Journal of Manufacturing Systems xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Manufacturing Systems

journal homepage: www.elsevier.com/locate/jmansys

A graph-based cost model for supply chain reconfiguration

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ARTICLE INFO

Keywords:
Supply chain reconfiguration
Graph-based model
Manufacturing
Cost model
Optimization

ABSTRACT

The emergence and growth of globalization require manufacturing enterprises to reconfigure their manufacturing systems and supply chains quickly and cost-effectively in response to market changes. In this paper, a supply chain reconfiguration problem for manufacturing enterprise systems was investigated. An optimization model was formulated to minimize the total cost of the supply chain network with the consideration of manufacturing operations and reconfiguration cost. To effectively model the reconfiguration cost of the supply chain, a graph-based method was proposed to characterize the similarity between supply chain configurations and to establish the relationship between the similarity index and reconfiguration cost. A case study on a supply chain for laptop computer manufacturing was presented to illustrate the proposed method and demonstrate its effectiveness.

1. Introduction

In a global manufacturing environment, more and more products with shorter life cycles have been introduced to the market. In order to retain the core competence of manufacturing enterprise, its systems and supply chains should be altered in response to the changing product requirement. Reconfigurability is well-known as a character that can achieve this goal: it enables the manufacturing enterprise to respond rapidly and cost-effectively to the global market [1]. Therefore, it is imperative to incorporate reconfigurability in the design and operations of manufacturing systems as well as supply chains.

Since Koren et al. [2] introduced the concept of reconfigurable manufacturing systems, the study on the reconfiguration of manufacturing systems has been extensively investigated [3–5]. However, the reconfiguration of the supply chain is relatively unexplored in literature. The objective of supply chain reconfiguration is to strike a balance between the supply chain operating cost and reconfiguration cost, where the operating cost includes transportation cost, procurement cost, and manufacturing cost, while the latter consists of the cost of replacing certain suppliers, cost of changing the transportation network, and so on. The biggest challenge is to determine the supply chain reconfiguration strategy in an efficient manner. Thus, there has been a lot of research interest in developing reconfiguration strategies for supply chain systems for manufacturing enterprise systems in recent years.

Existing studies on supply chain systems for manufacturing mainly focused on developing new models for the supply chain systems, with a special concentration on modeling of dynamic cellular manufacturing systems. For example, Aalaei et al. [6] proposed a new mathematical model for integrating dynamic cellular manufacturing into supply chain system with an extensive coverage of important manufacturing features, considering multiple factors such as plant location, multi-markets allocation, multi-period planning horizons with demand and part mix variation, and machine capacity. Saxena et al. [7] proposed an integrated model of dynamic cellular manufacturing and supply chain design with consideration of various issues such as multi-plant locations, multiple markets, multi-time periods, reconfiguration, etc. to minimize the sum of various costs. Aalaei et al. [8] proposed a new mathematical model for integrating a cellular manufacturing system into supply chain design with labor assignment to minimize the total cost and developed a robust optimization approach to solve the proposed model. Besides, multi-agent modeling and systems dynamics modeling are also used in this research field. For example, Lee et al. [9] reviewed the development and use of multi-agent modeling techniques and simulations in the context of manufacturing systems and supply chain management.

In addition to developing new models, researchers have been devoted to investigating novel approaches to efficiently design manufacturing system and supply chain system concurrently. For example, Hu et al. [10] proposed a unified measure of system complexity to assist in designing systems with robust performances [10]. In [10], complexity is defined as an entropy function of product variety and new

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https://doi.org/10.1016/j.jmsy.2018.04.015
Received 1 December 2017; Received in revised form 1 March 2018; Accepted 15 March 2018
0278-6125/

Nomenclature

o	plant location, $o \in O$
i	supplier index, $i \in I$
j	resource index, $j = 1, 2, ..., J$
Z	total cost of the manufacturing system and supply chain network
$TC_{i,j,o}$	transporting cost for delivering resource j from supplier i to plant o
$\beta_{i,o}$	transportation cost factor (per unit raw material per unit distance)
$L_{i,o}$	distance between supplier i and plant o
$S_{i,j}$	quantity of resource j supplied by supplier i
$\alpha_{i,j}$	importance factor of resource j from supplier i
$PC_{i,j,o}$	procurement cost for purchasing resource j from supplier i for plant o
$\gamma_{i,j}$	unit cost of resource j from supplier i
MC	total manufacturing cost
ω_o	manufacturing cost per unit of the final product at plant o
D	demand for the final product
p_o	scrap rate at plant o
λ_i	quality acceptance rate for resources provided by supplier i
D_j	demand of resource j in order to meet the demand requirement of the final product
RC	reconfiguration cost
$SIM_{i,o}$	similarity of two line segments between plant o and supplier i before and after reconfiguration
$\theta_{i,o}$	reconfiguration cost factor of the line segment between plant o and supplier i
l	graph length before scaling transformation
l'	graph length after scaling transformation
ΔS	surrounding area of two lines that are before and after scaling transformation
$l_{i,A}$	distance between plant and supplier i before reconfiguration
$l_{i,o}$	distance between plant o and supplier i after reconfiguration

