Knowledge Systematization for Operations Planning

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Abstract

Operations planning is a complex and knowledge intensive process. Products with large numbers of variants, such as products manufactured in a one-of-a-kind production scheme, require that large parts of the operations planning is done automatically or supported by computer-aided systems. Designing such a system for a flexible environment demands certain capabilities as f.e. simple understanding and thus maintaining of the knowledge base or possible user interaction during the planning process for gaining additional knowledge

This paper presents an overview over the demands on knowledge-based operations planning systems under special consideration of knowledge management aspects. Within an industry project, this and the results of the study of existing planning systems should lead to a specification and prototype implementation of a new operations planning system for sheet and coil material products.

1. Introduction

The operations planning is usually seen as a subtask of the production planning activities that has to find the processes, create a valid order among them and instantiate these processes with the necessary parameters such that an initial work piece is being transformed into the product ordered by the customer. In the sheet- and coil working industries, the initial work piece is an ingot or a metal sheet while the resulting product usually is a metal sheet, a coil or a foil. The basic actions of an operations plan are elementary manufacturing operations. It is therefore a special application of the general planning problem which can make use of additional constraints evolving from the respective domains.

In non-mass-production sheet- and coil-working industries, customer requirements are so specific that the same product almost never appears twice in the production program within a reasonable period of time. Even though the product, a sheet or coil of varying material, is always similar, its properties vary greatly in their dimensions, surface structure and characteristics, and other parameters. Mass-customization for competitive markets requires an efficient and inexpensive production planning. The cost arising within the production planning activities should remain in a fair proportion to the total product cost (Schwarze, 1996).

The general structure of the operations planning problem is given in Figure 1. Using the technical and process knowledge and the data of a specific customer order, some transformation is being searched for that creates an operations plan, a valid order of processes. The solutions for this transformation vary greatly. While for a long time this task was performed by human planning experts, software-supported systems (Computer-Aided Process Planning Systems, CAPP) have been increasingly introduced since the beginning of the 1980s. These systems can fulfill the full scale of planning tasks only in very few applications. In many applications, even the support for routine tasks is very limited. The main difficulty of CAPP projects is not so much finding appropriate problem solving methods but rather addresses the effort of modeling and maintaining process knowledge (Hamelmann, 1996).

2. Planning Principles for Operations Planning

While human planners often work intuitively and use different ways for solving problems depending mostly on the problem instance, the approaches that CAPP systems take to solve a planning task can generally be divided into three principles, whereas many systems combine some of these principles for gaining performance and flexibility. These three principles, generative planning, variant planning, and case-based planning (plan reuse), are compared shortly in this section and evaluated with respect to their application areas and the needs and advantages of human involvement. They differ mostly in how the process knowledge is made available to the planning system or the planner and how it is used during the planning process.

Generative planning is the synthesis of plans with no prior plan information. The process knowledge defines the conditions under which an operation must or could be part of a plan so that the resulting operations plan can produce the ordered product. There is additional knowledge for

