

## Machining processes time calculating tool integrated in computer aided process planning (CAPP) for small and medium enterprises (SMEs)

R. Blanch, N. Pellicer, M.L. G.-Romeu and J. Ciurana\*

Department of Mechanical Engineering and Industrial Construction, Universitat de Girona, Spain

(Received 16 May 2008; final version received 11 January 2010)

The goal of process planning is to propose route sheets for previously designed parts. Process planning provides detailed information about a sequence of operations and parameters (cutting speed, feed rate, etc.). The objective of this work is to present computer-aided software to calculate cutting time and unproductive time when machine operations are designed and its integration in computer-aided process planning (CAPP). Results obtained from this tool application are compared with those results obtained from CAM software and with real times from the machine operation. The aim of the designed system is to be useful for small and medium enterprises (SME) working on machining processes. These kinds of enterprises cannot acquire and maintain standard CAPP systems, which are usually very expensive and difficult to work on. In order to validate the results several parts will be planned and machined and results are compared in order to adjust the designed tool software.

**Keywords:** process planning; planning and production control; concurrent engineering tools

### Definitions

- Operation:** Ways to remove the material of the part (planning, turning . . .).
- Task:** This is the smallest complete portion of the machining process. It is completed without changes in the cutting tool, on the working surface or in the cutting speed or feed rate.
- Subphase:** Set of tasks carried out in the same clamping of the part.
- Phase:** Set of subphases carried out in a single working centre.
- Operations sheet (OS):** Document containing all the technical data of an operation, such as the feed rate, the depth, the tool rotation speed, etc.
- Route sheet (RS):** Document that shows the list of manufacturing tasks from the planning process of a part. Only the phases are detailed and the only piece of data shown is the production time.

### 1. Introduction

Process planning is used to explain all manufacturing operations with detailed information about processes parameters needed to turn from engineering design to

end product. Machining processes comprise the definition of information about machines, tools, fixtures and cutting parameters. In addition the operations should be ordered in a sequence to give the required final result. The information is known as route sheet and contains specific cutting speed, feedrate, and depth if machining processes are considered. (Gu and Norrie 1995).

A machining workshop normally deals with a great variety of manufactured parts, each one of them having a series of production requirements. The efficiency of this system can be improved with consideration of more alternative route sheets. Consequently, workshop production planning is easier if there is not just one but an entire set of them for each part (Dashora *et al.* 2008).

SMEs currently use the knowledge and experience of their engineers to do this (Guerra-Zubiaga and Young 2008). But there are implicit dangers in this way of working. One of them is in the use of traditional production methods, where engineers work mainly with familiar machines and tools, making it difficult to incorporate less commonly used elements into day-to-day operations. Another danger is the difficulty of comparing route sheets created by two separate people, since neither the nomenclature nor the traditional format are standardised.

The objective of creating a set of route sheets is not to invent extravagant ways of making a part, but to find the most suitable route sheet for each part at the

\*Corresponding author. Email: quim.ciurana@udg.edu

start of production, taking into account the current loads on machines and workers. That will make it easier correctly to distribute parts among machines and to meet the needs of each phase of the manufacturing process. This method will considerably increase workshop efficiency and market competitiveness. Process planning deals to help this task to select appropriate solution to obtain the part by relating design, manufacturing and production requirements (Ciurana *et al.* 2003).

Computer-aided process planning (CAPP) systems have evolved from the traditional/manual approach to variant and generative approaches. Traditional or manual approach means examining the drawing of the engineering part and developing plans for the manufacturing processes and instructions. The variant approach is based on obtaining the plan of a similar previous process and modifying it (Alting and Zhang 1989). The systems using the generative approach are designed to draw up, automatically, an individual plan for each part, using the appropriate algorithms that process the information in the manner required by the decisions that need to be taken (Kryssanov *et al.* 1998).

There are several research works which deal with finding and proposing solutions to make the process planning task easier. Ciurana *et al.* (2008) define a global activity model which contains an integrated tool to help in process and production planning. One of the activities defined is about how to calculate the cutting operation and unproductive time, and the tool presented in this work is part of all those activities. The work of Nassehi *et al.* (2006) and Yang and Xu (2008) explores ways to improve efficiency using a process planning system based on ISO standard 14649 (STEP-NC). The work of Culler and Burd (2007) also reveals that small manufacturers continue to create route sheets in traditional ways, using semiautomatic and manual methods. In their work they present a CAPP architecture that includes business activities and incorporates data from CAD/CAM systems. In other work, the CAPP focus is explored from the perspective of web-based manufacturing environments such as the tool and machine selector for a CAPP system in the work of Chung and Peng (2004).

In this work CAPP software developed by the authors is used. This software, as previously stated, helps production engineers to create route sheets for a specific product based on the characteristics of the product and the availability of work centres.

Current market solutions do not meet all the objectives of the SMEs of the sector. It is difficult for SMEs to use those commercial process planning systems. On one hand there is work to keep all the

information introduced in database and dedicated human resource is needed which is not eligible in SMEs. On the other hand those commercial software packages usually have expensive acquisition and customisation costs for being assumed by several SMEs. For that reason the GR3P research group of the University of Girona has developed a computer application called 'Programme to aid the process and production planning in machining operations' (translated from Programa per assistir la planificació del procés i la producció en operacions de mecanitzats, or PAPOM, in Catalan), with which it aims to fill this gap in the market.

The goal of this paper is to assess the cutting times and unproductive times of the machining operations created by PAPOM. The times are compared with those calculated by computer-aided manufacturing (CAM) software, named GOelan. This type of application programmes the numerical control (NC) code that will be sent to the machining tool and gives all the values of the intervening parameters (time, speeds, etc.). In this paper the methodology used to develop this comparison is described, and the results of two applications are given and compared. Finally the conclusions drawn from the analysis carried out are presented.

## 2. Methodology

Next, the set of followed steps during the development of the work are explained. First, parts have to be chosen. The Opitz classification (Opitz 1955) can be used to select parts which contain several operations (Ciurana *et al.* 2003). The developed computer tool is capable of calculating several operations as shown in Table 1.

It is necessary to analyse parts with features that can be calculated by both applications: GOelan and PAPOM. It is also important to assess a whole route sheet, not only a single operation.

Table 1. Operations grouped by typology.

Turning operations	Milling operations
Plain turning	Planning
Conical turning	Pocketing
Spherical turning	Grooving
Boring	Cross cutting
Reaming	Drilling
Drilling	Threading
Threading	Boring
Cutting off	Chamfering
	Drilling operations
	Drilling
	Chamfering

In the second step, the process planner has to create the route sheets with the parameters that have been selected into the PAPOM. A subsystem of the application, called Application to assist in the decision about the blank in machining processes is used (Quintana *et al.* 2008). This subsystem allows the raw material dimensions of the part to be calculated.

In the following step, parts are introduced into the GOelan with the same conditions as the previous step. This software creates the NC code and allows simulating the machining process in order to find any problem during the manufacturing process. Afterwards, in order to compare the time results calculated by PAPOM, the same parameters from the CAM application will be entered.

