A reference framework for integrating NC planning into Product Lifecycle Management (PLM)

Günther Schuh, Michael Lenders,
Ju-Young UAM

Laboratory for Machine Tools and Production Engineering WZL,
RWTH Aachen University
Chair of Production Engineering
Steinbachstrasse 19, D-52074 Aachen, Germany
Tel.: +49 241 80 27404, Fax: +49 241 80 22293
E-mail: g.schuh@wzl.rwth-aachen.de

Abstract: Today, there is a lack of support for NC planning by Product Lifecycle Management (PLM) solutions. Although NC planning is an essential process within the value chains of major manufacturing industries, there are still predominantly company specific or isolated NC planning IT solutions, quite contrary to the PLM philosophy. NC planning relies on product and product related information which experiences frequent changes. Because NC planning is often seen as an independent organisation, the NC planner has to access different IT solutions to gather all information needed. The lack of information continuity and consistency also leads to the fact that the NC planner can never be sure of the actuality of information. As the need for more flexible production and shorter production lead times rises, the NC planning process has to become more integrated, increasingly error-prove and more efficient. This article describes an approach for integrating NC planning into PLM. A PLM NC reference framework will be presented to discuss the requirements for integrating the NC planning into future PLM solutions as well as to display an approach for PLM integration possibilities today.

Keyword: NC, Reference Model, Product Lifecycle Management (PLM)

1 Introduction

Today, there is a lack of support for NC planning by Product Lifecycle Management (PLM) solutions. Although NC planning is an essential process among the value chain in manufacturing, there are still predominant company specific or isolated NC planning IT solutions, quite contrary to the PLM philosophy. NC planning relies on product and product related information which experience frequent changes. Because the NC planning is often seen as an independent organisation, the NC planner has to access different IT solutions to gather all information needed. The lack of information consistency also leads to the fact, that the NC planner can never be sure of the actuality of his information. As the need for more flexible production and shorter production lead times rises, the NC planning process has to become more integrated, more error-prove and more efficient.

Chapter 2 will give a short introduction into PLM and present the authors' understanding. Moreover the NC planning task will be described. The 3rd chapter will give a short overview about the research approach. In chapter 4 current results will be presented and discussed. Finally a conclusion and outlook will be given.

2 PLM and NC planning

2.1 PLM

PLM has become one of the main topics for companies who want to become more productive along the whole value chain. Today there are different understandings about what PLM consists of or what PLM refers to. From the different definitions of PLM in common literature we can derive the difficulty to explain what PLM is and what this acronym stands for (Schuh et al., 2008). There is still no definition of PLM generally accepted in science or industry. For Scheer (2006), PLM is an amplification of Product Data Management (PDM) core competencies to other areas and phases of value creation. PLM is the ability to manage company products in a most effective way during the whole product lifecycle (Scheer et al., 2006). PLM can also be seen as a strategic management task (Abramovici et al., 2004). Often the expression 'from cradle to grave' is used to express the holistic approach of PLM. Stark (2007) defines PLM as a "…business activity of managing a company's product all the way across their lifecycles, from the very first idea for a product, all the way through until it is retired and disposed, in the most effective way." (Stark, 2005; Stark, 2007, p. 115). Referring to Feldhusen (2007) PLM is a knowledge-based enterprise strategy for all processes and methods regarding the development of products from the product idea to recycling (Feldhusen and Bungert, 2007; Feldhusen and Gehbardt, 2007). All definitions have in common that they refer to a product's lifecycle and all information related with it. PLM describes a strategy, a strategic approach, a business activity or even a management philosophy. In the end, PLM combines all activities, within and beyond company borders, to manage product and product related information in a most effective end efficient way (Saaksvuori and Immonen, 2005; Schuh et al., 2008).

PLM as a strategy, business activity or strategic approach is supported by PLM IT

Solutions. Companies like Oracle (Agile), Dassault, PTC, UGS and others offer PLM systems and it can be noticed that every major company has business relations to at least one of the PLM system vendors. The growing importance of PLM systems can be derived by the increase of invest in PLM systems from 18 billion US$ in 2005 to 20.1 billion US$ in 2006. (Sontow and Uam, 2007). But in most cases, those IT systems are mainly focused on departments for development and engineering design or order processing, contrary to the PLM core philosophy.