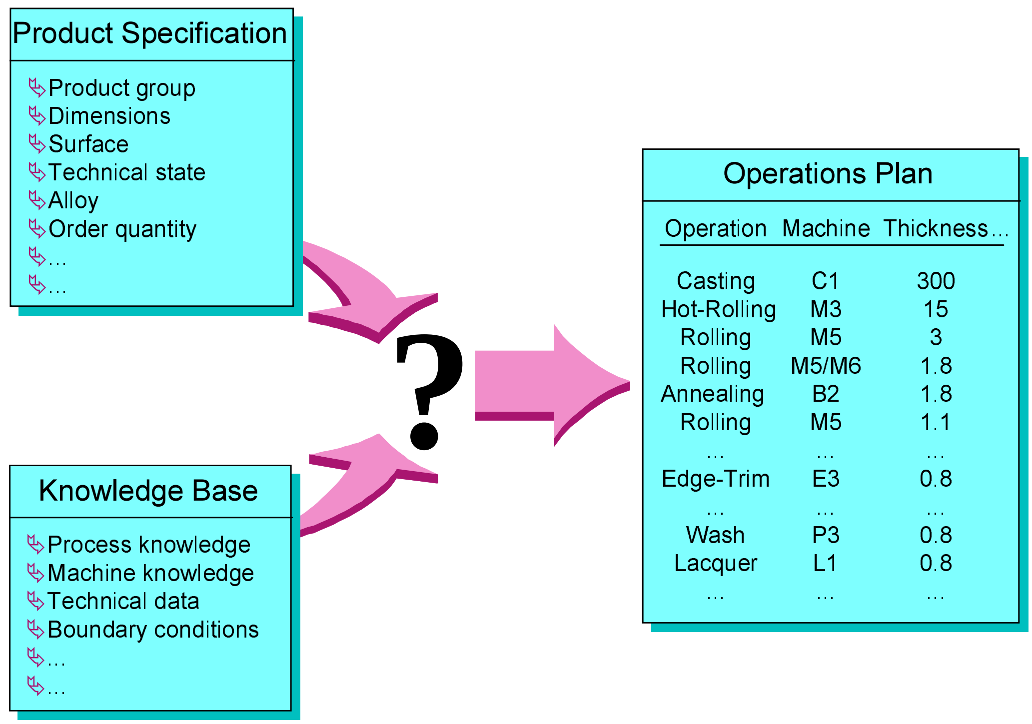

Figure 1. Structure of operations planning problem (refer to Alder, 1991).

structuring and arranging these operations into a valid order, finding operation parameters and finally optimizing the plan. Still, no prior structural knowledge is given as an input to the planning process.

Variant planning uses existing standard plans that describe the structure of an operations plan with its defining operations. During the planning process, these plans are detailed and filled with specified parameters. The parameters are either available from the customer order or can be calculated from those. Usually, standard plans are associated with a product family. The development of the standard plans requires a large effort. The set of plans must cover all parts of the product spectrum, so that each customer order can be assigned to one standard plan. Otherwise, remaining orders would need to be planned manually or with assistance of an additional system. On the other hand, many detailed standard plans for every special case create a knowledge maintenance problem. Standard plans need to be adjusted with every change in the manufacturing processes even though they are used only rarely. The definition of the plan level is therefore of great importance.

Case-based planning uses a large data base of previous orders and resulting operations plans. For every new order, the data base is searched for a similar problem instance which is then taken as the basis for solving the given problem. The retrieved plan is adjusted manually or automatically. Particularly in complex problem domains it is very difficult to define when two problem instances are similar or not (Aleven and Ashley, 1996). The intervals of the input variables in which a plan structure is still valid are usually not determined. A small variance in one parameter can result in a very different plan. A second problem is the determination of the number of problems that are stored in the case base. A large number increases the search effort for instances similar to a given problem and also increases maintenance effort. If the data base is too small, some areas of the problem space might not be covered and manual planning is necessary.

Many efficiency evaluations are made to determine which planning methods is suited best for which planning problem. Comparing generative planning on the one side and variant planning or case-based reasoning on the other side for aspects of knowledge management and knowledge maintenance, standard plans used for variant planning tend not to be up-to-date due to a frequently changing environment, a continuity in the generated plans cannot be guaranteed, and that the flexibility for optimizing plans is very limited (Alder, 1991). Tools for supporting manual change and optimization by the planners would reduce these drawbacks.

Generative planning, on the other hand, presents a more flexible way of planning and allows to faster react to changes in the environment. Still, the complexity of knowledge management and knowledge maintenance can become a major problem. In large systems, the complexity of the knowledge to be managed and the strong dependencies within the knowledge requires well trained specialists. This introduces a new kind of experts in addition to the planning or process experts: knowledge engineers. Since the development of a error-free generative planning system seems impossible, process experts have not at all lost their importance. The goal of reducing the importance of process experts can hardly be reached. Still, the major advantage lies in reducing the amount of routine work for planning experts.

Worst-case studies have shown that case-based reasoning approaches might even be more computationally expensive than generative planning. Finding a good reuse candidate may already be very expensive, leading to higher computational cost than generating a new plan. This assumption is also supported by empirical results in some domains (Nebel and Koehler, 1995). In other domains, reuse strategies seem to be quite successful. Systems that integrate large case-bases and well-understood reuse strategies have to be improved further to be of practical use (McDermott and Hendler, 1995).

