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Synthesis and optimization of manufacturing systems configuration using co-platforming

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ABSTRACT

A mathematical mixed integer linear programming momdel to synthesize the manufacturing system configuration based on co-platforming strategy by mapping product platform to a corresponding machines platform is introduced. The mathematical model is verified through mathematical example and implemented in case study from automotive cylinder block manufacturer. The proposed model is beneficial in synthesizing manufacturing system to reduce investment costs by maintaining a group of platform machines that do not change with the change in product variants in different production periods. The synthesized manufacturing system platform does not change with the introduction of new product variants with new features belonging to the same product family which supports economic sustainability of manufacturing systems.

Introduction

Frequent major product design changes can require costly reconfiguration of the manufacturing system. In addition, product design changes which are introduced late in the development stages will have significant effects on all downstream activities such as planning and manufacturing which are capital intensive, as well as various phases of the product lifecycle. One of the crucial phases within the product lifecycle is the manufacturing phase, which is characterized by high investment costs in terms of machine tools, controllers, material handling units . . . etc. Hence, product design changes can have significant impact on the manufacturing system in manufacturing company. Different manufacturing system paradigms have emerged over the years in order to accommodate the diversity of product variants and design changes such as Flexible Manufacturing Systems (FMS) and Reconfigurable Manufacturing Systems (RMS) [1,2].

Co-evolution of products and manufacturing systems [3,4] is a recent topic inspired by biology to track the features of individual products and their manufacturing system. Co-platforming is a new term coined by ElMaraghy and Abbas [5] and Abbas and ElMaraghy [6] which is defined as the synthesis of manufacturing systems through mapping of product platform to platform machines and non-product platform to non-platform machines. The objective of Co-platforming is to synthesize manufacturing systems capable of co-adaptation to changes in products' variants without significant changes in the manufacturing system which prolongs their useful life and reduces the cost of change as product variants evolve and change. The reuse of system machines using the product platform concept leads to reduction in lead time since system do not need to be re-designed or re-built from scratch.

Functional synthesis of manufacturing systems refers to the determination of type of machines as well as the required number of each machine type [6]. Physical level synthesis of manufacturing systems is the determination of the required types and numbers of machines in each production stage and the number of stages. Therefore, physical level synthesis of manufacturing system determines its configuration taking into consideration products demand.

This work extends the research in co-platforming [5,6] by introducing a mathematical mixed integer linear programming model in order to synthesize the manufacturing system configuration at the physical level.

The paper is organized as follows; Section “Literature survey” provides the literature review and gap identification, Section “Co-platforming methodology and manufacturing system configuration” illustrates the co-platforming strategy and manufacturing system configuration, respectively. Section “Mathematical model” is concerned with the mathematical model formulation, Section “Model verification using numerical example” provides a mathematical example for the model verification, Section “Industrial case study” provides a case study adopted

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from an automotive cylinder block manufacturer, Section "Results and discussion" provides the results and discussions to the case study and finally, Section "Conclusions" is the conclusion.

