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Variety-Driven Assembly System Layout Design by Design Structure Matrix Clustering Analysis

Xuejian Gong, Yitao Liu, Roger J. Jiao*

School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, Georgia, USA

* Corresponding author. Tel.: +1-404-894-9633. *E-mail address:* rjiao@gatech.edu

Abstract

Mass customization has been well recognized as an effective means of providing product variety while keeping mass production efficiency. As a critical aspect of fulfilling mass customization, assembly system design is facing the challenge of handling high product and process variety. This paper presents a variety-driven clustering method for assembly system layout design. Key issues include variety modeling and modularization of assembly process flows. Based on the minimization process of total coordination cost, the cluster analysis is formulated using the design structure matrix (DSM). A case study of automobile connector assembly system design is reported to demonstrate the feasibility and potential of DSM clustering analysis for dealing with product and process variety.

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Keywords: Mass Customization; Assembly System; Design Structure Matrix

1. Introduction

Mass customization has attracted much attention from both industries and academia alike, owing to its advantage in enabling product differentiation with mass production efficiency [1]. The traditional focus of mass customization has been geared towards product variety, with limited emphasis on the downstream process variety [2]. As a critical aspect of fulfilling mass customization, assembly system design is facing the challenge of handling not only high product but also large process variety [3]. Key technical issues of high variety assembly system design can be observed as follows:

- Assembly Representation and Sequence: High variety products implemented in assembly stage leads to high variety in assembling processes. The first step in assembly system design is a process of analyzing the product information input, both geometric and non-geometric, to obtain the necessary assembly information to achieve the assembly task. This information should represent the components and the hierarchy. Because of the limitation of the text-based representation, there are several graphic-based representational schemes, such as location graph [4] and virtual link [5]. The increasing product variety has led to new approaches in assembly representation. Evolving from Bills-of-Materials (BOM), the concept of generic BOM [6] excels in characterizing the functional and structural relations among components to represent product variants. Taking advantage of assembly liaison graphs, Gupta and Krishnan propose to identify maximal common subassemblies and in turn to plan product-family assembly sequences [7]. Computer-aided assembly planning technologies contribute to the goal of automatic assembly sequencing, which has profound implications for variety handling in mass customization [8].
- Assembly system configuration: Assembly system normally consists multiple assembly units, machines or setups, which are grouped in the cluster and located on the layout. To achieve high variety in an assembly system, the efficient layout arrangements and material flow path designing methodologies are important [9]. Montreuil et al. propose a dynamic manufacturing system and its design approach [10]

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and determine the optimal layout design along the offered material flow path [11].

2. Variety Representation and Propagation

The key challenges for high product variety realization through an assembly system can be viewed from the product and factory levels, respectively. The product level focuses on the derivation of an assembly process design to generate variety efficiently in accordance with certain product family design.

To utilize commonality underlying product diversity and process variation, the primary challenge is finding an effective variety management to handle the relationships between various product variants and the corresponding production process variations as well as the selection of various operations alternatives [6]. The assembly process should reflect the flow of material through the production process. It is possible to modify traditional BOM structure into a generic variety structure which provides a concise way to characterize variant derivation at different levels. The derivation of product variety also requires a reusable assembly process representation to avoid the time-consuming manual combination of assembly process design and verification.

As the backdrop of product families, a well-planned architecture will provide a generic umbrella to capture and utilize commonality, within which each new product is instantiated or extended to anchor future designs to a common product line structure [13]. There are two streams of research prevailing in the field of developing product platforms and representation. The first perspective refers to the development of a product platform as a physical one, namely a collection of elements shared by several related products. The other dominating view is to exploit the shared logic and cohesive architecture underlying a product platform, such that the families can be stretched and/or scaled.

Product data can be represented by a BOM that is used for an end-product to state related resource. Like describing a product structure using a BOM, a routing of operations can be constructed to represent the production structure for a given product [14]. A product platform, consisting of diverse product variants, is characterized by a Generic Product Structure (GPdS) [13]. It is proposed to characterize the source of variety based on the hierarchical decomposition of product structures. Product variants can share a common structure, which may be common product technologies, modules or configuration mechanisms. GPdS acts as a generic data structure for such variants. Accordingly, the corresponding production processes can be collated as standard routines in the form of a Generic Process Structure (GPcS). These standard routines constitute the basis of various process variations in consequence of product variety.

2.1. Generic Product Structure

The BOM product structure has been widely used in industry as a standard product structure for decades. In dealing with variety, the traditional approach is to treat every variant as a separate product by specifying a unique BOM for each variant. It is necessary to understand the implication of variety and to characterize variety effectively, for the purpose of dealing with a large number of variants.

Introducing a generic product structure will give control over complexity, especially when product family with high variety is involved. A generic product structure is of great value in (a) product management when planning new product development, (b) research and development of determining the input on what is needed to be a new design and which able to re-use the design, (c) production planning. Besides, it is not the least purchasing organization for procurement planning. All these disciplines produce information to a common structure and consume information from the same along the product's lifecycle.

The GPdS is a hierarchy consisting of constituent items at different levels of abstraction, where items can be either abstract or physical entities and named as modules in general. Because of the different kinds of modules, the nesting of core constructs is achieved by introducing compound module(s) as the component(s) of another compound module. In this sense, a nested GPdS can be regarded as a multi-level decomposition structure of compound modules.

The parent-child relationship between a parent module and child modules is called a structural relationship $\{SR_i\}$ its value can be 0 or 1 depends on the existence of the relationship. The presence of $\{SR_i\}$ means that the child module is included as the component of a parent module. Otherwise, it is excluded. Different variety generation can be implemented by defining such *SR* variants. All variants of modules in GPdS are controlled at the leaf nodes, because of the variety of a compound module can be achieved through its primitive modules. Therefore, the relationship between variants and the corresponding module can be observed as an instantiation of the module per specific conditions. Such variants and module relationships are represented by the including conditions $\{IC_i\}$.

2.2. Generic Product and Process Structure

In practice, process information is often described in various forms of documents. These documents are hard to maintain the traceability between domains. Therefore, it is necessary to develop a modeling formalism which can provide a powerful syntactic model to support rigorous analysis and manipulation of process variety. Aimed to find the relationship between product variety and process variety, determining the relationship between the product and process structures is necessary [3].

The link between product structure and process routing data can be established by specifying each component material in the product as required by the relevant operations of the routing for making its parent product. The material requirement and corresponding operation sequence links can synchronize the GPdS and the GPcS into a unified generic structure, which is called Generic Product and Process Structure (GPPS).

While the GPdS associates each component material directly with its parent product, a component material in the GPPS is associated with the relevant operation in the GPcS for producing its parent component. It reuses the elements of