SOME PROCESS PLANNING ISSUES IN A CAD/CAM MODEL FOR SPARE PARTS MANUFACTURING

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ABSTRACT

A CAD/CAM prototype model has been proposed in a previous work , to provide solutions for some problems encountered with spare part manufacturing. As a multi-phase system, the core and the primary integrating tool of the previous model is the process planning phase. A modular analysis of an automated process planning system is introduced here. Three sub-system modules are analyzed and demonstrated to tackle basic process planning practices, namely: Basic Part Analysis (BPA) module, Tool-Machine Combination (TMC) Selection module, and Operation Alternative Selection (OAS) module.

Keywords: *CAD/CAM- CAPP - Computer Integrated Manufacturing Systems.*

1. BACKGROUND

Spare parts production is of special nature in the manufacturing industries of the periphery (developing) countries[1]. Emphasizing the characteristics of manufacturing systems in periphery countries combined with features of this type of production, an earlier paper pointed out the lack of integration between the different aspects of the product development cycle, from one side, and the non existence of documentation, from the other side [2].

In this respect, a comprehensive prototype CAD/CAM system is proposed to deal with the problem, as illustrated in Figure (1). In conjunction with the production cycle, the system has four distinct phases (Stages); namely: design, planning, manufacturing, and inspection. The title of each stage looks familiar, however, the procedural knowledge and the logic steps to construct the system is totally distinct ,since it is tailored to fit the special type of input for the spare part problem. The design phase in the proposed system starts from a physical sample component which is required to be manufactured.

A hybrid 3-D digitization system is used to collect, interpret, and convert the necessary component data into readable format through a generic object modeler and viewer. Common design procedures are performed next (e.g. redesign, material determination, tolerencing, dimensioning schemes, and the production of part files having IGES format). Also suggested is the framework of process planning routines which adopts inputs from the design phase via data interface. A technique which is similar to the one reported in [3] is implemented, thus allowing an integration between the two consecutive phases; design and planning.

Since many of the problems related to spare part manufacturing are attributed to inconsistent planning environment, the work addressed here focuses on detailed analyses of some process planning functions. In a CAD/CAM model, process planning activities form the core of the system. Thus, a systematic implementation of a modular (CAPP) system leads to direct solution for the problem of lack of documentation attached to spare part manufacturing in developing countries.

Among the process planning tasks, converting the component design data to operation interpretable information is essential. Attempts have been made in this regard [4,5 and 6], but little work consider a hierarchical approach to analyze the part and component elements down to its basic operation features[7]. On the other hand, some of the developed (CAPP) systems incorporate tool/machine selection and operation alternative modules. However, few of these systems consider elements of the operation through-put (lead) time as a direct criterion for decision making at early planning stages [8,9]. In the next sections of this paper , three basic process planning modules will be discussed, namely: Basic Part Analysis (BPA) module, Tool-Machine Combination (TMC) Selection module, and Operation Alternative Selection (OAS) module.

