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KNOWLEDGE MANAGEMENT BASED PROCESS PLANNING SYSTEM

Process planning knowledge (PPK) is one of the most important knowledge in production manufacturing enterprise. The traditional method of organizing data into knowledge relies on manual analysis and interpretation. This paper analyzes the source and composing of process planning knowledge and state of arts on process planning discovery in production manufacturing enterprise. On the basis of the application of computer aided process planning (CAPP) system in mechanical manufacturing enterprise, the concept of process planning information model (PPIM) is proposed based on process planning databases. This paper provides a CAPP database developed in own research, clarifying how PPK and PPIM in CAPP database are related both to each other and to related fields, the technology database of process planning knowledge discovery is modeled based on object-oriented model-driven technology, and the process planning knowledge discovery script is designed.

1. INTRODUCTION

With the development of knowledge economic, knowledge resource becomes the most important resource in mechanical manufacturing enterprise. The competition superiority of enterprises comes from the effectively development and management on knowledge resource. Nowadays, with the rapid application of enterprise information software [1,14], the location of knowledge resource is changing from employee's brain and papery document to digital databases in mechanical manufacturing enterprise. These databases are the foundation and sources of knowledge management. How to change these data into knowledge is the work of knowledge discovery. Knowledge management in mechanical manufacturing enterprise can be divided into three parts; they are creating knowledge, finding knowledge and spreading knowledge. Figure 1 shows the aim of knowledge management.

Data mining is a recent popular theme in reflecting the effort of knowledge discovery from data. It provides the techniques that allow managers to obtain managerial information from their legacy systems. Data mining is made possible by the very presence of the large databases.

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While knowledge discovery often refers to the process of discovering useful knowledge from data, data mining focuses on the application of algorithms for extracting patterns from data. Knowledge discovery seeks to find patterns in data and to infer rules that common queries do not reached effectively.

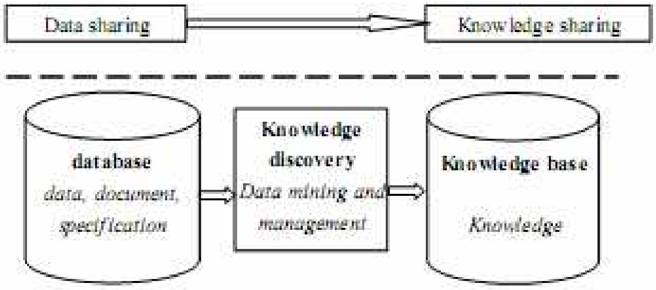

Fig. 1. From data management to knowledge management

Process planning knowledge (PPK) is one of the most important knowledge in mechanical manufacturing enterprise. It includes foundation data, process planning specification, experience of expert etc. for process planning. For the complexity of PPK, the PPK acquisition in process planning instances of papery documents needs human knowledge engineers to accomplish. With the in-depth application of Computer Aided Process Planning (CAPP) system, digital process planning data is accumulated rapidly in databases. How to accomplish knowledge discovery of technique, experience, data, principle, and specification in industry practice has been the key problem in mechanical manufacturing enterprise.

How to discover new knowledge and enrich process planning knowledge base (PPKB) based on the accumulated product process planning database (PPDB) is concerned by engineers significantly. It is a new technology as it is called process planning knowledge discovery (PPKD). Nowadays, knowledge discovery technology has been widely used in finance industry, communication industry, retail industry etc., but for mechanical manufacturing industry, especially on process planning knowledge discovery in CAPP application system, it has less report and research.

In fact, process planning discovery technology covers the theoretical issues related to data mining, learning-by-examples, knowledge acquisition, knowledge discovery, database, and information mapping. The PPKD is certainly not for humans entirely; actually, most analysis work needs to be automated [2]. A goal for PPKD is to build a foundation for the application of knowledge discovery based on CAPP database from an interdisciplinary perspective including artificial intelligence, database, software technology, statistics and management. Recent research achievement in expert system (ES), artificial intelligence (AI), knowledge management (KM), data mining (DM), database (DB) etc. have established abundant foundation for PPKD.

