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Evaluation and Derivation of Process Plans in Turning

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The objective of this paper is to formalize process planning selection to minimise the total processing time and the total number of processing steps. The study is performed by defining the processes and part description for turned parts. Two examples solved by the two proposed methods are reported. One of them is the derivation of a new plan which can be expressed as a function of the generated plans. The second method is based on the combination of process plans to generate a new plan which conforms optimally to the change in specification.

Keywords: Process plans; Turned components

1. Introduction

Process planning (PP) is the preparation of detailed operation instructions to transform an engineering design into a final part. The detailed plan contains the route processes, process parameters, machines and tools required for production [1]. Computer aided process planning (CAPP) systems based on the use of computer programs permit the generation of consistent and optimal manufacturing procedures and routes [2]. CAPP represents a major step towards bridging the gap between the design and the manufacture of a component [3].

The two principal types of CAPP systems are the "retrieval system" and the "generative system". In the former system, each part is classified based on a number of attributes, and is coded using a classification and coding system. The code and the process plan for each part are stored in a database. When it is required to generate a process plan for a new part, the part is coded and a process plan for a part similar to the new part is retrieved from the database. The retrieved process plan is modified if necessary. In the generative system, there are no process plans stored in the database. Instead, the database contains information about parts, machines, tooling, and process planning rules. Using this information, a generative process planning system creates the required process plan [4].

In order to perform the process planning activities, a process planner must be able to understand and analyse part requirements, and have extensive knowledge of machine tools, cutting tools and their capabilities. The planner must also understand the relationships between the part, the manufacturing quality and the cost [5]. One of the problems linking process planning with production planning and scheduling is the problem of selecting process plans [6].

In the field of turning operations, there are several alternatives for the planning of the machining sequence and its optimisation because of the possible use of different workpiece positioning, and clamping methods and the availability of several machining methods [7]. Korde et al. [8] present an approach for turned parts using fundamental and heuristic principles. The motivation for this approach is to make the required knowledge explicit and establish a structure, so that an analysis of why the system accepts or rejects a process plan can be performed. Yeo et al. [9] employ an expert system technique to provide a machining knowledge-based model that integrates the processes and constraints of manufacturing for the production of rotational parts. They aimed to integrate and automate operation planning, machinability data selection and NC code generation activities.

This paper addresses the rational choice of a process plan or route from several alternative plans in turning. The ability to select a particular process plan and rank with it alternative plans related to their advantages is helpful for parts scheduling in workshops. The scheduler can have the flexibility of choosing an alternative process plan if a particular process plan is unsuitable.

2. Problem Description

2.1 Process Constraints

One advantage of this method of process planning is the ability to generate an optimal sequence which is difficult in a

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real manufacturing environment. The sequence generated is near optimal when it is successful in minimising the number of set-ups and minimising the number of tool changes. There are basically two types of constraints: geometrical and technological. Geometrical constraints are those constraints which can be identified by the geometric relations between features; technological constraints are those due to power consumption, cutting force, etc. Also, there are constraints related to the deflection of the workpiece which can be used to determine the workpiece fixing method.

2.2 The Knowledge Base for a Process Plan

Process knowledge is knowledge about the capability of a manufacturing process. The machine and tool are the means for carrying out the manufacturing process. Therefore, the manufacturing process is influenced by the tool and machine. The following list summarises the most important parameters for a process plan:

The shape and size of the workpiece to be produced.

The dimensions and geometrical tolerances that can be obtained by the process.

The process constraints both geometrical and technological.

The economics of the process.

The work can be organised on four bases, each concerning an aspect of the decisions for process planning for turning (as in Fig. 1):

1. General basis. This considers the possibility of producing plans for the actual workpiece with the selected machine tool.
2. Criteria basis. This has been introduced to avoid the system trying too many ways among all the possible solutions as follows:

Machining the location surfaces first. In the case of a shaft, the two end faces and central holes should be machined first.

Machining all the roughing operations first because the relatively heavier cutting force and higher clamping forces in roughing tend to deform the component.

