Development of A Machine Selection Method for Computer-Aided Process Planning
- 컴퓨터원용 공정계획을 위한 기계 선택 방법의 개발-

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Abstract

컴퓨터원용 공정계획(CAPP; Computer-Aided Process Planning)은 CAD와 CAM을 연결하는, CIM의 완성을 위한 필수 기능이다. 지금까지 많은 CAPP 관련 연구 논문과 시스템이 발표되었으나, CAPP의 필수 기능인 기계의 선택 문제를 근본적으로 다루고 해결한 예는 없었다. 본 연구에서는 먼저 완전히 일반적인 기계 선택 문제의 모델을 제시하였다. 그 모델로부터 기계 선택 문제의 속성이 고찰되었다. 기계 선택 문제는 완전히 일반화해서는 경우의 수가 다룰 수 없을 만큼 크기 때문에 그것을 단순화하는 방법들이 제시되었다. 예를 통해서 그 방법의 효과를 입증하였다.

1. INTRODUCTION

In a manufacturing system, process planning determines the manufacturing processes. Accordingly, the productivity of a manufacturing system is affected considerably by process planning. It determines important measures of manufacturing performance such as time, cost, and quality. Many reasons make the introduction of CAPP to process planning compulsory [1]. The basic functions of CAPP are: the selection and sequencing of operations, the selection of machine tools, set-ups and cutting tools, the determination of cutting conditions, tool paths, NC part programs, and jigs and fixtures, and the estimation of production time and cost.

It is essential that machine tools are assigned for operations in process planning. But the many early CAPP systems did not have the machine assigning function, and today's CAPP systems do not deal with the problem satisfyingly. Even the basic properties of the machine selection problem are not clarified so far.

The machine selection problem is studied in this research. First, the fully generalized machine selection is considered. It is modeled and formally formulated. Its characteristics are studied from the generalized model. Then simplification methods are developed to solve the problem.

2. FORMULATION OF THE GENERAL MACHINE SELECTION PROBLEM

A part is considered as a set of features. Each feature is made by a series of operations. A machine is assigned to each operation. Then, a part is created by a series of machines. Finding a series of machines for the creation of a part is the machine selection problem.

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If a part is composed of N features, it is represented as:

$$A-PART = \{ F_i \mid i = 1, 2, \ldots, N \} \qquad (1)$$

where F_i represents a feature.

If feature e(1) has to be made first before feature e(2) is made, amd so on, the feature precedence conditions are represented by:

$$F_{e(1)} < F_{e(2)} < \ldots < F_{e(U)} < F_{e(V)} , \qquad (2)$$

where $e(i) \in \{1\ 2\ \ldots\ N\}$.

A series of operations creates a feature. This is represented by:

$$F_i = f(O_{i1})\ f(O_{i2})\ \ldots\ f(O_{ij(i)}) , \quad i = 1, 2, \ldots, N, \qquad (3)$$

where $O_{ij(i)}$ is the jth operation for feature i, and f is a feature generating function from an operation.

A machine may deal with several operations. When this is the case, it is represented by:

$$o(M_k) = \{ O(1)\ O(2)\ \ldots\ O(k_a) \}, \quad k = 1, 2, \ldots, L \qquad (4)$$

where M_k represents machine k, $O(k_a)$ is the ath operation which can be carried out on machine k, o is a possible operation function, and L is the total number of available machines.

When operation O_{ij} can be handled on several machines, it is represented by:

$$m(O_{ij}) = \{ M_{ij1}\ M_{ij2}\ \ldots\ M_{ijk(ij)} \} \qquad (5)$$

$$\subseteq \{ M_p \mid p = 1, 2, \ldots, L \}, \qquad (6)$$

where $M_{ijk(ij)}$ is the k(ij)th machine which can handle operation ij, and m is a possible machine function. $m(O_{ij})$ represents the set of machines which can perform the operation O_{ij}.

