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A Multi-Plant Process Planning Model for Products with Multiple Sets of Features in a Collaborative Manufacturing System

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Abstract. In a feature-based representation model, a set of features can be used in both design representation and process planning to integrate design and manufacturing. Process planning activities such as generation of machining tool path, planning of machining operations, sequencing of machining operations, and selection of machining machines can be executed using a feature-based approach. In a typical process planning scheme, the machining operations for producing a product are planned and arranged to be performed in a single manufacturing plant. However, in a multi-plant collaborative manufacturing environment in a global supply chain, a product can be designed and manufactured at different plants at multiple locations. In this research, a feature-based multi-plant process planning model is presented. A feature represents a machined volume that needs to be removed by certain machining operations to produce a portion of the product. A set of sequenced features represents a machining sequence for producing the part. A mathematical model is formulated to evaluate all the feasible machining sequences. The objective attempts to find the optimized multi-plant machining sequence with an aim of the minimizing the total manufacturing operation cost. As a result, the multiple machining sequences can be evaluated and the machining operations are assigned to the most suitable plants in a multi-plant collaborative manufacturing system.

Keywords: Process planning; machining features; multi-plant; collaborative manufacturing

1. INTRODUCTION

To integrate design and manufacturing, the design data needs to be transformed and linked with manufacturing information. The purpose of using machining features is to provide a link for integrating design and manufacturing. In a typical feature-based modeling approach, a set of features is used to represent the geometry of a product. The features can be obtained by recognizing from a part description in the feature recognition approach. Alternatively, the features can be incorporated directly in the design stage known as the feature-based design approach. A feature represents a special shape of machined volume and can be machined by certain machining operations. A set of machining features can be used in the subsequent process planning activity such as machining tool path generation, machining sequence planning, machine selection, and setup planning.

Given a set of features for representing the design of a product, the set of features can also be used for generating machining operations and sequencing machining operations. In previous research, the feature-based model has been applied to generate machining operation sequences. The related research includes Wong and Siu (1995), Irani *et al.*, Reddy *et al*. (1999), Chang and Chang (2000), Li *et al.* (2002), Sormaz and Khoshnevis (2003), Shakeri (2004), Hua *et al*. (2006), and Wang *et al*. (2006). However, for a complicated product, multiple sets of features may exist to represent the same product. The different sets of features differ not only in sequences but also in geometric shapes. From the machining point of view, the multiple sets of

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features are related with multiple ways for machining. There are multiple sets machining operations associated with the multiple sets of features that can be used to produce the same product. If a set of sequenced features represent a feasible way for producing the product, then there are different machining sequences. The different sets of features represent different ways for machining and producing the same product. As shown in Figure 1, an example product is used to illustrate the product with multiple feature-based machining sequences. Therefore, it is required to evaluate the different sequences of machining features to find the best way for producing the product.

In this paper, the research is pointed to a wider point of view by considering process planning in a multi-plant collaborative manufacturing environment. In a typical process planning scheme, the machining operations for producing a product are planned and arranged to be performed in a single manufacturing plant. In a feature-based model, the features are arranged and planned to be machined in a single plant site. The available machining operations and machining machines are restricted in a single plant. Also, the machining costs associated with the machining operations are constrained in a specific plant location. The traditional approaches to process planning and machining sequence planning are performed based on the considerations restricted in a single plant.

However, in a multi-plant collaborative manufacturing environment in a global supply chain, a product can be designed and manufactured at different plants located at different geographic locations. Due to the increasing product complexity and increasing production scale, a multi-plant manufacturing scheme is usually adopted to reduce production costs and to expand production capacity. It is required to analyze the process planning factors related to the multi-plant collaborative manufacturing environment. It is important to find the best place to machine each of the features to produce the final product.

In this research, a feature-based multi-plant process planning model is presented. In this multi-plant process planning model, multiple sets of features are used as input to represent the product. A set of sequenced features represent a feasible way for producing the product. In a multi-plant machining sequence, each feature is assigned to a plant to be machined with machining operations for producing a portion of the product. After all the features are processed, the product can be completed.

In this research, a feature-based model is applied and presented. A set of sequenced features represents a machining sequence for producing the product. With the multiple sets of features as input, the different sequences for machining are evaluated. A linear programming model is formulated to evaluate all the feasible machining sequences. The objective attempts to find the optimized multi-plant machining sequence with an objective of the lowest total manufacturing cost. The cost items include machining operation cost, manual operation cost, handling cost, and setup cost. As a result, the multi-plant machining sequences can be evaluated and the machining operations can be assigned and distributed to the most suitable plants.

This paper is organized as follows. Section 1 presents an introduction. Section 2 presents the multi-plant feature-based process planning model. Test results and discussions are provided in Section 3. Finally, conclusions are presented in Section 4.

2. FORMULATION OF MULTI-PLANT PROCESS PLANNING MODEL

Since the feasible machining sequences may be combinatorial, the focus of the research is on developing a new model for finding the optimized multi-plant machining sequence with a minimized cost. Using the different sets of features representing feasible machining sequences as input, the following presents a linear programming model for evaluating the multi-plant machining sequences. To formulate the problem under investigation, the following notations are used.