In a research project supported by the German Federation of Industrial Association (AIF) and carried out by the Laboratory for Machine Tools and Production Engineering WZL at RWTH Aachen University and the Computer Language Research Cooperation for Manufacturing facilities (FVP), a reference framework for integrating the NC planning task into PLM systems especially for small and medium-sized enterprises (SME) is developed. This research will discuss the possibilities and potentials as well as reveal deficits and consequences for SMEs.

2.2 NC planning

One of the main levers for industrialization is the ability to measure narrow tolerances. This ability has empowered repetition on a broader basis. Not till then, it has it been possible to reconstruct experiments and derive correlations between causes and effects. Against this background, it is possible today to manufacture products with nearly identical tolerances and quality in almost every lot size. Especially in metal cutting industry numeric code (NC) machining can be seen as a key technology. NC machining realizes complex parts and free-freedom surfaces with high productivity and accuracy towards narrow tolerances. This technology uses automatic machining technology driven by NC instructions, the NC code (Li et al., 2007). Some companies have special digital control departments for designing NC programs for the processing machinery (Yeh and Chen, 2006). The NC program itself is a composition of instructions, written in an assembly-like format. The task to generate the NC program is called NC planning.

The NC planning has to be carried out before a raw part can be machined. The main purpose of NC planning is to generate the NC program as well as to calculate the machine operation time. Although the code lines for a NC program can be written manually, companies often uses NC planning expert IT solutions (NC expert system). These NC expert systems (CAM) allow carrying out the NC planning in a 3D environment.

2.2.1 The need for PLM in NC planning

The NC planning distinguishes between two main planning tasks: the creation of a NC program for a totally new component and the adaption of a NC Program for a component that has already been manufactured. In the first case, the whole NC planning process has to be passed from the beginning. In this case, the NC planner can rely on the latest information within the particular IT systems. In the second case, the NC planner has to analyze on which set of information the used NC program has been generated and if this information is still actual. The identification of documents can be implemented by assigning unique versions for each data and information. With the help of this technique a specific 3D CAD file or a process plan for example can easily be identified even if new versions are available.

The manufactured component highly depends on the NC program and the NC program depends on the actuality of information used during the planning process. When changes in information occur, a NC program can normally not be used in its original version. Moreover, the NC planner has to anticipate these changes and redefine relevant parameters according to the latest information.

One of the biggest challenges in the whole product creation process is the handling of changes. Changes occur in all parts of the value chain and their impact and consequences vary according to their occurrence in a product's lifecycle. In general, changes in late phases of the value chain are far more expensive than changes in early phases (Pfeifer, 2001). This is why companies have put much effort into the implementation of an adequate change management especially in the development phases. Despite this importance, change management has hardly been expanded to other phases like NC planning.

Changes on the one hand, the necessity of a versioning and the requirement of a consistent information basis on the other hand enforce an IT system that combines the different stakeholder, the access of information as well as the possibility to deal with changes in a highly effective way. Today's PLM systems already offer function to version documents or to manage the workflow when changes occur. Against this background, the question occurs, how the current NC planning task can be integrated in current PLM IT solutions. The benefit of PLM in general is evident. Several papers and books have pointed out the potentials PLM has to offer. Therefore, the authors will not discuss the benefit of PLM any further.

3 Research project approach

While large enterprises have already begun to integrate NC planning into their PLM systems, this task is still a challenge for SME. While the benefit is evident, SME have to face difficulties because of different basic conditions. The results of this research project will prepare SME for the challenge to integrate their NC planning into PLM and to encourage them as well as to support them according to their endeavour.

One of the main results will be a reference model of the NC planning task as well as a design guideline to support the lifecycle philosophy from a technical and methodical perspective. In addition a demonstrator will be developed to validate the findings of this project.

According to Feldhusen (2007) a reference model is a generic information model with a variable application context. A reference model features universal validity. Upon a reference model different scenarios can be derived. Furthermore this model can be seen as a guideline for specific application models (Feldhusen and Bungert, 2007). Against this background the reference model approach was chosen to derive requirements for the integration of the NC planning task into PLM systems. The following paragraphs will present the current results.