Generative planning is widely applied in industrial contexts. Still, only about 20% of the companies use a system that supports the planning task. Usually, CAPP systems only support the planner in finding relevant cases and are thus counted to belong to case-based planning approaches. The adaptation of the plan for fitting the given customer order is then done manually (Baum, Uhlig and Zahn, 1997).

3. Requirements on an Operations Planning System

The evaluation of different interests needs to be a first step before specifying system requirements for a new CAPP system. There are four areas of tasks that are affected by operations planning: system development, knowledge engineering, planning, and manufacturing. One person performs not necessarily only tasks in one of the areas. This largely depends on the size and organization of the company. The most relevant jobs to be done in these areas are:

- Manufacturing: Interpretation and execution of operations plans.
- Planning: Generating plans and checking for correctness. Apply manual changes or adaptations, especially in cases of variant or case-based planning approaches. Persons involved in planning need to have the expert process knowledge.
- Knowledge Engineering: Keep the knowledge base up-to-date. This includes not only modifications due to changed machinery (new machinery or extended capabilities), changed production processes (new regulations or modified process descriptions), and alterations in the product specifications (new or extended products, special customer requirements) but also improvements of the knowledge structure and error tracking and solving.
- System Development: Guarantee correctness of planning process. It is responsible for the structural design of the knowledge base and general reasoning system maintenance.

For the fulfillment of each task, requirements for a CAPP system can be derived. The requirements presented here are mostly usability driven. Technical boundary conditions are not described since they largely depend on the given application. In addition, user requirements do often not get enough attention in technical applications since their development is mostly lead by technical considerations, usually with only little contact to the users. An overview over the most relevant user requirements for knowledge-based planning systems is given in Figure 2. The requirements are again grouped with respect to the different interest groups:

- Manufacturing: Most important is the correctness of the operations plans. The plan should include all process information as well as possible references to manufacturing rules that must be obeyed. Determination of alternative machines and process tolerances help operators interpreting their action potential. This should give liberty for reacting on process uncertainties or special customer requirements not covered by the planning system. Technical processes are not always understood completely so that the ability of flexible reaction needs to be maintained.
- Planning: The most important requirement by the planning personnel is that the reasoning steps taken to develop the operations plan must be transparent. This is necessary for eventually making manual additions or changes but also for understanding error messages of the planning system. Further on, the planning system should be flexible enough to allow interaction during the planning process for influencing or avoiding wrong decisions. Interaction, on the other hand, requires a reasonably fast system reaction time.
- Knowledge Engineering: Knowledge engineers are looking for a powerful form of knowledge structuring which allows them to define general principles on a very abstract level but also enables a simple representation of specific exceptions to these principles. The most important aspect in this context is to find a comprehensive structure of knowledge which includes a

