

CNC machining process planning productivity – a qualitative survey

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ABSTRACT

Process planning is the link between design and manufacturing and consequently an important function, since it influences many of the company objectives. However, many companies have little knowledge about their process planning function and the efficiency is thus not optimal. The paper focuses on the automation level of process planning as a mean to improve process planning efficiency. Six CNC machining companies was interviewed and accordingly analysed through a five dimensional automation level model to understand their process planning work. The main findings are that the automation level is low and concurrent engineering is lacking in many of the investigated companies.

Keywords:

Process Planning, Efficiency, CAPP, PLM, CAM

1 INTRODUCTION AND BACKGROUND

Process planning is the act of transforming an engineering design into a work instruction to manufacture a physical product. Process planning for CNC machining is complex, due to the large requirement of data and information. This to a large extent but not entirely concerns manufacturing data, such as identification of operations, machines, tools, machining parameters, etc. Information about customer demands is also essential for performing effective process plans. Data must be evaluated and decided upon in order to create a process plan that meets requirements [1]. To be able to reach optimal or near optimal machining operations, the use of various supports/aids is often necessary and desired. There are a wide variety of computer-aided tools on the market for process planning (and design), such as different CAD/CAM, CAPP (Computer-Aided Process Planning) and PLM (Product Lifecycle Management) solutions, that integrate essential company functions and automate manual labour. Despite this, process planning is still in many companies often characterised by a substantial part of manual work. The paper targets this issue by presenting a qualitative survey of six companies' work with process planning of CNC machining.

Earlier research through a quantitative survey highlighted some of the problems of process planning in the Swedish metal working industry [2]; Process planning work lacks clear management and companies only have vague knowledge about their process planning efficiency. This possibly comes as a consequence from a lack in use of methodologies and measurements of the process efficiency. Another questionnaire survey strengthened these assumptions, by showing a number of short comings in the measurement of process performance in

general and process planning performance in particular [3]. Ref. [2] also pointed to a large potential for process planning efficiency improvements through improved information management.

The starting point of the research presented here is the theory about total productivity improvement. Which is defined as the product of the three factors or losses - *method*, *utilisation* and *performance* [4]. Method losses come due to inefficient methods, which mean that excess personnel and machinery are needed. Performance losses follow due to low performance of personnel and equipment. Utilisation losses come as a consequence from underutilisation of personnel and/or equipment. This means that the ways of improving productivity is by improving one, two or all of the factors. The paper however focuses on the method factor in the metal working industry as a mean for increased process planning productivity. The focus on the method factor is motivated, since it is the single most important factor, and can have a tenfold influence on productivity in a manufacturing situation, for which the theory is originally developed [5]. However it can also be applied in engineering work, such as process planning. It is in this perspective essential to ensure that the most appropriate method (e.g. technology, working methods, routines and process aids) are being used. Automation of process planning activities is an important part of developing efficient working methods. Automation is often regarded in a physical manufacturing situation, but the concept is wider than that. CAM is a good example of this, since it aids and replaces traditional NC programming work, with simple mouse clicks and instead of letting the programmer calculate each tool path trajectory, the software does it. Automation of manual work can be

motivated from different perspectives (e.g. cost and lead time reduction or quality enhancements). There is however often a risk when automating that flexibility is lost and particular for engineering work that innovative solutions are not encouraged. It is also more difficult to automate engineering work, since the outcome often is ambiguously defined.

Implementation of computer aids such as PLM systems provides a fundament for information and data management as well as coordination of work activities within processes. Conversely, the implementation of PLM systems in SMEs has yet not been very successful, which is due to certain characteristics of SMEs, compared to larger enterprises. The available PLM systems mainly suit in-house mass production manufacturers and many SMEs are sub-contractors to larger enterprises with small batch production and wide product variation [6]. Other explanations are limited IT resources and resources dedicated for process improvements [7]. To implement PLM and other process planning aids (e.g. CAM, CAPP) is resource and time consuming.

The above problems are also presented by Ref. [6] where a number of flaws in knowledge management is found in particular for SMEs with small batch production:

- CAD/CAM is often implemented in SMEs, while CAPP is not;
- Lack in management of infrastructure knowledge;
- Production process knowledge is not managed, only documented;
- Limited knowledge discovery – hence similar jobs are difficult to identify, thus only relying on employee memory;
- Digital information is transferred from designer to manufacturer, but lack in digital data feedback from manufacturer to designer.