4 Current results

4.1 Possibilities of Integration

The NC programming can be carried out in different ways. The differences between the programming types are nebulous. In general, literature distinguishes between machine based and non machine based programming methods (Dubbel, Grote and Feldhusen, 2007; Gevatter and Grünhaupt, 2006; Poprawe, 2005). In case of machine based methods, the NC program is generated directly at the machine. The main disadvantage is the limited reuse of the NC program. The reason for this is the machine specific control system as well as the specific machine dimension itself. In case of non machine based programming the NC program is generated in two steps: a machine neutral step and in a machine specific step. The advantage of this type of programming is the reuse of information. When a product has to be manufactured on a different machine or a different period, the information generated in the machine neutral step can be reused. Therefore, the reference model will be designed for the non machine based programming approach.

For the non machine based programming approach the digital control department uses expert systems (Gevatter and Grünhaupt, 2006), which allow 3D NC planning and programming respectively. 3D programming increases in importance, because the use of 3D CAD models has become accepted throughout the industry and 2D drawings are loosing relevance (Arnold et al., 2005; Spur, 1993). Within these expert systems, the NC planner has to define tools, clamping devices and other parameters. To define these parameters, information from different departments among the value chain is needed. Today these expert systems have hardly any interfaces to data management systems like Product Data Management (PDM)- or Enterprise Resource Planning (ERP)-system for example. Every time the NC planner has to access other IT systems a disruption in information consistency occur and a possibility for integrating the NC planning into PLM can be revealed. Against this background, PLM systems have to offer interfaces which allow expert systems access to other IT systems without leaving its own system environment.

The 3D CAD model from engineering design department is often not appropriate for generating the NC program. The 3D CAD model contains information about the final product, its final dimension and shape. Additional information about the machining steps or the selected machine is provided by the process planning department. But information about the available raw material and its dimensions, tolerances or surfaces is not given. The NC planner has to generate this information and link them to the specific 3D CAD model as metadata (Spur, 1993). Therefore the interfaces to the PLM system have to be bidirectional and offer the possibility of altering information out of the expert system itself. To assure a proper information transfer between the different IT systems a standardized data format should be used.

A similar situation occurs when the planning of clamping devices and tools has to be carried out. During the NC planning task a machining strategy based on work piece position, clamping devices and tools has to be defined. A tool as well as a clamping device can be made up of several components. For designing clamping devices and tools, the reference model assumes that a Tool Management System (TMS) is available. The main function of a TMS is to provide the necessary information of tools and clamping devices in stock as well as their availability.

For a consistent 3D NC planning not only the 3D CAD model of the manufactured component, but also all tools, clamping devices and machines have to be available as 3D CAD models. Therefore the TMS has also to manage this kind of information whereas the models themselves are not part of the TMS. As all 3D CAD models should be stored in PDM systems or Engineering Databases (EDB), it is only the management of information but not the storage itself that TMS has to perform. Nevertheless TMS need also to have a bidirectional interface to PDM or EDB respectively.

With all this information and models available, the NC planner can start to define the machining strategy and run simulations of the cutting operation to optimize the cutting strategy, the selection of clamping devices or tool for reducing machine operation time. All this can be carried out without taking the specific machine into consideration. Not until all parameters have been defined, a machine specific postprocessor is used to translate the non machine specific parameters into a machine readable format, taking the machine specific control systems into consideration.

Besides the NC program, the NC planning task provides the calculated machine operation time including primary process time as well as auxiliary process time. This information can be used to plan the manufacturing process in detail by using Manufacturing Execution Systems (MES) for example. To provide this information the NC expert system needs an interface to the order processing systems or ERP respectively which should be realized via PLM.

As described above, the complex topic of change management will be another lever to improve the NC planning task by PLM. Furthermore PLM can facilitate the sequence of recurring tasks by implementing workflows or services.

4.2 Information access and authorization

Within the scope of change management a table has been used to display and define the types of information, their storage location, the desired data format, the information owner, the need for versioning as well as the information flow (q.v. Figure 1, The table is not complete. It should just give an impression how to work with this tool.). Only two types of information are listed in this table. One type of information is generated by another department and form the basis of information the NC planning has to rely on. Such information is for example the 3D CAD model of the product or the process plan. The other type of information is generated during the NC planning process. But only that information is relevant, which is needed as an input for the postprocessor.

On the horizontal axis there are different categories like data format, data storage and data flow. The category data format display the necessary format of information which can be used by NC expert systems. The format of the process plan for example has to be a database table whereas a 3D CAD model can be available in a standardized or proprietary data format.

