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Research and Development of Process Knowledge Management System in OKP Company

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Abstract

The coming of knowledge-based economic era has greatly changed manufacturing environment. Knowledge has become the most important and valuable asset for manufacturing companies. For most of One-of-a-Kind Production (OKP) companies, innovation based on knowledge is their opportunity and the sharpest competitive weapon to compete and thrive in current global market-driven environment. Process knowledge is a special type of knowledge that controls how products are manufactured. The knowledge may help OKP companies manufacture high value-added products with best quality and shorter times at competitive cost. Managing process knowledge is very important, and its benefits are enormous. This paper proposes a framework and definition of Process Knowledge Management System (PKMS) after analysis of the characteristics of process knowledge and requirements in OKP companies. A hybrid approach aiming at representation of three main types of process knowledge is discussed. One of the ways for representing dynamic process flow knowledge is introduced in detail, which is solved using an approach based on Parameter Flow Charts (PFC). The proposed approach supports experts to create knowledge repository themselves. A prototype system is developed to validate the proposed framework and approach.

Keywords Knowledge management, Knowledge representation, One-of-a-kind production, Knowledge-based engineering, Process planning

1 Introduction

We are now in a knowledge-based economic era[1], in which manufacturing situation has changed greatly and can be characterized by the following buzzwords: customer-oriented, globalization, and time-driven competition. This is not only a challenge, but also an opportunity for manufacturing companies, especially for One-of-a-Kind Production (OKP) companies to compete and thrive in this global market environment. These OKP companies might be small and middle-sized, but their survival and success depend on producing newer, better, quicker and more innovative products and services, not simply rely on size and strength as before. Innovation plays an important role in their strategies and is becoming one of the sharpest competitive weapons for them to manufacture high quality products at lower costs with shorter development times. The foundation and source of innovation is knowledge. Knowledge and intellectual capital have become the most important and valuable asset for organizations. This has attracted much research interest in the areas of Knowledge Based Engineering (KBE) and Knowledge Management (KM) over the past years [2-7].

Process knowledge in manufacturing industry is a special type of knowledge. Most of them are the kernel technical secret that may help companies manufacture high value-added product with best quality and shorter times at competitive cost. The process knowledge may exist in the mind of experts or skilled employees. Survey showed that to train an expert or a skilled employee of process planning might take at least 5 years or more. For most OKP companies, the shortage of knowledge workers is one of their biggest obstacles to grow and the problem has to be solved. Hence, exploiting and managing process knowledge is very important for OKP companies and its benefits are enormous. Process Knowledge Management System (PKMS) can help OKP companies develop, build, and deploy process knowledge assets effectively and profitably. Considerable research effort has been placed in this area [8-13]. However, most of existing work are based on fixed process knowledge representation schema and fixed system architecture. They were applied to a particular kind of manufacturing environments and are very specific, and are difficult to adapt to continuous technology developments and changing manufacturing environment.

To resolve these issues, a tiered framework of PKMS is proposed in this paper. A hybrid and open approach for process knowledge representation is discussed in detail. The prototype version of system has been developed and demonstrated with case studies.

2 Definition and Framework of PKMS

2.1 Analysis of Process Knowledge in OKP Companies

Before discussing the framework of PKMS, the characteristics of process knowledge in OKP companies are analyzed firstly. For most OKP companies, their market strategies are either make-to-stock, or assembly-to-order, or make-to-order. They are facing special critical problems including high customization, 'Once' successful approach, loose or fatter production, and complicated product data and information flow, etc[14]. This determines their manufacturing environment is customer-oriented and has been undergoing changes often. Hence, process knowledge in these OKP companies also has special different characteristics that can be summed up as followings:

(a) Dynamic and Changing. Process knowledge should be updated along with the emergence of new techniques and new methods.

(b) Form diversity. there is a variety of process knowledge format, including description sentence, tables, pictures, drawings, formulas, and numerous other representations.
(c) Universality. Process knowledge comprises of not only internal knowledge in a company, but also external knowledge of suppliers and customers. Internal knowledge includes all the knowledge from market survey to product maintenance after sale.
(d) Uncertainty. Process knowledge comes from experiences and skills of experts, and it is implicit and hard to represent by computer.