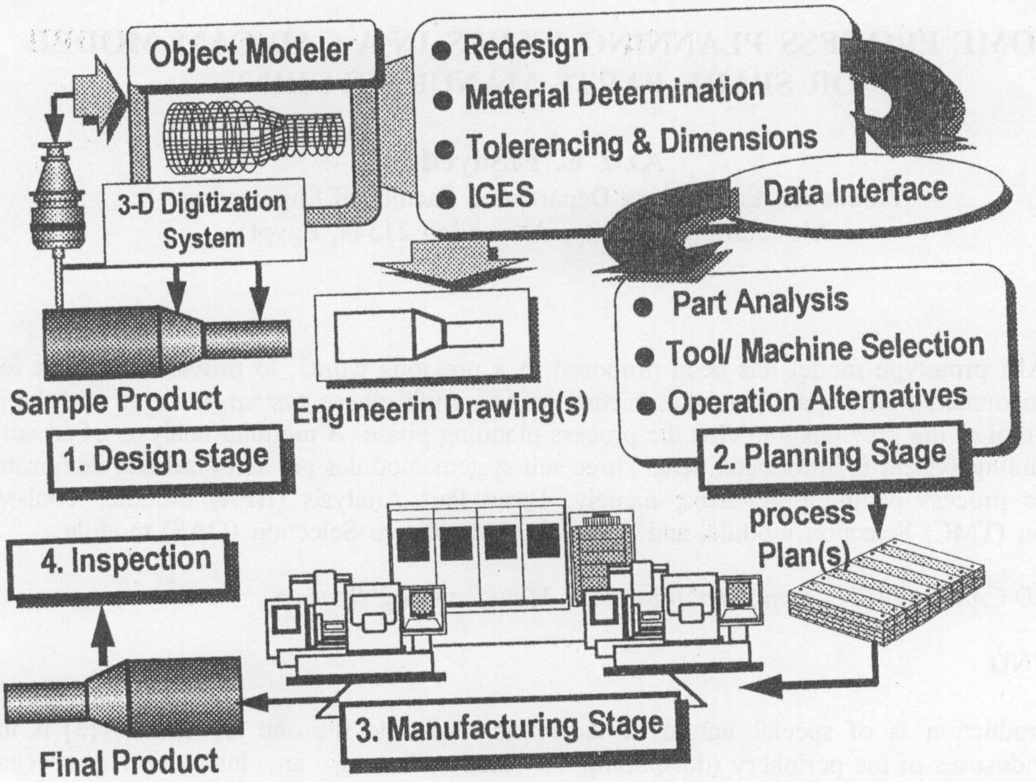


Figure (1). A prototype CAD/CAM Model for Spare parts Manufacturing [2].

2. BASIC PART ANALYSIS (BPA) MODULE :

Basic part models are usually the output from the design phase. The output could be feature-based CAD representation, or any other primitive-dependent form. In any case, a process planning system must receive inputs in the form of manufacturing related data (i.e. operation/process elements) rather than design (i.e. part/component elements) format. Whether it is a module of the design system or a preliminary procedure in the process planning phase, such a conversion is necessary. A generic representation of that concept is shown in Figure (2), where an example part is disassembled to its basic components (sub-assemblies).

The sub-assemblies are then analyzed to basic geometric elements. The analysis is hierarchically displayed in Figure (3). Besides the part (P), the components (C_n), and the component elements (E_i), one more level is added to the arrangement , i.e. the operation level (F_i). A mapping transformation between the component elements space (P) to the operation element space (H), as shown in Figure (4), would be done through the relationship depicted in (1).

$$\text{For Each } E_i \in H \rightarrow \exists \text{ only one } F_i \in P \qquad (1)$$

In the system proposed here, a dis-aggregation procedure for the part down to its basic operation elements (F_i) is considered the input to any consequent process planning activity.

Figure (5) depicts an interpretation of the conversion procedure, as presented by the relationship (1). The shown sample component has the component elements $\{E_1, E_2, E_3, E_4\}$, and they are transformed to $\{F_1, F_2, F_3, F_4\}$.

3. TOOL - MACHINE COMBINATION (TMC) SELECTION MODULE:

Selecting suitable machines and adequate tools, to produce a specific component part, are basic process planning routines. The following procedure is suggested within the system to tackle this problem. Let (M) be the set of all machines available in the manufacturing system, and (L) is the set of all tools (L). For a certain element (F_i), only a specific number of tools, among the set of all tools (L), would be appropriate.

