Hybrid Intelligent System Applications

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Contents:

PREFACE

I am very pleased to be involved with this book on "Hybrid Intelligent System Applications". As you are well aware, the intelligent systems field has emerged into a hybridization of systems. The focus of the book deals with the integration of intelligent systems technologies, most notably hybrid expert system-neural network systems. This is one of the few books that concentrates on this area, bringing a worldwide perspective on this important and growing topic.

The intelligent systems, or knowledge technology, field has matured to the point where powerful systems are being created and deployed through a coupling of various intelligent systems (and conventional systems) technologies. These hybrid intelligent systems are synergistic in nature, where each respective technology is enhancing the capabilities of the other. For example, a neural network typically lacks the ability to provide explanations, whereas a knowledge-based system (which usually has an explanation capability) could be coupled with the neural network to allow explanations to occur. A counter example is using a neural network to act as a filter for determining good quality satellite data, for example, which in turn, the good quality data is processed by an expert system for classification or interpretation. Looking at the synergy between intelligent systems technologies and emerging interactive technologies, an expert system could be integrated with interactive multimedia to act as a guide for navigating through the hypermedia. Similarly, interactive multimedia may be used to enhance the consultation, explanation, and conclusion presentation of an expert system.

In the years ahead, the integration and hybridization of intelligent/conventional systems will continue to proliferate. The basic idea is to leverage one technology with the other in creating a "whole is greater than the sum of its parts" phenomenum. Businesses, government, and universities are actively becoming involved with the development and implementation of these hybrid systems and soft computing. There is even a recently formed, non-profit organization called the International Society for Intelligent Systems (ISIS), based in Rockville, Maryland, that is providing educational seminars, conferences, and research in the intelligent systems arena.

I feel that this book is rather unique and adds significantly to the existing literature in the intelligent systems field. I would like to thank the valuable contributions from all the authors worldwide, the reviewers, Robert Miranda, Cognizant Communication Corporation, and ISIS for making this book a reality. Additionally, I would like to thank George Washington University for their encouragement in this book project. And without question, this book would not have been possible without the continuous support and love from my family--my parents, Janet, Jason, Kenny, and Mazel. Enjoy!

... Jay Liebowitz, D.Sc., Editor
George Washington University
Washington, D.C., 1995

Process Planning Using An Integrated Expert System And Neural Network Approach[1]

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Abstract. This chapter presents a unique computer aided process planner for metal furniture assembly, welding and painting using a rule based expert system integrated with an artificial neural network. The process planner creates parts lists, process plans and estimates standard times for individual product variations using input of product number or selection of product features. Although fundamentally a variant process planner, the rules and neural network allows some generalization capability to new products. This demonstrates that a composite intelligent approach can be useful for process planning in real manufacturing situations.

1. Introduction

The development of process plans and the determination of standard processing times are essential functions for many manufacturing organizations. These functions are time consuming and require significant skill and/or a great deal of experiential knowledge. To fully or partially automate these functions would certainly provide very tangible benefits to many organizations. This study deals with the use of neural network and expert system computing tools in an integrated fashion to effectively perform process planning and process time prediction activities. The study used a metal furniture manufacturing environment as a test bed for the prototype system.

1.1. Process Planning Basics

Process planning is the activity of taking the product design or specification, which is defined in terms of the design engineer's terminology (e.g., size, shape, tolerances, finish, and material properties/treatment), and transforming it into a detailed list of manufacturing instructions which are stated in terms that are useful to manufacturing personnel (e.g., specifications for materials, processes, sequences and machining parameters). The process plan is the recipe that is followed by all shop floor personnel to produce the desired end product; as such the process plan plays a key role in the manufacture of high quality and cost efficient products. For many products there is no unique manufacturing method and many variations of the process plan could provide an acceptable end product. However, the process plan chosen can have a significant impact on the manufacturability of the product. Developing a good process plan given the current manufacturing system constraints requires extensive experiential knowledge and is a time consuming process.

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Computer-aided process planning (CAPP) systems have been devised to help simplify, improve, and provide consistency within the process planning function. Computer-aided systems have the potential to capture and retain the experiential knowledge of expert process planners which may have taken years to develop. Furthermore, capturing this expertise in a knowledge base provides the ability to easily replicate process plans and expertise. There are two basic types of CAPP systems, variant and generative. The variant approach groups parts into families based on geometric similarities and stores standard process plans for each family. The standard plans can be retrieved automatically and annotated to conform to the specific product of interest. The generative approach uses a detailed feature description and decision logic to synthesize process plans, optimizing for each individual part and tool.

