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Control mechanism of expert system with representation of knowledge in the form of hierarchical decision nets

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Abstract

Based on the results of investigation into the decision- making process, the model of knowledge in the form of hierarchical decision nets was developed. Two principal types of knowledge can be distinguished in this model: control knowledge and classification knowledge. The paper also presents the control mechanism for the processing of such arranged knowledge. The approach was verified through the development of the expert system for machining process planning.

1. Introduction

Planning is one of the elements in manufacturing process, which is carried out in planning system and can be treated as a complex decision process resulting in solving the planning task. Investigation into the planning processes shows some similar structural features and the decision problems solved during the planning process create a very complex decision system.

In general two tasks can be distinguished in solving the decision problems:

- Classification task, which can be described as the selection of the solution from a predefined, finite set of permissible solutions, taking into account all the facts and data concerning the considered object. The classification problem can be solved using a traditional architecture of a rule-based expert system.
- Synthesis task meaning the finding of such sequence of planning actions that allows to achieve the set goal. The traditional architecture of expert system does not satisfy the requirements of this task.

Based on the results of investigation into the decision- making process, the model of knowledge in the form of hierarchical decision nets was developed. The control mechanism responsible for finding the solution is also presented.
The presented approach was used in the development of the expert system for machining process planning.

2. The model of knowledge in the form of hierarchical nets.

Taking the nature of the decision processes into account, the problems solved in the decision process create a multi-level decision system which can be divided into several planning subsystems. On the one hand, planning because of its complexity is made in stages, from general solution concept to particular solutions by iterative actions. On the other hand, some order can be established on each level of detail because of the characteristics of the planning task.

The nature of the decision process in planning is represented by the knowledge model. The decision problems are solved on several different level and the number of level depends on the complexity of the problem. Each i-th level of details can be described by nets:

$$S_i = \langle D_i, T_i, R_i \rangle$$

where:

- D_i - a set of planning decision determining the rules of selection of planning actions for i-th level,
- T_i - a set of planning actions or transition to the other planning decision for i-th level,
- R_i - relations defined on the set of planning decisions $d_i \in D$ and actions $t_i \in T_i$ for the i-th level,
- i - = 1...n
- n - number of levels

Each planning action $t_{i1}, t_{i2} ... \in T_i$ can be described using the net of the lower level. The idea of building the knowledge model is given on fig. 1.

The rules for the selection of the planning actions can be presented as a decision tree. The decision tree is a graph-tree, the root of which is created by the selected attribute Q of the planning task, and the particular branches represents the values of this attribute q. The graph nodes on the higher levels of the tree have assigned further attributes occurring in the classification task, whereas the nodes on the lowest level describe the corresponding planning actions. The actions can be described by means of the net of the lower level.

