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Products-manufacturing systems Co-platforming

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ABSTRACT

A new Co-platforming methodology is introduced for mapping product features platform and corresponding manufacturing system machines platform. A cluster of platform and non-platform system machines are derived using matrix formulation and manipulation. The objective of Co-platforming is to establish the mapping between platforms of products and manufacturing machines for use in synthesizing systems capable of adaptation to changes in product variants without significant changes in the platform machines. This prolongs manufacturing systems useful life and reduces the cost of re-tooling as products evolve and new models are introduced. Fabrication of automobile cylinder blocks is used for demonstration and verification.

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1. Introduction

In an era characterized by diversity and frequent changes in customer requirements for products, manufacturers strive to limit the effects of propagation of those changes at different enterprise levels and different phases of products life cycle [1]. Manufacturing systems represent significant investments in machine tools, material handling units, controllers, etc. Therefore, it is desirable to design products, which best utilize the capabilities of manufacturing systems. This paper introduces a new method for the joint development of products and their manufacturing systems called *Co-platforming* where the manufacturing system machines platform is synthesized through mapping of the products platform.

2. Literature review

Various research works dealing with the joint development of products and systems exist in literature. Zhang et al. [2] proposed a methodology to automatically generate production processes from a family of products through knowledge discovery of data as well as production rules generation for specifying variable parameters related to customer requirements. Bryan et al. [3] proposed a mathematical model that simultaneously designs the product family and its corresponding assembly system. AlGeddawy and ElMaraghy [4] developed a model of co-evolution using Cladistics to track the symbiotic co-evolution of features of individual products and their manufacturing systems. Demoly et al. [5] presented a framework for integration of product design and assembly sequence planning but without considering the machines and various system modules. Michaelis et al. [6] proposed a model which integrates products and manufacturing system design during the conceptual design phase where the two domains are represented by function means formalism. AlGeddawy and ElMaraghy [7] presented a new optimization model based on Cladistics to construct the optimum layout of a delayed differentiation single line assembly system. Tekraj et al. [8] used multistage stochastic programming for designing a manufacturing system architecture in which the level of flexibility is focused on specific production requirements. Shabaka and ElMaraghy [9] developed a matrix-based methodology to synthesis individual reconfigurable CNC machines according to products features. The most recognized and well established work for mapping between domains using matrices was introduced by Suh [10] who quantitatively mapped between functional, design and process domains using a design matrix. However, every two considered domains are defined a priori and the design matrix is formulated and analyzed for determining whether product design is coupled, decoupled or uncoupled.

Previous research work aimed at integrating and mapping between products and manufacturing systems considered individual features of each. In contrast, the proposed new method maps the platforms of both the products features and manufacturing system capabilities using a design matrix like formulation. The result is used to *synthesize* manufacturing systems capable of adapting to changes in products variants without significant changes in the manufacturing system platform. The implementation of this methodology can lead to significant savings in the cost of designing, building and upgrading manufacturing systems as products change and evolve.

3. Co-platforming methodology

The Co-platforming methodology and its elements: mapping matrix, input vector and output vector is shown in Fig. 1. The considered product features are machining features as defined in STEP AP224 protocol ISO standard [11]. Product platform are the common core features among members of the product family. Manufacturing system "platform" represents the core machines capable of performing all the processes required to fabricate the core product features. The term machines are used to represent all processes and tools that allow it to perform many operations and processes to produce certain product features. Therefore,

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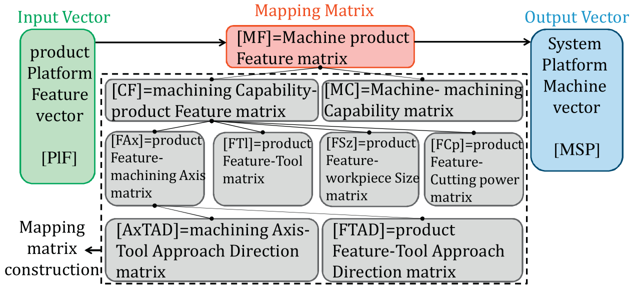

Fig. 1. Co-platforming mapping methodology.

platform features and platform machines refer to product platform and manufacturing system platform, respectively. The Co-platforming methodology produces vectors showing platform and non-platform machines. Platform machines are a function of platform features which are common within product variants in all production periods. Non-platform machines depend on non-platform features which cause diversity among product family.

3.1. Machining capability-product feature matrix

A machining Capability-product Feature matrix [CF] is a matrix which relates machines capabilities to product features. The elements of the [CF] matrix are defined as:

$$c\,f_{d,n} = \begin{cases} 1, & \text{if capability } (d) \text{ can machine feature } (n) \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

The machining capability index d refers to total number of considered machining capability such as machining axes, cutting tools, work piece size, cutting power (depends on material type), etc. and hence, $d = 1, 2, \ldots, P, P+1,, \ldots, P+T, P+T+1, P+T+2$ where P is the total number of machining axes considered (for example $d = 1$, 2 and 3 for 3, 4 and 5 axis, respectively with $P = 3$), T is the total number of cutting tool types, work piece size with index $d = P + T + 1$ and cutting power with index $d = P + T + 2$. A product feature can be produced by a certain machining axes configuration and certain cutting tools taking into consideration work piece size and required cutting power. Hence, the [CF] matrix is constructed by: (a) product Feature-machining Axis matrix [FAx], (b) product Feature-cutting Tool matrix [FTl], (c) product Feature-work piece Size [FSz] vector, and (d) product Feature-Cutting power [FCp] vector. The derivation of the [FAx] matrix requires the formation of two sub matrices. First, a product Feature-Tool Approach Direction (TAD) matrix [FTAD] which describes the 3-D orientation of a feature within a product is defined as:

$$ftad_{n,j} = \begin{cases} 1, & \text{if feature } (n) \text{ is in the } (j) \text{ direction} \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

where $j = 1, 2, 3, 4, 5, 6$ corresponds to the Cartesian directions $x+$, $x-$, $y+$, $y-$, $z+$ and $z-$, respectively. Second, a machining Axis-Tool Approach Direction (TAD) matrix [AxTAD] is defined to relate the machining axes type to the product feature. The elements of the [AxTAD] matrix are:

$$axtad_{p,j} = \begin{cases} 1, & \text{machining axis type } (p) \text{ can machine in } (j) \text{ direction} \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

A relationship between product features and the type of machining axes (i.e. [FAx] matrix) can be derived from Eqs. (2) and (3). However, matrix multiplication of Eqs. (2) and (3) will produce unfeasible results in some cases such as $ftad_{n,j=1,2,\ldots,6} = [000101]$ and $axtad_{j=1,2,\ldots,6,p} = [000001]$ in which the nth row (feature Fn) of the [FTAD] matrix is multiplied by the pth column (capability Cp) in the [AxTAD] matrix. Machine capability Cp can machine in the negative z-axis only. Feature Fn has an orientation component in the negative y-axis and negative z-axis. The result of multiplying these two vectors is “1” indicating that capability Cp can completely satisfy feature Fn which is not true. To avoid this outcome, an intermediate product Feature-machining Axis matrix [FÂx] is proposed as:

$$f\hat{a}x_{n,p} = \frac{1}{\sum_{j=1}^{J} ftad_{n,j}} \sum_{j=1}^{J} ftad_{n,j} \times axtad_{p,j}, \; \forall n, p \tag{4}$$

From Eq. (4), the [FAx] matrix can be defined as:

$$fax_{n,p} = \begin{cases} 1, & \text{if } f\hat{a}x_{n,p} = 1 \\ 0, & \text{otherwise} \end{cases}, \quad \forall n, p \tag{5}$$

In order to obtain the final form of the [CF] matrix, a relation between product Features and cutting Tools for the [FTl] matrix is established. The cutting tool types and product machining features are defined according to Kalpakjian [12]. The [FSz] and [FCp] vectors elements are continuous values of the maximum work piece size and cutting power requirements, respectively, corresponding to feature Fn, and therefore:

$$CF = \left[FAx^T \quad FTl^T \quad FSz^T \quad FCp^T \right]^T \tag{6}$$

3.2. Machine-machining capability matrix

The Machine-machining Capability matrix [MC] is a matrix with elements defined as:

$$mc_{q,d} = \begin{cases} 1, & \text{if machine } (q) \text{ contain capability } (d) \\ 0, & \text{otherwise} \end{cases} \tag{7}$$

Landers et al. [13] and Katz [14] identified several manufacturing processes applied in the automotive industry to both horizontal and inclined surfaces. In this paper, the considered processes include all rough and finish milling, drilling, boring and honing operations on horizontal and inclined surfaces. Indices $d = P + T + 1$ and $d = P + T + 2$ represent the machines working envelop and available power.

3.3. Machine-product feature matrix

A Machine-product Feature matrix [MF] is derived from the [CF] and [MC] matrices such that:

$$\begin{aligned} m\,f_{q,n} = \frac{1}{B}[&\max\nolimits_{d=1,\ldots,P} \min(mc_{q,d}, c\,f_{d,n}) \\ &+ \max\nolimits_{d=P+1,\ldots,P+T} \min(mc_{q,d}, c\,f_{d,n}) \\ &+ \mathbb{1}\{mc_{q,P+T+1} \geq c\,f_{P+T+1,n}\} \\ &+ \mathbb{1}\{mc_{q,P+T+2} \geq c\,f_{P+T+2,n}\}], \quad \forall q, n \end{aligned} \tag{8}$$

The indicator function $\{mc_{q,P+T+1} = cf_{P+T+1,n}\}$ equals to 1 if the condition within the brackets is satisfied and 0 otherwise. Value of B is the total types of machining capabilities ($B = 4$ in this case) and it varies according to considered machining capabilities.

3.4. Product platform feature vector

In order to represent features within a product, a binary matrix called Product Feature matrix [PtF] is defined as:

$$pt\,f_{k,n} = \begin{cases} 1, & \text{if product } (k) \text{ contains feature } (n) \\ 0, & \text{otherwise} \end{cases} \tag{9}$$

The product platform features are extracted from Eq. (9) and written in a vector form (input vector in Fig. 1) as:

$$[PlF] = [pl\,f_1 \;\; pl\,f_2 \cdots pl\,f_n \cdots pl\,f_N] \tag{10}$$

where

$$pl\,f_n = \begin{cases} 1, & \text{if } pt\,f_{1,n} = pt\,f_{2,n} = \cdots = pt\,f_{K,n} = 1 \\ 0, & \text{otherwise} \end{cases}, \quad \forall n \tag{11}$$

3.5. Machine-product platform feature matrix

System platform machines can be extracted by applying the intersection operator between [MF] matrix and [PlF] vector since the product platform features are a subset of all product features. The intersection operator between two sets is treated as a minimum operator [15], hence:

$$m\,f^p_{q,n} = m\,f_{q,n} \cap pl\,f_n = \min(m\,f_{q,n}, pl\,f_n) \tag{12}$$

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