Carrying out as much machining as possible at one setting and avoiding unnecessary repositioning of the work, since this can be a very time consuming business.

Carrying out as much machining as possible with each cutting tool called, avoiding unnecessary tool changing or indexing.

3. Clamping basis. This allows the selection of different clamping possibilities by analysing all the possible workpiece clamping surfaces and checking the stiffness in each case.
4. Feasibility basis. This examines the possibility of machining every required surface, according to its geometry, the selected clamping, the geometry of the adjacent surfaces and the positional tolerances.

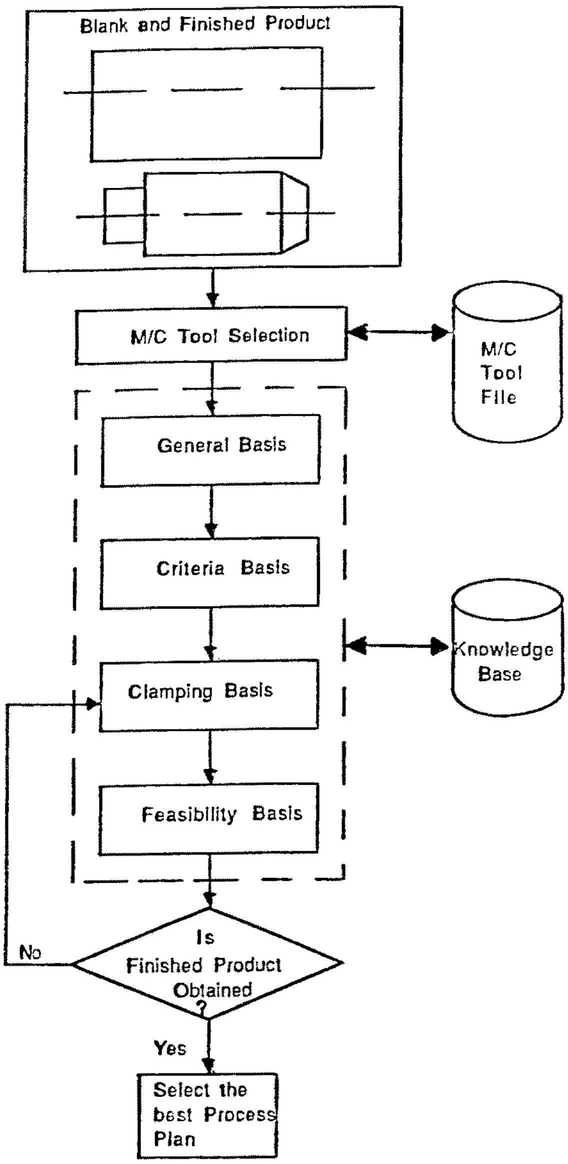

Fig. 1. Flowchart for machining plan generation.

3. Generation and Evaluation of the Problem

If it is assumed that there are n process plans $A_1, A_2, \ldots, A_n$ together with a set of criteria $C_1, C_2, \ldots, C_m$ and it is required to generate one or more process plan(s) from such plans which is (are) acceptable with respect to the given criteria. Thus can be realised by comparison of the existing process plans or by generation of the process plan(s). The choice of the best process plan can be performed according to the following steps:

Step 1: Define the criteria basis used for the product.

Step 2: Generate the process plan(s) showing the number of clamping positions used and the reference surface.

Step 3: Construct a separate network for each plan showing the machining route, then combine all of them in one network.

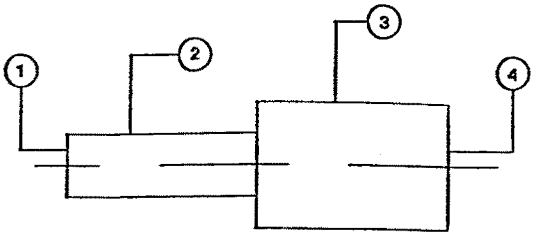

Fig. 2. Workpiece example 1.

Step 4: Calculate the number of set-ups, number of tools used and machining time for each route, then compare different network routes related to the desired criteria basis.