2.2 Definition and Framework of PKMS

The definition of PKMS here refers to a system based on information technology for managing process knowledge in OKP companies, supporting creation, capture, representation, storage, dissemination and share of information. PKMS aims to enhance the innovation ability of OKP companies by accumulating and sharing of personal, organizational, and industrial process knowledge. Based on above analysis, the most important requirements and characteristics of PKMS are:
(a) Supporting management of all kinds of process knowledge. Not only the knowledge based on rules, but also the knowledge embedded in drawings, documents, formulas and other representations needs to be managed.
(b) Open and extensible. When manufacturing situation and technology change, the knowledge database can be updated and reconstructed.
(c) People oriented. The source of knowledge is people. The knowledge database in PKMS should be maintained and used by these skilled employees, not just by other IT employees or system developers. Companys own experts should be able to create, capture and storage their process knowledge in PKMS.
(d) Combination of technological advancement and practicability. As process knowledge is tacit and implicit, its difficult to capture and transform this kind of knowledge clearly and automatically, new methods need to be developed.
Based on the requirements and characteristics mentioned above, a proposed framework of PKMS has been constructed and is shown in Fig.1. The framework includes five layers. Each layer is devoted to a specific task and is designed to link the interface with the framework from different levels of abstractions and functionalities.
(1) Support layer: It provides the necessary computer net environment that supports the system running. Support layer includes a computer network, a Database Management System (DBMS), Operation Systems (OS), desk PCs, and Servers.
(2) Database layer: It is the core knowledge repository of PKMS that stores all kinds of process knowledge of a OKP company. The process knowledge is classified into four main types. Process resource knowledge refers to information of

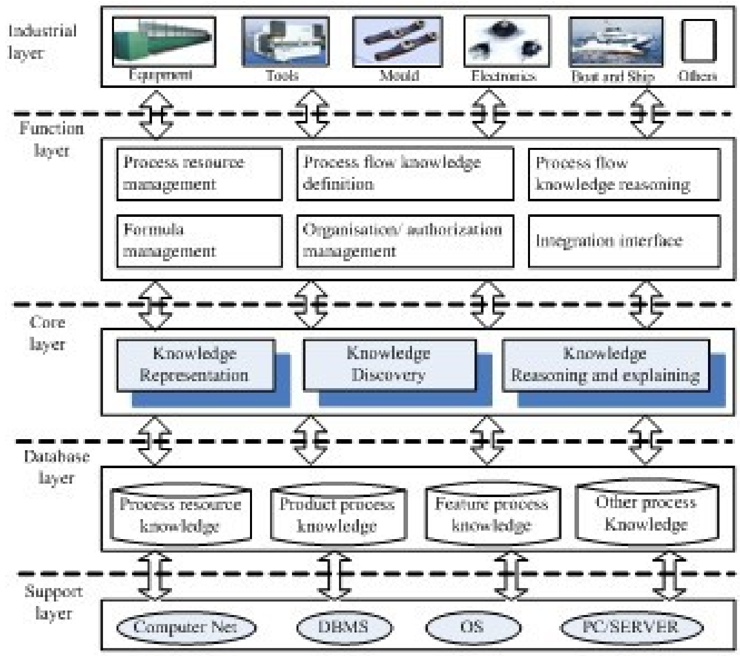

Fig.1 Framework of PKMS in OKP companies

machine tools, fixtures, cutters, materials, and quantity standard used in cutting, etc. Product process knowledge is typical process knowledge used regularly in companies.Feature process knowledge includes recommended process routes of all sorts of machining features. Other process knowledge refers to other often used process planning information, such as basic concepts in process planning, formulas of working hour calculation, etc.

(3) Core layer: It is comprised of knowledge representation, knowledge discovery, and knowledge reasoning and explaining. Knowledge representation is to provide environment and methods for representing various types of process knowledge. Knowledge discovery is used to search for appropriate process knowledge in repository. Knowledge reasoning and explaining deal with the search result and give helpful output process knowledge.

(4) Function layer: It is the functional implement layer for the purpose of process knowledge management. Function modules in this layer include the creation, presentation, modification, searching, and browsing of all the process knowledge stored in the database. For the purpose of managing diverse forms of process knowledge, a process resource management module, a process flow knowledge definition module, and a formula management module are developed.