2. MANUFACTURING SYSTEM ACTIVITIES

The product development and manufacture involves several production management activities with a series of individual tasks that are to be completed in order to design and manufacture a product of a required quality. These tasks are usually carried out in a linear sequence, but very often the feedback is necessary from the subsequent task to the previous one. Many of these feedback loops are requests to modify the previous task's solution in order to generate a better solution in the subsequent one. This interlinking is what has become known as concurrent or simultaneous engineering.

2.1. MANUFACTURING ACTIVITIES MODEL

Product development cycle may be seen as a set of answers to a series of simple questions [3,4]: Why to produce? What to produce? How to produce? Where to produce? Who to produce? When to produce? The answers of these questions will identify what functions a necessary in the cycle from developing an idea to the realization of the final product. Answers to these questions may be given by connecting them with particular manufacturing functions: marketing function, design function, process planning function, resource planning function, production control function (shown of Fig. 2). The product development cycle is not a linear path without obstacles. Usually, the product development follows some zigzag pattern between functions with frequent needs to feedback information from a function to previous one. There are numerous feedback loops and overlapping between functions. Therefore, there are process planning tasks that can not easily be classified into particular functions and these tasks lead toward integration between these functions.

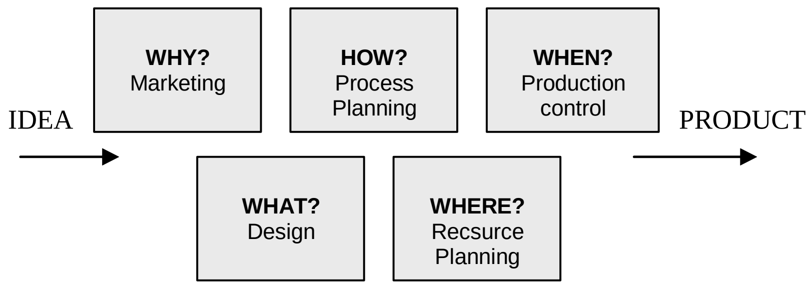

Fig. 2. Basic product development cycle planning functions

Starting from analyzing set of tasks of process planning and other activities, it is possible to develop the model that shows interactions between process planning and them. The model of these interactions is shown in Fig. 3, where each activity represents with circle, consists a set of tasks that are to be done in the product development.

