprise in the same level of supply chain; 5) delivery of shipments in a low-priced way, due to freight consolidation and economy of scale; 6) saving costs of supply chain comprising manufacturers/SMEs owing to decreasing inventory level and enhancing inventory management; 7) lessening of capital investment, because of hiring holding space from SDHIC instead of holding inventories at the warehouses of manufacturers/SMEs; 8) relaxing the manufacturers' need for resources like equipment, inventory holding space, labor, etc., focus on core competencies.

In the considered problem in this research, since the adjacent manufacturers have no private warehouses, all necessary raw materials for and products made by manufacturers/SMEs are stocked at SDHIC. Since the capacity of SDHIC is limited, raw materials and finished products compete with each other for getting more storage space. Once an order is received by SMEs, a copy is simultaneously sent to 3PL to facilitate cooperation. The 3PL serves logistically to all manufacturers either for transporting or holding their inventories. Based on the received demand and set production schedule, the needed raw materials are brought by the 3PL's vehicles from suppliers and then stocked at SDHIC before being consumed. Each supplier supplies only one type of raw material and each manufacturer produces only one type of finished product. Also, each supplier and manufacturer has a limited capacity for supplying the ordered raw materials and producing the products, respectively. Once the finished products are produced, 3PL sends its vehicles to SMEs to collect the products to be stored at SDHIC before being dispatched to the customers. Since the ordered demand by customers might not be satisfied, shortage is allowed and backlogged, however it is assumed that all backordered demands must be satisfied in the last period. The shortage could be occurred due to the constrained storage capacity of SDHIC. Fig. 1 depicts the above-described interactions of entities in such a supply chain.

Of the main characteristics of this type of ICs, one can say that this IC well fits into those industries which has the short product life cycles (PLCs) such as electronics industries, high-tech industries, and those industries with perishable products. Since perishable goods should be delivered to customers as soon as possible and this matter necessitates to have the short lead times and short response time. Also, this type of IC is appropriate for pull strategy with low level of stock (owing to expensiveness of products) which is one of inherent features of high-tech industries.

One of our main contributions in this study is simultaneously optimizing the supply and demand sides of supply chain in a shared center. In better words, the proposed hub in this study (SDHIC) plays an important and specific role in holding balance between supply and demand sides in supply chain. Actually, we merged supply hub (raw materials section) and demand hub (finished products section) into one consolidated hub called SDHIC. By doing so, a competition/portioning between raw materials and finished products occurs. This competition creates a bottleneck in supply chain in which reduction or increment in any side (supply or demand) causes an increment or decrease in other side and above that, it makes effect on different parameters of supply chain; from production rate and transportation costs, to holding costs of inventories, etc. Technically speaking, this assumption makes the proposed approach real and attractive, since the total costs of supply chain could be decreased by holding balance between supply and demand sides (through a central decision making). This is considered for the first time in the literature which increases attraction of the proposed approach.

In this paper, a new swarm-based nature-inspired optimization method, called intelligent water drops (IWD), is developed in a bi-objective approach on such a multi-echelon supply chain problem. The goal of this research is simultaneously to optimize two objectives: 1) minimizing total incurred logistics costs including ordering cost, inventory holding cost and transporting cost, and 2) maximizing the total service level of customers.

The main contributions of this research could be listed as follows:

- Proposing an applied mathematical supply-distribution model for ICs using a 3PL-managed public warehouse called SDHIC.
- Applying multi-objective IWD algorithm to a supply chain problem.
- Covering some of the present substantial gaps in current research in this area by making real-world assumptions.
- Optimizing the collaborations of suppliers, SMEs and customers in such a supply-distribution chain under the umbrella of an IC.
- Enhancing the customers' satisfaction by maximizing the service level criteria and minimizing the total incurred logistics costs to the whole supply chain through optimum usage of lands, facilities, labors, etc.
- Showing the synergic results of using 3PL in an IC to accomplish the logistics activities of SMEs including warehousing, inventory management, transportation of inventories, etc.
- Demonstrating the validity of the proposed approach through comprehensive crucial statistical analysis.

The rest of this paper is organized as follows: Section 2 describes the literature review. In Section 3, the proposed mathematical model in a bi-objective approach is presented. Section 4 explains adopted solution approach including the details. Experimental results including parameter tuning and comprehensive statistical analysis are demonstrated in Section 5. Conclusions and future studies are finally stated in Section 6.