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Optimal supply chain network design with process network and BOM under uncertainties: A case study in toothbrush industry ☆

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ABSTRACT

Design of supply chain network significantly affects supply chain performance for long period. Since each industry has a unique set of characteristics which evidently drive the design supply chain network, a number of various models have been formulated to meet the needs of such business contexts. Even though many models have been proposed for manufacturing industry context, most of them are based on the facility location model. It tends to lead the supply chain network design model to be complicated. Therefore, the purpose of this research is to propose an alternative approach to formulate manufacturing network design problem. Features, such as multi-echelon, multi-commodity, products structure, and manufacturing process, are taken into consideration as characteristics of the studied environment. Moreover, uncertainty factors are also integrated to the model by employing possibilistic theory. Eventually in addition to the methodology, a case study in a consumer product firm is used to demonstrate applicability of the proposed method. Two models, deterministic and fuzzy models, have been explored in the study and both of them have demonstrated the validity of the proposed formulation method. Moreover, it is shown that the fuzzy model has outperformed its deterministic counterpart in term of cost effectiveness.

1. Introduction

Under tough pressure of competition on global playground and high expectation from customer nowadays, businesses are pushed to pay more investment and focus on managing their supply chains effectively. A supply chain is a network of facilities and streams of commodities that flow among them. Those facilities are composed of suppliers, manufacturing plants, warehouses, distribution centers, and retail premises, while commodities comprise raw materials, work-in-process, and finished goods. Supply chain management (SCM) defined by Simchi-Levi, Kaminsky, and Simchi-Levi (2007) as "a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and the right time, in order to minimize systemwide costs while satisfying service level requirements". By this definition, it is indicated that SCM involves activities at many levels ranging from strategic through tactical to operational within a business. Chopra and Meindl (2007) described that strategic level aims at determining the optimal structure or design of supply chain network. The addressed decisions are about number, location, and size of warehouses and/or plants as well as the connections among them. Both Watson, Lewis, Cacioppi, and Jayaraman (2012) and Simchi-Levi et al. (2007) demonstrated that such decisions at this level have a high impact on supply chain performance since they are expensive and difficult to be changed. It is discussed that roughly 80% of supply chain expenses are trapped in its facilities which is equivalent to that of the cost kept in a product design. As a result, strategic network planning or supply chain network design (SCND) has drawn much attention from management and has required extensive research.

In different industrial contexts, Vila, Martel, and Beauregard (2006) argued that nature of SCND problem has changed significantly. In retail or distribution context, the main concerns are the movement of products and locations of facilities because flows from origin to destination are identical. On the other hand, the stream is no longer uniform in the context of manufacturing because most of the products are not simply collected and transported. Instead, there are series of transformation activities which are performed among production facilities to convert materials into a particular product. Each product has its own recipe of materials and set of desired production stages. The recipe of materials involves in

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supply side sourcing decisions, while the set of desired production stages associates with capital decisions and configuration of the network. Therefore, it is necessary to address impacts from not only movement of goods and locations but production processes and product architectures in manufacturing-related-network design problem.

Melo, Nickel, and da Gama (2009) accomplished a thorough review on development of optimization models which support supply chain management. They revealed many studies that are related to manufacturing context. Most of those research works had been developed and formulated based on classical facility location models which are centered on facility decision. However, this approach makes the models become more complicated.

The objectives of this paper are as follows.

1. To develop a new approach for SCND that utilizes a combination of process network and bill of materials (BOM) which is more efficient than the classical facility location approach.
2. To demonstrate an effective application of the approach using a real case study of toothbrush supply chain.
3. To point out the benefits of optimal supply chain design under fuzzy scenarios over that under deterministic scenario.

Although this paper aims to develop the approach and mathematical models to handle SCND problem of a real toothbrush supply chain, the proposed approach and models are general enough to be applied with other industries with similar characteristics. Thus, it is useful to clarify the characteristics of interest of the SCND problem. The characteristics of the SCND problem under consideration are summarized as follows.