3. Representation of planning knowledge in the form of rules and frames

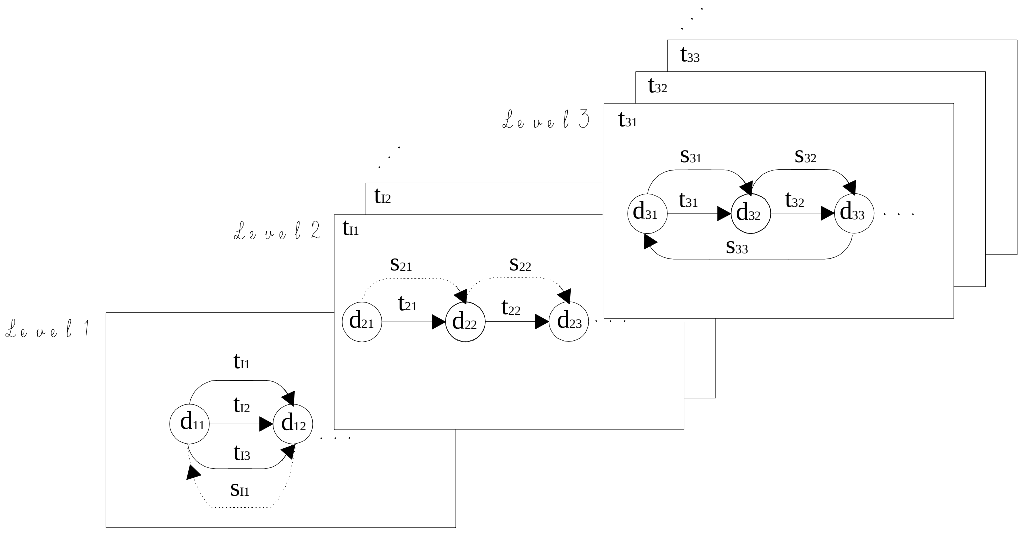


Fig. 1 The idea of building the knowledge model

On the basis of the above presented model, two principal types of knowledge can be distinguished (fig. 2): control knowledge and classification knowledge. The classification knowledge, represented as production rules, specifies the conditions which must be satisfied to execute elementary process planning actions. The control knowledge determines the set of planning operations adequate to the current planning context, so it is used to determine the possible sequence of planning operations. Thus the role of the control knowledge is supervisory - it controls the rule-based knowledge database, applied to solve the classification task.

Control knowledge

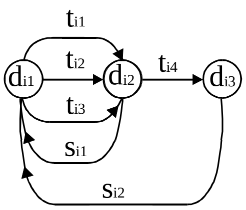
The control knowledge is represented by means of frames. Each net of the ith-level is described by the frame. The idea of representation of control knowledge is shown in fig. 2b. The frame has three columns where the first one gives the start decision nodes, the second gives the planning actions and the third the end decision nodes. There are also pointers which connect frames together (fig. 3). So, the planning knowledge database consists of the set of frames and the set of production rules.

Classification knowledge

The classification knowledge can be presented in the form of a decision tree. The idea of building the decision trees is presented in fig. 2b. On the basis of the decision tree $d_i \in D_i$, a set of rules (IF...THEN) defining the principles of the selection of planning actions can be determined.

a)

$S_i = <D_i, T_i, R_i>$



$D_i = \{d_{i1}, d_{i2}, d_{i3}\}$
$T_i = \{t_{i1}, t_{i2}, t_{i3}, t_{i4}, s_{i1}, s_{i2}\}$

b)

R

Previous decision node	Planing actions	Next decision node
d_{i1}	t_{i1}	d_{i2}
d_{i1}	t_{i2}	d_{i2}
d_{i1}	t_{i3}	d_{i2}
d_{i2}	s_{i1}	d_{i1}
d_{i2}	t_{i4}	d_{i3}
d_{i3}	s_{i2}	d_{i1}

c)

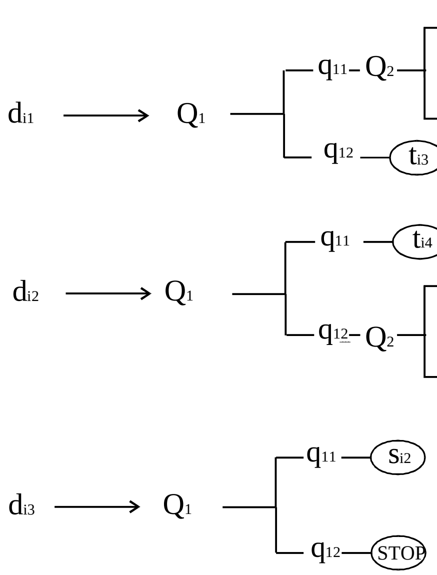


Fig. 2 The idea of knowledge representation for the i-th level
a) net for the i-th level
b) control knowledge for the i-th level
c) classification knowledge for the i-th level

```
IF    condition 1
 (and/or)condition 2  checking the conditions of
 (and/or)condition 3  occurrence of the planning operation
   ...
THEN
   t            planning operation
 and p1=... allocation of parameters values
 and p2=...
   ...
 and procedure (p1, p2, ...)  calling the procedure related with
                              the planning operation
```

In the THEN part of the rule values are assigned to parameters of the procedure related with the selected planning operation p1, p2, ... and the procedure is called.