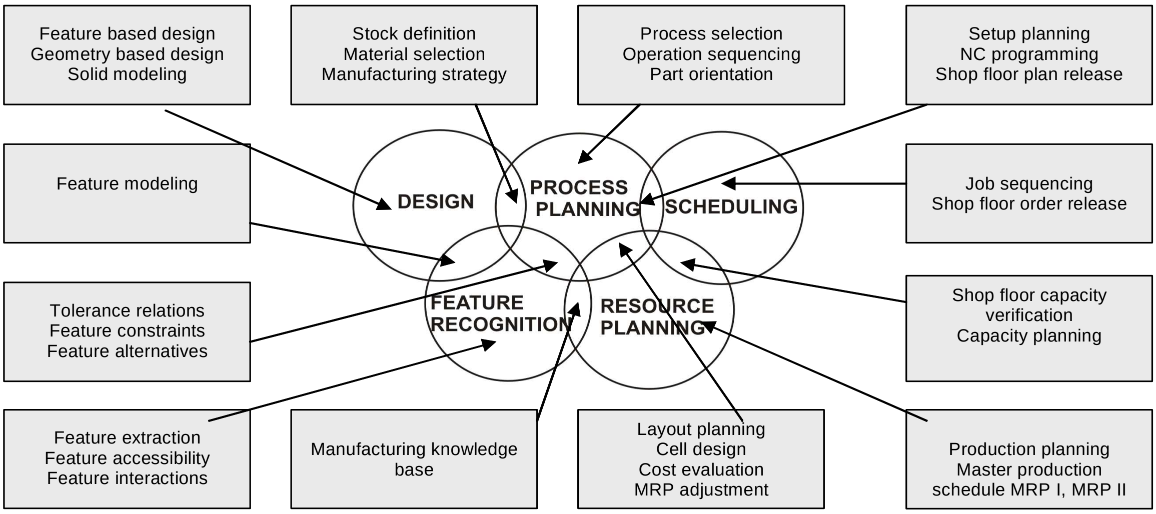

Fig. 3. Product development tasks

All of these activities are identified in manufacturing planning literature as activities required during the product development and manufacture. The classification shown in the Figure 3 represents a starting point for the use of this method in each individual factory. There are numerous tasks that require interactions between two or more activities. They are shown within overlapping circles of activities and represent integration links.

2.2. PROCESS PLANNING KNOWLEDGE

Knowledge discovery in database have been attracting a significant amount of research, industry attention in recent years. Process planning knowledge (PPK) is one of the most important knowledge in mechanical manufacturing enterprise. The traditional method of turning data into knowledge relies on manual analysis and interpretation. On the basis of the widely application of computer aided process planning (CAPP) system in mechanical manufacturing enterprise [13], the concept of process planning knowledge discovery (PPKD) is proposed based on process planning databases.

Planning of manufacturing processes provides the link between design and production. Its task is to determine a plan of discrete manufacturing operations that, when executed in an actual production environment, will produce the part as required by its design description. Computer-Aided Process Planning (CAPP) may result in better designs, lower production costs, larger flexibility, improved quality and higher productivity and they are develop by the application of artificial intelligence (AI) methods and tools [12]. The reasons of this are two:

- CAPP is a complex problem that includes part analysis, selection of operations and resources, operation sequencing, setup planning, fixture design, and the determination of process parameters. The domain knowledge of a process planner has to cover geometry and tolerances, material properties, manufacturing processes and tools, fixtures, as well as machine tools. Besides generating executable plans, the optimal allocation of resources is the main concern of planning.

- General-purpose AI planning systems provided clear-cut logic-based representation formalisms and more and more efficient solution methods. However, the restricted representation formalisms did not allow to capture all of the relevant domain knowledge and to define planning strategies. Solvers could not handle optimization objectives and support mixed-initiative, interactive problem solving. Hence, they could not fit the real-world problems like the CAPP problem.

2.3. THE CAPP PROBLEM

The problem of CAPP in the domain of manufacturing can be stated as follows: given (1) the descriptions of the blank part and of the finished part (in terms of geometry, dimensions, tolerances, material, and quantity), (2) the available production resources (machine tools, fixtures and tools), (3) the technological knowledge and (4) some optimization objective, find an executable and close-to-optimal plan [5,6].

There are two main approaches to process planning, the variant and the generative one. Variant methods are based on the retrieval and the (manual) adaptation of previous plans; they can be supported by database retrieval, and as recently, by case-based reasoning. Generative planners synthesize process plans. They almost unanimously depart from the geometrical CAD model of the part and work with descriptions enhanced by manufacturing features. Features (like e.g. holes, slots, pockets, etc.) tie together frequently occurring sub-problems with their corresponding solution patterns, i.e., geometry and tolerances with particular production methods and resources [6]. Features realize micro-worlds with both design and manufacturing related information Features decompose the problem and make it to efficient and automated problem solving. Features - or rather the operations that produce them - often interact, hence the selection and merging of the appropriate plan fragments is not that straight forward. Further on, planning has to account for global technological requirements and overall optimization objectives as well.

The process plan describes how to produce the part by using the available resources. It specifies the operations and their resources (tools, fixtures and machines), the sequence of operations and the groups of operations - so-called setups - that will be performed together, by using some common resource(s). Every setup begins with mounting the part to the machine tool. The orientation of the part on the machine tool determines which operations can be executed. For some operations the orientation of the part must be changed.

The planning process can be usually considered as the hierarchy of:

1) Setup planning: The determination and sequencing of setups and the selection of machine tools.
2) Operation sequencing: The determination and sequencing of operations and the selection of tools.
3) Operation planning: Determination of the machining parameters (cutting speed, feed rate etc.) and the trajectories of the tools.