When the operations for N features can be performed on a set of machines, they are a subset of the all operations of those machines. This is represented by:

$$\{ O_{11} \cup O_{12} \cup \ldots \cup O_{1j(1)} \cup \ldots \cup O_{N1} \cup O_{N2} \cup \ldots \cup O_{Nj(N)} \}$$

$$\subseteq \{\ o(M_1) \cup o(M_2) \cup \ . \ . \ . \cup o(M_L) \tag{7}$$

$$= \{\ O_1\ O_2\ . \ . \ .\ O_S\ \} \tag{8}$$

where S is the total number of possible operations on L machines under the consideration.

A part is comprised of features. Each feature is generated by a series of operations. An operation is performed on a certain machine. These are represented from Eqs. (1), (3), and (5) as follows:

$$
\begin{aligned}
A-PART &= \{\ F_1\ F_2\ F_3\ . \ . \ .\ F_N\ \} \\
&= \{\ f(O_{11})\ f(O_{12})\ . \ . \ .\ f(O_{1f(1)}) \\
&\qquad f(O_{21})\ f(O_{22})\ . \ . \ .\ f(O_{2f(2)}) \\
&\qquad . \ . \ . \\
&\qquad f(O_{N1})\ f(O_{N2})\ . \ . \ .\ f(O_{Nf(N)})\ \} \\
&= \{\ f(m^{-1}(M_{b(1\ 1)})\ \ f(m^{-1}(M_{b(1\ 2)})\ \ . \ . \ .\ \ f(m^{-1}(M_{b(1\ C(1))}) \\
&\qquad f(m^{-1}(M_{b(2\ 1)})\ \ f(m^{-1}(M_{b(2\ 2)})\ \ . \ . \ .\ \ f(m^{-1}(M_{b(2\ C(2))}) \\
&\qquad . \ . \ . \\
&\qquad f(m^{-1}(M_{b(N\ 1)})\ \ f(m^{-1}(M_{b(N\ 2)})\ \ . \ . \ .\ \ f(m^{-1}(M_{b(N\ C(N))})\ \} \\
&= \{\ h(M_{b(1\ 1)})\ \ h(M_{b(1\ 2)})\ \ . \ . \ .\ \ h(M_{b(1\ C(1))}) \\
&\qquad h(M_{b(2\ 1)})\ \ h(M_{b(2\ 2)})\ \ . \ . \ .\ \ h(M_{b(2\ C(2))}) \\
&\qquad . \ . \ . \\
&\qquad h(M_{b(N\ 1)})\ \ h(M_{b(N\ 2)})\ \ . \ . \ .\ \ h(M_{b(N\ C(N))})\ \}\ ,
\end{aligned} \tag{9}
$$

where $M_{b(N\ C(N))}$ is the machine for feature N and its *C(N)*th operation, m^{-1} is an inverse function of m, and h is equal to fm^{-1} and it is a feature generating function from a machine.

Then the general machine selection problem is defined as:
Determine the Equation (9) according to an imposed criterion such as minimum production time and minimum production cost.

3. SEARCH TREE OF THE GENERAL MACHINE SELECTION PROBLEM

The tree for the machine selection is shown in Figure 1. The tree is drawn for only one feature. In the figure, M_{ijk} represents the *k*th machine for *j*th operation of *i*th feature. Operation number j increases according th the depth of the tree, and machine number k increases according to the width of the tree.

If the number of the operations for a feature is fixed as N_P, and the number of the machinesis fixed as N_M, then the number of paths is

$$N_{PATH} = N_F * N_M^{N_P} . \tag{10}$$

If the machining order of the features is not fixed and the number of the features is NF, then the number of paths is