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Fig. 4 The scheme of operation of the control mechanism

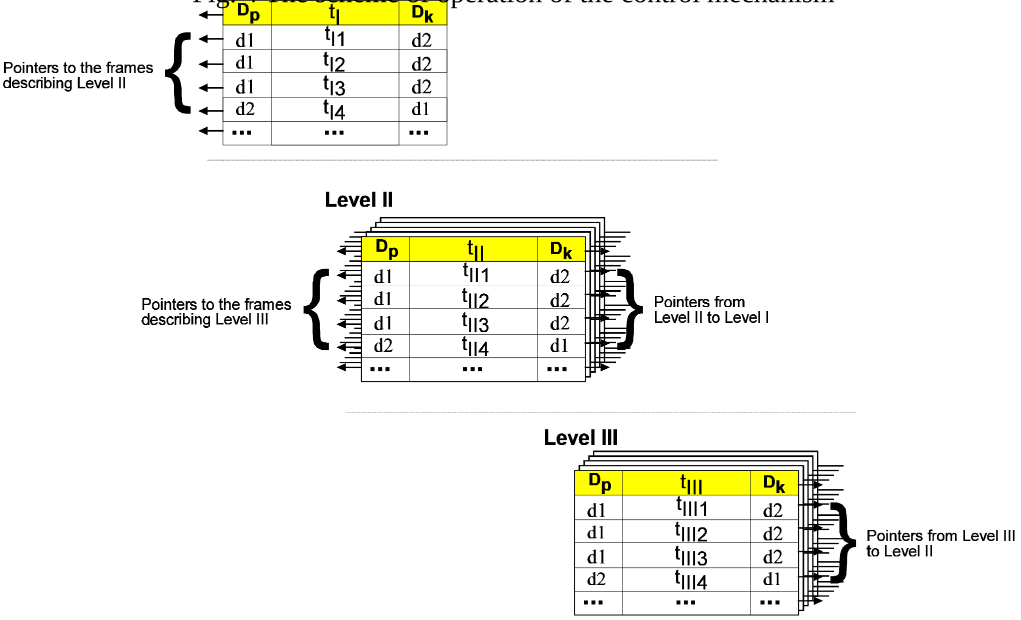


Fig. 3 The idea of representation of control knowledge by means of frames

4. Control mechanism

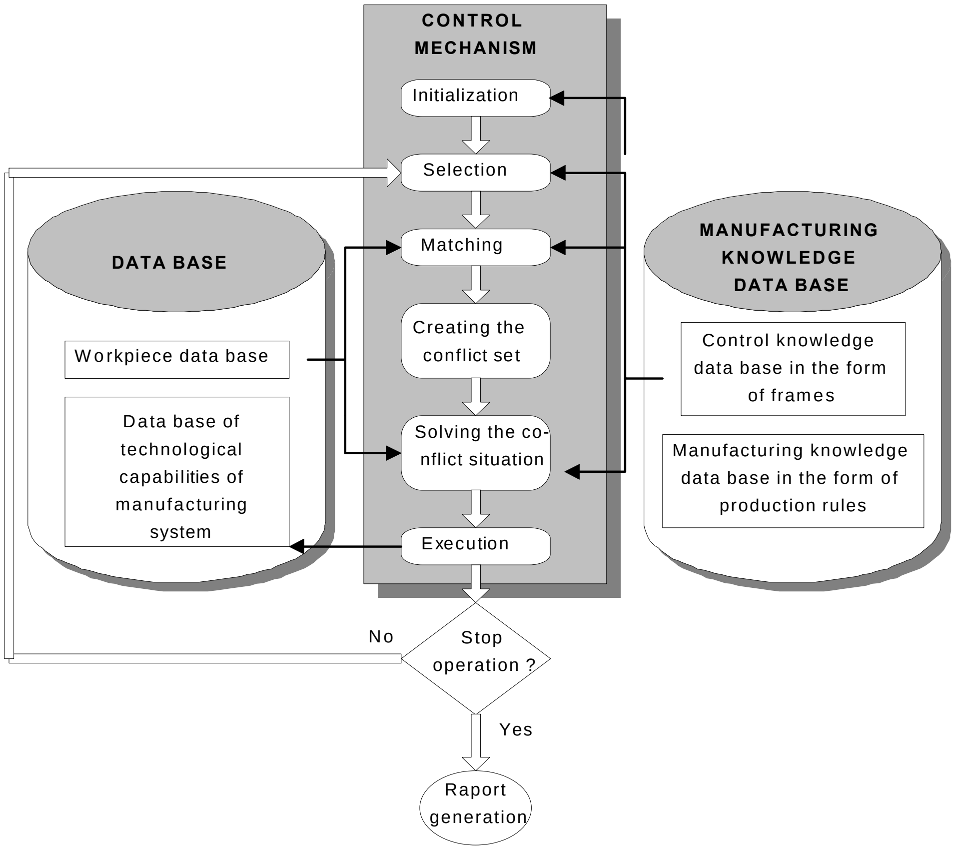
The task of the control mechanism is to process the knowledge represented as described above. The following steps can be distinguished in the operation of the control mechanism(see fig. 4):

Initialization - initialization of the context of the planning situation. The context is always determined by a variable containing the frame name with the description of the level structure and by a variable containing the identifier of the current decision node.

Selection - comprises the selection of rules (planning action) to be adjusted. All the rules incident to the current decision node D_P are selected. They are established by searching through the frame describing the level.

Matching - the operation aimed at finding the rule, which can be adjusted to the facts describing the state of the workpiece and included in the database. The adjustment is considered as the reference of the right side of the rule with the database contents. If the rule can be refereed to more than one set of facts, it can be adjusted many times. The set of adjusted rules creates so-called "conflict set".

Solving the conflict situation - comprises the selection of a rule to be released from the conflict set, on the ground of the algorithm for each stage of the manufacturing process planning. The solving of the conflict situation will depend on the assumed model of taking the planning decisions (which means the context of the planning situation).