(5) Application layer: This layer provides industrial solutions for a given com-

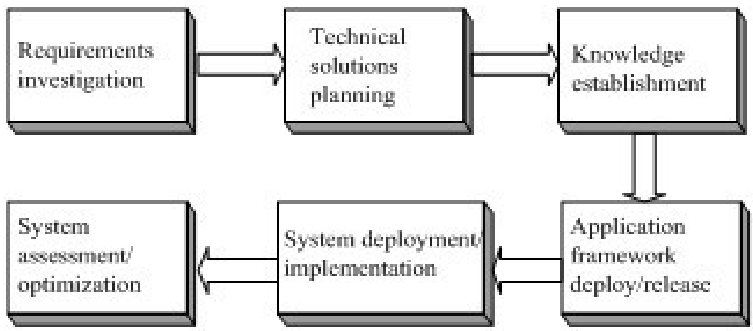

Fig.2 Design support strategy for PKMS

pany or industry, such as equipment, machine tools, mould, boat and ship, etc. The knowledge repository is deployed flexibly according to the requirements of a particular company or industry.

2.3 Design support strategy for PKMS

According to the proposed system framework as shown in Fig.1, the design support strategy is proposed to implement PKMS as shown in Fig.2. The following summarizes the key issues of the design support strategy.

(1) Requirements investigation. To know the current situation and requirements of process knowledge management in OKP companies, collect process knowledge of personal, company and industry. The investigation results are used as input and foundation for PKMS development and implementation

(2) Technical solutions planning. Based on the result of investigation, the technical route, function models, and task schedule for PKMS are planned and determined.

(3) Knowledge establishment. Classify all kinds of collected process knowledge, create, modify, update knowledge database using function modules of system.

(4) Application framework deployment and releasing. Configure PKMSs running environment according the situation of a particular company and release it.

(5) System deployment and implementation. Establish implementation team, install and deploy the system, train companys employees to use the system.

(6) System assessment and continuous optimization. After running for a period of time, collect feedback, assess, improve and maintain the system.

To develop this proposed PKMS, one of the key issues is the representation and management of a variety of process knowledge. As mentioned above, the diversity and dynamic characteristics of process knowledge makes it hard to be represented effectively through only one approach. A hybrid and open approach for process knowledge representation is required.

3 Hybrid approach for representation of Process Knowledge

3.1 Classification of process knowledge

Process knowledge is classified into three main types (see Fig.3) according to the form of process knowledge described as following:
(1) Knowledge of process flow is rule-based knowledge with process routes or working operations. It comprises knowledge of feature process/product process/typical process. Feature is the definition of components basic geometry entity for manufacturing. Popular form features include cylinder, hole, plane, etc, which have typical recommended process scheme for each of them. Knowledge of product process refers to process route information of product family or similar products, which may change according to the input manufacturing data. Knowledge of typical process is the mature process route information which has been validated by practice and is used frequently
(2) Knowledge of resource refers to static manufacturing resource information, which includes all kinds of process resource, such as machine tools, fixtures, cutters, machining data, materials, etc.
(3) Knowledge of calculation refers to information obtained through calculation. In process planning, the selection of working hour and material quota is a regular activity.

For these three types of knowledge, process flow knowledge is most difficult to capture and represent, because they are rule-based, dynamic, determined by many factors. Most of them come from experience of experts or skilled employees. In the proposed PKMS, a visual expressing method based on Parameter Flow Charts (PFC) is used to represent them. This method combines the parameter technology, flow chart technology, and visual technology. For resource knowledge, an approach of classification tree is used to represent them. A formula management tool is used to represent calculation knowledge. The focus of this paper is placed on the approach of PFC.

3.2 Representation approach based on PFC

3.2.1 Definition of PFC

Definition 1: Parameter (P)

P is an element that has effects on the description or reasoning of the knowledge, e.g., when machining a hole in a part, the diameter, machining precision, and surface roughness will influence the machining route, therefore the elements can be extracted as:

$$P = f(P_g, P_a, P_r, C_{cons})$$

f()is the definition function. is the geometric information of P. is the attributes of P, such as name, ID, data type. is the action range of P, such as global parameter, local parameter. defines the constraints. P has two types, one is