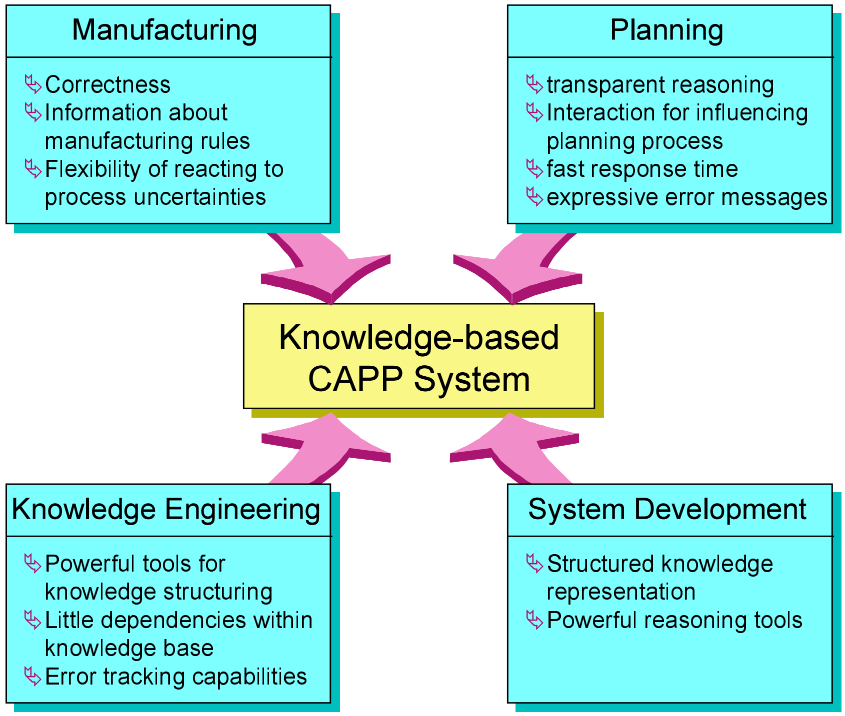

Figure 2. Requirements for knowledge-based planning systems by different interest groups.

minimization of dependencies within the knowledge that cannot be represented in this structure. This helps determining side effects of any changes in the knowledge base. In addition, the knowledge engineer is interested in being supported by the system for tracking possible errors in reasoning steps taken.

- System Development: The requirements of system developers are somewhat similar to those of knowledge engineers. On top of that, the methods given by the system for reasoning with the knowledge should be powerful enough for reaching a good performance of the planning process.

These results show that knowledge management is a central aspect of a knowledge-based planning system. Knowledge management may in complex systems become even more important than the actual reasoning capabilities. The success in knowledge management and maintenance largely influences the flexibility as well as the cost of such a system.

The second important question is to which extend a planning system should be automated. A high degree of automation will reduce average planning time and enlarge the scope of possible applications. This goes along with a poor flexibility of reacting to special customer requirements. The higher the degree of interaction with the planner is, the more adaptable can the planning process be designed.

These are the primary criteria for evaluating new approaches of handling the operations planning task.

4. Approaches for Handling the Planning Task

4.1. Knowledge Systematization and Knowledge Maintenance

The representation of process knowledge is a crucial aspect while designing an operations planning system. Maintenance of the knowledge base is a cost driving factor in expert systems and must be kept very simple so that even non-specialists can perform changes. The danger is high that knowledge engineers become a second kind of experts in addition to the process experts. This is somewhat contradictory to the original goal of knowledge-based systems of getting less dependable of expert knowledge. At the same time, flexibility is inhibited by complex systems. Side effects of changes in the knowledge base grow in complexity and make changes a difficult task.

One of the most transparent ways of presenting planning knowledge in form of structured decision processes is by means of decision tables. Decision tables have only a very limited area of application and cannot be used as the only form of representing planning knowledge in non-trivial problems (Juettner and Feller, 1989). They might though present a good way of solving easy sub-problems. The descriptive component of decision tables makes it easy to understand the decisions taken.

Rule-based systems are the most widely used planning systems. With growing knowledge bases, they tend to lack distinctness. Most of the observations made in the previous sections have been made with rule-based planning systems even though they are of rather general nature. The efforts in structuring knowledge have lead to some improvements. The method of hierarchical planning works by first constructing an abstract plan in which details are left unspecified, and then refining these components into more detailed subplans until enough of the plan has been elaborated to ensure its success. The essence of hierarchical planning is the use of different levels of abstraction both in the planning process and in the description of the domain (Wilkens, 1988).

An alternative to rule-based planning systems is arising through recent advances in constraint programming. A Constraint Satisfaction Problem (CSP) is typically defined as the problem of finding consistent assignment of values to a fixed set of variables given some constraints over these variables (Tsang, 1993).

Constraint-based techniques present some advantages over rule-based techniques which are usually used for solving similar problems, especially with respect to knowledge maintenance aspects. This is due to the fact that knowledge representation using constraints can better demonstrate relationships between variables. Consequences of changes are traced better. Furthermore, less parts of the knowledge base might be effected by knowledge changes (Faltings and Weigel, 1994). On the other hand, constraint techniques cannot very well explain why a given solution is correct and how it was found. They can rather demonstrate why a given set of constraints cannot produce any solution.