Step 5: Simplify the connections (eliminate loops) and obtain the best process plan which is a combination of the different plans.

The best plan must be selected related to the maximum production rate or minimum machining time criteria.

To demonstrate the above methodology, an example for a turned part which has four features is illustrated in Fig. 2. It is required to generate a process plan for this workpiece.

4. Solution Strategy and Results

In the absence of constraints, many alternative process plans can be generated. When the knowledge basis is applied, the number of the generated process plans will be reduced. In the present study, the strategy of generating the process plans is based on an analysis of all the surfaces which can be clamped and allows the generation of more than one plan. It is also required to select a process plan from alternative plans so as to minimise the total process time and total number of process steps and the dissimilarity between the selected plans.

These process plans are generated by determining the clamping surface and the operations to be performed related to this clamping. In the present example, related to the number of surfaces which can be clamped, three different process plans are generated which are summarised in Tables 1, 2 and 3. The first process plan can be obtained as follows (Table 1). Clamping of surface (3) allows the facing operation for surface (1) and the roughing operation for surface (2) to be performed. Rechucking occurs and the workpiece is clamped on surface (2), which allows surface (4) and (3) to be machined. Finally, the workpiece is held between centres for finishing profiles (2 and 3). In each of the process plans, it is important to know how many times the tools are changed. A similar procedure can be used for the other two process plans (Tables 2 and 3).

Table 1. Process plan 1; Example 1.

Reference surface	Operation	Notes
Clamping surface (3)	Facing end (1)	Call facing tool and facing cutting parameters
	Rough tuen (2)	Change tool and cutting parameters (roughing)
Clamping surface (2)	Facing end (4)	Change tool and cutting parameters (facing)
	Rough turn (3)	Change tool and cutting parameters (roughing)
Between centres	Finishing profile (2) and (3)	Change tool and cutting parameters (finishing)

Table 2. Process plan 2; Example 1.

Reference surface	Operation	Notes
Clamping surface (3)	Facing end (1)	Call facing tool and facing cutting parameters
Clamping surface (2)	Facing end (4)	
Between centres		Change tool and cutting parameters (roughing)
	Rough turn (2) Rough turn (3)	
	Finishing profile (2) and (3)	Change tool and cutting parameters (finishing)

Table 3. Process plan 3; Example 1.

Reference surface	Operation	Notes
Clamping surface (3)	Facing end (1)	Call facing tool and facing cutting parameters
Clamping surface (2)	Facing end (4)	
	Rough turn (3)	Change tool and cutting parameters (roughing)
Between centres	Rough turn (2)	
	Finishing profile (2) and (3)	Change tool and cutting parameters (finishing)

A separate network for each process plan is then constructed as shown in Fig. 3. Finally all the networks are combined in one network as shown in Fig. 4. Construction of the network, starts by viewing an activity as a straight line, between two events (circles). The first activity is placed at the lefthand side of the network and is followed by other activities in a certain sequence. The network proceeds until all the activities and events are depicted. After the network has been constructed and the different activities have been defined, the time needed for these activities must be estimated. Each activity in the network represents a call for tool or a cutting operation or a tool change. A list of the activities showing their sequence and description as well as their estimated times is given in Table 4. The elapsed time is calculated by the summation of all activity times in each plan route.

Comparison of the three different process plans is carried out as shown in Table 5. This comparison shows that plan 2 is the best one because it satisfies the required constraints. The next best is plan 1 and the third is plan 3. Comparing