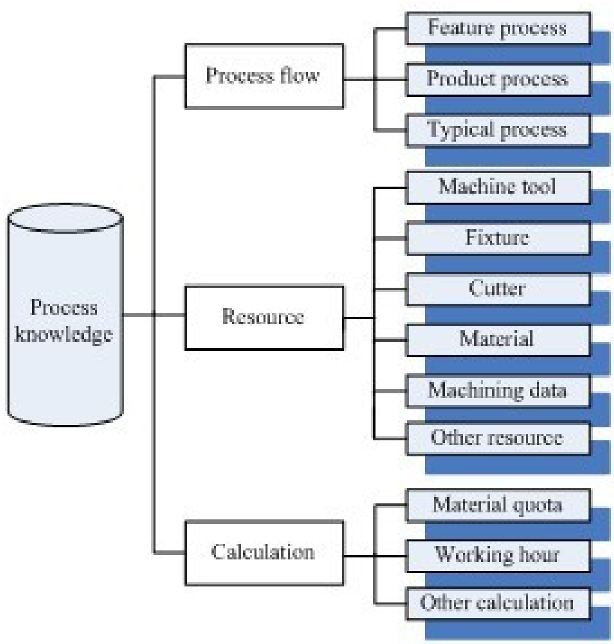

Fig.3 Process knowledge composition and classification model

individual, and the other is dependent. The value of the individual P is directly from designers input or is derived from the superior process; the value of the dependent P is from the calculation result among other individual P according to the constraints.

Definition 2: Parameter Table (PT)

PT is a set of information that arrays the parameters of the knowledge using a table form. It can efficiently support parameter storage, classification, discovery, and comparison.

$$PT = f(PT_A, P, UI, M)$$

$PT_A$is the attributes of PT, P is the parameter set in PT; UI is the user interface set of the PT; M is the manipulation set of PT, e.g, add, delete and edit. For process planning, the evaluations of the parameters often have mixed number and string operations, including the illegibility operation.

Definition 3: Chart Unit (CU)

CU is the basic node that makes up of the PFC, which presents an action of the knowledge expression simulating the human beings. In different application domains, the actions are different, and the tasks and the aims of the actions are different too, so CUs are different. According to the requirements of KE in different domains, the types and the attributes of CUs can be extended. Generally, a CU consists of seven types.

$$CU = f(BU, EU, VU, RU, OU, IU, SPFC)$$

BU refers to the beginning of the PFC(see Fig.4,*BU1*). refers to the end of PFC (see Fig.4, *BU1*). sets value for parameters (see Fig.4, *VU1, VU2*). *RU* depicts the reasoning logics according to the parameters. *RU* has single branch (see Fig.4, *RU1*) or multiple branches (see Fig.4, *RU2*).The *RU* with single branch denotes the judgment of YES or NO logic. The with multiple branches defines several decisions according with several conditions.

OU defines the output (see Fig.4,*OU1, OU2, OU3*). is the attention graphic unit (see Fig.4,*IU1*). *IU1* assists in judging and validating for KE, which can help the designers find the incorrectness and remind designers to revise it.

SPFC represents a sub-process and nesting is available in the (see Fig.4,*SPFC1*). By establishing the database of and calling the *SPFC* in the main process, the whole knowledge is available.

Fig.4 is a simple example of representation form for process flow knowledge based on PFC. It's a visual and direction knowledge chart, starts from chart unit *BU1* and ends at chart unit *EU1*. *VU1* and *VU2* are used to set values for parameters. *RU1* and *RU2* are responsible for judging the input data and determining the next flow step. *SPFC1* is a sub-PFC that is defined in another place *OU1,OU2,OU3* , and are chart units of output, such as work operations. Through drawing such flow chart with predefined chart units, a rule-based process knowledge can then be represented.

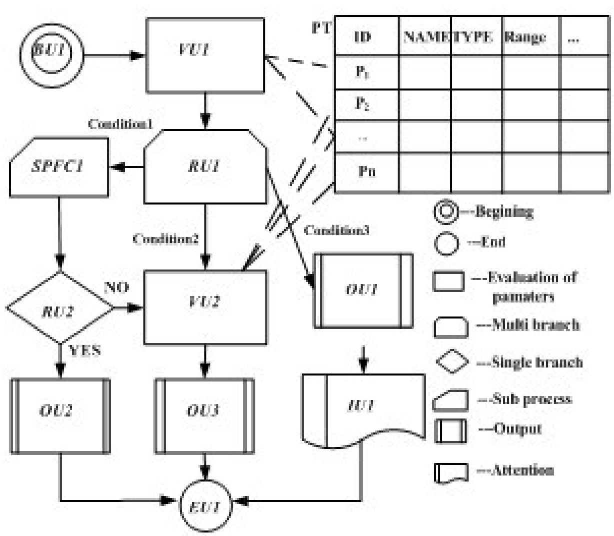

Fig.4 An example of representation form based on PFC

Definition 4: Parameter Flow Chart (PFC)
PFC is a direction chart for knowledge description and reasoning that consists of parameter tables, chart units and the logical routes among the chart units (see Fig.4). PFC presents the contents and the structure of the knowledge.