1. The supply chain network produces multiple products which can be divided into product families.
2. The supply chain network has multiple echelons which mean that the production facilities have many production stages. The product families have multi-level product structures or bill of materials (BOM).
3. There are worldwide customers that have different demands of product families. Moreover, it is difficult to forecast the demands accurately since the business condition in the future is uncertain. However, it is possible to forecast the demand under most likely, pessimistic and optimistic business conditions.
4. There are worldwide suppliers which offer different unit cost for purchased parts. Since they have different locations, the costs of transportation to the production facilities are also different.
5. There are some related costs that are difficult to be estimated accurately as a crisp value, for example, the annualized cost of opening the location, annualized cost of setting up the facilities to have the required production capacity, and unit production cost. Nevertheless, these costs can be estimated as fuzzy numbers representing the costs under most likely, pessimistic, and optimistic situations.
6. It involves some strategic decisions for selection of production technologies, locations and capacity levels of facilities. In this case the decisions must be made at current time only once (single period model). However, the concept can be extended to be a multi-period model.
7. The objective of the decision is to minimize total cost of the supply chain which also include the shortage cost in case that the demand is not completely satisfied, instead of maximize the total profit since the revenue is greatly affected by marketing promotion policy which is short term in nature and cannot be included in the strategic nature of SCND problem.

This paper is organized as follows. The review of related past works is presented in the next section to clarify how this paper is related to past works. In Section 3, the conceptual design of the proposed approach and its associated mathematical models are explained. Then, the information of the case study and experimental design are explained. Results are presented and discussed in Section 4. Finally, conclusions are drawn and further studies are proposed.

2. Literature review

Supply chain network is defined as a set of facilities such as suppliers, plants, distribution centers, and customers. All of them are linked by transportation routes carrying raw material, semi-finished goods, and finished products. With increasing competition and market uncertainty on global basis, supply chain management (SCM) is getting more and more attention from many companies around the world as a key competitive capability. Based on the length of time horizon, SCM decision levels has been divided into strategic, tactical, and operational levels. Strategic decisions have a long term effect on supply chain performance, since they involve determining number, location and capacities of various types of facilities, or the flow of material in the system. Such decisions require a large sum of capital investment, which is difficult to recover once it is allocated. Also, those facilities tend to stay in operation for extended periods of time from now which makes them vulnerable to be affected by external factors. Any change which occurs during their life-time may turn a selected site from a good choice to an undesirable one. Consequently, strategic supply chain planning has become the most important part of SCM. It is the reason that this topic gains much attention from academic researchers. The intention of this section is to review studies in supply chain network design, especially in manufacturing area. At first, the relationship between strategic SCM problem and facility location problem (FLP) has been outlined. Secondly, basic extensions of FLP which were conducted to handle the strategic SCM problem are examined. After that, special extensions for manufacturing sector have been discussed. Finally, conclusion is drawn from the review to provide supports for the proposed research.

Currently, terms such as *network design*, and *supply chain network design* (SCND) are often used, in most cases, as strategic SCM. As SCND is concerned with optimal number, location, and size of warehouses and/or plants, it is apparent to recognize the connection between network design and FLP in which locations are considered to be selected from a limited set of potential candidates in order to satisfy customers. If it is the case that setup cost is not different among all sites, the problem is defined as p-median problem with the objective of minimizing total travel distance or cost of meeting customers requirements. Otherwise, it may be considered as uncapacited facility location problem (UFLP). On the other hand, when capacity is known in advance, UFLP is renamed as capacitated facility location problem (CFLP). All above models have shared common characteristics that are single period, deterministic parameters, single product, mono type of facility, and location-allocation decisions. The FLP has provided a solid foundation for developing SCND models. However, the FLP models contain only a fundamental decision, location-allocation, and features which do not reflect complicated relationship involving different kinds of decision and advanced characteristics. Therefore, many extensions should be included to cope with complicated circumstances.

In practical networks as defined above, there exist many types of facility which play various roles in the network such as supplier, plant, and warehouse. Each facility has been grouped into sets, called