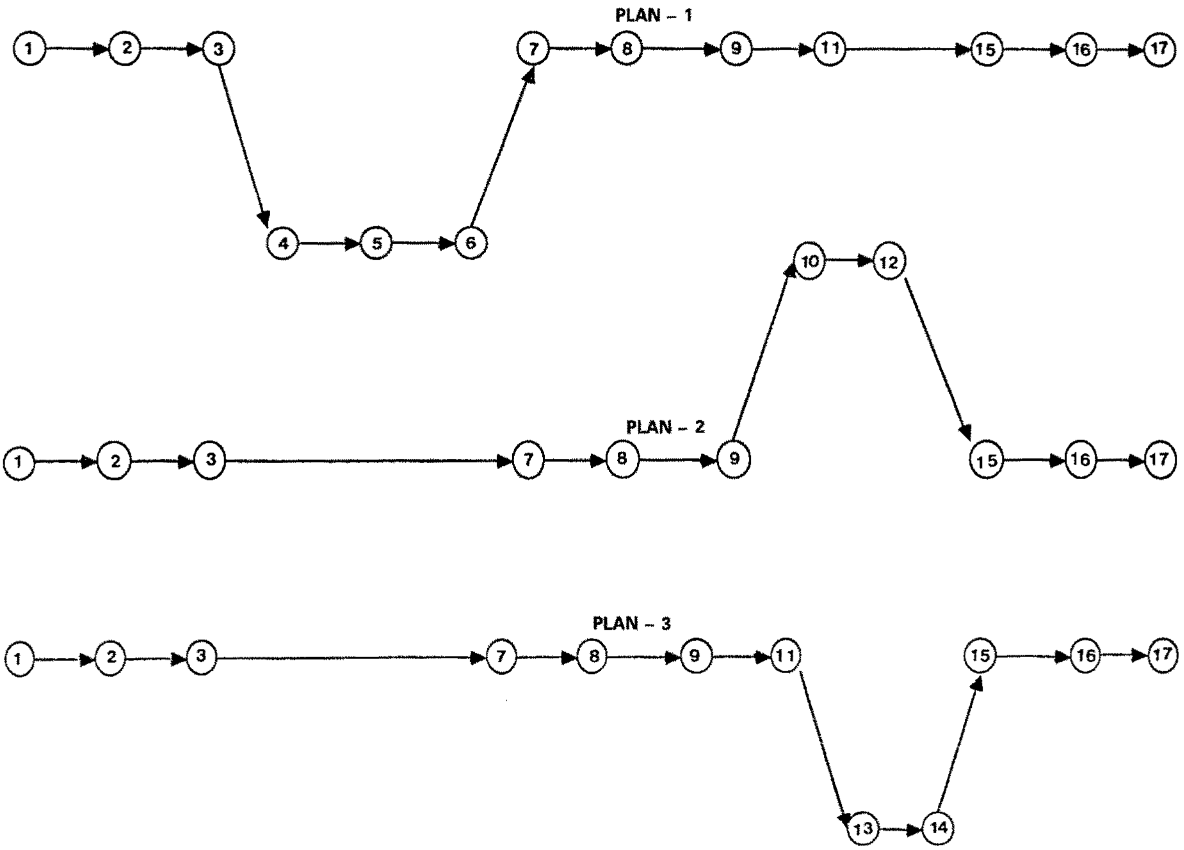

Fig. 3. Three network plans.

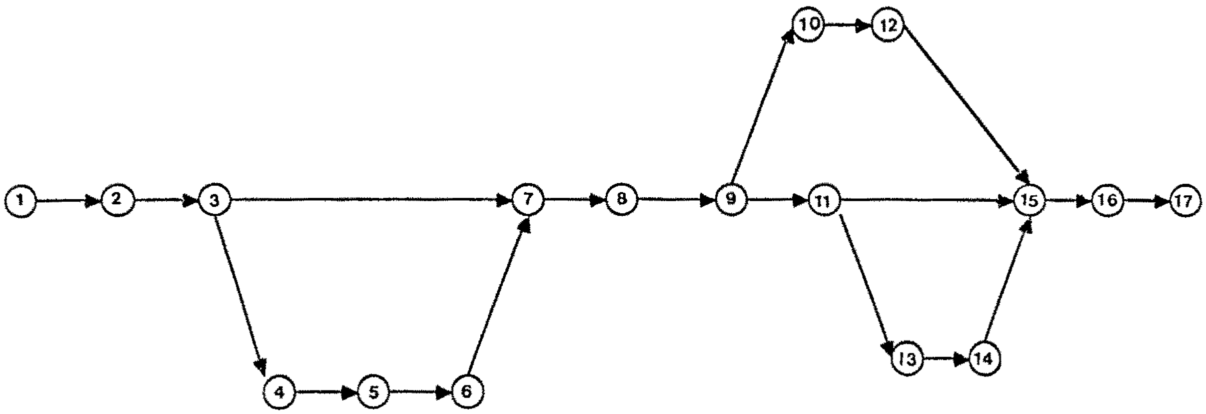

Fig. 4. One network for three plans.