On the contrary, most of the above are targeted in PLM systems and to parts in CAPP. Ref. [8] claims that CAD/CAM and PDM (Product Data Management) is often efficiently implemented in the industry and its suppliers, so that a complete information flow is achieved.

Efficient information management is important in order to ensure an overall efficient product realisation process, since process planning is the link between design and manufacturing. For a company to possess efficient process planning influence the total product realisation process and thereby constitute one of the fundamentals for a sustainable production organisation. In aforementioned previous study, more than half of the responding companies spent at least 26% of the total process planning time, recreating information [2]. This means that there is a foundation for substantial productivity improvements to be made.

The use of the above stated technology and philosophy is a strategically important way to target the *method* factor, where expected benefits are more efficient information and data management and better communication. Better use of resources will lead to shorter lead times, quality, and lower product cost. To enable automation of value

adding activities; underlying functions must be automated as well, in order to maximise the automation outcome. The research effort for this paper is thus an investigation of the level of automation of process planning for CNC machining. Process planning activities are difficult to automate, since the input and outcome is often not defined sufficiently. One of the reasons for this is that engineering processes tend to be performed by organisations where the contribution from specific activities in relation to specific outcomes often are unclear [9].

1.1 Research scope

This paper aims at highlighting the main strengths and deficiencies regarding process planning efficiency and working methodologies for typical CNC machining companies. The paper presents employed and potential future process planning aids in theory and practice for a number of companies. The main research question is to investigate a number of companies' process planning automation level. This generated a set of sub-questions to answer:

- How is process planning work carried out?
- The usage of computer aids in process planning?
- How are process planning data, information, and knowledge managed?

1.2 Method

The research method is based on qualitative semi-structured interviews with process planners. Each interview session was 1 to 3 hours, where a simple part model was used at the centre of discussions. The interviews were conducted on company sites and comprising 1 to 6 persons in each company. In order to be able to answer the research questions (section 1.1), the process planning workflow was constructed for each company. This was carried out by using a set of predefined building blocks (activity, computer aids, information and knowledge source) (see Figure 1).

The company interviews were analysed using a model of the automation level of process planning functions. The model focuses on the main value adding activities in of process planning (Table 1). This is a shorter list than the number of activities that any company carry out (Figure 2). However, the five activities are the fundament of process planning, hence motivated to shortlist the activities. Each company is categorized according to the model, which gives an understanding for the studied companies' present position regarding the automation level of process planning. The analysis model is based on theory regarding process planning and computer aids for process planning [10, 11, 12]. The results are presented in a radar chart, which describes the level of automation of process planning work.

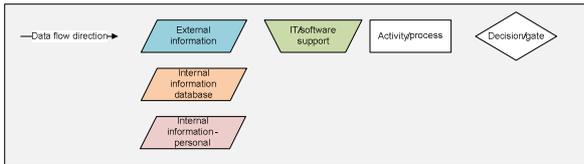


Figure 1: Flow chart building blocks

2 PROCESS PLANNING FOR CNC MACHINING

Process planning is essentially the act of turning a set of specifications (geometrical, technical, financial, logistical, environmental etc.) into a document over how to manufacture a part. CNC machining is interesting to study since it encompasses many different parameters that must be managed in order to optimise the manufacture process. The main parameters include tool selection, fixturing, machining data, tool path generation. The output from these parameters are manufacturing lead time, product quality, machine down time and overall economics. Altogether this makes CNC machining a challenging process to manage and optimise.