Execution - execution of actions assigned to a selected planning operation. The scope of these actions comprises the allocation of values to parameters of the planning operation procedure and the calling of that procedure. Taking the control into account, the planning operations can be divided into the following operations:

a) resulting in switching to the lower level,

b) resulting in s switching to the higher level,

c) resulting in changing the decision node within the frame.

In the case (a) when switching to the lower level the name of the target node level is retained. This data is used when returning to the higher level. In the case (c) the target node is not the parameter of the switching. It is read from the frame describing the current level.

5. The verification of the concept in the area of computer aided process planning (CAPP)

CAPP (Computer Aided Process Planning) system is the vital link to integrate CAD/ CAM (Computer Aided Design/ Computer Aided Manufacturing). One of the most promising approaches is the use of expert systems [10]. The task of an expert system for process planning is to select the planning operations and define their sequence in a way providing the optimum manufacture of the product with respect to the manufacturing cost and time, taking all available means (process capabilities, machine tools, equipment, personnel) into consideration.

The main problem during the development of expert systems for process planning is to define the model of process planning. Kiritsis [11] distinguishes three main domains regarding this problem:

- decision logic i.e. how a computer makes decisions,
- knowledge representation i.e. which are the method of representing data and knowledge about machine tools, tools and processes,
- process modelling i.e. how process and process plan can be represented.

