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Grouping part/product variants based on networked operations sequence

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ABSTRACT

Operations flow based similarity is an important criterion for grouping variants. Similarity coefficient for product variants with networked sequence of operations has not been considered in the literature. Previously proposed similarity coefficients, which are based on operation/assembly sequence, focused on variants with serial operations sequences where the order of processing operations is fixed; while in practice, there are many part/product variants with flexible operations sequence options. A novel similarity coefficient for part/product variants is proposed based on the networked operations sequence similarity inspired by the analysis used in the field of biology (e.g. enzymes structures comparison). An extension of the proposed coefficient is also presented with an example for illustration. A more comprehensive similarity coefficient is developed by including operations similarity and production volume criteria. The popular operations similarity coefficient, called Jaccard's similarity, is applied and extended. A new coefficient using volume similarity criterion is also developed. Part/product variants are then clustered and grouped based on the combined similarity coefficient using the average linkage clustering (ALC) algorithm. The main applications of the proposed similarity coefficient are addressed. The grouped variants are sequenced as a secondary application of the proposed similarity coefficient. The sequence obtained from the proposed approach is compared with that obtained from a developed mathematical model. The result shows the accuracy of the proposed sequencing approach and can serve as a good preliminary sequence. A case study is also provided for demonstration.

1. Introduction

Currently, many manufacturing systems have been applying mass customization strategies. Some of the reasons behind this shift are frequently changing demands and the advent of new competitors. Therefore, in order to survive and prosper in this competitive environment, manufacturers should be able to efficiently manage their part/product variety [1]. One strategy used to manage part/product variants is to decrease setup and changeover times/costs incurred when switching variants.

A part/product variant (or variant in brief) usually requires a number of operations. Examples of these operations are machining, assembly, painting, finishing, and packaging. The term "operation" in this study includes both "fabrication" and "assembly" processes. Operations usually have precedence constraint relationship but it is not necessarily serial. Most of the time, based on the features of a variant, some operations have flexibility to be done before, or after or simultaneously with other. In this case, the operations sequence of the variant would similar to a network of connected operations. This situation usually adds more complexity to the manufacturing system in terms of flow of operations and managing the changeover between different variants. Grouping variants based on operations flow similarity has several advantages including ease of system reconfiguration [2] and reduction of changeover time.

An "operation precedence graph" is a good representation of operations sequence. FigFig. 1 illustrates the difference between operation precedence graphs of two variants with sequential serial operations and networked operations. For example, as seen in Fig. 1, Operations 2 and 3 of the second variant can be processed before or after each other or at the same time and this commonly occurs in manufacturing/assembly systems.

Similarity measurement for variants having networked operations sequence has not been considered in literature. There is also a need to develop a novel operations flow based similarity coefficient to measure the similarity between the variants with network structure to be used in grouping them.

In this paper, the proposed operations flow based similarity coefficient considers this processing order flexibility which is

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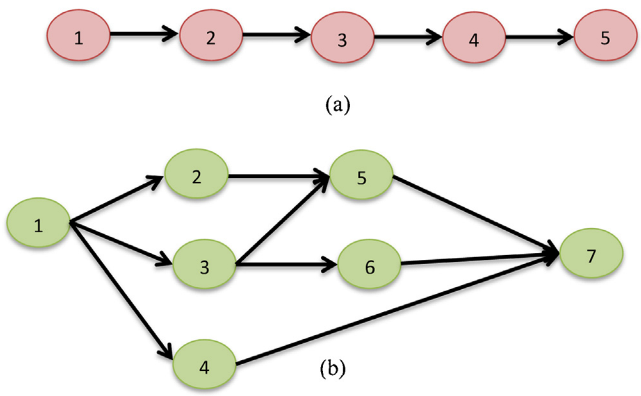

Fig. 1. An example of comparison between operation precedence graphs of two variants with: (a) sequential serial operations and (b) networked operations.

different from routing flexibility. In the present work, it is required to process all the operations of the operation precedence graph; however, some operations have flexibility of being processed in different order.

The proposed operations flow based coefficient is in fact based on analysis and principles used in comparing the similarity of biological structures. The comparison of different metabolic pathways in different systems has enabled biologists to understand the evolutionary and structural relationships between different species [3]. In this field, there are many biological systems which have network structures. Consequently, various methods have been proposed in order to compare these metabolic network structures [3,4].