Table 1 : Automation level of process planning activities

Generation of tool paths	
0.25	Manual NC programming
0.5	Manual CAM programming
0.75	Semi automated CAM programming using predefined strategies
1	Fully automated tool path generation - no manual interference
Tool selection	
0.2	Manual tool selection (new each time)
0.4	Manual tool selection (reuse of old tools no database)
0.6	Manual tool selection (reuse of old tools w. searchable database)
0.8	Semi automated using wizards with suggested tools
1	Fully automated tool selection - no manual interference
Machining parameters selection	
0.2	Manual parameter selection (new each time)
0.4	Manual parameter selection (reuse of tools no database)
0.6	Manual parameter selection (reuse of tools w. searchable database)
0.8	Semi automated using wizards with suggested parameters
1	Fully automated parameter selection - no manual interference
Fixture selection	
0.2	Manual fixture selection
0.4	Manual fixture selection (reuse of fixtures no database)
0.6	Manual fixture selection (reuse of fixtures w. searchable database)
0.8	Semi automated using wizards with suggested parameters
1	Fully automated fixture selection - no manual interference
NC program verification	
0.2	Online physical program testing
0.4	Online operating panel control testing
0.6	CAM simulation
0.8	Virtual collision testing
1	Virtual cutting process verification

Figure 2 shows the principal process planning activities. These activities are generic for any company, product and process planning situation. In most cases company

or product specific standards and work methodologies expand the number of activities. All the activities have in common that the process planner (human or computer-based) is required to act upon and make decisions in accordance to discovered and delivered data and information.

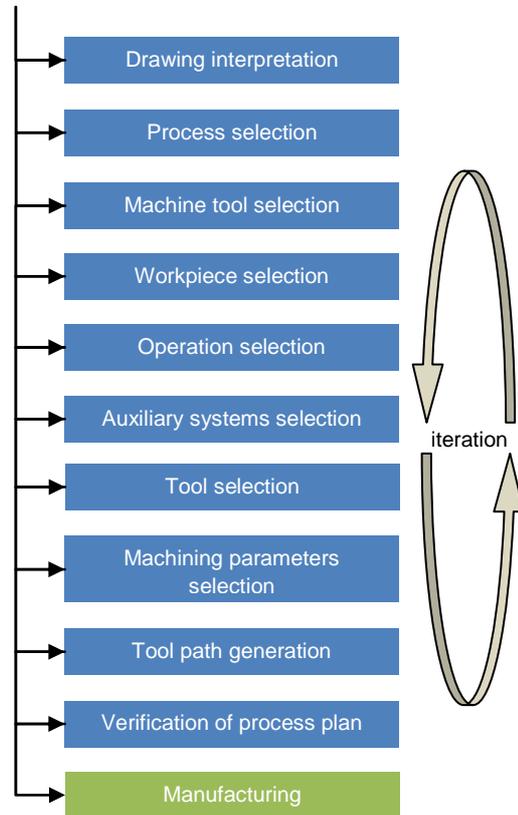


Figure 2 : Main steps in process planning for CNC machining

2.1 Automation level of process planning

Creative work is difficult to automate. However, process planning includes work activities that are more routine, clerical and tedious (repeating calculations), hence more appropriate to initially focus on. These have been targeted in different ways for improvements:

- Tool path generation, e.g. CAM software is directed towards automated tool path generation contra manual NC programming, where each trajectory, must be individually defined by the programmer;
- Tool selection, automatic tool selection for different machining features and materials;
- Efficiency of data, information and knowledge management;
- Work instructions writing (e.g. templates, wizards, automatic generation);

The last point in the above list is not included in the paper scope, but the use of standardised forms and working methods facilitate increased automation level, since data and information can be classified and standardised accordingly.

2.2 Tool path generation

There are principally three ways of generating tool paths for CNC machining operations:

- NC (ISO) programming - CNC program is written line by line using G and M codes to define machine moves and actions;
- CAM – Tool paths are generated semi automatically through a graphical interface directly on a solid model of the part;
- CAPP - Rule-based/intelligent automatic generation of tool paths

Each of these methods is roughly connected to an automation level. The gap between CAM and CAPP is narrowing – where modern CAM systems often provide functions where machining strategies can be defined for certain features and parts and feature recognition [13].

2.3 Tool and machining parameters selection

The selection of tools sets the boundaries for machining parameters and consequently greatly influences the machining time and machining economics. There are an almost endless variety cutting tools, and accordingly even more alternatives for the selection of machining parameters. The automation level regarding the geometric preparation is usually high in CAM programming, but the technical preparation regarding machining parameters, e.g. spindle speed, feed rate, depth of cut and cutting direction is often less automated and must therefore be specified by the process planner [14]. Machining parameters are often selected from machining handbooks, experience, through discussions with colleagues or tool vendors' tables or sales persons. However newer CAM tools often include some CAPP functionality (e.g. feature recognition) [6], meaning that the level of automation between different CAM systems can differ.