$$PFC =< A, PT, CU, CR >$$

A, PT, CU and *CR* refers to the set of attributes, parameter tables, chart units and the relations among the chart units of PFC respectively. CR is classified as joined *CR*, unjoined *CR*, paratactic *CR* and branchless *CR*. For representing complicated knowledge, it can be represented by several sub-PFC.

3.2.2 Model of the software system based on PFC

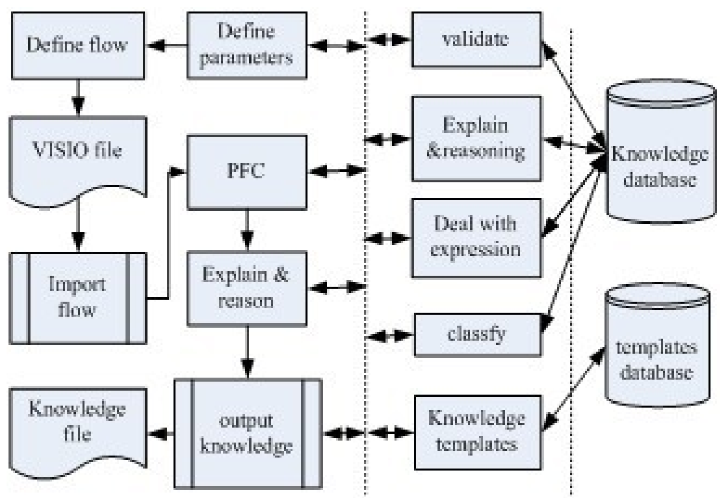

Fig.5 Model of the PFC software system

Based on the analysis of the process flow knowledge and the definitions of PFC above, the model of the software system based on PFC is shown in Fig.5. The parameters are defined via interactive interfaces, including extraction and semantic description of the parameters. The process flow chart is defined via Microsoft Visio, a popular flow design software system based on the component object. VISIO is customized and integrated with the proposed software system. Hence, the capabilities of extendibility, visualization and readability of system are achieved. When explaining and reasoning using the PFC, the system will firstly read the related information from the PFC file (VSD file), then call the main module to load corresponding file via automation interface, finally explain and reason the flow chart. The system provides two operations, Reasoning in step and Reasoning continuously, to meet the requirements of debugging and output of process planning knowledge. During the process of explaining and reasoning, if errors occur, the system will notify the user and ask for solutions. After the process flow chart has been explained and reasoned successfully, the results will be formalized with a table form via neutral file.

3.3 Other representation approach

Resource knowledge comprises machine tools, fixtures, machining data, etc. They are static and have diverse forms. Classification tree is used to represent them. The node of the classification tree indicates the type of resource knowledge, and its self-defined attributes show the description and information of resource knowledge. Such hierarchical structure of tree is very similar to practical process resource management. The structure of node is defined as following:

```
class CProceeResNodeTree
{
public: int nNodeKey;          //node ID
int nParentNodeKey;            //parent node ID
int nSibling;                  //sequence number in sibling
int nChildren;                 //whether has child node
CString sNodeName;             //node name
int nNodeTableKey;             //database tale ID of node
int nNodeGraphicsKey;          //document ID of node
CString sNodeEditAccess;       //permission of edit
CString sNodeViewAccess;       //permission of browse
}
```

For calculation knowledge, the key issues include creating user-defined formula, definition of variable value source, and definition of suitable condition for the formula. The data structure of calculation knowledge is abstracted as following:

```
class CFormulaKnowledge
{
public: int nFormulaKey; // formula ID
CString sFormulaType; // type of formula
CString sFormula; // formula expression
CString sDescription; // formula description
int nConditionTableKey; // table ID of condition
int nVariableTableKey; // table ID of variable value source
}
```

To represent the calculation knowledge, a formula management tool based on the above data structure is developed and is shown in following case study.