The model of process planning , reflecting real circumstances accompanying process planning was presented in [4, 5]. This model is based on the manufacturing knowledge model represented as hierarchical nets. The expert system for process planning which uses this model was developed. Its architecture is shown on fig. 5. The expert system for process planning is considered as a combination of the following components:

- a database describing the processing capabilities of the manufacturing system,
- control knowledge database and planning knowledge database,
- a control mechanism, responsible for the processing of knowledge according to the assumed form of its representation,
- a library of external procedures.

The knowledge database has three level of details:

LEVEL I - comprises the manufacturing knowledge determining the rules of assigning the workpiece the knowledge concerning the planning of the generalised structure of the machining process.

LEVEL II - comprises the manufacturing knowledge determining the rules of the planning of the generalised structure of the process for a given object. For a given set of similar (by processing characteristics) objects the structure of the process indicates some kind of processing order owing to increasing accuracy of surfaces being machined and also to the shape and mechanical properties of the workpiece. This order reveals in the phase-stage structure assumed in [4]. Phases and stages are the basis for the separation of the parts of the process structure, where the machining of the object surface subsets should be executed with determined accuracy.

LEVEL III - comprises the manufacturing knowledge determining the rules of the planning of the structure of the manufacturing process for the range of a particular stage and phase of the process. The manufacturing knowledge on such level allows for the selection of an appropriate model of operation, suitable for the requirements concerning the workpiece and taking into account the constraints of the manufacturing system capabilities.

The presented scheme of operation of the control mechanism is used at all the planning stages described below. At each stage different part of manufacturing knowledge is utilized.

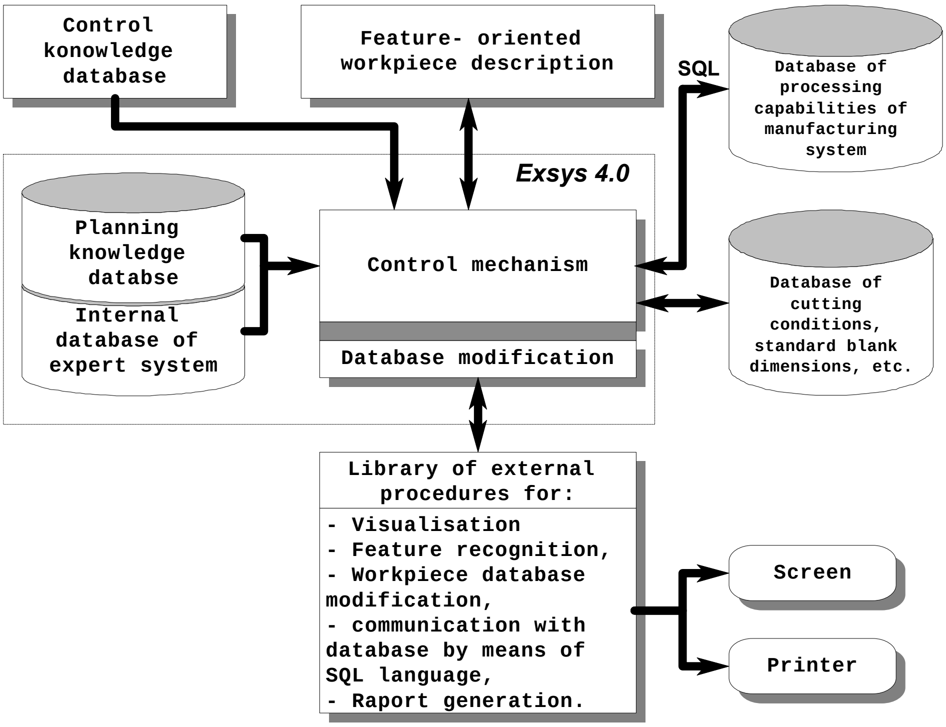


Fig. 5 Architecture of the expert system for process planning

Selection of a generalized structure of the manufacturing process

The basis for selection of a generalized structure of the manufacturing process is processing and geometrical characteristics of the product. The products is evaluated taking into consideration the values of its attributes, according to the sequence resulting from the structure of decision tree. Using such a reasoning the planning operation $t_{11} \in T_1$ (which means the selection and transition to manufacturing process planning on the basis of chosen structure) can be determined.