After, the parts will be machined and finally, the three cutting times (GOelan, PAPOM and real) and the unproductive times calculated in both applications are analysed, compared and discussed.

**2.1. Experimental set-up**

All parts will be machined on a Deckel Maho 64V Linear 3-axis machining centre, with FANUC 180i Control and using a gag system as clamping device. Cutting conditions are exposed below for each work part introduced. Cutting tools used in those processes presented in this work are shown in Table 2. The tools were selected to help in machining different operations introduced in Table 1.

Parts used to assess the calculating time tool as a subsystem of PAPOM are presented. It is important to compare a whole route sheet with several operations in order to validate the application. Thus, two parts with a reasonable number of simple operations have been chosen and used to explain the case study. In this paper, operations are limited to milling with turning being analysed in further work.

**2.1.1. Part 1: column centring device**

The first part is a column centring device (Figure 1), used in dies and moulds manufacturing. The part was selected owing to the number of operations used to be

manufactured. The main feature of the work piece is the central holes. Thus, pocketing operation is useful for this geometrical requirement. Pre-process planning has been done in order to prepare the convenient geometry. This part has four holes, so drilling operation has been also introduced in the manufacturing process. A planning operation is used to acquire the final height.

The manufacturing route sheet for carrying out the work piece is described in Table 3. All the operations used are explained with geometrical requirements when manufacturing is done. The initial blank is proposed by PAPOM subsystem (Quintana *et al.* 2008) as 50 × 50 × 46.5 mm calibrated steel square bar. Table 3 also shows the steps used to manufacture this part, and how the clamping operation divides the process in three subphases. Each operation in Table 3 has its cutting machining conditions, such as cutting speed, feed rate and depth of cut. Finally, Table 4 presents relations defined with operations, tools and cutting conditions. One example is the planning operation, (Op.1 in Table 3), which uses a 63 diameter

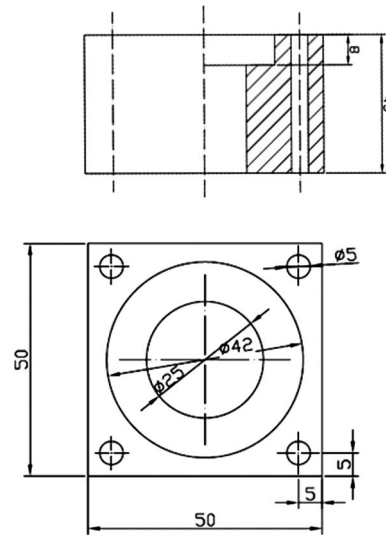


Figure 1. Part 1: Column centring device.

Table 2. Summary of the cutting tools.

Tool number	Description	Diameter [mm]
1	Radius Mill	63
2	Drill	20
3	Drill	10.5
4	Drill	5
5	Flat Mill	16
6	Counterbore	18 × 10.5
7	Tap	M12 × 1.75

Table 3. Summary of the route sheet of part 1.

Phase 1. Band saw	Phase 2. NC milling
<i>Sub phase 1.1</i>	<i>Sub phase 2.2</i>
Clamping the part	Clamping the part
Blank creation	Hole d = 20 mm (Op2)
Phase 2. NC milling	Circular pocket milling, 42 mm (Op3)
<i>Sub phase 2.1</i>	Circular pocket milling, 25 mm (Op4)
Clamping the part	4 holes d = 5 mm (Op5)
Planning	
1.5 mm (Op1)	

radius mill tool, (tool 1 in Table 2), with cutting conditions needed to manufacture the geometrical feature.

Tables 3 and 4 contain all information about steps, tools and cutting conditions to manufacture the parts in Figure 1.

2.1.2. Part 2: clamping device

The second part is a clamping device (Figure 2), which has been designed as a tool used in order to clamp rounded bars on the machining table.

Four holes are elaborated for placing the two flanges, which will ensure the right positioning of the

part. Special features of this part are the two boring operations, which are necessary for the integration of the screws within the part. A grooving operation has also been planned in areas of aligning the rounded bar with the clamping device. Finally, the two threaded holes will be used for two screws to fix the three components (clamping device, rounded bar and flange).

Table 5 shows the manufacturing process of part 2. The initial blank is also proposed by PAPOM subsystem (Quintana *et al.* 2008) as 50 × 50 × 86 mm calibrated steel square bar. Table 5 also shows the steps used to manufacture the part, and how the clamping operation divides the process in three subphases.

The operations in the route sheet have their particular cutting conditions described in Table 6. Tools used in the process are linked with each operation.

The two workpieces presented above contain several operations with different tool and cutting parameters information, which represents different case studies and helped more to validate the support time calculating tool.

3. Applications

3.1. PAPOM

The PAPOM application was conceived and developed to create and manage route sheets, defining the operations and establishing relationships between the

Table 4. Cutting conditions for part 1.

Operation	Tool	Cutting speed (m/min)	Feed rate (mm/min)	Cutting depth (mm)
Op 1.	1	120 <sup>1</sup> /180 <sup>2</sup>	400 <sup>1</sup> /300 <sup>2</sup>	0.3 <sup>1</sup> /0.2 <sup>2</sup>
Op 2.	2	20	50	–
Op 3.	5	78 <sup>1</sup> /100 <sup>2</sup>	205 <sup>1</sup> /200 <sup>2</sup>	0.3 <sup>1</sup> /0.2 <sup>2</sup>
Op 4.	5	78 <sup>1</sup> /100 <sup>2</sup>	205 <sup>1</sup> /200 <sup>2</sup>	0.3 <sup>1</sup> /0.2 <sup>2</sup>
Op 5.	4	15	50	–

<sup>1</sup>Roughing conditions.

<sup>2</sup>Finishing conditions.

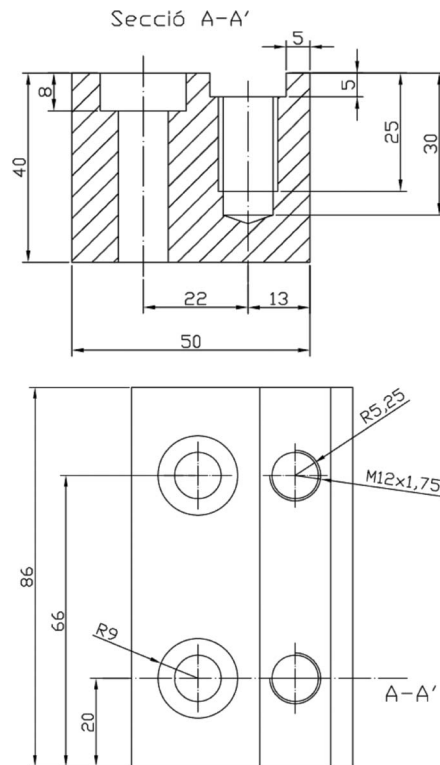


Figure 2. Part 2: Clamping device.

Table 5. Summary of the route sheet of part 2.