the worst plans (plan 1 and plan 3) related to the conjunction nodes 3, 9 and 11 and simplifying the loops 3–4–5–6–7–3 and 11–13–14–15–11, a new route is obtained which is 1–2–3–7–8–9–10–12–15–16–17. This route is the route of plan 2, this means that, plan 2 is a function of both plans 1 and 3 and it can be formulated as:

$$P2 = f\{P1 \,\&\, P3\}$$

The above formulation can be generalised for n generated process plans of a workpiece, which means that the best plan is a function of two or more plans related to the defined constraints.

It will be necessary to apply further evaluation criteria when some features can be machined in more than one step. The evaluation aspect and conflict between different evaluation criteria should be developed to achieve more industrial relevance. This can be achieved in principle as follows:

The access principle which refers to the standard method for removing material as indicated by the feature. For example, when a face is a combination of two adjacent turned diameters on either side, then the access precondition requires the machining of either of the turned diameters to access the face.

Table 4. Description of network activities.

Activity	Description of activity	Estimated time (min.)
1– 2	Call facing tool and cutting parameters	1
2– 3	Facing end 1	2
3– 4	Change tool and cutting parameters – rough	1
3– 7	Change workpiece position (re-chucking)	5
4– 5	Rough surface 2	7
5– 6	Change workpiece position (re-chucking)	5
6– 7	Change tool and cutting parameters – facing	1
7– 8	Facing end 4	2
8– 9	Change tool and cutting parameters – rough	1
9–10	Change workpiece position – between centres	5
9–11	Rough surface 3	4
10–12	Rough surface 2	7
11–13	Change workpiece position (re-chucking)	5
11–15	Change workpiece position – between centres	5
12–15	Rough surface 3	4
13–14	Rough surface 2	7
14–15	Change workpiece position – between centres	5
15–16	Change tool and cutting parameters – finishing	1
16–17	Finishing profile 2 and 3	3

Table 5. Comparison between 3 plans.

Comparison factor	PP 1	PP 2	PP 3
Route	1–2–3–4–5–6–7–8–9–11–15–16–17	1–2–3–7–8–9–10–12–15–16–17	1–2–3–7–8–9–11–13–14–15–16–17
Set-up	3	3	3
Tools used	5	3	3
Time (min.)	33	31	36

The non-destructive constraint which can be stated as the next machining operation should not destroy the required properties of previously machined features; e.g. a thread should not be machined before an adjacent chamfer or its parent turned-diameter.

The required holding principle states that a part should be held so that all the features can be machined to meet the required specification. The required holding constraint refers to the order in which the features should be machined as dictated by the tolerance and the datum specifications for the part.

5. New Process Plan Generation

Suppose there are two process plans A and B, ranked 1 and 2, respectively, based on some given criteria C. Now, if the criteria changes from C to new criteria D, the process plans A and B may not be optimum related to the new criteria D, so it is required to generate new process plan(s) from the given plans A and B which is (are) feasible and good related to criteria D.

5.1 Methodology

Step 1. Analyse the new criteria and determine the effective factors.

Step 2. Analyse the existing process plans and determine the weak points related to the new criteria.