models are developed to describe the complexity propagation in multi-stage assembly systems and multi-echelon supply chains. Khoei et al. [11] developed an integrated model of the supply chain management information system supported by empirical evidence and employed a case study of an automotive manufacturing industry to demonstrate the effectiveness of the proposed model. Zarandi et al. [12] proposed a new type-2 fuzzy method to evaluate and reduce the bullwhip effect in fuzzy environments of a supply chain, which had less error and a higher accuracy than traditional methods. Jalali et al. [13] implemented a recommender system based on collaborative filtering in the supply chain to offer a combination of the best suppliers, producers, and distributors which have the minimum cost and the maximum customer satisfaction.

As for the studies on supply chain reconfiguration, researchers mainly focused on developing reconfiguration strategies. Lu et al. [14] proposed a web-based agile architecture of supply chain management system to reconfigure supply chain agilely. Komoto et al. [15] proposed a discrete event simulation technique to evaluate economic, environmental and delivery performance of a supply chain and developed a multiple-objective genetic algorithm to reconfigure supply chain flexibly. Osman et al. [16] developed a bilinear goal programming model and a modified Benders decomposition algorithm for the supply chain reconfiguration and supplier selection problem, in order to meet the requirements of demand increase and customer satisfaction regarding delivery dates and amounts. Kristianto et al. [17] improved the level of integration in all aspects of supply chain reconfiguration, such as the inventory allocation and manufacturing process involved, by incorporating manufacturing and product design into the logistic design, so that the supply chain can be efficiently reconfigured. Winsper et al. [18] presented a multi-agent system which models a supply chain logistics network to efficiently reconfigure supply chains with varying levels of collaboration between partners in response to dynamic disruptions in production at key members of the supply chain. Dev et al. [19] presented an integration of agent-based simulation and decision tree learning as the data mining techniques to determine adaptive decisions of supply chain reconfiguration.

Other recent developments in this field mainly concentrate on the design of strategies for dynamic supply chain reconfiguration. Zhou et al. [20] applied the method of fractal theory and artificial intelligence to improve the adaptation ability of supply chain operation in uncertainty environment and to improve adaptability and automatism of supply chain reconfiguration. Zhang et al. [21] proposed dynamic reconfiguration in agent-based supply chain management systems from autonomy-oriented computing point of view. Wilhelm et al. [22] proposed a traditional formulation and a network-based model of the dynamic supply chain reconfiguration problem to minimize total cost.

These studies produce many valuable models on manufacturing supply chain system, as well as methods of supply chain reconfiguration, providing very important references for further studies. However, there lacks literature developing an effective model to calculate the reconfiguration cost. Since the optimal supply chain reconfiguration policy significantly depends on the reconfiguration cost, and the reconfiguration cost depends on various factors such as the easiness of the reconfiguration and the complexity level of reconfiguration, it is imperative to develop a model to quantify the reconfiguration cost.

In this paper, a graphical similarity method was proposed to calculate the reconfiguration cost. Existing methods on graphical similarity were mainly used in remote sensing field and mathematical field. For instance, Baeza-Yates et al. [23] proposed an image similarity measuring method by transforming it to approximate the distance between two extended region adjacency graphs. Cheong et al. [24] proposed a distance for geometric graphs to measure the similarity of geometric graphs. Falomir et al. [25] developed a computational approach for comparing qualitative shape descriptions of objects within digital images. Sun et al. [26] proposed a novel spatial feature index named regular shape similarity index to identify objects with different shapes. Leonard et al. [27] presented a multilevel analysis of 2D shapes and used it to find similarities between the different parts of a shape. Hao et al. [28] pioneered a novel approach for measurement of similarity between graphs based on formal concept analysis to clearly describe the relationships between nodes.

In this study, an optimization model for the supply chain reconfiguration problem was first formulated, where the cost of reconfiguration is influenced by various factors. A graph-based method was then proposed to characterize the similarity between supply chain configurations and to establish the relationship between the similarity metric and the reconfiguration cost. Illustrative examples were provided to further explain the proposed method. A case study including two scenarios on the supply chain for laptop manufacturing was employed to demonstrate the effectiveness of the proposed method.

The remainder of this paper is organized as follows. Section 2 describes the model formulation, including variables, objective function, constraints, and model assumptions. Section 3 presents the proposed graph-based method for modeling SCCs similarity and quantifying the reconfiguration cost. Section 4 provides a case study to illustrate the proposed method. Finally, conclusions are drawn in Section 5.