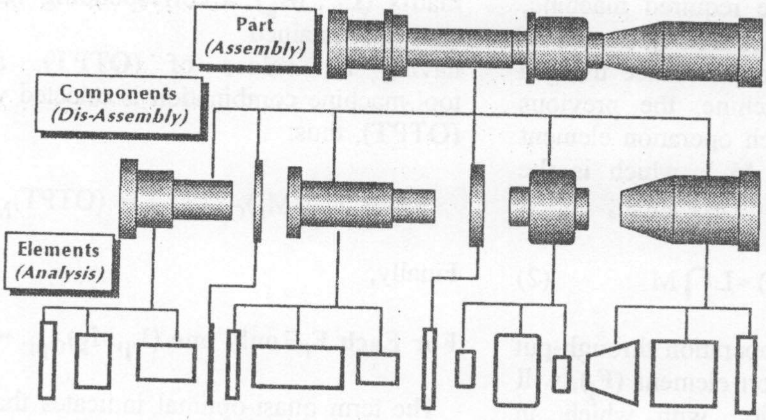


Figure (2). A generic Part Assembly, Components, and Elements

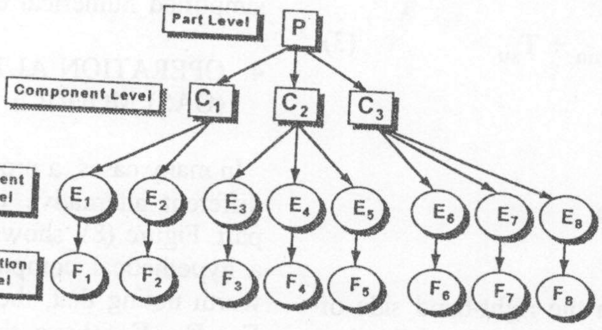


Figure (3). Part Analysis and Planning Levels

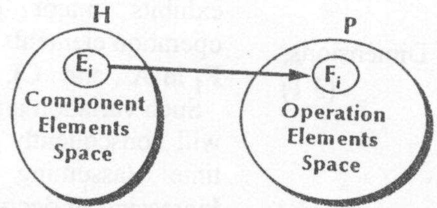


Figure (4). Component Element Space and Operation Element Space

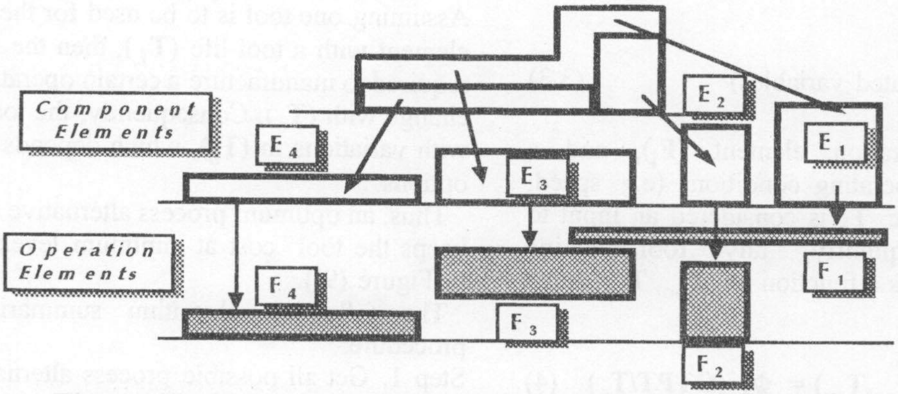


Figure (5). Example Component and Operation Elements

Such a situation is true for the required machine, because only a number of machines among the set of all machines (M) would be suitable. Since using a tool is always related to a machine, the previous analysis is summarized as; for each operation element (F_i), there exist a matrix (L_j , M_k) ,which is the intersection of the two sets (L) and (M), thus ;

$$\textbf{For Each } F_i \ \exists (L_j, M_k) = L \cap M \tag{2}$$

As illustrated in Figure (6),the operation through-put time (**OTPT**) for a given operation element (F_i), will be used as the decision criterion with which an optimum combination of (L_j , M_k) could be selected. A representation of (**OTPT**) is given as:

$$\mathbf{OTPT} = T_o + T_{no} + T_{su} \tag{3}$$

where ;

T_o = Operation time
T_{no} = Non-Operation time
and,T_{su} = Set-up time

Each of the time elements on the right-hand side of relationship (3) could be interpreted in the following functional sub-relationships:

$$T_o = \Phi_1(\text{Operating Conditions, Element Dimensions, etc.}) \tag{3.1}$$

Also,

$$T_{no} = \Phi_2 \ (\text{Mainly tool related parameters}) \tag{3.2}$$

and,

$$T_{su} = \Phi_3 \ (\text{Machine related variables}) \tag{3.3}$$

For a specific operation element (F_i), and a recommended set of operating conditions (e.g. speed, feed), T_o is constant, i.e. T_o is considered an input to the system. Consequently, any tool-machine combination (L_j , M_k) is a function of (T_{no}, T_{su}), such that:

$$(L_j, M_k) = \Phi_4 \ (T_{no}, T_{su}) = \Phi_5 \ (\mathbf{OTPT}/T_o) \tag{4}$$

Expression (4) indicates that for each element in the matrix (L_j , M_k), a corresponding value for (**OTPT**) could be obtained.

having all values of (**OTPT**), a quasi-optimal tool-machine combination is selected which minimizes (**OTPT**), thus;

$$(L_j, M_k)_{\text{Optimum}} \rightarrow (\mathbf{OTPT})_{\text{Minimum}} \tag{5}$$

Finally,

$$\textbf{For Each } F_i \exists \textbf{ only one } (L_j, M_k)_{Opt} \rightarrow (\mathbf{OTPT})_{\mathbf{Min}} \tag{6}$$

The term quasi-optimal indicates that the problem is solved assuming no constraints.

Figure (7) illustrates the previous procedure with a simplified numerical example.