With rules and constraints alone, it will be difficult to describe the full amount of knowledge available to a human planner. There are several different types of constraints on operations plans that must be able to be formulated either directly or indirectly in a knowledge representation. These types are:

I. a fixed position of an operation in the plan
II. a direct sequence (operation B follows operation A directly)
III. alternatives for subsequent operations, to be chosen by fixed criteria
IV. dependencies upon the existence of other operations in the plan
V. optional operations (or sets of operations)
VI. operations with a position in the plan which relation to other operations is not immediately known from the order data
VII. exceptions
VIII. special priorities or wishes

These different types are not a complete list. Knowledge based on experience which are rarely defined in crisp terms, cannot be represented easily by rules. On top, it is difficult to first verify and then use the knowledge efficiently if this is largely represented in a textual form.

The conditions evaluated for finding the position of an operation or for choosing one of a set of alternatives can use the following criteria which are available at the beginning of the planning process or become available in its progress:

A. order data
B. criteria that can be deduced directly from order data
C. calculated values, often dependent on the prior operations in the plan

4.2. Standard Plans and their Visualization

The research within this project is currently investigating suitable ways of visualizing the knowledge in form of networks. Every path through such a network could represent a possible operations plan whereas not all of these plans are valid. Such a visualization is shown in Figure 3. The graph represents a standard plan as the basis for a variant planning process. In this case, all possible variants are encoded in the standard plan. Information is stored in many ways in this graph. Each node (operation) has some parameters associated with it which are needed to calculate the related constraints. Sequencing and position constraints are described through the graph structure, alternatives are defined alongside the edges of the graph. Constraints that relate operations in different parts of the plan, are defined outside the plan.

The representation of standard plans by the above means works well for plans with limited complexity. The combinatorial aspects (i.e. a set of operations whose sequence is determined mostly by parameters that need to be calculated) should not be large for the plan to remain readable. Furthermore, exceptions (i.e. under a certain condition swap these operations) can hardly be displayed, unless all combinatorically possible cases are shown explicitly.

Some of the mentioned drawbacks can be reduced by using an enhanced plan representation as shown in Figure 4. The optional operations are part of the plan only under certain conditions. If an optional operation is not needed, it is just skipped and the preceding operation is followed directly by the succeeding operation. This eliminates many edges describing all these possibilities. Operation E would represent the type of operation which determines its position during the planning process due to local information and thus eliminates the explicit description of all possibilities in the graph.

This enhanced visualization seems to be capable of describing more complex operations plan structures even though it introduces more types of items than the previous model. Still, reactions from the users on the approach presented are acceptant and promising. This positive feedback is largely due to the fact that maintenance of visualized standard plans is by far easier than the maintenance of a large rule set. The explanation of solutions and their possible alternatives is also seen as a big plus.

For using the standard plans and the associated knowledge in the reasoning process, it is necessary to transform it into a representation that can be used by solving algorithms. The translation, which in the present prototype stage is done manually, should be automated so that changes in the graphical representation can be compiled quickly into the algorithm representation.

When the sequence of the operations is found by the solving algorithm, the operations parameters can be determined by propagating the starting values through all operations.