The aim of the development of CAPP systems is to replace the process planner with artificial intelligence, using computers [15]. Rule-based systems such as computer information systems and simulations are efficient aids in repeated decision processes [16]. Since process planning work includes a long sequence of decisions, the employments of such aids are also motivated for process planning support.

2.4 Fixture selection

The fixture or clamping device provides the connection between workpiece and machine. It has influence on tolerances, number of setups, cutting conditions and tool paths [10]. For more complex parts it can be difficult to find a fixture that ensures reachability, stiffness etc. and

fixtures must sometimes be designed and manufactured for a dedicated part.

2.5 NC program verification

To ensure that the process plan produces the desired product, the NC program must be verified. In CAM this is often done offline through simulations. For manual NC programming, the program can be verified in the machine control system or a plug-in simulator. Sometimes the program is verified online through soft material or air machining to verify the tool paths. To do online verification requires machine time, which means that the machine temporarily must be taken out of production. If major program error exists, the program must be modified and again verified in the machine, which is time consuming. It is in this perspective desired to use offline software simulations, that not only verify tool paths, but also collision (tool/machine/workpiece) testing, but it can also include cutting simulations.

2.6 Integration – a data, information and knowledge management issue

The method by which tool paths are generated has influence on the possibilities for efficient use of process planning aids. How efficient the use of computer aids in the process planning is, depends to some extent on the interface between the different software used. The aim is seamless data transfer. When manual NC programming and CAM systems without systematic storage of data is used, the integration with other systems is difficult and data must be extracted from existing or old NC programs. This means that the method of tool path generation inflicts boundaries on information transfer. As a consequence, it is the process planners' experience and knowledge that decides how successful the information reuse is. Information and knowledge management is one of the major inefficiencies within most companies in the industry. It is estimated to have an improvement potential of ~27% [2].

A CAM system is by its nature easier to integrate with the company database or a PLM system, so that CAD data, cutting data and tools can be imported directly into the work with the product design compared to manual NC programming. This means that the work and information flow during process planning can be automated to a greater extent than what is possible for manual NC programming. Using a seamless integration between CAD and CAM systems also enables higher quality, since all translation and interpretation of geometries; tolerances etc. are potential error sources.

Information management is not directly related to automation of value adding process planning activities, but a large part of the process planning time is dedicated to information and data exchange and retrieval [2, 17]. However information management is in many cases a requisite for enabling automation of many value adding activities and increasing the overall productivity of automation. IT support, such as PLM/PDM systems used in the process planning can facilitate automatic data collection. Efforts such as development of the STEP-NC standard has been made to ensure more efficient

information exchange between CAD/CAM systems and CNC machines [18]. CAPP systems also targets this inefficiency [19]. Important to keep in mind is however that computer-based tools for information and knowledge management cannot influence all aspects of the information flow, since a substantial part of communication is verbal. Although verbal communication is efficient in many situations, computer-based knowledge is not subject to time. [8]

3 RESULTS AND DISCUSSION

The characteristics for each company are presented in Table 2. The 3D machining parts column in the table gives a rough understanding for the geometric complexity of the machined parts. A 3D part means that more than simple milling, turning and drilling operations are performed. How process planning cost is included in the manufacturing cost is relevant, since it in most cases is regarded as administrative OH, no matter the actual cost. The inclusion of process planning cost would put numbers on the resources invested in process planning for a certain product.

All in all, the automation level of process planning work is low in the investigated companies (Figure 3). Process planning is dominated by manual labour, where tool paths are generated either by NC programming or directly added tool paths in CAM software. Four of the companies have no systematic information and data management, while two companies have rather automated data management through ERP and/or PLM systems, while the information retrieval and value adding is essentially manual. In the investigated companies, the optimisation of machining parameters in respect to requirements is to a great extent performed in the head of the process planners, thus not based on any formalized optimisation algorithms. This observation is also supported by theory [10].

