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Technical Paper

Design synthesis of machining systems using co-platforming

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ABSTRACT

Modern manufacturing environment is characterized by frequent product design changes in order to satisfy evolving customer requirements. Various strategies are implemented in order to efficiently manage the consequences arising from the product design changes starting from product design to planning and manufacturing. This paper focuses on synthesizing manufacturing system using the co-platforming concept which maps product platform features and components to the manufacturing system candidate platform machines. A matrix-based mapping model is proposed in order to determine the candidate platform and non-platform machines. Product-related characteristics including manufacturing features, feature orientation, dimensional and geometrical tolerance, cutting power requirements, workpiece volume and surface finish are considered. Characteristics of machines in the manufacturing system include machining axes, accuracy, working envelop and available power. A case study adopted from an automotive engine cylinder block manufacturer is used for demonstrating synthesizing manufacturing systems, based on co-platforming, which are capable of adapting to new products variants without changes to the platform machines. This prolongs the life of the manufacturing system and reduces costs associated with retooling and replacing it.

1. Introduction

Modern manufacturing is characterized by diversity and frequent changes in products and production volume requirements. This diversity in products is due to the changes in customer requirements, legislation and environmental issues. As a result, manufacturing firms strive to continuously offer a variety of product designs while minimizing investment cost. Changes in product design are likely to propagate through the different phases of the product lifecycle such as design, planning and manufacturing.

Various techniques, methodologies and models have emerged to efficiently manage products variety within each phase of the product lifecycle in terms of cost and time to market [1]. Product family architectures [2,3] and product platforms and families [4] are widely used strategies to manage variety in the design phase. Master process planning and variant process planning methods [5] are used to generate process plans for different product variants of a product family within the pre-defined family boundary.

Manufacturing is one of the critical phases within the product lifecycle which is characterized by high investment costs in terms of machine tools, controllers, and material handling equipment. Reconfiguration of manufacturing systems is cost intensive which requires constructing adaptable manufacturing systems that need the least amount of modifications in order to produce the new features and components. Various manufacturing paradigms have evolved over the years in order to cope with the frequent changes in product design such as flexible manufacturing system (FMS) which is characterized by high initial investment cost due to the use of generalized flexibility equipment, and reconfigurable manufacturing systems (RMS) with customized flexibility where equipment is added/removed when needed and as needed [6].

Joint development, co-development or concurrent design of products and manufacturing systems have been of interest for researchers and scholars as they aim to address different approaches for the integration of product and manufacturing systems design [7]. Significant cost reduction can be achieved by using concurrent rather than the sequential methods in which product and manufacturing systems are designed separately [8]. The co-evolution of products and manufacturing systems [9,10], its mathematical modelling and applications in jointly synthesizing products and systems together has many developments recently and was inspired by co-evolution in nature to track the features of individual products and their corresponding capabilities in manufacturing system.

This paper focuses on product variety management in manufacturing by utilizing the concept of co-platforming [11,12] in

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order to synthesize manufacturing systems capable of adapting and co-developing with the products. Co-platforming is achieved by synthesizing manufacturing systems through mapping of product platform and non-platform components and features to platform and non-platform machine candidates in the manufacturing system, respectively.

The paper is organized as follows: section 2 provides literature review, section 3 illustrates the co-platforming methodology, section 4 illustrates the definition of features and their various types, section 5 illustrates the various machining capabilities used in this paper, section 6 is dedicated to formulation of the mathematical model, section 7 provides a case study to illustrate and validate the developed systems design synthesis approach, section 8 contains results and discussion and finally, section 9 presents the conclusion.