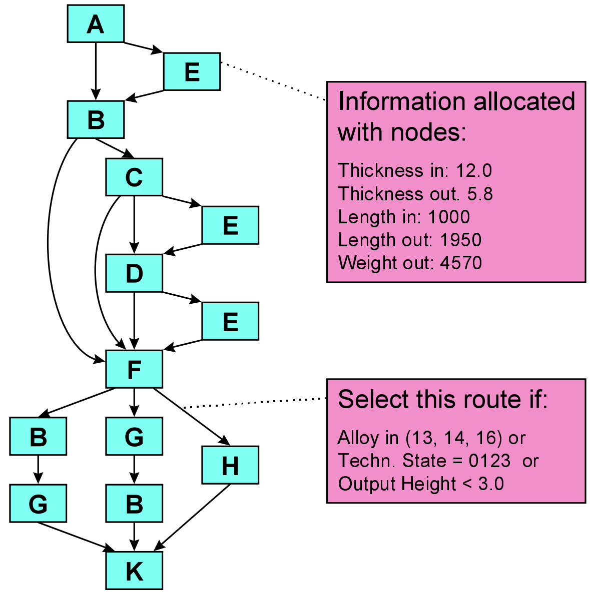

Figure 3. Visualization of a standard plan as seen by the user

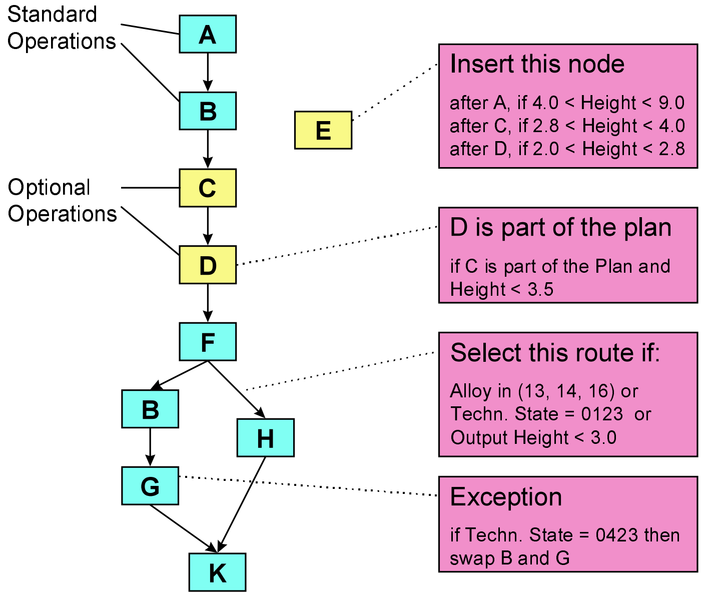

Figure 4. Enhanced visualization of standard plans as seen by the user

4.3. Degree of Automation

One question which needs to be discussed when designing a knowledge-based system is the planned degree of automation. This decision has a great impact on how the system can be embedded in the surrounding processes. As soon as one human is involved, the process has to be designed according to the needs, jobs, and abilities of this person. If persons are concerned with checking the correctness of every operations plan, it makes no sense to use the operations plan as a basis for price calculations during the online offer preparation since a limited response time acceptable to the customer cannot be guaranteed.

Besides these restrictions the question is to be answered whether a full automation is at all desirable. Is there a guarantee that all generated plans are correct? Even if the correctness check is done manually, an automated operations planing allows to generate plans in batch runs independent of office hours. This seems to reduce the human involvement to a minimum.

Still, an engagement of the planner in the planning process makes more structural knowledge available and might thus enhance the planning. The way planers find a first solution without computational help - defining the plan structure with only few key parameters of the input values - is very effective but difficult to perform by a planning system. In a combined approach, the planner could design the structure of the plan while the planning system calculates the operations parameters, checks for plausibility or optimizes the actions. Difficult calculations and routine tasks are those jobs that take much time without being very difficult for humans and should therefore be passed on to the planning system.

If this approach is extended, the question must be raised whether really all of the production system's capabilities should be modeled in the knowledge base. The effort of modeling all special cases and exceptions to general rules and the resulting complexity enlargement might be much higher than passing on special plans to humans directly. This assumes again that the planner is responsible for the design of the plan but receives help in complex calculations and plausibility checks by the system.

In this context, a variant planning approach seems very reasonable. For each product family, there exist one or several standard plans which can in standard cases be filled with parameters by the computer system and in special cases, in an interactive process, be changed by the planner according to the customer order. If no standard plan fits to a given order, the planner could use his experience to develop a new plan. It is important that a comfortable user interface supports each of these steps. The best success can be expected in cases where the planning process matches best with the intuitive approach of planners. This also supports the error tracking in case of necessary changes to the knowledge.

5. Summary

Operations planning has always been in the conflict between independence of experts and efficiency considerations that require a planning process to be mostly automated on the one hand and need for flexibility, fast reaction and a low degree of maintenance effort on the other hand. Until today, it seems impossible to find knowledge structures that fulfill the requirements of the different kinds of users while at the same time being easy to manage. Also, operations planning problems are usually too complex for being solved without human interaction.

There is no perfect solution. Rather, new avenues have to be tried. The possible solution presented in the last section reduces the amount of knowledge maintenance by large and involves the planners actively in the planning process without only bothering him with controlling tasks. This leads to a highly increased flexibility within the planning process. The effort of keeping the standard plans up-to-date seems reasonable compared to the amount of knowledge maintenance saved.

6. Acknowledgements

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