There are many commercial tools to aid the last step. However, the first two steps are very hard because the knowledge provided by the experts is usually fragmentary and inconsistent. In computer aided systems such contradictions must be solved by the human experts. Nowadays the manufacturing process is more or less automatic, but process planning still requires much work of qualified personnel. Process planning is the “bottleneck” of the production [7].

3. PROCESS PLANNING KNOWLEDGE MANAGEMENT IN MECHANICAL MANUFACTURING ENTERPRISE

3.1. ANALYSIS OF PROCESS PLANNING KNOWLEDGE IN MECHANICAL MANUFACTURING ENTERPRISE

Process planning knowledge in production manufacturing enterprise includes foundation data, process planning specification, and experience of expert etc. for process planning. All types of PPK are synthetically used generally, for example, selecting manufacturing method, designing fixture, arranging route etc. In commonly, PPK can be divided into four types.

(1) *Handbook knowledge:* It includes data and knowledge in handbook and engineering standard for process planning, for example, tolerance, material, cutting feed and process planning specification etc.

(2) *Manufacturing resource knowledge*: It implies data and knowledge that has close relation with manufacturing environment, such as machine, cutter, fixture and process planning database etc.

(3) *Decision-making knowledge*: It is compose of experiential rule, procedure algorithm and control knowledge for process planning that commonly exists in engineering expert’s brain.

(4) *Model knowledge:* It includes process planning data model and process planning knowledge model, for instance, product, part, process planning, operation, step, fixture, machine etc.

The traditional method of turning data into knowledge relies on manual analysis and interpretation. PPKD is the process of mining and formalization domain process planning knowledge in manufacturing enterprise. Nowadays, the main method of PPKD is done by human knowledge engineers assisted by domain expert from literature, document, handbook, process planning file etc. in papery information source. For example, in mechanical manufacturing enterprise, it is common for experts to periodically analyze current trends and documents in enterprise, and on a quarterly or yearly basis. The experts can provide an outline document of the analysis to the engineering department; the effect of this document for decision-making and planning on new product is rather limited [8]. In addition, this form of manual probing of information set is slow, expensive, and highly subjective, and depends on domain experts greatly. In fact, as information volumes grow dramatically, this type of manual information analysis is becoming completely impractical in engineering work, and these problems result in the poor implementation of PPKD.

In fact, with the application of CAPP system in manufacturing enterprises, process planning knowledge is implicated in digital process planning databases. It becomes a main PPK source in manufacturing enterprise. Based on representation of process planning knowledge model, technology and method, discovering knowledge from digital process planning databases can be an effective method to solve the PPKD.

The PPKD refers to the overall process of discovering useful process planning knowledge from CAPP database, and process planning data mining is a particular step in this process. The whole steps in the PPKD include, such as data preparation, data selection, data cleaning, incorporation of appropriate prior knowledge, and proper interpretation of the results of mining, are essential to ensure that useful knowledge is derived from the CAPP database.

3.2. MECHANICAL MANUFACTURING ENTERPRISE PROCESS PLANNING INFORMATION MODEL

In order to represent the commonness of PPK in mechanical manufacturing enterprise, process planning information model (PPIM) is founded based on the overall analysis of process planning information in mechanical manufacturing enterprise. PPIM is the foundation of PPKB and PPDB. PPKD is founded on the analysis of PPKB and PPDB based on PPIM in CAPP system. PPIM includes all fundamentals process planning object (product, part, process planning, manufacturing resource, route etc.). PPIM establishes the protocol on PPKD in CAPP system database by the standard description of concept, item and model for the sharing on PPK. Fig. 4 shows the relation of PPKB and PPDB based on PPIM.