Reversible planning of the semi-finished product and intermediate shapes of the product

The elements of the generalized structure, i.e. stages and phases, are the basis for determining so called intermediate states describing the shape and processing properties of the workpiece, which are to be achieved as the result of an appropriate (i.e. consistent with assumed phase-stage structure, see description of the Level 2 manufacturing knowledge) execution of the machining process. On the basis of geometrical and processing characteristics of the product and the manufacturing knowledge the intermediate shapes and the semifinished product may be determined by using the reversible (from the product to the semi-finished product) method, on the basis of the algorithm given in [4]).

Generating the machining process

For each determined in the previous planning step planning objective the task can be formulated in the following way: Choose the methods and means leading to an intermediate state for particular determined stage and phase. In order to solve the task the decision problems were identified by presenting the successive planning stages in the form of a graph-tree.

For the i-th planning objective the decision-making process will be realized in an iterative way. After defining the model of shape change and the way, in which it is obtained, the transformation of the workpiece shape and processing properties is carried out. The process will be repeated until the intermediate shape, which corresponds to the realized goal is obtained.

Such configuration of the expert system can solve decision-making problems on the basis of the characteristics of the planning task determining the production (batch) size, and on the basis of geometrical and processing characteristics of the workpiece. As a consequence of planning decisions the databases of the expert system are modified, reflecting the progress in the process planning.

The algorithm of the expert system operation presented above was implemented using the internal programming language of EXSYS PROFESSIONAL v.4.0 shell expert system. The mechanisms for running external programs (written for the WINDOWS environment) and for the data exchange between the EXSYS and external programs were utilized. The example of output of expert system is shown on fig. 6. It has been verified by building the expert system for process planning for rational parts manufactured in the CPTORl machining center.

6. Conclusion

The hierarchical model of manufacturing knowledge used in the development of the expert system covers both the knowledge about the process planning structure (control knowledge) as well as the knowledge about the selection of machining methods (planning knowledge). Such knowledge representation enables:

- arrangement the domain knowledge and simplify its modification and expansion,
- processing only the knowledge which is relevant to the current process planning context,
- collection of knowledge for different classes of parts in a single knowledge database,
- use of the same scheme of expert system operation regardless of the parts being processed.