Some information has to be managed by PLM solutions to guarantee the global availability and data consistency. That does not mean that this information is necessarily stored by PLM. Furthermore, certain information has to be assigned with a unique version number. Because changes in information happen, information can only be identified by its unique version number. Finally the table displays the data flow of information. The source indicates in which system the information should be stored. The target displays the system that has to get access to the information. So the process plan should be stored in ERP-Systems. Finally, this information has to be made available to the NC expert system (CAM).

Figure 1 NC planning information and data definition

ERP: Enterprise Resource Planning CAM: Computer Aided Manufacturing PDM: Product Data Management TMS: Tool Management System CAP: Computer Aided Planning CAD: Computer Aided Design NC: Numeric Control	Data format								Data storage		Data flow	
	Database table	Text (ASCII)	Graphic	Proprietary	Standard CAD	CAD-Internal	CAM-Internal	CNC	Adminis-tration via PLM	Classifi-cation	Source	Target
Order information	X										ERP	CAM
List of necessary 3D CAD models	X										ERP	CAM
2D- / 3D CAD models				X	X				X	X	PDM	CAM
Process plan	X									X	ERP/CAP	CAM
List of NC relevant process steps	X										ERP	CAM
Raw part 3D CAD model				X	X				X	X	PDM/ERP	CAM
Prepared 3D CAD model (NC model)	X			X	X	X	X		X	X	PDM	CAM
Machine 3D CAD model				X	X				X		PDM	CAM
Machine documentation	X	X									TMS	CAM
Dimension of machining section	X	X									PDM	
Clamping device stock	X	X									TMS	ERP
Clamping device 3D CAD model				X	X				X		PDM	CAM
Clamping device list	X	X									CAM	TMS

Figure 2 displays a matrix to identify user rights for expanding change management to NC planning. As not all participants within the NC planning task should have the right to alter information a rights management is needed. On the vertical axis, the different information whereas on the horizontal axis, the relevant users within the NC planning task are listed. This table can not only be used to set up change management, but also to identify bidirectional or one way interfaces for data flow.

Figure 2 Defining read / write data access

r/w: read / write ro: read only	Users					
	Engineering 1	Process planning 2	Production equipment planning 3	NC planning 4	Production equipment preparation / maintenance 5	Production 6
Order information	ro	ro		ro	ro	ro
List of necessary 3D CAD models		r/w		ro 2		
2D- / 3D CAD models		r/w	ro 2	ro 2		ro 4
Process plan		r/w		ro 2		
List of NC relevant process steps		r/w	ro 2	ro 2		ro 2
Raw part 3D CAD model				r/w		
Prepared 3D CAD model (NC model)			r/w	ro 3		
Machine 3D CAD model			r/w	ro 3		
Machine documentation				r/w		ro 4
Dimension of machining section			r/w			
Clamping device stock			r/w	ro 3		
Clamping device 3D CAD model				r/w	ro 4	ro 4
Clamping device list				r/w		ro 4

Order information for example can only be read (ro: read only). Only users who are information owners have the right to alter information and therefore to read as well as to write data (r/w). If a user without r/w authorization wants to alter information, he has to address himself to the information owner and apply for a change request. The number behind “ro” indicates the information owner.

4.3 NC planning reference framework

On basis of this framework the reference model of the NC planning task has been designed. The authors have used the Business Process Modeling Notation (BPMN) to design the reference model (ww.bpmn.org). Not only in industry but also in academic research this language claims increasing interest. This modelling language is simple and makes it easy also for non-experts to describe business processes within nearly every domain (Endert et al., 2007).