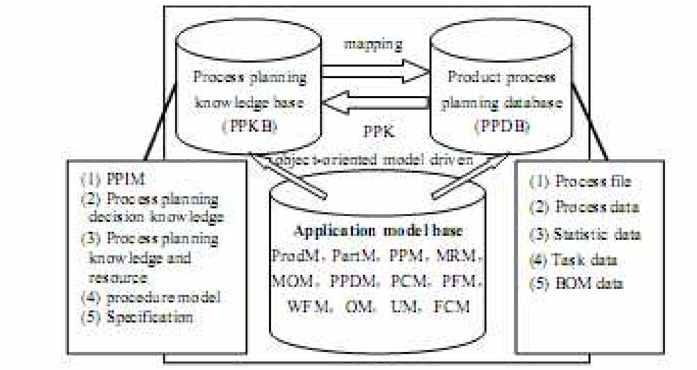

Fig. 4. Process planning database and knowledge base based on PPIM

4. PROCESS PLANNING INFORMATION MODEL-DRIVEN ARCHITECTURE IN CAPP DATABASE

The realization of CAPP development platform design on object-oriented information model-driven is the guarantee to the maintenance, expansion of CAPP system. CAPP system can run in uniform information model, it can realize the dynamic change of system data structure and data flow by the change of information model for adapting to the change in manufacturing enterprise. The information model of CAPP development platform uses object-oriented technology as modelling method. Object-oriented method is a way that uses object, class, instance, etc. concepts to describe software system, it's a fundamental method to understand research domain in natural way, the definition and identification of information model entities are in human's impersonality thinking way. The knowledge base in CAPP development platform can be divided into two levels.

1) Special information model for a manufacturing enterprise: It includes product information model, part information model, process planning information model, manufacturing resource information model, manufacturing information model, process planning decision information model, process card information model, process file information model, work flow information model, organization information model, user information model, and function configuration information model.

2) Based on the information model-driven mechanism in CAPP development platform, the object instance and method are used in process planning knowledge base to describe process knowledge, such as typical process, typical operation etc. The knowledge in process planning knowledge base can substitute handbook and can retrieve process instance to improve the design efficiency. In the information model-driven CAPP system, process knowledge and data is stored in the form of object instance in process planning knowledge base and process planning data base. In CAPP system, exact and entire process planning knowledge base model is the basis and central for PP knowledge management. In addition, with the improving on process planning level and the change on manufacturing environment, the process planning knowledge base model need to be changed constantly.

4.1. THE OBJECT-ORIENTED INFORMATION MODEL DESCRIPTION IN PROCESS PLANNING KNOWLEDGE BASE

Using the object-oriented modelling tool, the process planning knowledge base (PPKB) model is founded in the development of CAPP development platform. It is the basis on the realization of information model-driven mechanism in CAPP system. The CAPP application information model can be denoted on different views based on PPKB model, such as organization view, personnel view, workflow view, document view and data view. In CAPP system, the PPKB model is analyzed and optimized by different views to realize system development.

In CAPP development platform based on information model-driven, object-oriented method is adopted to describe the relation and manipulation of entities structure and object in CAPP system [9]. Object class is the basis on describing process information and knowledge. Object instance represents the actual data. Object method and rule describes process planning decision-making knowledge and system configuration. In the follow part of the paper, it is described the object oriented model developed in our research [10,11] for development of CAPP platform based on the PPKB.

5. PROCESS PLANNING KNOWLEDGE BASED SYSTEM

The process planning with several incorporated procedures described in this paper is part of a largest CAPP knowledge based decision system for process planning, called OPTICAPP (Optimized Computer Aided Process Planning) [8], the general layout of which is shown in Fig. 5.

The OPTICAPP system is implemented under the Microsoft Windows environment using the object-oriented programming with C++ program language. This system is structured with two basic program’s module. Using a theory of graphs, mathematical logic and semantics, production rules and procedures are defined. Their structure is based on the interaction between technological orders of the machining (construction of workpiece, ordering of machining operations - mulltipass machining operations where one pass presented the sub-operation (rough or finish pass, or one cutting tool pass), priorities of the cutting operations, selection of tools, generation of optimal cutting data etc.). The optimization is made by a set of technological constraints, which include tool life, surface finish, machine power and available spindle speeds and feeds.