In addition to proposing a new operations flow based coefficient which is dominantly based on the operations sequence, two other important similarity criteria used in the literature, namely operations similarity and volume similarity, are also taken into consideration to yield a more comprehensive similarity measurement which encompasses different similarity aspects.

The most common and well-known similarity coefficient in the literature, regarding operations similarity, is Jaccard's similarity introduced by McAuley [5]. Therefore, this coefficient is used in the present work to satisfy the operations similarity aspect.

Volume similarity identifies and groups the variants with similar volume in order to increase the utilization of machines. One of the most well-known coefficients for volume similarity was developed by Galan et al. [6]; but it has a drawback. Therefore, in this paper, a new volume similarity coefficient is developed which is in fact a modification on the coefficient developed by Galan et al. [6] to obviate its drawback.

After considering all three similarity coefficients (i.e. operations flow based similarity, Jaccard's similarity, and volume similarity) and obtaining the combined similarity coefficient, variants are grouped accordingly using the Average Clustering Algorithm (ALC). Grouping variants is useful particularly in a cellular manufacturing system where each cell has its own machines responsible for processing families of similar variants which increases utilization and productivity of machines/stations [7].

A secondary application of grouping variants based on their similarity is finding an appropriate sequence of variants for production/assembly. This application is most suitable when the system processing one variant at a time, then setup is changed for production/assembly of the next variant. The obtained sequence serves as a good starting sequence for production planners and requires modification based on processing time, due dates, etc. The sequencing application is also considered in this paper and a proper method of sequencing variants is developed and validated mathematically.

The rest of the paper is organized as follows: Section 2 of this paper includes a literature review of previous work in similarity coefficient. Section 3 describes the scope and the proposed operations flow based similarity coefficient. Section 4 presents other considered similarity criteria. Grouping and sequencing application are illustrated in Sections 5 and 6 respectively. A case study is provided in Section 7, and Section 8 concludes the paper.

2. Literature review

There are many similarity coefficients proposed for grouping variants based on different criteria. Most methods have been developed as group technology (GT) for the cellular manufacturing environment (e.g. [8,9,10,11]). Some methods were proposed for reconfigurable manufacturing systems (e.g. [6,12,13]). There are different criteria for which the similarity coefficients have been developed in any of the studies systems. The most common criteria are operations similarity (e.g. [14]), operations sequence similarity (e.g. [15,17]), volume/demand similarity (e.g. [6,14]), and operations time similarity [16].

Choobineh [17] developed a method for measuring similarity coefficient between two parts which uses the common sequences of length 1 through L between two components. The number of cells and assignments of parts to the cells are calculated. The proposed method applies two criteria, parts' operations and operations' sequences, where the later criterion is the significance of the work. However, serial operations sequences were considered in calculating similarity coefficient.

Askin and Zhou [18] proposed a method to form flow lines in manufacturing cells. Process planning and operations sequence of each part were applied to form the families. The objective was to find a set of flow-line cells at minimum cost of machines and material handling. The cells were assumed to be independent. Two concepts were applied to form the part families: longest common sub-sequence and shortest composite super-sequence. A method was proposed to calculate the similarity coefficient and a modified hierarchical clustering algorithm was proposed to group the parts. The optimum machine sequence for each cell was found using an augmented graph based on the capabilities of machines in performing the operations. The computational experiments showed the efficiency of the method.

Regarding multiple process routing, Gupta [19] considered a problem in flexible manufacturing systems where alternative routing is possible to address machines failure. A similarity coefficient was designed based on machines, not parts, and it incorporated production volume and number of trips. A dendogram was used to illustrate the final grouping of machines. A case study was provided using MANUPLAN software and the results show the efficacy of this method.

Alhourani [20], in a more recent work, addressed the cell formation problem by considering different criteria such as multiple process routings, operations sequence, batch size, production volume and the capacity of machines. He claimed that the mentioned criteria have not been considered together in literature. The proposed method of grouping machines is based on minimization of intercellular movements. Each part has at least one process route when considering multiple process routings and each route may consist of a set of different machines compared to other process routes. This method was compared to other existing methods proposed by other researchers such as Yin and Yasuda [21], Lei and Wu [22], and Spiliopoulos and Sofianopoulou [23] and proved that the proposed method outperforms others in terms of inter-cellular moves.

Alhourani and Seifoddini [8] developed a new ordinal production data similarity coefficient to form a machine cell in a cellular manufacturing system. The method is based on sequence of operations in which a part visits different machines and the batch size of each part. The results were compared with the current