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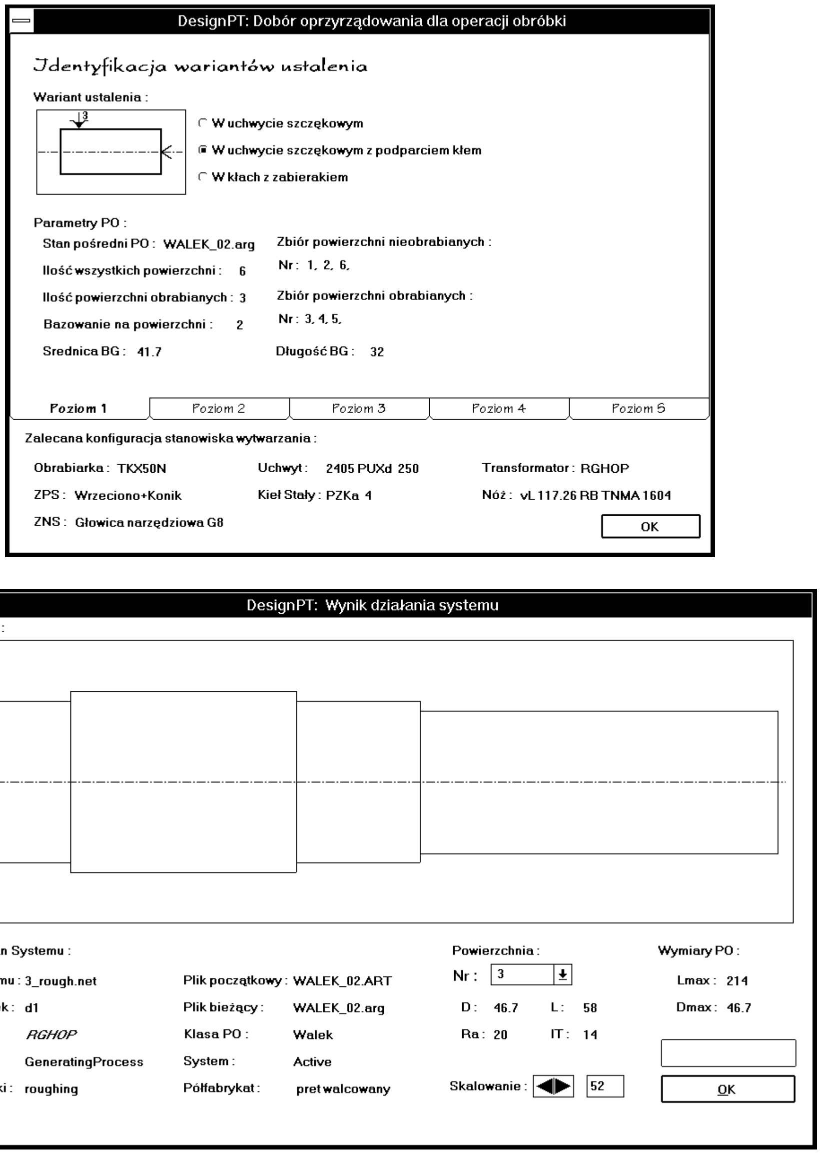

Fig. 6 Copies of the screen images produced during the process planning session

The purpose of the further research is to develop CAD interfaces and procedures for the recognition and the transformation of the workpiece.

Index: process planning, expert system, knowledge representation, control mechanism, CAPP.

7. REFERENCES

[1] BOLC l. COOMBS M.J. Expert system appllication, 1989, Springer Verlag

[2] CHANG T.C. Expert system for process planning, 1990 Addison- Wesley Publishing Company, Inc.

[3] DUDA J, POBOZNIAK J., Hierarchiczny model wiedzy technologicznej Politechnika Krakowska Monografie 150, Krakow 1993 (in Polish)

[4] DUDA J. A Proposal for Creating a Set of Decision Rules in an Advlsory System for Technology Design. 24th CIRP International Seminar on Manufacturing Systems Copenhagen 1992.
[5] DUDA J. Modelling of fhe Decisions Process in an Advisory System for technological Design [in:] Int J Adv Manuf Technol vol. 1 nr 1 1994
[6] DUDA J. Modelling of the knowledge in an advisory system for process planning Concurrent Engineering: Research and Application vol. 1, nr 41993
[7] DUDA JAN, HABEL JACEK, POBO¯NIAK JANUSZ Prototype of CAPP system based on expert system technology, Advanced Manufacturing Processes, Systems and Technologies (AMPST 96), Bradford, Wielka Brytania, Marzec 1996
[8] DUDA J., POBOZNIAK J., Rewersyjna metoda projektowania kszta³tów poœrednich i pó³fabrykatu w komputerowo wspomaganym projektowaniu procesów technologicznych IX Konferencja "Metody i œrodki projektowania wspomaganego komputerowo" IPBM Politechnika Warszawska (in Polish)
[9] DYM, C.L. LEVITT RE. Knowledge based systems for engineering , 1991 McGraw - Hill, Inc.
[10] HAM I., LU S., Computer Aided Planning The present and the Future, Annals of the CIRP
[11] LEUNG H.C. Annotated bibliography on Computer Aided Process Planning, Int J Adv Manuf Technol. 12/96
[12] KIRTITSIS D. A review of knowledge based expert systems for proces planning. Methods and problems, Int J Adv Manuf Technol. 10/95