5.1. MODULE OF PARAMETRIC MODELLING

The first module is computer aided designer, named GRAPH (Graphic Modeller). This module is used for work-parts modelling, based of features geometry recognition generated interactively by the operator, using a simple icon-based interface. The GRAPH modeller is based of a parametric method of modelling using developed icon based interface, where each icon represent one feature as an elementary work-part geometrical form. It is geometrical defined more than thirty different features, described with specific geometrical parameters (attributes). During modelling of one work-part it is necessary to selecting and definition of several features in according to the construction model of the work-part. During definition of geometrical parameters for each selected feature, this program module needs from user to define the technological parameters, as a work-part material, surface roughness and tolerances.

This module is based of the object-oriented original developed mathematical methodology for modelling of mechanical part as a complex structure of features based of theory of graph, mathematical logic and semantics. The main characteristic of this module is the fact that, as an output, a dynamic model of the mechanical part is generated. The GRAPH modeller, for each modelled part, develops original dynamic database as a Double Linked List (DLL), core of the algorithm, holder of all geometrical and technological data for part. Dynamic database is based on the oriented multy-graphs and data linking with pointers in DLL (Fig. 6).

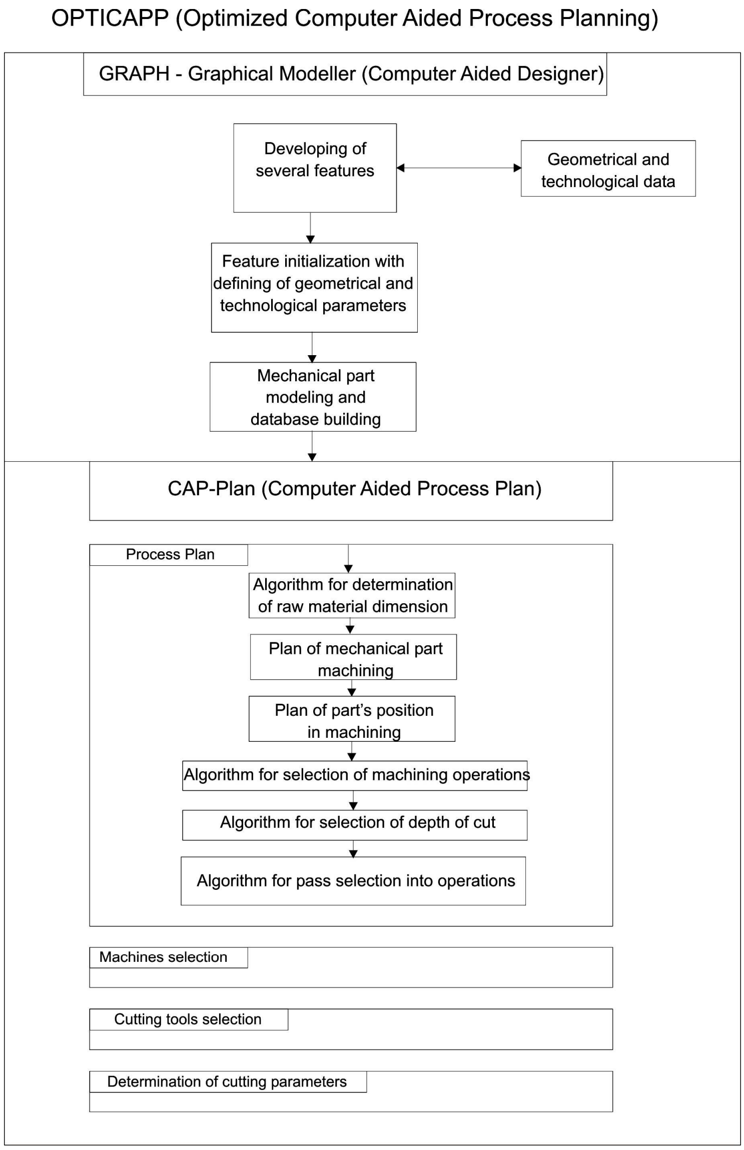

Fig. 5. Overall layout of OPTICAPP

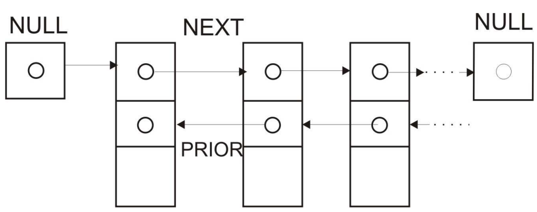

Fig. 6. Double Linked List (DLL) with graphical presentation of pointers (next and prior)