Phase 1. Band saw	Phase 2. NC milling
<i>Sub phase 1.1</i>	<i>Sub phase 2.2</i>
Clamping the part	Clamping the part
Blank creation	Grooving 5mm (Op2)
Phase 2. NC milling	2 holes d = 10.5 mm, 30 mm (Op3)
<i>Sub phase 2.1</i>	2 holes d = 10.5 mm, 40 mm (Op4)
Clamping the part	2 boring holes 18 × 10.5 mm (Op5)
Planning	2 threading holes M12 (Op6)
	10 mm (Op1)

Table 6. Cutting conditions for part 2.

Operation	Tool	Cutting speed (m/min)	Feed rate (mm/min)	Cutting depth (mm)
Op 1.	1	80 <sup>1</sup> /100 <sup>2</sup>	350 <sup>1</sup> /300 <sup>2</sup>	0.3 <sup>1</sup> /0.2 <sup>2</sup>
Op 2.	5	80 <sup>1</sup> /100 <sup>2</sup>	300 <sup>1</sup> /250 <sup>2</sup>	0.3 <sup>1</sup> /0.2 <sup>2</sup>
Op 3.	3	30	180	–
Op 4.	3	30	180	–
Op 5.	6	30	150	–
Op 6.	7	30	1390	–

<sup>1</sup>Roughing conditions.

<sup>2</sup>Finishing conditions.

route sheets and various aspects of the process (parts, planning, machines, etc.).

A schematic of the application using a use cases diagram using UML nomenclature (Larman 2001, Rumbaugh 1999), is shown in Figure 3, which shows the inputs and outputs of the system. The system inputs have been defined as the physical elements of the workshop (machines, cutting tools, fixtures, etc.) and the organisational elements (sales orders, purchase orders, etc.). Among the system outputs are the reports produced by the application (route sheets, operation sheets, plans, etc.). The system has been divided into several subsystems to make the problem easy to process and to group together the various functions required by users. Figure 4 shows full computerised application and different subsystems.

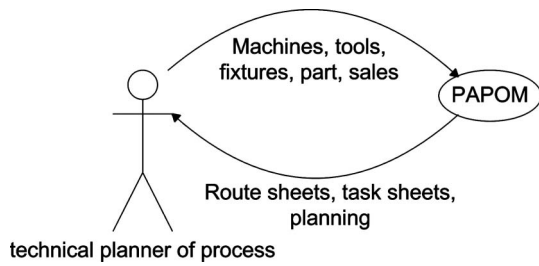


Figure 3. PAPOM Use case level 0.

The PAPOM is made up of five large subsystems. The following paragraphs briefly explain what they consist of:

*Production planning.* The route sheets and sales orders available to the system are used to carry out the production planning in this subsystem. Various algorithms are used to provide several different plans for the workshop.

*Workshop management.* The various elements making up the workshop (machines, tools, etc.) can be created, modified and removed in this subsystem.

*Management of product.* To define for a part so principal geometric features as organisation features (stocks, prices, lot sizes). The part can be created, modified and removed in this subsystem.

*Management of sales.* The sales orders of the workshop clients are entered, modified and cancelled in this subsystem, which provides an idea of how they evolve over time.

*Process planning.* The various sets of created route sheets in this subsystem, which will be explored in depth since it contains the logic used to manage the route sheets.

The whole PAPOM system is designed but it has not been computerised, tested or verified yet. Considering the process planning subsystem which is the most

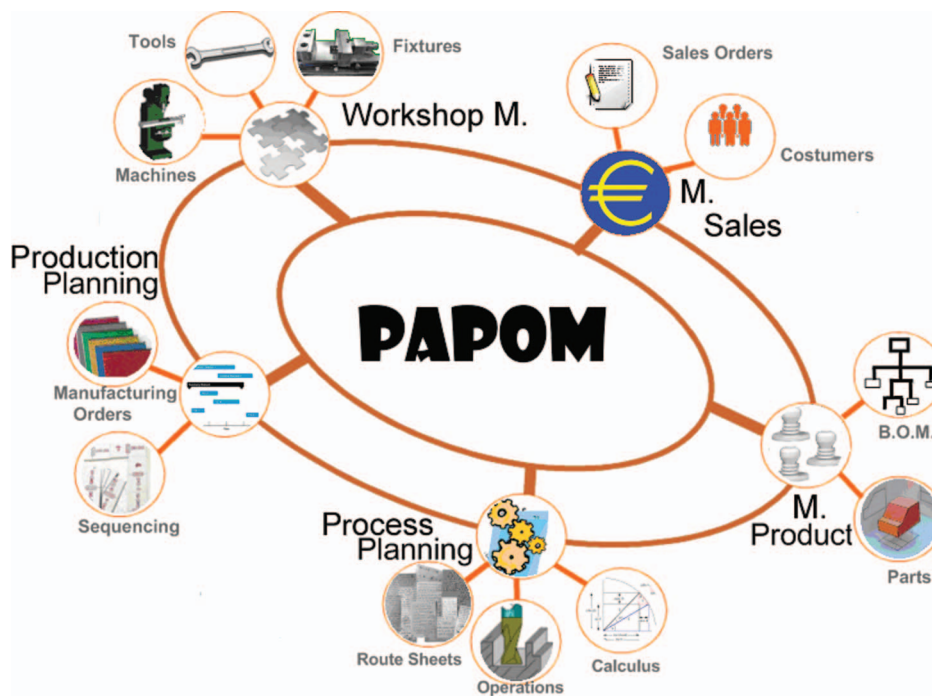


Figure 4. Scheme of subsystems PAPOM.

developed, the first work to be done it is to verify how the computer aided system is running and how the reliability level is. Figure 5 shows the process planning subsystem which is divided in three applications, route sheet creator, operations definition and time and cost calculator for each operation done.

3.1.1. Process planning subsystem

The process planning subsystem, shown in Figure 5, organises route sheets for each part and allows relationship between route sheets and the rest of the subsystems because a working environment in which all the necessary elements are available is required to create these route sheets. In addition, these required elements cannot be generic: the user must have access to those elements that are actually available in the workshop.

As mentioned previously, one route sheet is not enough; it would be more suitable to have an entire set of alternatives available for the same part, as shown in Figure 6. This set of routes sheets needs to agile production planning. A route sheet is structured in phase, subphase and task (from more global to more detailed).



Figure 5. View of Process planning subsystem.

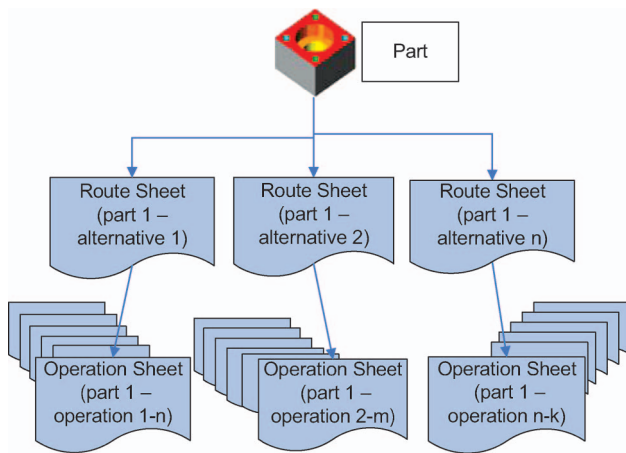


Figure 6. Scheme of the relation of a part with its route sheets.