$$N_{PATH} = N_M^{N_P N_F} . \tag{11}$$

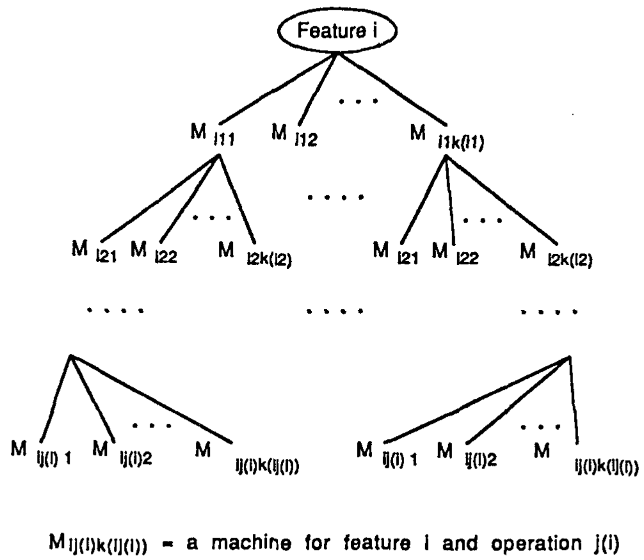

Figure 1. Search tree of the general machine selection problem

Therefore the number of the paths explodes as the numbers of machines, operations, or features increases. If the machining order of the features are not fixed, this numbers gets far larger. As an example, when the number of features is 5, the number of operations is 3, and the number of machines is 4, the number of paths is about 10^9.

4. SIMPLIFIED MACHINE SELECTION PROBLEM

To simplify the general machine selection problem of the previous section, we must first reduce the size of the search tree. Then production rules may be applied for feature assignment to machine tools.

4.1. Reduction of Search Tree

The machining order of the features of a part can be fixed based on precedence. It is determined based on the feature relationships of the parent features and child features before machines are selected. A parent feature is machined first before its child feature is machined. When the parent-child relationship of features does not exist, generally the features of flat surfaces precedes the features of circular surfaces. Then the completely general machine selection problem is much simplified as Eq. (11) is simplified to Eq.(10) by fixing the machining order of the features of a part.

4.2. Production Rules

Simple production rules may be used to assign a machine tool to a part feature. These rules are based on standard manufacturing pratice.

(1) Usually a finish machining accompanies a rough machining, and the machine for a finish machining is also assigned to a rough machining if it is assumed that the power of the machine is not confined.

(2) When any characteristics of a specific machine tool give advantage to a certain part, the number of the machines for an operation can be reduced by excluding other competing machines. Some examples of this case are as follows:

(2a) A large workpiece and a part which has several holes can be easily dealt with by a radial drilling machine rather than an upright drilling machine.

(2b) When a large number of duplicate parts are going to be machined, a production type machine such as a turret late and a NC-machine is preferred.

(2c) A vertical milling machine can deal with angular surfaces more easily than a horizontal milling machine.

5. EXAMPLE

As an example, the part of Figure 2 is process planned. A CAPP system already developed has generated a process plan without the assignment of machine tools and with the fixed feature precedence as follows: (1) rough face-milling for Rectangular-Hexahedron1, (2) Rough end-milling for Step1, (3) Rough end-milling for Slot1, (4) Finish end-milling for Slot1, (5) Rough end-milling for Linear-Chamfer1, (6) Drilling for Hole1, (7) Reaming for Hole1, (8) Drilling for Hole2, (9) Reaming for Hole2. Then machine tools are selected for this plan according to a criterion such as minimum production time or minimum production cost. The calculation according to the above two criterion can be performed using the following two equations, which are well explained in the Reference [1].

$$t_{pr} = t_{m(n)} + t_h + t_t(t_{m(n)}/t) \tag{12}$$

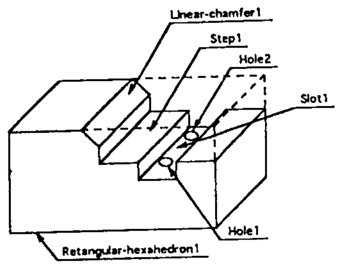

Figure 2. An example part

where t_{pr} is the processing time per component, $t_{m(n)}$ is the machining time of multipass, t_h is the material handling time, t_t is the tool change time, and t is the tool life.

$$C_{pr} = (C_b/N_b) + C_m[\ t_{m(n)} + t_h + (t_t + C_r/C_m)\ (t_{m(n)}/t)\ ]\ , \qquad (13)$$

where C_{pr} is the production cost per component, C_b is the set-up cost for a batch, N_b is the batch size, C_m is the total machine and operator rate, and C_r is the tool cost.