It is database for sorting and storing data for modelled mechanical part. Sorting of data in dynamic database is with network of knots and pointers (Fig. 7), holder of data for all features in part's model.

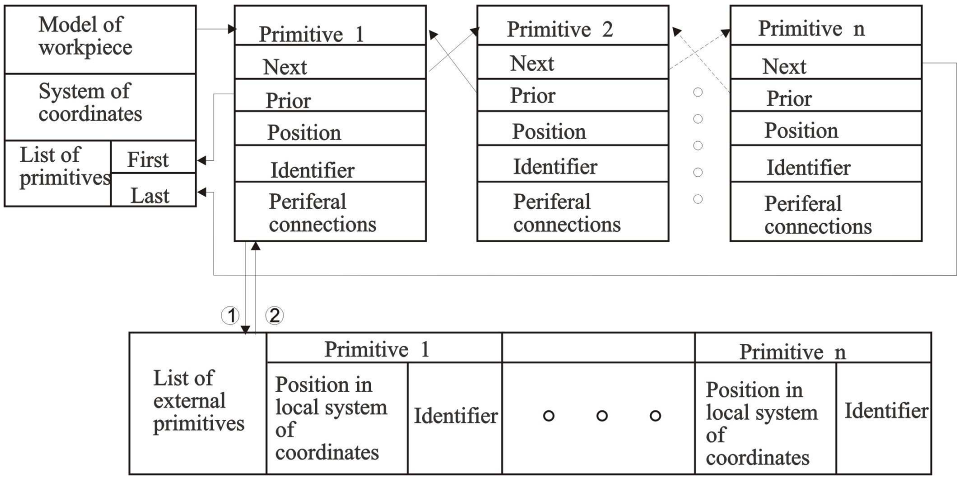

Fig. 7. Dynamic database with network of knots and pointers

The main advantage of this parametric modelling based design module is possibility for dynamical change of the created work-part model within the selected features. Software inter-communication is based of the complex part model (DLL with annexed oriented vectors) and many algorithms and procedures, as: algorithm for search, algorithm for subordination etc.

5.2. MODULE FOR GENERATING PROCESS PLAN NETWORK

The second module, it is generated process plan network for machining of modelled work-part by using the GRAPH modeller, module of OPTICAPP system. This module is named CAP-Plan (Computer Aided Process Plan). In this research, it is programming object-oriented algorithm using C++, based on a generative method with intelligent approach, as an expert system shell. This algorithm constitutes mathematical methodology with many developed rules and procedures for modelling of process planning. This algorithm can perform the following functions:

- Creating technological knowledge database for modelled mechanical part using the data from designer module,
- Presenting the technological knowledge with created rules for decision making,
- Algorithm for modelling process plan network for production with selection and succession on the operations and sub-operations,
- Modelling of each operation with order of sub-operation and optimized cutting parameters for each sub-operation,
- Select of cutting tools and machines for complete manufacturing process,
- Output presentation of generated process plan network.

5.2.1. CHARACTERISTICS OF THE OBJECT-ORIENTED MODELLING OF PROCESS PLANNING

Decision for created a module for object-oriented modelling of process planning approach for automatic ordering of operations and sub-operation in machining process, it is based of the following reasons: generative approach of modelling as a method for individual design and modelling, recognition and process planning for each created mechanical part, open possibility for connection and integration of developed system in complex integrated CAD/CAPP/CAM system.

The module for process planning CAP-Plan, as inputs, uses:

- The dynamical database oriented model of the mechanical part generated in graphic modeller-GRAPH.
- The technological database of the model, carrier of a technological knowledge for modelled part necessary for process planning / generated in this program's module in the research/.