The route sheet information is organised in different classes using UML nomenclature.

The class diagram presents all the interrelated aspects involved in the creation of a route sheet, as shown in Figure 7. This includes the classes that store information as well as those from which the user gathers it. To help users develop route sheets, the figure has been divided into two zones (presentation and storage). In the presentation zone (FrmRouteSheet, FrmOperation) route sheet is shown to the user. The FrmRouteSheet class is interactive with RouteSheet class and will build route sheet structure.

In the storage zone, the information on the route sheet is saved for facilitating future updates as well as listing. The RouteSheet class store general information (the select part, creation date, #order, raw material, etc). The Phases class and Subphases class store manufacturing production structure and Task class store operations parameters to make as well as the tools, machine and fixture that will be used. The rest of the classes are used to obtain information of the system.

The operation package shows the calculus results by a determinate task. The various operations have been grouped together in typologies, Table 1.

3.1.2. Algorithms for calculus subsystem

The methodology used by the PAPOM to calculate the route sheet time will be explained below.

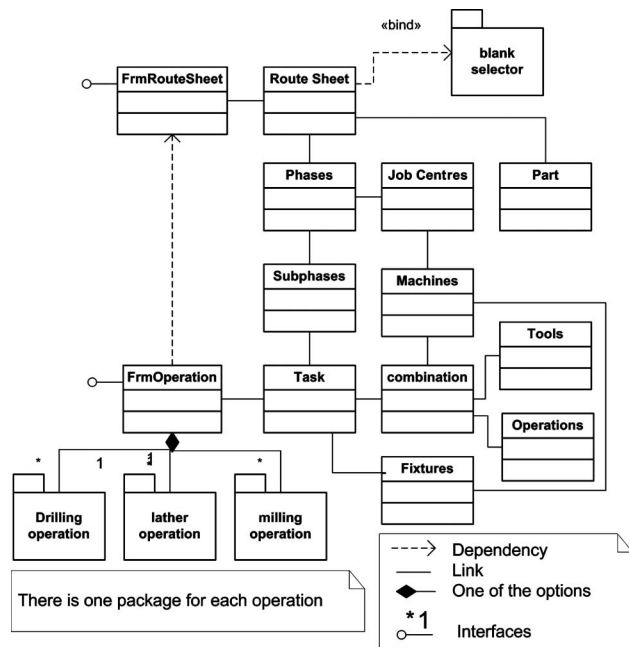


Figure 7. Class diagram for new route sheet.

The total cost of a machining operation depends on the time required to carry it out (Boothroyd and Knight 1989)

$$C_t = (t_u + t_p + t_{ch} \cdot t_c/T + t_c) \cdot P_0 \quad (1)$$

where:

$C_t$ : total cost  
 $T_u$ : unproductive time  
 $T_p$ : preparation time  
 $T_{ch}$ : tool change time  
 $T_c$ : cutting time  
 $P_0$ : price per hour

*Unproductive time,  $t_u$ .* This is the time during which the machine is not removing material but is in movement. The programme calculates it using the following expression

$$T_u = T_{u1} \cdot Nl + \left( (Nl - 1) \cdot \frac{D_{tool} - S}{Vt} \right) \quad (2)$$

where:

$T_u$ : unproductive time, min  
 $T_{u1}$ : unproductive time of a run, min  
 $Nl$ : nr. of longitudinal runs  
 $D_{tool}$ : tool diameter, mm  
 $S$ : tool overlapping, %  
 $Vt$ : transversal velocity, mm/min

*Preparation time,  $t_p$ .* This is the time it takes to prepare a specific operation. Because this is information that only the individual company can know as a result of their experience, and only in an approximate way, it cannot be calculated. For that reason PAPOM lets this information be entered manually on the parameter entry screen for each operation.

*Tool change time,  $t_{ch}$ .* This time is not relevant to each operation, but it must be weighted and distributed among all the operations carried out by a tool during its lifetime. It must also be entered manually, since it depends 100% on human factors and cannot be calculated.

On looking closely at the expression of total machining time, it can be seen that it is weighted by the factor ' $t_c/T$ ' to take into account the proportion of the lifetime of the tool assigned to perform the operation. The programme requires that the parameters for the lifetime of the tool be entered, and finds the  $T$  parameter using Equation (3). The following expression explains the calculation of  $t_c$

$$T = \frac{K^{1/n}}{V^{1/n} \cdot A^{a/n} \cdot P^{p/n}} \quad (3)$$

where:

$K$ ,  $a$ ,  $p$  and  $n$ : parameters for the lifetime of the tool;  
 $V$ : cutting speed, m/min  
 $A$ : feed rate, mm/rev  
 $P$ : depth, mm  
 $T$ : time of the lifetime of the tool, min

*Cutting time,  $t_c$ .* This is the time needed to cut away raw material. In order to calculate it in each operation PAPOM includes two independent calculation algorithms adapted to each machining operation. Figure 8 shows the common diagram of the two possible ways to obtain the times of the operation.

The Halevi algorithm (Halevi and Weill 1995) calculates the feed rate and the depth in each iteration (each level of depth of the process), in order to obtain a part with the desired surface roughness. In this way one phase of the route sheet (grinding) can be eliminated and part production time and cost will be reduced when grinding operation is not needed.

To calculate it, the algorithm divides the thickness to be machined into different layers (named zones) as shown in Figure 9:

*Zone A:* Finishing run, very important for obtaining the desired surface finish. It has to have a specific depth calculated from roughness requirement by using specific formula (Halevi and Weill 1995).

*Zone B:* Preparatory finishing run, which leaves the part prepared for the finishing pass.

*Zone C:* Roughing run, which may be several runs. The power of the machine and the features of the tool will be taken advantage of to the maximum to optimise the time.

*Zone D:* Intermediate run, this is the remaining thickness that is taken away after roughing, leaving the part ready for the preparatory run.

To determine the depths of the run and the feed rates the algorithm carries out a series of rough intermediate calculations to solve the equations that Halevi proposed in Halevi and Weill (1995). The detailed operation of this algorithm can be seen in the work by Vidal *et al.* (2005). Figure 9 shows implementation of Halevi's algorithm in process planning subsystem integrated in PAPOM applications.

The simplified algorithm does not take into account the desired surface finish, only differentiating between the roughing runs and the finishing runs. The operation is summarised below.

The user has to enter the feed rate and depth parameters in the roughing and the finishing phases.