In machine selection, the relationship between machine tools and operations in Table 1 is used. The optimal process plan according to the criterion of minimum production cost is generated as the Figure 3.

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PROCESS PLAN OF :
Part-Name  = BLOCKH          Part-Number = 50191
------------------------------------------------
[1] Feature: RECTANGULAR-HEXAHEDRON1
      *Operation: ROUGH-FACE-MILLING
      *Machine: VERTICAL-MILLING-MACHINE
    Tool=3.0 Speed=380.0 Feed=0.0096 Depth=0.12
    (Expected-time = 8.82  Expected-cost = 26.49)
[2] Feature: STEP1
      *Operation: ROUGH-END-MILLING
      *Machine: VERTICAL-MILLING-MACHINE
    Tool=2.0 Speed=80.0 Feed=0.004 Depth=0.1
    (Expected-time = 11.29  Expected-cost = 33.91)
[3] Feature: SLOT1
      *Operation: ROUGH-END-MILLING
      *Machine: VERTICAL-MILLING-MACHINE
    Tool=0.75 Speed=80.0 Feed=0.0032 Depth=0.1
    (Expected-time = 2.63  Expected-cost = 7.9)
[4] Feature: SLOT1
      *Operation: FINISH-END-MILLING
      *Machine: VERTICAL-MILLING-MACHINE
    Tool=0.75 Speed=84.0 Feed=0.0024 Depth=0.024
    (Expected-time = 2.03  Expected-cost = 6.1)
[5] Feature: LINEAR-CHAMFER1
      *Operation: ROUGH-END-MILLING
      *Machine: VERTICAL-MILLING-MACHINE
    Tool=0.75 Speed=80.0 Feed=0.0032 Depth=0.1
    (Expected-time = 1.82  Expected-cost = 5.47)
[6] Feature: HOLE1
      *Operation: DRILLING
      *Machine: RADIAL-DRILLING-MACHINE
    Tool=0.875 Speed=68.0 Feed=0.0127 Depth=0.0
    (Expected-time = 1.22  Expected-cost = 1.24)
[7] Feature: HOLE1
      *Operation: REAMING
      *Machine: RADIAL-DRILLING-MACHINE
    Tool=1.0 Speed=40.0 Feed=0.01 Depth=0.0
    (Expected-time = 0.72  Expected-cost = 0.72)
[8] Feature: HOLE2
      *Operation: DRILLING
      *Machine: RADIAL-DRILLING-MACHINE
    Tool=0.875 Speed=68.0 Feed=0.0127 Depth=0.0
    (Expected-time = 0.59  Expected-cost = 0.6)
[9] Feature: HOLE2
      *Operation: REAMING
      *Machine: RADIAL-DRILLING-MACHINE
    Tool=1.0 Speed=40.0 Feed=0.01 Depth=0.0
    (Expected-time = 0.72  Expected-cost = 0.72)
------------------------------------------------
Expected-total-time = 29.84
Expected-total-cost = 83.14
(0.0's of some specs represent inapplicable specs.)
(Unit: Tool: inch  Speed: feet/min  Feed: inch/rev
      Depth: inch  Time: min       Cost: dollar )
================================================
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Figure 3. Process plan of the example part according to minimum production cost

Table 1. Machines and their operations used for process planning in the example

Machines	Possible Operations (simplified for the example)
Upright drilling machine	drilling, reaming
Radial drilling machine	drilling, reaming
Engine lathe	drilling, reaming, boring
Production lathe	drilling, reaming, boring
Horizontal milling machine	drilling, face-milling, end-milling, reaming, boring
Vertical Milling machine	drilling, face-milling, end-milling, reaming, boring

6. CONCLUSIONS

The assignment of machine tools is not a simple problem in process planning. In the existing CAPP systems, the machine selection problem is not dealt with in a structured and formulated manner, and the used machine selection method was not complete. In this research, at first, the fully general machine selection problem was modeled and formulated formally, and its characteristics were illustrated. As its result, the general machine selection problem can not be dealt with without simplification. So, some simplifying methods for the machine selection were developed and an example was shown. The proposed simplifying methods were effective and practically applicable for CAPP.

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