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Hierarchical clustering for structuring supply chain network in case of product variety

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ABSTRACT

To compete in the market, manufacturers often need to offer multiple product variants to different customers. Given such a challenge of product variety to supply chain, the postponement strategy has been adapted that the differentiating modules are handled at the later stage of the process to minimize the impacts from demand variations. Given the information of product variants and their mix ratios, this paper focuses on the problem of structuring supply chain network that indicates the precedence orders of suppliers and sub-assemblers. The solution approach is based on hierarchical clustering, in which the tree structure is applied to construct the supply chain network. One core technique is to investigate the coupling values between the modules by characterizing the grouping condition in the structuring process. A complexity measure is also adopted to compare the quality of resulting supply chain networks. Five numerical examples are utilized to demonstrate the applicability and effectiveness of the proposed clustering method.

1. Introduction

Offering product variety to satisfy a broad range of customers has been the essence of today's manufacturing. For example, BMW claims that "every vehicle that rolls of the belt is unique" and the number of possible variations in BMW 7 series could reach 10^{17} [1]. Therefore, it is a challenging task to design a production system and supply chain to handle such high variety while maintaining quality and productivity at the same time. In order to cope with the challenges caused by product variety, manufacturers implement modular design [2], in which a product is decomposed into different functional modules, and the variety is achieved by offering several options for each module. A wide range of product variants can then be synthesized by combinational assembly of different modules.

Powered by modular product architecture, nowadays manufacturing activities become more spatially dispersed. As a result, manufacturers do not have to perform all manufacturing steps by themselves in a single facility location. Instead, some of the manufacturing and assembly processes can be assigned to suppliers, and the final assembler receives few sub-assemblies for further processing and producing the finished products [3]. Examples can be found in various industries like automobile and personal computers where customers are offered a variety of product options within a short delivery time. For instance, Volvo S80 model has 17 pre-assembled units that 11 of which are operated by suppliers [2]. Assigning some of the assembly tasks to the suppliers allows manufacturers to exploit comparative advantages of different locations. However, it can dramatically increase the complexity of a supply chain system [3].

In order to tackle challenges due to high product variety in supply chain, manufacturers implement postponement strategy. Postponement strategy which is enabled by modular product design is one key for mass customization [4], and it can be used to increase supply chain responsiveness [5]. Based on the modular product structure, one essence of postponement is to delay the points of differentiation so that product variety is introduced at the later supply chain stage [6]. However, it is observed that the points of differentiation are often determined and fixed in supply chain analysis. For example, the problem of supply chain configuration is concerned with the selection of suppliers and processes "at each stage in the supply chain" [7, p. 1165], implying that supply chain stages are already fixed. In contrast, this paper aims to construct the "generic supply chain network", the term coined in [8], which concerns the precedence relations of suppliers and assemblers. From the standpoint of

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the final assembler, the generic supply chain network indicates whether some sub-systems should be acquired from outside as standard supplies or assembled in the factory. This is also relevant to the concepts of modular and non-modular supply chain [9,10] to be discussed in this paper.

In this paper, a methodical procedure is developed to construct the supply chain network in a way to support postponement and reduce the complexity of the network. The structuring problem specifically considers two pieces of product variety information: (1) the number of different types of product variants to be offered and (2) the demands of various product variants. Generally, if the number of variant types is small and most demands come from only few variants, the final assembler may choose to assemble most of the modules by themselves due to the economy of scale. Alternatively, if the number of variant types is high and most demands of different variants are generally dispersed, the final assembler may try to determine the modules that are required by most variants and assign them to the upstream suppliers. This approach is aligned with the concept of postponement that the final assembler can focus on product differentiation at later stages of supply chain network.

Considering this structuring problem, it has been observed that there is a similarity in the process of structuring supply chain network and hierarchical clustering as both try to bundle the elements in the multi-stage structuring process. Thus, this paper proposes hierarchical clustering as the numerical tool to facilitate the structuring process of supply chain network. The specific new concept of this paper is to formulate the coupling values based on the product variety information and construct the supply chain network accordingly.