Step 3. Combine the existing process plans using their advantages related to the new criteria and try to cover their weak points by generating the new process plan (an analysis table can be built up to assist). If there are *n* process plans, simplify the problem by reducing the number of plans one by

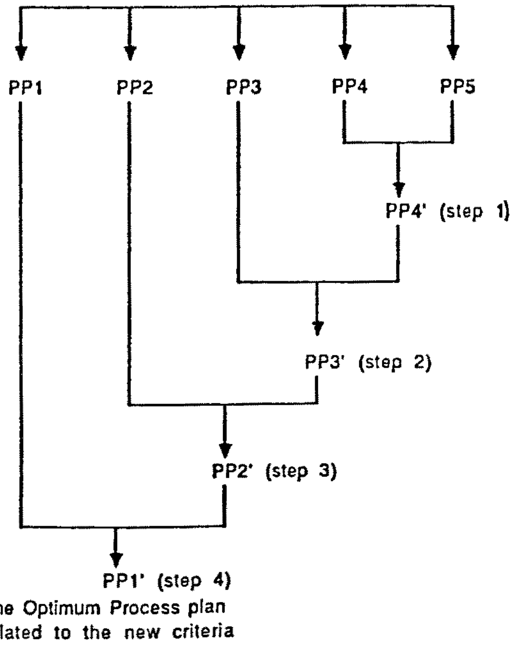

Fig. 5. Combination of process plans.

one starting from the last in rank to generate the new one as shown in Fig. 5.

Step 4. Check the feasibility basis of the new process plan related to the new criteria by examining the possibility for each feature to be held so that the feature under consideration can be machined according to the specifications required.

5.2 Demonstration

An example of this process plan generation is shown in Fig. 6. Two process plans are generated for this workpiece as mentioned before, plan A and plan B, see Tables 6 and 7, respectively. These two process plans, ranked 1 and 2 respectively, are based on the criterion "Carry out as much machining as possible at each setting and avoid unnecessary repositioning of the workpiece". If the criterion changes to: "Carry out as much machining as possible with each cutting tool called and avoid unnecessary tool changing or indexing", then the two process plans A and B are not the best related to the new criteria. Generating a new process plan following the last methodology can be carried out by an analysis of the new criteria.

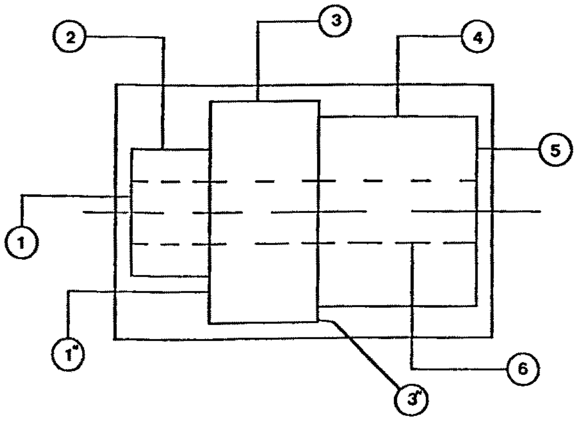

Fig. 6. Workpiece example 2.

Table 6. Process plan A.

Reference surface	Operation	Notes
Clamping surface (1)	1. Rough facing surface 5	
	2. Rough turning surface 3	
	3. Rough turning surface 4	
		Change tool
	4. Drill hole no. 6	
		Change tool
	5. Ream hole no. 6	
		Change tool
	6. Finish facing surface 5	
	7. Finish facing surface 3″	
	8. Finish turning surface 3	
	9. Finish turning surface 4	Change tool
Clamping surface (4) or (3)	1. Rough facing surface 1	
	2. Rough turning surface 2	
		Change tool
	3. Finish facing surface 1	
	4. Finish surface 1″	
	5. Finish turning surface 2	

Table 7. Process plan B.

Reference surface	Operation	Notes
Clamping surface (4)	1. Rough facing surface 1	
		Change tool
		Change tool
	2. Drill hole no. 6	
	2. Rough turning surface 3	
	3. Rough turning surface 2	
Clamping surface (2)	1. Rough facing surface 5	
	2. Rough turning surface 4	
		Change tool
	3. Finish facing surfrace 5	
	4. Finish facing surface 3″	
	5. Finish turning surface 4	
Clamping surface (3)		Change tool
	1. Ream hole no. 6	
		Change tool
	2. Finish facing surface 1	
	3. Finish facing surface 1″	
	4. Finish turning surface 2	
	5. Finish turning surface 3	

It is found that the effective factor is to minimise the number of tools. By analysis of the two existing process plans, it is found that process plan A has 2 set-ups and 5 tool changes while process plan B has 3 set-ups and 5 tool changes. A combination of the two plans is performed related to the new criteria and a new process plan is produced as shown in Table 8. Table 9 represents an analysis table for generating a new process plan in which grouping and/or separating of machining operations related to the defined criteria are

Table 8. Process plan (new).