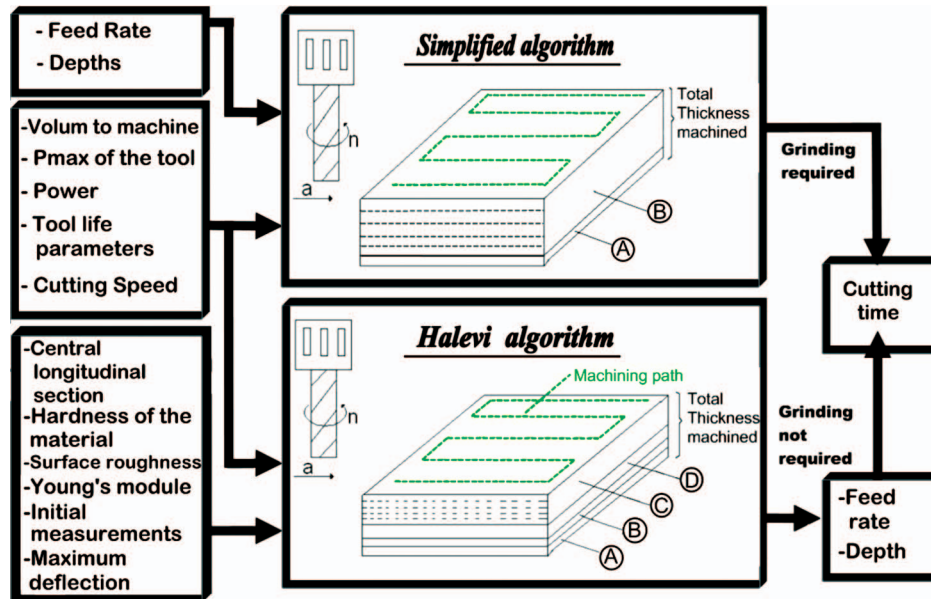


Figure 8. PAPOM scheme to calculate the cutting time by planning operation.

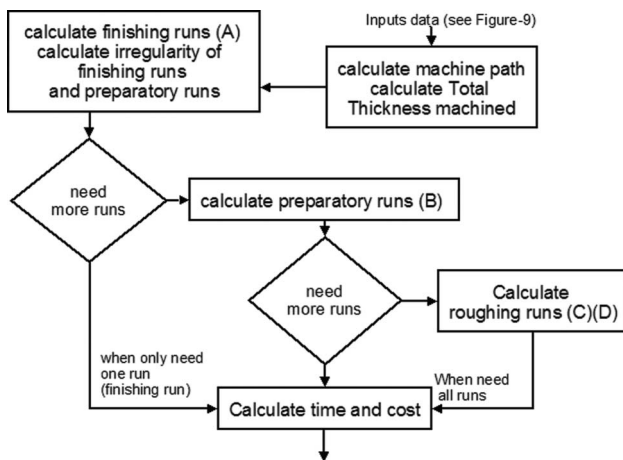


Figure 9. Flow diagram of Halevi algorithm.

These values are processed by algorithm as shown in Figure 10.

The algorithm analyses two different scenarios, which might result from it:

- (1) If the thickness to be removed is less than or equal to the finishing depth, the operation will be done in only one pass under finishing conditions.
- (2) If the thickness to be removed is greater than the finishing depth, one finishing run and  $n$  roughing runs will be performed.

Calculated in the following way:

$$RRN = \left\lceil \frac{Thickness - Fdepth}{Rdepth} \right\rceil \quad (4)$$

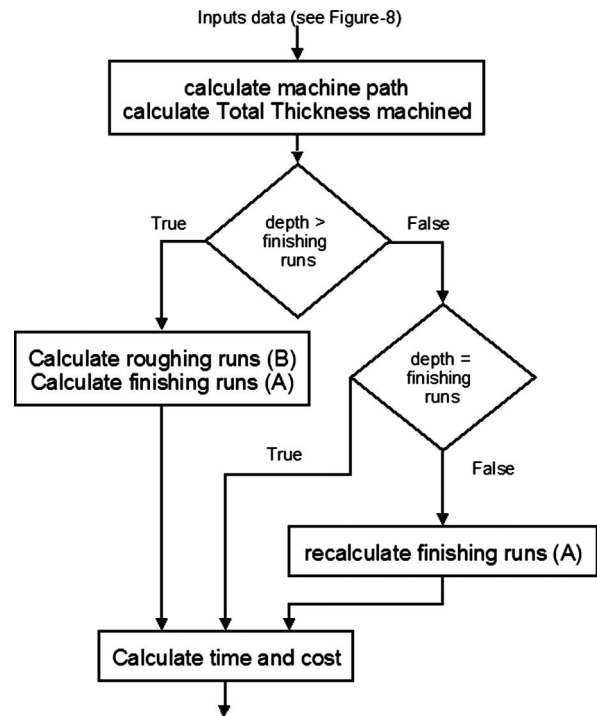


Figure 10. Flow diagram of simplified algorithm.

where:

- RRN: roughing runs number
- thickness: thickness to be machined, mm
- Fdepth: finishing depth, mm
- Rdepth: roughing depth, mm

and the equation is rounded up to the nearest integer.



The true value of each one of the roughing runs will be:

$$Rdepth = \frac{Thickness - Fdepth}{RRN} \quad (5)$$

where:

- RRN: roughing runs number
- Thickness: thickness to be machined, mm
- Fdepth: finishing depth, mm
- Rdepth: roughing depth, mm

The common objective of the two algorithms is to calculate the total length to be machined, which when divided by the feed rate speed will give the machining time as shown in Equation (6):

$$t_c = \frac{Lcut}{Va} = \frac{Lcut}{a \cdot n} \quad (6)$$

where:

- $t_c$ : cutting time, min
- Lcut: cutting length, mm
- Va: feed rate, mm/min

- A: feed rate, mm/rev
- n: spindle speed,  $min^{-1}$

Figure 8 demonstrates that in order to carry out Halevi's algorithm the application needs many more parameters, the majority of which are not known to the SMEs of the sector and sometimes are difficult for the machine operator to know. That is why it is important to have as an alternative the simplified algorithm. The operations for which the PAPOM currently calculates the  $t_c$  with the two algorithms are detailed in Table 1, and an example for planning process is shown in Figure 11.