An important factor for a company's future competitiveness is how well the company functions answer to future customer needs and demands. In a process planning perspective it is therefore important to have strategies for the development of the process planning function, since it is an important function, which possibly will increase in importance with higher demands on shortened lead times, cost reductions, and quality improvements. However, when asked, none of the companies appear to have a real plan for the future. Even though three of the companies plan to implement either a

PLM system, new CAM system or are developing current PLM system, the scope does not go any further.

3.1 Main characteristics of interviewed companies

Hereunder the main characteristics of individual companies are stated:

- Company A: Despite long lead times and substantial resources invested in process planning, the resource use is not systematically captured for cost calculations. Process planning is managed using a PLM system. The company uses several virtual tools to aid the process planning activities.
- Company B: Homogenous input due to in-house design. Former attempts with implementation of CAM was terminated after low consistency between virtual models and actual machining.
- Company C: Inhomogeneous input. Quoting is made by a separate company within the company group and process planning is made by a single process planner in another entity in the company group.
- Company D: Inhomogeneous input. The process planning work is estimated in the quotes using empirical standard times for various process planning activities, e.g. 0.5 min to generate one tool path in CAM multiplied by the number of required tool paths. It is estimated to have a 20% error.
- Company E: The company uses a traveller created in the ERP system that contains all information regarding the product and its manufacture. The document is continuously finalised throughout the process planning chain. The process input is highly inhomogeneous, where a sketch is the only input in some cases, whereas in other cases a 200 page document follows an order.
- Company F: Highly ad hoc process planning, where the type of product, requirements and novelty of the order to a great extent renders the process planning activities. All process planning work is carried out from the personnel's experience. No outspoken process planning methodology or strategy exists.

Table 2 : Company characteristics

Company	Business area	Supply chain position	No. of employees at plant	Typical production batch size	3D machining parts	Process planning cost	Location
A	aerospace	OEM/ODM/sub-supplier	~2300	medium/large	yes	general OH	Sweden
B	hydraulic equipment	ODM/sub-supplier	~300	large	no	general OH	Sweden
C	heavy automotive	OEM/sub-supplier	~150	large	no	general OH	Sweden
D	general engineering	OEM/sub-supplier	~10	small/medium	no	est. time = cost	Australia
E	heavy industry	OEM/sub-supplier	~80	small/medium	no	general OH	Australia
F	tool making	OEM/sub-sub-supplier	~20	small	yes	general OH	Australia

3.2 Information input standardisation

For sub-suppliers the problem of heterogeneous input is often a major problem, since jobs can be based on CAD-models, paper drawings, and simple sketches on the fax. An increased usage of computers in the planning process, such as CAPP, imposes constraints on the process input for efficient employment. If a computer is used to automatically assign tools, machining parameters and generate tool paths, the input to the computer must be standardised in order for the computer to interpret the data. A customer drawing must thus be coded into a computer readable format [15]. Since the input format differs in many companies (as between supplier vs. sub-suppliers) there is a substantial need for coding activities. In many cases the coding time probably accounts to the same time it takes to directly generate the NC code interpreting the drawing. In this perspective it is important to reflect upon how process planning can be aided, if non-standardised input is received. In this case fully automated process planning is not possible. For sub-suppliers it is currently a difficult situation since they often have a relatively large free-moving base of customers, where no long term relationship is withheld, thus difficult to agree on a common standardised input format. It is an important issue to target both on company and software provider level. Until the interface between supplier/sub-supplier is not standardised, process planning aids must be flexible with respect to input. However, standardisation of information input can also cause problems, since some suppliers consider CAD models as intellectual property and not shared with external parties. A seamless integration between supplier and sub-suppliers through PLM systems and common databases is in this perspective not facilitated. The heterogeneity of the

process input for many sub-suppliers is probably also one of the key factors that explain the need for flexibility in the process planning work and a lack of too strict work methodology.

3.3 Concurrent Engineering and process planning

In all but two companies, one person principally carries out all the process planning work for each product. There is consequently no functional division of process planning work. Concurrent Engineering (CE) is not easily facilitated. In the companies where more than one person is involved in the process planning, use of computer aids should both give aids to reach more CE and directly improve the individual process planning activities. The use of only one process planner implicates a lack of CE and has a number of implications for how the process planning work is performed:

- The process planner is required to have a wide knowledge span.
- Concurrency between process planning activities are difficult, thus longer lead times are expected.
- The process planning is highly manual and experienced based; little computer aids are used.