2. Literature review

At the manufacturing systems level, ElMaraghy and Kashkoush [13] proposed a mixed integer linear programming model to synthesize assembly systems using association rules and knowledge discovery. The main inputs include existing or historical data available in the manufacturing firm about products and their features and the manufacturing systems capabilities used to produce the product. The model output is a relationship matrix relating each product feature to the corresponding manufacturing capabilities, which is used to determine the capabilities required to assemble a new product. Abbas and ElMaraghy [12] proposed a mathematical programming model for the functional synthesis of manufacturing system using co-platforming. The results indicate that cost savings are achieved when manufacturing systems are synthesized with platform system machines compared to manufacturing systems synthesized without considering platform system machines. However, it focused on functional synthesis by determining only the optimum types of platform and non-platform machines (e.g. 5 axis CNC machines, honing machine. . .etc.) without providing the list of potential platform candidates with further machining capabilities (accuracy, cutting power, working envelop. . .etc.) in order to assist decision makers in choosing the platform machines. Hanafy and ElMaraghy [14] proposed a design methodology using Bayesian networks which extracts relationships between product features and manufacturing capabilities based on available current and historical data. These relationships are utilized to synthesize manufacturing capabilities associated with newly introduced products with different features. ElMaraghy and Abbas [11] proposed a novel concept in manufacturing system synthesis known as "Co-platforming" in which manufacturing systems are synthesized by mapping product platform and non-platform components/features to platform and non-platform machines, respectively using matrix-based formulation. Product features include the machining features and their orientation within the product. The synthesized manufacturing system is characterized by core machines for processing the product features platform which remain unchanged in different product variants and production periods identified non-platform machines can be added or removed depending on the characteristics of new products. This strategy extends the useful life of manufacturing systems for use with more products variants and generations. The proposed model only considered only machining axes and cutting tools as machining capabilities. Bryan et al. [15] introduced a mathematical model using genetic algorithm for Assembly System Reconfiguration Planning (ASRP) method that takes into account the product family design evolution over generations and its related assembly system concurrently by minimizing the manufacturing system capital cost. Bryan et al. [8] formulated a mathematical model using genetic algorithm for concurrent design of product family and reconfigurable assembly systems without considering the relationship between the product platform and the assembly system. Results from the concurrent and sequential design mathematical models were compared and it was concluded that implementing the concurrent approach reduces manufacturing cost. AlGeddawy and ElMaraghy [16] proposed a new approach using cladistics inspired by co-evolution in nature to synthesize manufacturing capabilities for new products based on existing data of product features and their corresponding manufacturing capabilities. The proposed model is based on association rules and knowledge discovery which is achieved using tree classification and tree reconciliation algorithms. Its usefulness for future manufacturing systems synthesis and product design was demonstrated, Ozdemir and Ayag [17] proposed an integrated method to design assembly lines using the Branch and Bound algorithm to find alternative system configurations and Analytical Hierarchical Process (AHP) was used to evaluate each alternative. They focused on assembly system equipment cost, required operations as well as assembly line balancing. Wang et al. [18] proposed a multi objective optimization model which considers the complexity of co-development between products and assembly systems with the objective of increasing product variety while reducing the induced complexity within the assembly system. Michalek et al. [19] developed a mathematical model which takes into consideration the manufacturing, product and market domains and the trade-off between revenue and cost. Xu and Liang [20] proposed a mathematical model which concurrently selects product module type and assembly line design. The types of module instances within products are selected based on four performance criteria (product reliability, product function, cost of system reconfiguration and line smoothness) and the assembly line is designed based on balancing and resources issues by considering alternative assembly machines, robots or human resources. Webbink and Hu [21] proposed an automated method which generates the complete set of system configurations as well as assembly sequence and assigns different tasks to the different machines within each configuration. Performance measures for each configuration such as productivity were evaluated to find the system with the best performance. De Lit et al. [22] used the concept of functional entities to design product families and synthesize the corresponding assembly system design. Functional entities were used to represent the different components or modules within a product family. For example, four variants of car body were referred to as one functional entity. Similarly, three chassis variants were considered another functional entity and so forth. The interrelationship and mapping between product platform and manufacturing system platform machines for manufacturing system synthesis was not taken into consideration in the previous papers.

At the machine synthesis level, Shabaka and ElMaraghy [23] developed a methodology to synthesize a reconfigurable CNC machine tools which defines the optimum machine configuration with minimum capabilities (e.g., number of motion axes) required to machine given product features, which can be efficiently altered when the product/process plan changes. The research focused on machine tools kinematic structure configuration and required tools. Chen et al. [24] developed a methodology for the synthesis of optimal yet sufficient reconfigurable machine tool for parts family. The mapping between machining features and machine tools was implemented using Analytical Hierarchical Process. This methodology was applied only to machine tools.

Most of the literature considers the manufacturing system synthesis using investment and operation cost criteria. In addition, previous research focused on relating individual product features or operation tasks and machines capabilities without considering the notion of mapping and finding relationships between platforms or common components of both products and manufacturing systems. It is evident that no work in the literature has been conducted