For Figure 11, the main form zones are described below:

- (1) Definition of the operation: Machining strategy and machining surface's width, length and height are defined. Picture helps to define the values in the boxes.
- (2) Blank definition: The blank needed to manufacture work piece is calculated following the parameters defined in box 1.
- (3) Operation's conditions: Data input for parameters such as cutting speed, overlapping, preparation time and cost per hour. The

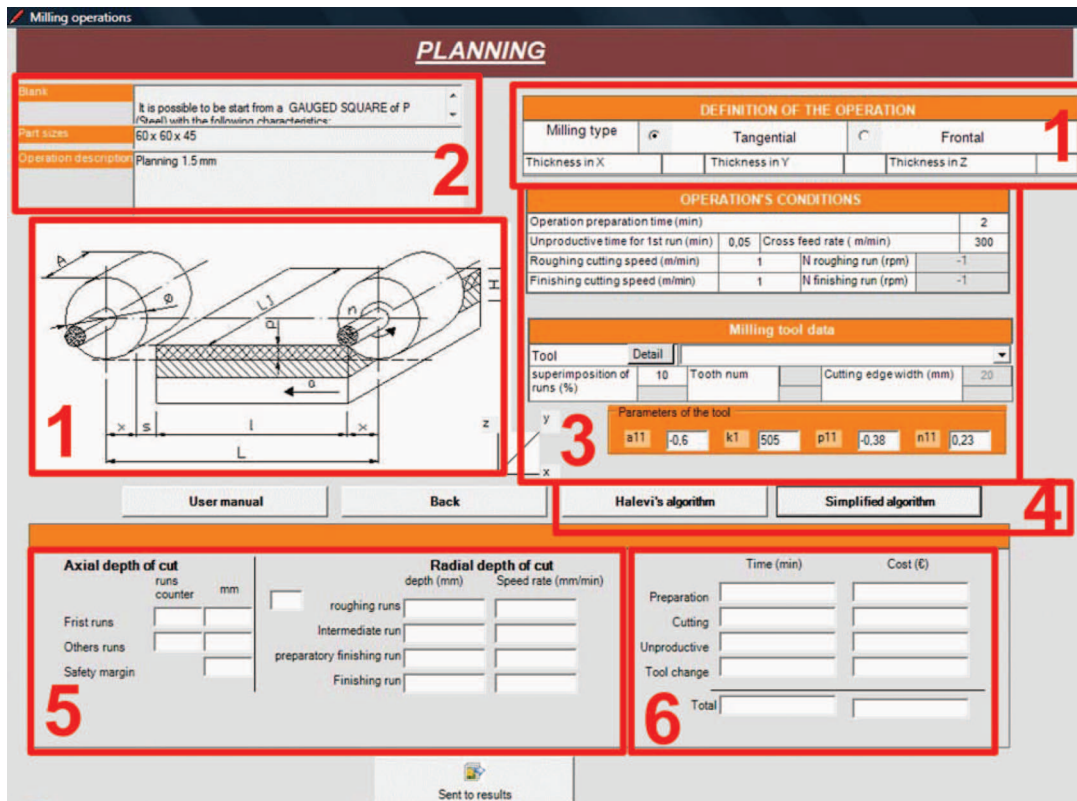


Figure 11. Example of PAPOM's operation calculation interface.

application takes parameters from the data-base, as tool diameter or tool change time, among others.

- (4) Algorithms: Process planner can choose between simplified algorithm and Halevi's algorithm.
- (5) Cutting depth output: The cutting depths for the whole process are calculated depending on the chosen algorithm.
- (6) Time and cost output: PAPOM calculates, as shown in Equation (1), total cost taking into account four different times. These are exposed separately, and two of them are used in the analysis (unproductive and cutting times). The others (preparation and tool change times) are not considered in this paper, because the GOelan does not consider them.

### 3.2. GoElan

GoElan is a commercial CAM software system developed by Missler Software (GoElan 2009). As CAM software it defines manufacturing cycles or operations and their corresponding ISO output file (NC commands) in order to manufacture parts. In

addition, it has other features that make it a valuable solution for use by manufacturing specialists. Among these features the following stand out: overview of tool characteristics and the cutting conditions used, calculation of manufacturing time (total or per cycle), simulation and visual help of material removal, generation of the CNC programme, transfer to the machine of choice, etc.

The analysed part designed in GOelan is shown in Figure 12. In the left hand figure, the route sheet of the process is structured as a tree model. The central part is the working area, where the process planner creates the operations and carries out the simulation.

One of the new outputs offered in later GOelan versions is called operation schedule (Figure 13). This output, together with the features mentioned above, makes it possible to know the cutting and unproductive time for each operation.

### 4. Results

After machining the parts in a real manufacturing shop floor, the cutting and unproductive times have been compared. To improve similarity between real machine time, GOelan application and calculus PAPOM application, the simplified algorithm must be chosen.

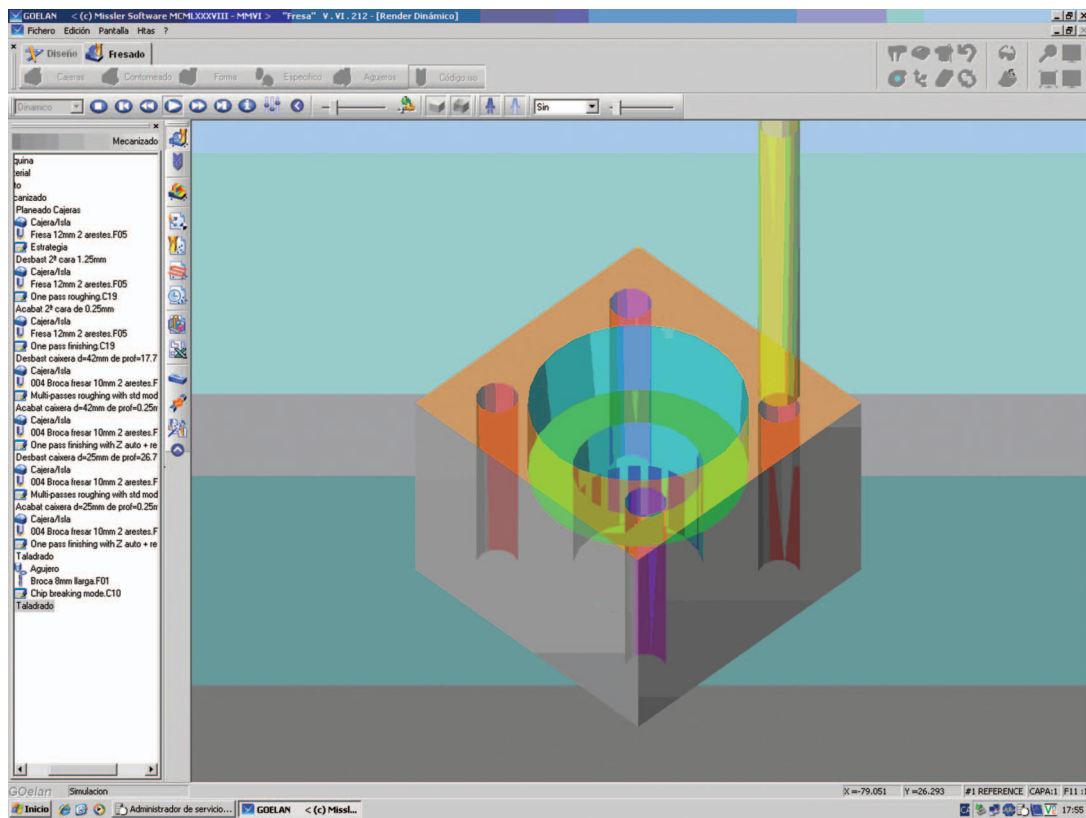


Figure 12. Design of the part in GOelan's interface.