Reference surface	Operation	Notes
Clamping surface (3)	1. Rough facing surface 5 2. Rough turning surface 4	
Clamping surface (4)	1. Rough facing surface 1 2. Rough turning surface 3 3. Rough turning surface 2	
		Change tool
	4. Drill hole no. 6	
		Change tool
	5. Ream hole no. 6	
		Change tool
	6. Finish facing surface 1 7. Finish facing surface 1″ 8. Finish turning surface 2 9. Finish turning surface 3	
Clamping surface (3)	1. Finish facing surface 5 2. Finish facing surface 3″ 3. Finish turning surface 4	

Table 9. Analysis table for generating new process plan.

Analysis factors	Old plans analysis
Weakness of the existing plans w.r.t. the new criteria	Dividing a specific machining operation into several groups, requires the tool to be changed several times (as in roughing and finishing operations). This is done to comply with the old criteria.
The advantages of the existing plans related to the new criteria	There are no restrictions for machining any feature. The same machining operations can be grouped for all surfaces and performed in sequence; allowing the required tool to be used once.

discussed. The new plan depends on using each tool just once, starting with the roughing tool which did all the roughing operations, then the tool is changed for the drilling and reaming and finally the tool is changed for finishing the whole workpiece. The new process plan is feasible because the part can be held so that all the features can be machined to meet the required specifications and the geometrical precedences are satisfied (surface 3 can be machined before surface 2).

The new plan is also good related to the new criteria because the tool is changed 3 times only instead of 5 in the process plans A and B.

6. Conclusion

A process plan is a detailed specification of how material must be transformed to its finished form. The paper presents a strategy in which the process plan is generated based on the analysis of all the surfaces which can be clamped and allows the generation of more than one plan. A selection of a process plan for a turned part from alternative plans is demonstrated in which the total process time and total number of process steps and the dissimilarity between the selected plans has been minimised.

It is concluded that "if *n* process plans for a workpiece are generated, the best plan is a function of two or more of the plans related to the defined constraints". It is also found that the new process plan related to the new criteria is a combination of the proposed plans.

References

1. T. C. Chang and R. A. Wysk, *An Introduction to Automated Process Planning Systems,* Prentice Hall, NJ, 1985.
2. C. B. Besant and C. W. K. Lui, *Computer-Aided Design and Manufacture,* 3rd edition, Ellis Horwood Limited, 1986.
3. D. L. Goetsch, *Modern Manufacturing Process,* Delmar Publishers Inc., 1991.
4. S. Joshi, T. C. Chang and C. R. Liu, "Process planning formalization in an AI framework", *International Journal for Artificial Intelligence in Engineering,* **1**(1), 1986.
5. T. C. Chang, "Expert process planning for manufacturing", Addison-Wesley, 1990.
6. A. Kusiak, *Intelligent Manufacturing Systems,* Prentice Hall, Englewood Cliffs, NJ07632, 1990.
7. F. Giusti, M. Santochi and G. Dini, "KAPLAN: a knowledge-based approach to process planning of rotational parts", *Annals of the CIRP,* **38**(1), pp. 481–484, 1989.
8. U. P. Korde, B. C. Bora, K. A. Stelson and D. R. Riley, "Computer-aided process planning for turned parts using fundamental and heuristic principles", *Transactions of the ASME, Journal of Engineering for Industry,* **114**, pp. 31–40, February 1992.
9. S. H. Yeo, Y. S. Wong and M. Rahman, "Integrated knowledge-based machining system for rotational parts", *International Journal of Production Research,* **29**(7), pp. 1325–1337, 1991.