Figure 3 Elemental NC planning steps

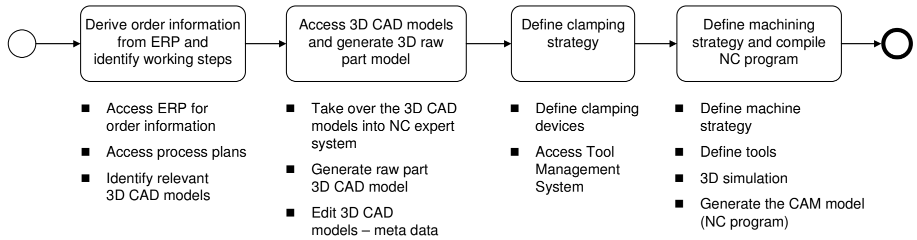
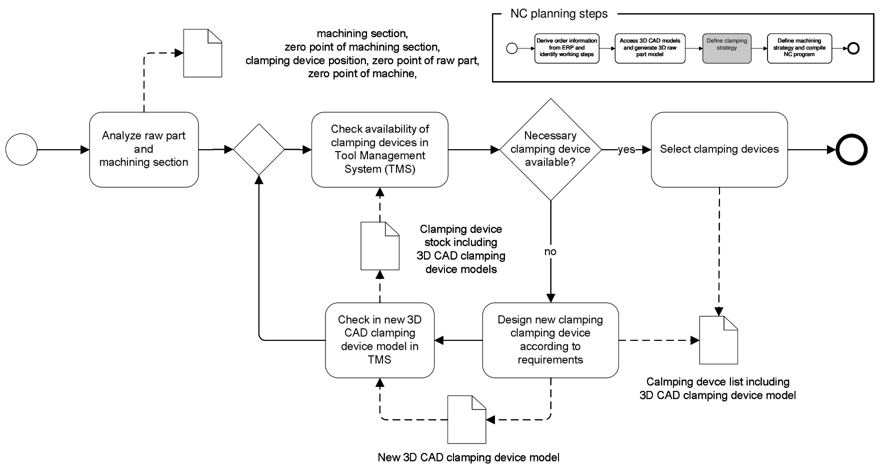


Figure 3 displays the main four steps within the NC planning task. Every step can be extended to a more detailed exposure. As an example, the following paragraph will present step three in detail. A presentation of all steps in detail would go beyond the scope of this paper.

Figure 4 Step 3: Define Clamping strategy



During step three the machining strategies as well as the clamping set ups are defined. In the first step several positions of the raw part on the machining section have to be defined according to the process plan. Against this background, the zero-point for the machine, tools and raw part can be determined. In the next step clamping devices have to be selected. The NC planner uses the TMS und gets access to the existing clamping devices in stock. If an adequate clamping device is available, the 3D clamping device model has to be made available for the NC expert system. This does not mean that the clamping device model is downloaded into the expert system. In fact, the clamping device model is still stored in the database but the expert system has access to the database and can display the model in its own environment via interfaces. If an adequate clamping device is not available, the expert system offers the opportunity to create a new device in its own environment, just according to the actual need. An interface to the TMS makes it possible to register the new device into TMS and archive the 3D CAD model into the PDM via TMS. Finally the next step can start.

5 Conclusion

In general, it is possible to integrate the NC planning into Product Lifecycle Management solutions. This reference framework presents methods and tools to develop an IT based solution to support the NC planning process. The presented results are just the beginning and further research has to be done. The development of a proper change management for NC planning for example is one more field of action that needs further consideration. Furthermore the architecture of the different IT solution will be another challenge that has to be accomplished. Especially the last point is essential, if data consistency throughout different IT solutions should become true.

Change management has to go beyond NC planning. Because the NC program depends on the CAD model, the department responsible for the design of the CAD models has to be involved. Equally the production department has to be involved, because the machine operator often alters the original NC program due to difficulties during the machine set up. The reasons for the change of the original NC program are numerous. But it is often not clear, if these changes are permanent or just temporary due to the current heat or air flow condition for example. The matrix in figure 2 as well as the reference framework will be used to set up the change management process with data, people and processes involved.

The architecture of the different IT solutions will be another topic that has to be detailed. In this context, the architecture addresses the set up of interfaces needed to create a consistent data flow throughout all involved IT solution. Data consistency is necessary to provide valid date during the whole NC planning process. This aspect is related to change management. Furthermore, this aspect is a requirement to simplify the handling of IT solution for the NC planner by accessing other IT systems without leaving the familiar NC expert system environment. Against this background, the matrix in figure 1 presents a tool, to identify the data flow as well as the data format, to create the necessary interfaces between the different IT solutions.

Finally, by integrating the NC planning process into Product Lifecycle Management solutions, the production lead time becomes shorter, changes can be anticipated more accurate and time-to-market can be reduces to strengthen the competitiveness especially for SMEs.

6 Summary and Outlook

The NC planning task is part of the value chain. Especially for the metal cutting industry NC machining is a key technology in machining complex parts with high productivity and accuracy. Despite this importance, the NC planning task is not integrated in current PLM IT solutions. The benefit of a consistent data basis is evident. In this paper a reference model approach has been presented to integrate NC planning in current PLM solutions. The reference model assists companies to set up their digital control department and enlarge the scope of their current PLM solutions. Further research will be required to analyze current PLM solutions and to prove that the presented reference framework as well as the requirements set can be transferred in day-to-day business.

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