4. OPERATION ALTERNATIVE SELECTION (OAS) MODULE:

In many cases, a process planner has to decide among different alternative routes to manufacture a specific part. Figure (8) shows four distinct options to produce a hypothetical component, namely; A,B,C, and D. It worth noting that, the four component elements { E_1, E_2, E_3, E_4 }have the corresponding four operation elements {F_1, F_2, F_3, F_4 }. However, the hatched areas exhibits major discrepancies between the same operation elements among the different alternatives (e.g. F_1 in A , and C).

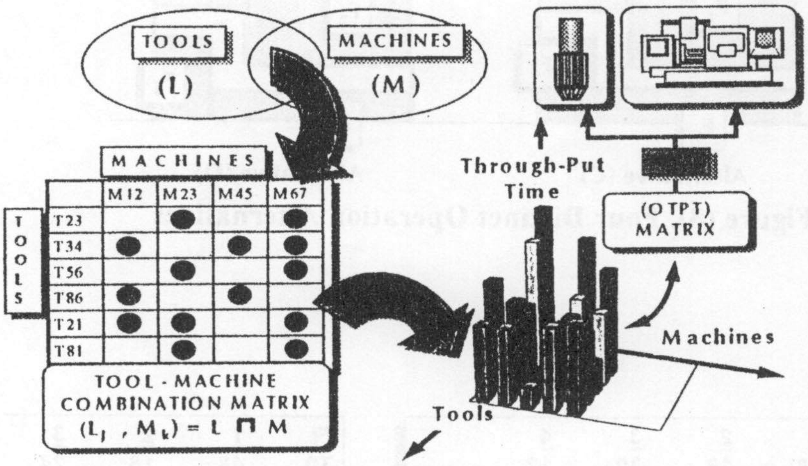
Such variation among the same operation element (F_i) will consequently alter the material removed per unit time (assuming constant operating conditions). Increasing or decreasing the volume removed (again at constant operating conditions) will increase or decrease the operating time (T_o) for each operation element. Assuming one tool is to be used for the same operation element with a tool life (T_L), then the number of tools required to manufacture a certain operation element will change with (T_o). Consequently, the tool cost will vary with variations in (T_o), which depends on the different options.

Thus, an optimum process alternative is the one which keeps the tool cost at minimum levels (Alternative C in Figure (9)).

The following algorithm summarizes the above procedure:

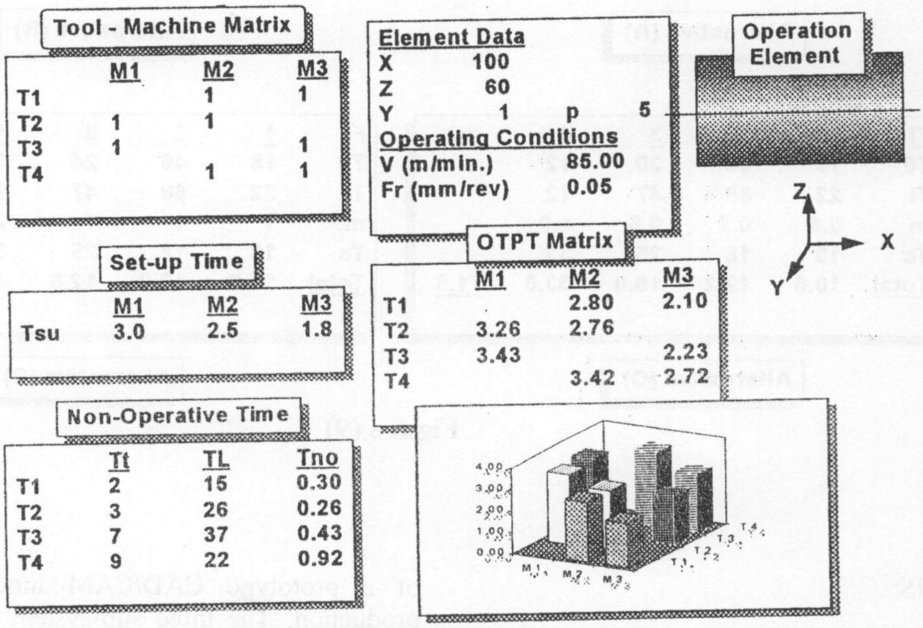
Step 1. Get all possible process alternatives (q)
Step 2. For each (q), obtain (F_i) for i = 1,2, ..., n
where n = number of operation elements
Step 3. Set **q** = 1