Literature survey

ElMaraghy and Abbas [5] proposed for the first time a methodology using matrix formulation to synthesize manufacturing systems by mapping product platform features and components to systems platform machines. Abbas and ElMaraghy [6] developed a model for the functional synthesis of the manufacturing system using co-platforming and used it to illustrate the cost savings achieved when implementing the co-platforming strategy. The manufacturing system configuration was not considered in Refs. [5,6]. ElMaraghy and Kashkoush [7] proposed a mixed integer linear programming model based on knowledge discovery and association rules to synthesize assembly systems. The model produces a relationship matrix which associates product features with the corresponding capabilities required to assemble a new product based on legacy data and knowledge. The relationship between the common manufacturing system components and product components were not taken into consideration. Hanafy and ElMaraghy [8] proposed a model to develop the assembly system layout for delayed product differentiation based on phylogenetic networks using both assembly and disassembly of components for customizing the product platform for various variants. Bryan et al. [9] proposed a mathematical model which considers the product family design evolution over generations and its corresponding reconfigurable assembly system without considering the relationship between common components in product and manufacturing system. AlGeddawy and ElMaraghy [4] developed a novel concept of co-evolution of products and their manufacturing systems and used cladistics to track their co-evolution path and predict the future development of new products and manufacturing systems. Demoly et al. [10] proposed a framework based on concurrent design and assembly planning for integrating product design and assembly system design without considering the manufacturing system domain. Michaelis et al. [11] proposed a model which integrates products and manufacturing system along with the manufacturing process using functional modeling. The model was intended for the conceptual phase in design and reusing machines, processes and design solutions without taking into consideration the relationship between common components in product and manufacturing system. Gedell et al. [12] proposed a framework for the co-development of products and their production systems and represented them as co-equal objects with interfaces, interactions and subsystems. AlGeddawy and ElMaraghy [13] presented a new optimization model based on cladistics to develop layout of a delayed differentiation single line assembly system for a mix of product variants and optimized the location of the products delayed differentiation points. Zhonghui and Ming [14] proposed a mathematical model which concurrently selects the product module type and instances of the product based on product reliability, product function, cost of system reconfiguration and line smoothness, and the corresponding assembly line design (based on balancing and resources issues such as choosing alternative assembly system either assembly machine, robots or human resources). However, product family was not differentiated based on platform and non-platform components. Ko and Hu [15] developed a mathematical programming model for line balancing of asymmetric assembly lines configuration designed for delayed product differentiation. The product structure was not considered in the mathematical model. Ko and Hu [16] proposed a mixed integer programming model for manufacturing systems design and configuration taking into consideration the recurrence of tasks within the different product generations. However, the relationship between the common product and manufacturing system components was not considered. Youssef and ElMaraghy [17] proposed a model that optimizes the capital cost of reconfigurable manufacturing systems (RMS) configurations taking into consideration multiple-aspect including arrangement of machines, equipment selection and operations assignment using genetic algorithm to determine the arrangement of machines, equipment selection and operations-machines assignment. De Lit et al. [18] discussed functional entities and their effect on product family design and synthesizing the corresponding assembly system for the product family. Suh et al. [19] applied axiomatic design in order to design manufacturing systems satisfying functional requirements such as maximizing the return on investment and selecting design parameters such as the type of manufacturing system to provide the products at minimum cost. In product platform and family design, Qu et al. [20] developed a two stage method for product platform identification. The first stage is concerned with identification of initial product platform based on maximum clique in graph theory which is solved through genetic algorithm. The second stage is concerned with selection of the final product platform based on performance loss which is carried out through sensitivity analysis, however, the manufacturing system was not considered.

Zhang et al. [21] proposed a knowledge based system to generate production processes for product variants. It utilized integrated product and process structures as well as petri-nets to generate the different production processes based on the parameters specified according to the customer requirements such as car body color, engine horse power and type of gear transmission. Zhang and Jiao [22] proposed adopting the graph rewriting systems to generate production processes for the different variants within a product family. They defined the system using PROGRES that includes three levels of abstraction: meta model at meta level, generic model at family level and instance model at variant level and demonstrated it through a study case on spindle family. Lianfeng and Rodrigues [23] studied the logic of configuring production process using dynamic modeling and visualization to develop a new form of nested colored times Petri-nets. They identified three types of nets: process nets, assembly nets and manufacturing nets all combined with a net system and implemented their methodology on a family of vibration motors as a case study. More than one production process were obtained each consisting of different feasible machines combination in order to fulfil each of the vibration motors requirements. Li et al. [24] proposed a nested combinatorial optimization algorithm to generate the asymmetric assembly system configuration for repetitive tasks within the product hierarchy and equipment selection and applied it to automotive battery. Bryan et al. [25] formulated a mathematical model for concurrent design of product family and reconfigurable assembly systems without considering the relationship between the platform of the product and the assembly system and compared the results with a sequential mathematical model. They demonstrated through a case study that implementing the concurrent approach results in lower cost than the sequential approach. Roemer and Ahmadi [26] provided a framework to address product design and manufacturing process concurrently. They used two approaches that synchronize production flow through the manufacturing system. The first approach was the exact Design Selection Algorithm which addresses all product designs simultaneously through the same linear flow. The second approach separated the product set into subsets by preserving the linear portion of the flow line for common operations and dividing the line to accommodate different operations within the product family members. The results obtained from the previous two