5.2.2. TECHNOLOGICAL KNOWLEDGE DATABASE

Technological knowledge, as a basic for process planning, is composed of data and information, which is spectrum of know-how (Figure 8). Generally, the technological knowledge can be to divide on:

- Basic technological knowledge
- Experienced technological knowledge

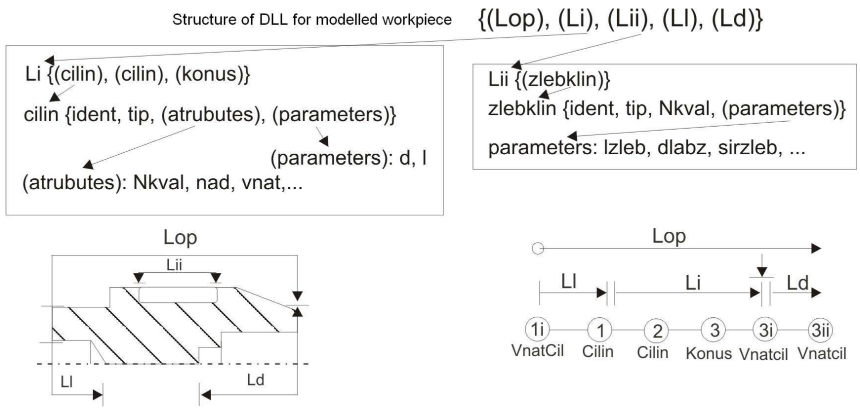

Fig. 8. Logical structure of technological knowledge database

Basic technological knowledge is accumulated in literature and technological atlas books, as a principle on tabular or described form.

Experienced knowledge in the literature is known as "know-how". This knowledge is composed with experience and it is accumulated by the engineers during the years, but it's almost un-possible to attend this methodology in order to be formalise concrete and in whole.

5.2.3. MATHEMATICAL METHODOLOGY FOR TECHNOLOGICAL PLAN DESIGN

Mathematical methodology for process planning and developing of technological plan is made with many algorithms and production's rules. The most suitable form for presentation of the technological knowledge is the form of modular production’s rules, where each rule determines environs technological statement and it is free from other rule. Technological knowledge has been structured with the help of four types of the production’s rules.

With object-oriented programming in the module for process planning, there are created following algorithms, which comprise logic for decision for each component of the process planning:

- The algorithm for define dimension on starting work part,
- The algorithm for design the form and the succession of the technological operation,
- The algorithm for modelling the actions into each operation (multi-pass operation),
- The algorithm for modelling the optimizing trajectory of cutting tool movement between the position points of machining.
- The algorithm for evaluation of justification for machining with one tool in all positions where it is predicted, or changing tool in certain position.

In the research, proposed OPTICAPP system, near two main modules for modeling and process planning consist sub-module for optimization of cutting parameters for each machining operation and action, designed in process planning. It is developed as a multi-objective programming mathematical model where the optimal solution is obtained by using a deterministic method and a genetic algorithm, described in [8]. The cutting data optimization criterion is selected from minimum machining time or cost, maximum production rate.

6. CONCLUSION

Process planning knowledge discovery and management is the important foundation work of mechanical manufacturing enterprise. It is one of the most difficult works in knowledge management for mechanical manufacturing enterprise. It includes concepts, terms, typical operation, typical step, typical process and manufacturing resource etc. Process planning discovery and management can not be success implementation by the supporting of software system. By the industry practice of using PPKD technology in CAPP system developed based on CAPP platform, PPKD can be executed automatically in PPDB and PPKB. It can help the standardization and specification of process planning data effectively.

In that line, this paper shows comprehensive knowledge representation system. This representation includes the following approaches: (1) connection of feature and process knowledge with the part geometric model; (2) object-oriented technological database for presentation of technological knowledge and (3) generation of proposed process plans. These new contributions provide for a new generation of CAPP systems based on PPKD and PPKB that can be adapted for various manufacturing systems and can be integrated with other CIM modules.

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