Step 4. Calculate (T_O) for each (F_i)
Step 5. Get (Estimate) (T_L) for each (F_i)
Step 6. Having Tip cost, calculate Tool Cost for each (F_i)
Step 7. Sum Tool cost (TTC) for (q)
Step 8. Repeat steps from 3 to 7 for q = q+1
Step 9. Find Lowest Value of (TTC)
Step 10. Stop



	M12	M23	M45	M67
T23		●		●
T34	●		●	●
T56		●		●
T86	●		●	
T21	●	●		●
T81		●		●

Figure (6). Tool-Machine Combination Selection Procedure



Tool - Machine Matrix

	M1	M2	M3
T1		1	1
T2	1	1	
T3	1		1
T4		1	1

Set-up Time

	M1	M2	M3
Tsu	3.0	2.5	1.8

Non-Operative Time

	Tt	TL	Tno
T1	2	15	0.30
T2	3	26	0.26
T3	7	37	0.43
T4	9	22	0.92

Element Data

X 100
Z 60
Y 1 p 5

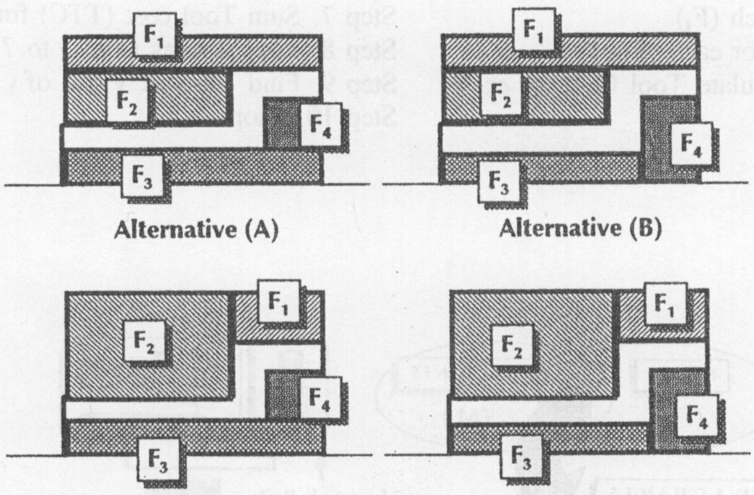
Operating Conditions

V (m/min.) 85.00
Fr (mm/rev) 0.05

OTPT Matrix

	M1	M2	M3
T1		2.80	2.10
T2	3.26	2.76	
T3	3.43		2.23
T4		3.42	2.72

Figure (7)



Alternative (A)

Alternative (B)

Alternative (C)

Alternative (D)

Figure (8). Four Distinct Operation Alternatives

Fi	1	2	3	4	
T0	48	16	30	12	
Tl	22	68	47	12	
m	2.2	0.2	0.6	1.0	
Tc	13	18	25	33	
Total	28.4	4.2	16.0	33.0	81.6

Alternative (A)

Fi	1	2	3	4	
T0	48	16	24	18	
Tl	22	68	47	12	
m	2.2	0.2	0.5	1.5	
Tc	13	18	25	33	
Total	28.4	4.2	12.8	49.5	94.9

Alternative (B)

Fi	1	2	3	4	
T0	18	46	30	12	
Tl	22	68	47	12	
m	0.8	0.7	0.6	1.0	
Tc	13	18	25	33	
Total	10.6	12.2	16.0	33.0	71.8

Alternative (C)

Fi	1	2	3	4	
T0	18	46	24	18	
Tl	22	68	47	12	
m	1	1	1	2	
Tc	13	18	25	33	
Total	10.6	12.2	12.8	49.5	85.1

Alternative (D)

Figure (9)

5. CONCLUSIONS:

This paper exhibits three functional modules of an automated process planning system, which is the core of a prototype CAD/CAM model for spare part production. The three sub-system modules are: Basic Part Analysis (BPA) module, Tool-Machine Combination (TMC) Selection module, and Operation alternative Selection (OAS) module. Hierarchical dis-aggregation of part into components and operation elements is utilized as means to provide data to the succeeding planning functions. Analytic approaches (operation through-put time, tool cost) were presumed as decision criteria for direct selection of tool-machine combination(s), and operation alternatives to manufacture a given component part. More future realistic formulation of the previous models would consider linkage to comprehensive data and knowledge base interfaces. Also, the addition of other basic process planning routines (e.g. operation sequence selection module) is forthcoming.

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