Notations

p : machining plant,
f : machining feature,
s : feasible machining sequence,
r : machining operation,
P : set of machining plants,
F : set of machining features,
S : set of feasible machining sequences,
R_f : set of machining operations for feature *f*,
Cg_{fp} : rough-cut machining operation cost for feature *f* at plant *p*,
Co_{fp} : finishing machining operation cost for feature *f* at plant *p*,
Cm_{fp} : manual operation cost for feature *f* at plant *p*,
Ch_{fp} : material handling cost for feature *f* at plant *p*,
Cs_{fp} : machine setup cost for feature *f* at plant *p*,

H_{fp}: (0, 1) decision variable, a value of 1 indicating that feature *f* is assigned to be machined at plant *p*.

The model can be represented as follows.

Objective

$$\text{Min} \sum_{f=1}^{F}\sum_{p=1}^{P} Cg_{fp} \times H_{fp} + \sum_{f=1}^{F}\sum_{p=1}^{P} Co_{fp} \times H_{fp} +$$

$$\sum_{f=1}^{F}\sum_{p=1}^{P} Cm_{fp} \times H_{fp} +$$

$$\sum_{f=1}^{F}\sum_{p=1}^{P} Ch_{fp} \times H_{fp} + \sum_{f=1}^{F}\sum_{p=1}^{P} Cs_{fp} \times H_{fp} \quad (1)$$

$$\text{st.} \quad \sum_{p=1}^{P} H_{fp} = 1 \qquad H_{fp} \in 0,1 \quad \forall f \in F$$

The objective describes the total manufacturing operation cost for machining all the features to produce the product. The constraint restricts that each machining feature is assigned only one time to a plant. The machining operation cost can be calculated as the machining operation time multiplied by the unit operation cost. The types of machining operation cost can be classified into two main types, rough-cut machining operation cost and finishing machining operation cost. The costs of the two types of machining operations can be categorized as two different levels of operations. The cost for finishing machining is typically very high for machining operation. In contrast, the cost for rough-cut is usually lower than finishing cut. This is an important factor for plant assignment. Another important factor is manual operation cost. Some machining features may require manual operation to finish the complete manufacturing process. The manual operation cost is usually different from plant to plant according to the place that the plant is located. Some plant may be located at a place where the manual operation cost is lower. In this case, the assignment of plant may be directed to the favored plant with a lower manual operation cost. In other cases, the material handling cost and the machine setup cost may affect the plant assignment to a certain degree. For example, if the product is relatively heavy, then the material handling cost may be very high. Therefore, the plant assignment may try to avoid moving the product to different plants. On the other hand, the machine setup cost may play an important role in the plant assignment. Before a machining operation can be performed on a machine, certain setup works are required to place and fix the product and to setup the tools and machines. Therefore, if a product is moved from one machine to a different machine at a different plant, an additional setup time may be needed. The above cost items describe the key cost factors in practical machining operations in a multi-plant collaborative manufacturing environment. With the above formulation, the optimized output can be computed and obtained.

3. TESTING AND DISCUSSIONS

The presented models were implemented and tested by developing software on a personal computer. The linear programming model is solved using the Lingo software. The feasible machining sequences are represented using sets of sequenced machining features. The preliminary test results show that the model is feasible and efficient for solving the feature-based multi-plant process planning model. Given the required cost information as input, the output of the model includes the machining sequence of features, the total manufacturing operation cost, and the plant locations.

It is observed that if the machining operation cost of a plant is too high, then the features will not be assigned to the plant. On the other hand, if the machining operation cost of a plant is low enough to cover the handling and setup costs, then the machining operation can be assigned to that plant. In some cases, the product can be assigned to a plant where the manual operation cost is lower if the manual operations take a large portion of the process. This is a practical situation in the collaborative manufacturing environment in the current global supply chain. In the presented model, the features of a product are assigned to the suitable plant with an aim of minimizing the total manufacturing operation cost. The manufacturing and machining operations can be distributed to the most suitable plants with justified cost considerations.

4. CONCLUSIONS

In a collaborative manufacturing environment in a global supply chain, a product can be designed and manufactured at different plants at multiple locations. In this research, a feature-based multi-plant process planning model is presented. The machining sequence is represented using a set of features. In the feature-based representation model, a set of features can be used in both geometric representation and process planning to integrate design and manufacturing. A set of sequenced features represents a machining sequence for producing the product. A linear programming model is formulated to evaluate all the feasible machining sequences. The objective attempts to find the optimized multi-plant machining sequence with an objective of the lowest total manufacturing cost. The cost items includes rough-cut machining operation cost, finishing machining operation cost, manual operation cost, handling cost, and setup cost. With the presented model, the multiple machining sequences can be evaluated and the machining operations can assigned to the most suitable plants in a collaborative manufacturing system. In the multi-plant process planning model, the features are assigned to the suitable plants to perform the machining operations to achieve a minimized total cost. Further research should be concerned with development of a more complete cost model and testing with more complex features and products.

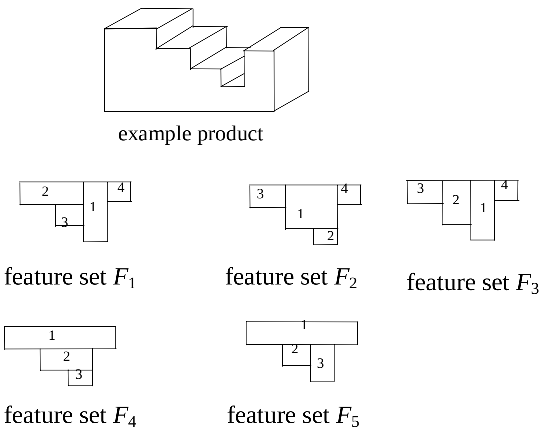

Figure 1: The multiple sets of features representing different machining sequences for producing the product.

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