If Hallevi's algorithm is used the two route sheets could not be compared, since each application (PAPOM and GOelan) would use different parameters

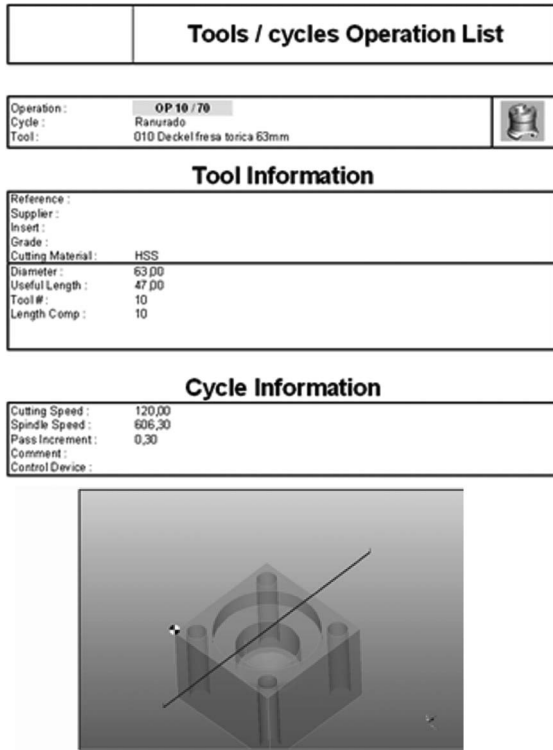


Figure 13. GOelan's operation schedule sheet.

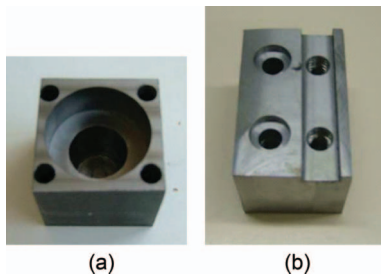


Figure 14. Final manufactured parts. Column centring device (a) and clamping device (b).

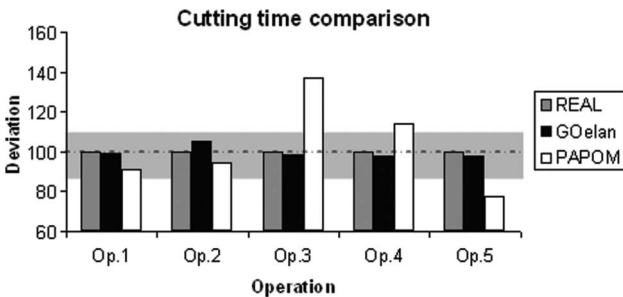


Figure 15. Relative times comparison of part 1.

for the same operation (Figure 8). The final manufactured parts are shown in Figure 14:

In order to compare times, it is interesting to compare them in relative terms, owing to the difference in time values between operations. Therefore, a more objective analysis can be done.

As the calculating subsystem PAPOM is an application designed for SMEs, it cannot be a tough interface. Thus, the hypothesis is to establish a reasonable 10% error, which is proposed by some machining enterprises, in areas of increasing simplicity. For this reason, operations within this range will not be analysed. The deviation among the cutting times is analysed in Figures 15 and 16. Real time is considered as 100%.

Operations within the tolerance of  $\pm 10\%$  (Figures 15 and 16) are satisfactory.

In pocket milling operations (Op.3 and Op.4 in Figure 15) PAPOM subsystem calculates a higher time. This is because the tool path calculated by PAPOM's subsystem algorithm and the one made by de NC code are slightly different. PAPOM's subsystem algorithm supposes a perfect spiral movement, whereas GOelan produces a more circular movement, as shown in Figure 17:

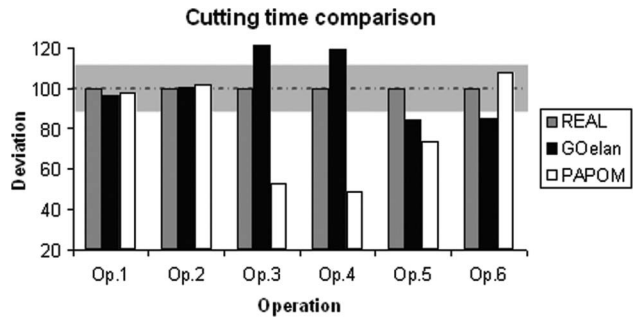


Figure 16. Relative times comparison of part 2.

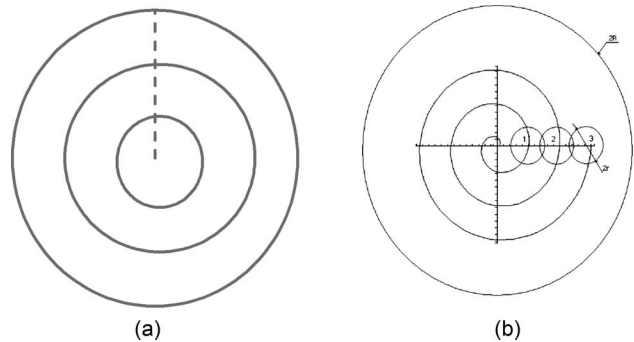


Figure 17. Tool paths from GOelan (a) and PAPOM (b) for pocket milling operation.

Table 7. Numerical results of part 1.

Operation	GOelan		PAPOM		REAL	
	Tc[s]	Tu[s]	Tc[s]	Tu[s]	Tc[s]	Tu[s]
Planning 1.5 mm (Op1)	111	3	102	6	112	N.E.
Planning 1.5 mm (Op2)	49	0	44	0	47	N.E.
Circular pocket milling, 42 mm (Op3)	947	18	1320	6	963	N.E.
Circular pocket milling, 25 mm (Op4)	496	10	577	6	507	N.E.
4 holes d = 5 mm (Op5)	271	2	216	0	278	N.E.

Table 8. Numerical results of part 2.

Operation	GOelan		PAPOM		REAL	
	Tc[s]	Tu[s]	Tc[s]	Tu[s]	Tc[s]	Tu[s]
Planning 10 mm (Op1)	870	30	880	12	901	N.E.
Grooving 5 mm (Op2)	299	10	302	6	298	N.E.
2 holes d = 10.5 mm, depth 30 mm. (Op3)	39	1	17	0	32	N.E.
2 holes d = 10.5 mm, depth 40 mm. (Op4)	58	1	24	0	49	N.E.
2 bored holes (Op5)	8	1	7	0	9	N.E.
2 threaded holes M12 (Op6)	3	0	4	0	4	N.E.