4 Case Study

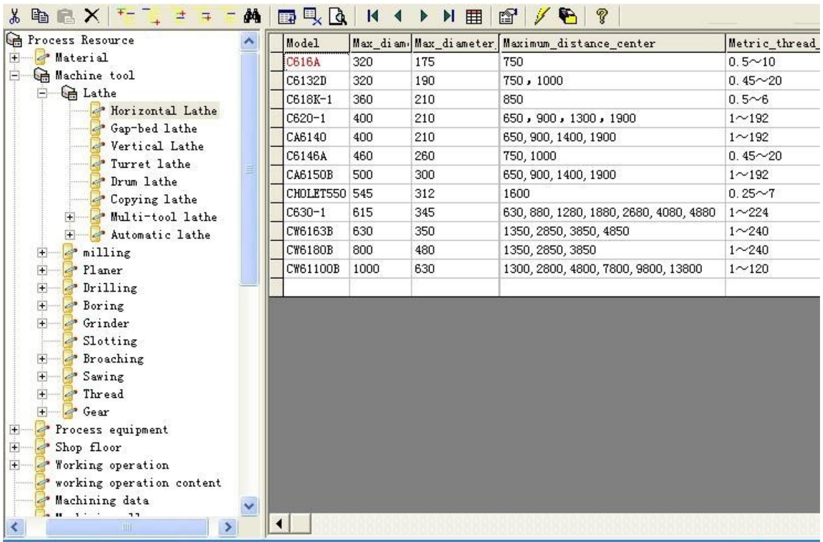

Fig.6 Manage machine tools in PKMS

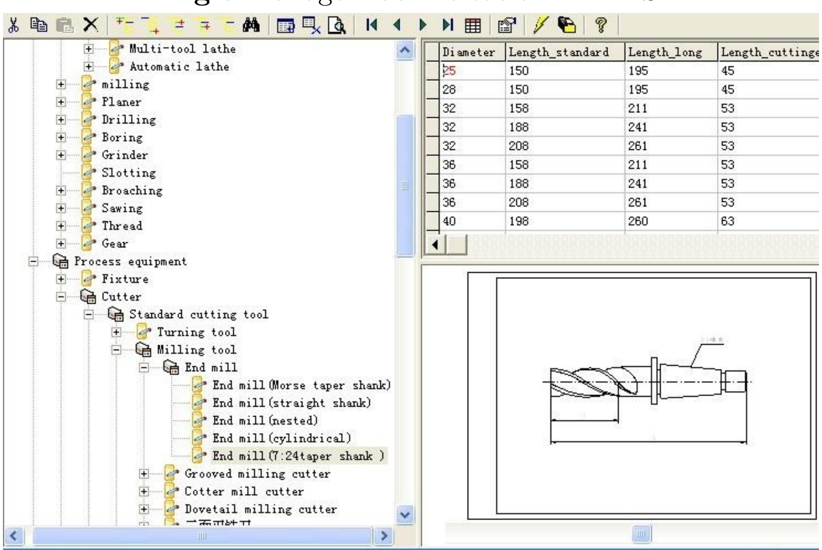

Fig.7 Manage cutting tools in PKMS

A prototype system of PKMS has been developed to validate and demonstrate the feasibility and the compatibility of the proposed PKMS. Microsoft Visual C++ is employed to develop the framework and functional modules. Microsoft SQL Server 2005 is utilized to construct the systems repositories. Microsoft Visio

2003 is customized and used to draw process flow charts. A variety of standard industrial process knowledge has been established using functional modules of the prototype system.

Fig.6 and Fig.7 are screenshots of process resource management module using classification tree method. The left side of Fig. 6 shows the resource classification tree that comprises of process resource nodes. The data structure of node is defined as mentioned above, including its name, parent node, database table and related document, etc. The nodes of tree can be created, deleted, searched according companys situation given authorization. The right side of Fig. 6 shows the information of current selected resource node, a list of horizontal lathes with their technical parameters, which may guide to select appropriate lathe when carry on process planning. Fig.7 is an interface of managing standard cutting tools. The drawings of current selected end mill are also captured and displayed.