The research results are relevant for supply chain managers who need to make decisions in different supply chain practices such as postponement, procurement policy and supplier selection. It offers managerial insights to enhance supply chain performance through considering postponement strategy in the structuring of supply chain network. Five sample cases are developed to demonstrate the applications of the proposed method on the decisions that should be made by supply chain managers in terms of postponement strategy as well as verifying the capability of the method to suggest a supply chain network with lower complexity.

The remaining part of this paper is organized as follows. Section 2 provides some background information and literature review on structuring supply chain network and its computational complexity. In Section 3, we describe the research problem along with the complexity model for a supply chain network. Section 4 establishes the methodical procedure for structuring supply chain network based on product variety information. Section 5 presents some numerical examples to show the application of the proposed method in supply chain practices. Finally, Section 6 provides some closing remarks and describes our future research direction.

2. Background and related works

2.1. Supply chain network and postponement

The performance of a supply chain network for a product family is determined by design decisions of products, assembly processes and supply chain. Supply chains are often modeled as multi-stage assemblies and inventory networks [8]. For example, Graves and Willems [7] developed a supply chain configuration optimization model that minimizes the total supply chain costs. However, they address the supply chain configuration problem in terms of selecting suppliers, processes and transportation modes for a supply chain network that has already been fixed. Similarly, Wong et al. [11] evaluated postponement as an option to improve the performance of the supply chain system for the soluble coffee. Their results show that significant cost saving can be achieved by considering postponement in supply chain network.

According to the literature of supply chain network, improvements have been suggested based on the current (or fixed) structure of the supply chain network. The supply chain networks are usually developed based on the knowledge and expertise of the experts (like the notebook supply chain in Graves and Willems [7]), and so far limited systematic methods have been proposed in literature about the structural construction of supply chain network. The most relevant work on structuring supply chain network can be found in Wang et al. [2]. In this work, they employ the concepts of information entropy and module-based product family architecture to structure assembly supply chain in order to minimize the complexity of the structure.

The structure of supply chain network is one key determinant of efficiency and complexity in a supply chain system. Nowadays, one important trend in supply chain management enabled by modular product design is the emergence of modular supply chain [9,10]. The concepts of modular supply chain and non-modular supply chain are illustrated in Fig. 1. In modular supply chain, final product apportions to sub-assemblies that are mostly outsourced to suppliers and therefore only few assembled modules will be delivered to the final assembler for the final assembly operation. Modular supply chain has many applications in automotive and aerospace industry [1]. In contrast, non-modular supply chain mainly represents the case of mass production where the economy of scale is more important. Also, the complexity of the whole network is usually lower in this case as fewer elements (e.g., suppliers and sub-assemblers) are engaged in the process.

The concept of postponement has a long history in terms of both practical applications and academic literature. While the practical application of the concept can be traced back to the 1920s, the early empirical descriptions of postponement appeared in 1960s [12]. In terms of literature, the postponement concept was established by Bucklin [13]. Postponement is also known as “delayed product

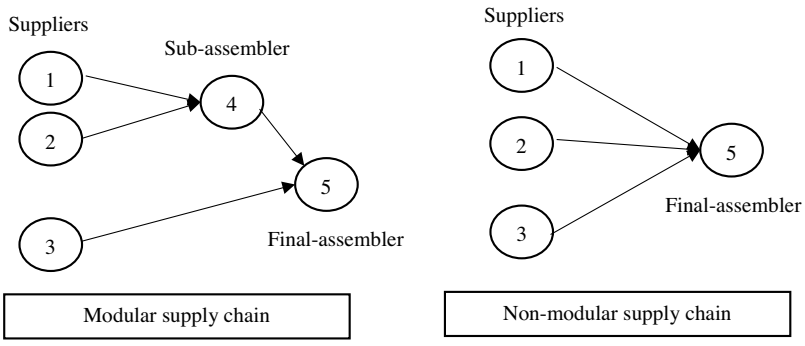

Fig. 1. Modular supply chain vs non-modular supply chain.