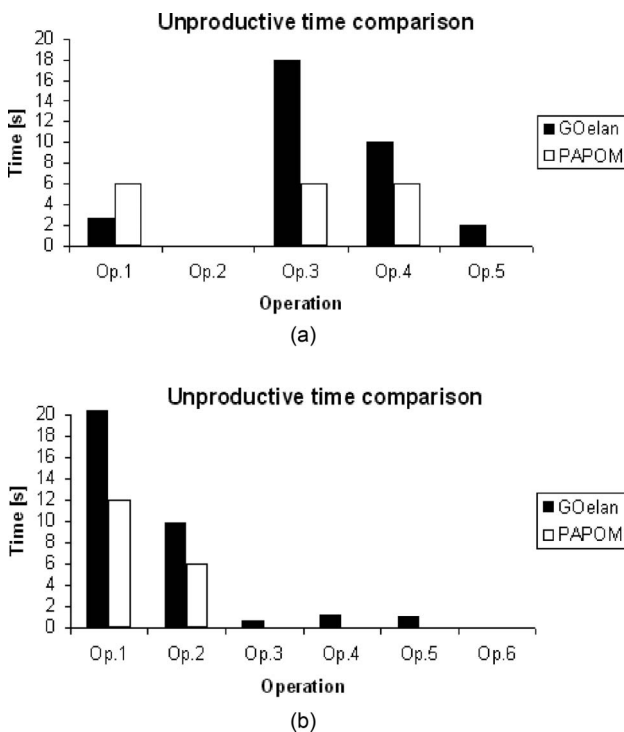


Figure 18. Obtained unproductive times from part 1 (a) and part 2 (b).

In drilling and boring operations (Op.5 of Figure 15, Op.3, 4 & 5 of Figure 16), PAPOM's subsystem time is always lower than the real one. There are two reasons for this:

- PAPOM subsystem does not consider the distance between different holes when more than one is machined.
- PAPOM subsystem does not consider the several backward movements done by the drill during the real process.

Numerical results times obtained in various different ways are presented in Tables 7 and 8.

Regarding the unproductive time, Tu, it has not been evaluated in the real process and PAPOM subsystem only considers it between different cutting steps. Therefore, this analysis has been done in absolute terms. Figure 18 shows the results, it can be observed that results between the two applications are different, but they follow the same trend.

## 5. Conclusions

This paper outlines the reliability of developed CAPP system to determine cutting time for different machining operations. The results obtained from comparing the proposed calculus subsystem in PAPOM cutting time with those taken from GOelan CAM software and from the real manufacturing of the part prove they are good and the difference is known and predictable.

This work presents methods by which to calculate cutting time. The first one based on Halevi and Weill (1995) is not utilised in workshops because it is too difficult to operate by users so an application helps to use it (Vidal *et al.* 2005). The second one is based on

traditional methodology used for workers. The work also does a comparison between methods and reality to validate how the application really has been adjusted. To implement those calculation methods in a CAM system is not possible so a CAPP application developed named PAPOM helps users to calculate cutting time with both methods. The application developed also helps to create route sheet without forgetting any essential parameter for cutting process.

The calculus process planning subsystem of the developed PAPOM application has been presented in detail. It has been developed to be user-friendly. This subsystem is within the application that considers widely the variables related to the creation of a route sheet that has been created. Regarding the cutting time:

- Drilling and boring operations algorithms have to be improved in order to take into account the real movement of the tool. Definition of distances between different holes is not significant because the tool moves at a high feed rate level.
- Pocket milling operation algorithm can be improved, following the real tool path. Another option is to calculate a table with different correction factors depending on the pocket diameter.

Time evaluation can be provided by the PAPOM system depending on the real job shop state. Therefore this paper has discussed and presented a successful attempt in the well-known framework of the integration of CAPP and CAD/CAM technologies,

However, the consideration of unproductive time is not important, because it is usually very low owing to the high performance of new machines, with automatic tool change and high feed rate, which dramatically reduces it.

#### Acknowledgements

The work presented is part of a project currently under development in the GREP research group of the University of Girona, and is sponsored by the project of the Ministry of Education in Spain, with reference DPI 2006-00799.

#### References

- Alting, L. and Zhang, H., 1989. Computer aided process planning: the state-of-the art survey. *International Journal of Production Research*, 27 (4), 553–585.
- Boothroyd, G. and Knight, W.A., 1989. *Fundamentals of machining and machine tools*. New York: Marcel Dekker.
- Chung, C. and Peng, Q., 2004. The selection of tools and machines on web-based manufacturing environments. *International Journal of Machine Tools and Manufacture*, 44, (2–3) 317–326.
- Ciurana, J., Garcia-Romeu, M.L., Castro, R., and Alberti, M., 2003. A system based on machined volumes to reduce the number of route sheets in process planning. *Computers in Industry*, 51 (1), 41–50.
- Ciurana, J., G.-Romeu, M.L., Ferrer, I., and Casadesús, M., 2008. A model for integrating process planning and production and control planning in machining processes. *Robotics and Computer Integrated Manufacturing*, 24 (4), 532–544.
- Culler, D.E. and Burd, W., 2007. A framework for extending computer aided process planning to include business activities and computer aided design and manufacturing (CAD/CAM) data retrieval. *Robotics and Computer-Integrated Manufacturing*, 23 (3), 339–350.
- Dashora, Y., Tiwari, M.K., and Karunakarna, K.P., 2008. A psycho-clonal-algorithm-based approach to the solve operation sequencing problem in a CAPP environment. *International Journal of Computer Integrated Manufacturing*, 21 (5), 510–525.
- GOelan. Available from: <http://www.goelan.info/us/> [Accessed 14 December 2009].
- Guerra-Zubiaga, D.A. and Young, R.I.M., 2008. Design of a manufacturing knowledge model. *International Journal of Computer Integrated Manufacturing*, 21 (5), 526–539.
- Gu, P. and Norrie, D.H., 1995. *Intelligent manufacturing planning*. Chapman & Hall.
- Halevi, G. and Weill, R.D., 1995. *Principles of process planning: a logical approach*. London: Chapman & Hall.
- Kryssanov, V.V., Kleshchev, A.S., Fukuda, Y., and Konishi, K., 1998. Building a logical model in the machining domain for CAPP expert systems. *International Journal of Production Research*, 36 (4), 939–956.
- Larman, C., 2001. *Applying UML and patterns: an introduction to object-oriented analysis and design and the unified process*. 2nd ed. Upper Saddle River, NJ; Harlow: Prentice Hall; Pearson Education, 627.
- Nassehi, A., Newman, S.T., and Allen, R.D., 2006. STEP-NC compliant process planning as an enabler for adaptive global manufacturing. *Robotics and Computer-Integrated Manufacturing*, 22 (5–6), 456–467.
- Opitz, H., 1955. In: W.R. MacConnell, ed. *A classification system to describe workpieces*. Oxford: Pergamon Press.
- Quintana, G., Ciurana, J., and G.-Romeu, M.L., 2008. Design of an application to assist in the decision about the blank in machining processes. *Engineering Computations*, 25 (2), 140–154.
- Rumbaugh, J., 1999. *The unified modeling language reference manual*. Reading, MA: Addison-Wesley.
- Vidal, A., Alberti, M., Ciurana, J., and Casadesús, M., 2005. A decision support system for optimising the selection of parameters when planning milling operations. *International Journal of Machine Tools and Manufacture*, 45 (2), 201–210.
- Yang, W. and Xu, X., 2008. Modelling machine tool data in support of STEP-NC based manufacturing. *International Journal of Computer Integrated Manufacturing*, 21 (7), 745–763.

Copyright of International Journal of Computer Integrated Manufacturing is the property of Taylor & Francis Ltd and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.