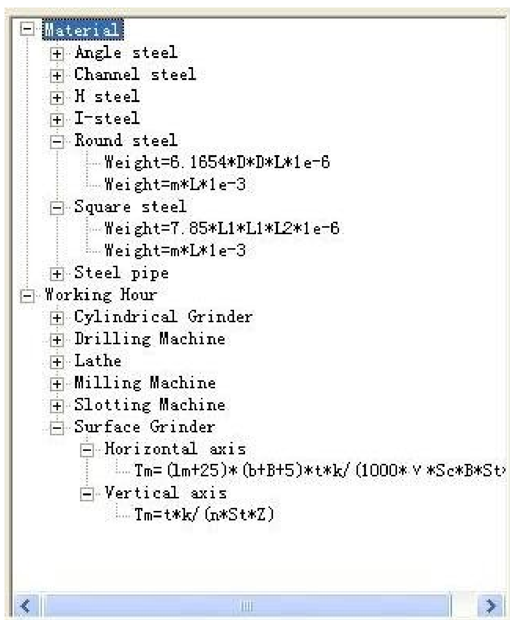

Fig.8 Manage calculation knowledge in PKMS

Fig.8 is the screenshots of formula management module, which takes charge of managing calculation knowledge. Two types of formula used often in process planning are built in case study, one is for material calculation, and the other is for working hour calculation. A whole formula may have its expression, variables, applied conditions, and categorization, etc. Its data structure is defined as mentioned above.

Fig.9 is the screenshots of representation approach based on PFC. The example

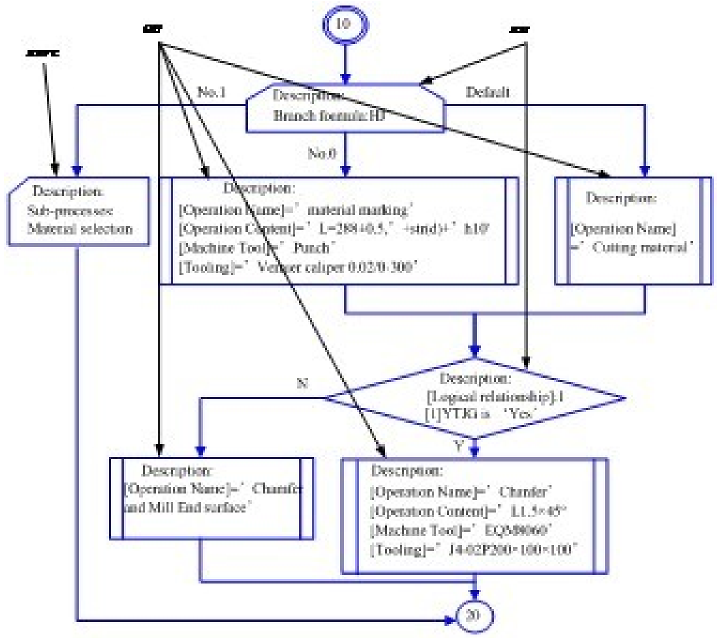

Fig.9 Manage process flow knowledge in PKMS

flow chart is drawn in Microsoft Visio 2003 using predefined chart units. mentioned above. There are two, four and one in Fig.9, which are pointed by arrows, is used to judge the next information flow direction according to the input conditions. stands for working operation of process. is a sub-PFC defined elsewhere. The directed flow chart represents knowledge of a parts process route.

5 Conclusion

In this paper, the characteristics of process knowledge in OKP companies have been analyzed; a definition and framework of PKMS in OKP companies were introduced as well. To overcome the difficulty of representing diverse type of process knowledge, a hybrid approach aiming at three main types of process knowledge was proposed. A prototype system has been developed to validate the proposed ideas. From this research work, the following conclusions are drawn:

(1) The proposed PKMS is open and extensible, the process knowledge database can be established and updated through developed interfaces.

(2) The introduced hybrid approach can represent all kinds of process knowledge effectively; especially approach based on PFC can represent dynamic and rule-based process flow knowledge successfully, which has been validated in our case study.

(3) The proposed approach is people oriented. Microsoft Visio, which is the most popular diagramming tool and easy to learn and use, is utilized to define process flow knowledge. Skilled employee or experts can build process knowledge themselves without having to have much knowledge on information technology and without software programming.

Future research work is still required to improve the proposed system. This includes the development of new tools for process knowledge discovery, demonstration of the prototype system in different OKP companies, and integration of other new approaches of knowledge representation, etc.

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