Virtual tools (for virtual process verification, etc.) and other computer aids (in particular PLM systems) can increase and is under certain circumstance prerequisites to increase the CE in process planning.

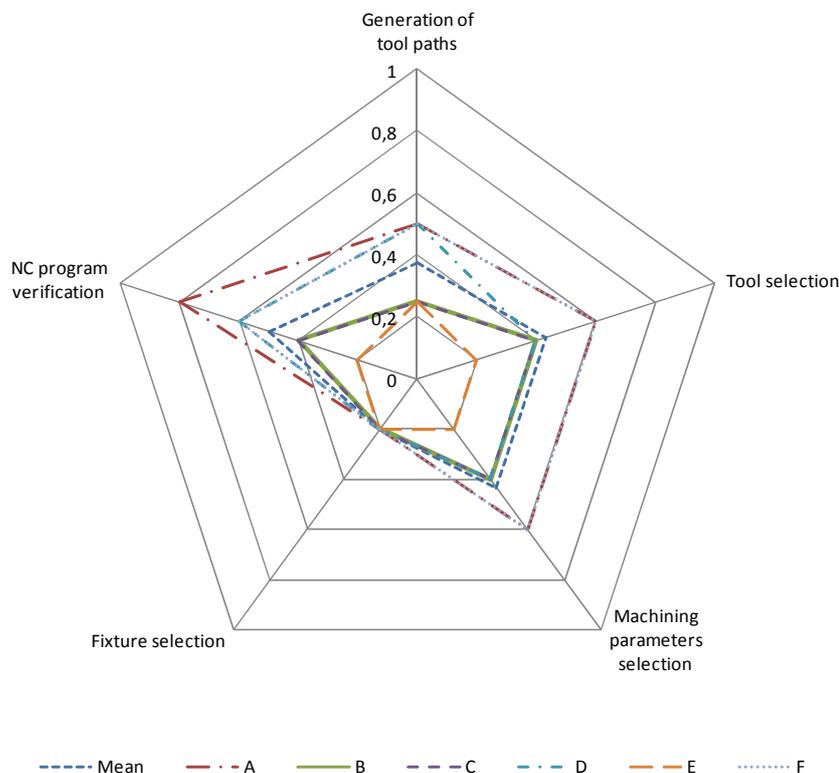


Figure 3 : Process planning automation level of interviewed companies.

Three of the investigated companies use manual NC programming. The reasons are mainly that the operations are simple; hence short programming time. However, simple operations should also be easier to automatically plan for. Another company stated that they once tried to implement CAM, but due to discrepancy between the CAM generated program and the machined result was too great, the implementation was aborted.

The radar chart presents the result from the main findings from the interviews (Figure 3). It gives an understanding for the automation level of process planning work in each of the investigated companies. Each category and grading from Table 1 is found in Figure 3.

4 CONCLUSION

The paper provides an enhanced understanding for the prerequisites for making advancements in process planning for the metal working industry. The main results from the interviewed companies are:

- Low level of standardisation of input;
- Low automation level of process planning activities;
- Data, information, knowledge are generally not managed systematically, hence no systematic recycling of knowledge;
- Few computer-aids are used – and in many cases no ambition to change the current situation exists.

The above findings render an increased understanding for how future computer-aids should support process planning. During use, the computer-aids should be flexible regarding input and automation level, thus able to adapt to changing input formats and different levels of human interaction. This can be done if the process planner is supported in the planning activities, so that administrative and clerical work and information retrieval etc. is facilitated by the computer-aid. In general computer-aids must be resource and cost efficient during use and implementation. Therefore, implementation should be gradual, so that necessary databases are developed over time, thus continually decreasing the need for human interaction.

In order to make any general statements about not only the companies in this study, but the metal working industry at large, a larger sample of companies must be investigated. The sample size in this study is too small to draw any conclusions regarding process planning function in relation to company characteristics, such as company size, type of products or country of location.

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