1.2. Standard Process Time Basics

A standard process time for a given manufacturing process is the average amount of time for the average worker to complete the operation. Standard process times are typically determined via the use of detailed time studies of the operation. The time studies involve repetitively timing the operation with various operators and making some subjective assessments about the operator's performance. Time studies are time consuming and tedious, however, the availability of standard process times is a valuable tool for many manufacturing organizations. Standard process times can be used to balance the flow of products through a manufacturing cell, estimate production costs, predict throughput times, and evaluate operator performance.

When the members of a product family vary significantly in the amount of time required to complete certain manufacturing operations the effort required to determine standard process times increases dramatically. This is because a single standard time does not apply to all members of the family, and thus a standard time for each specific product variation must be determined. Since determining a standard process time involves repetitive timing cycles, the determination of standard times for all products in the family can quickly become impractical. The ability to generalize the time study data taken from a small sample of the product family to all other members of the product family would provide a significant reduction in the effort required to develop good standard times. This is the approach which is taken in this chapter.

1.3. Neural Network Basics

Artificial neural networks are massively parallel computing mechanisms modeled after the biological brain. They consist of nodes, linked by weighted connections. Neural networks are built hierarchically in layers with connections between layers, and sometimes within a layer. Neural networks learn relationships between input and output vectors by iteratively changing interconnecting weight values until the outputs over the problem domain represent the desired relationship. This empirical learning is an attractive alternative to the slow process of knowledge acquisition for expert systems or the explicit coding of algorithmic systems. The resulting "trained" network consists of fixed weights and parameters which will then produce outputs for new inputs. This process of translating new inputs into outputs is referred to as recall. Neural networks are noted for their ability to perform with incomplete and noisy data, and their ability to generalize their learned representations to handle new circumstances. This last quality makes neural networks an attractive tool for process planning and process time prediction activities, where each new product is likely to differ somewhat from past ones.

1.4. Expert System Basics

Expert systems capture knowledge about a given domain in the form of a knowledge base of rules and facts. In this way expert systems have the potential to duplicate and standardize human expertise which may have taken years of experience to develop. Expert systems are quite different from traditional algorithmic computer programs in the way in which knowledge is organized Expert systems have three distinct modules of information 1) rules, 2) facts, and 3) control strategy. This organization allows for the ready adaptation of the expert system architecture to various problem domains. These intelligent systems have proven effective in many problem domains. However, there are well established drawbacks of expert systems including the difficulty and effort involved during the knowledge acquisition phase, and the brittleness of the rule base in regard to handling new or modified features.

The control strategy for an expert system is the means by which attribute values are pursued. The control strategy may be forward chaining, backward chaining, or a mixture of both. Forward and backward chaining refer to the method in which IF-Then rules are processed. During forward chaining whenever an attribute changes value all rules which have that attribute as the antecedent will be evaluated. For any of these rules, if the IF portion of the rule evaluates as true then the rule will fire and conclude one or more attribute values. These recently changed attributes will similarly be evaluated in all other rules in which they appear in the antecedent and so on in a chained fashion. During backward chaining an attribute value is pursued via locating all rules in the knowledge base which conclude that attribute. Each of these rules is then evaluated by examining the antecedent of the rule. The values of these attributes are then determined by evaluating all other rules which conclude these attributes. This process is followed in a chained fashion until the chain reaches a known value.

2. Previous Related Research

The automation of the process planning function using various software approaches has been and continues to be an active research area. Expert systems have been studied in depth and implemented to perform some process planning functions. Gupta and Ghosh [1] provided a survey of expert systems in manufacturing and process planning. This paper presents various applications of expert systems to the problem domain of industrial and manufacturing engineering. Each system is discussed in terms of the problem definition, implementation scheme, and special features. Another survey of expert system approaches to process planning was published by Gupta [2] which discusses available process planning expert systems. The important features and limitations of the various systems are presented, with respect to their part design input scheme, knowledge base representation, and control strategy. Other approaches to the automation of process planning have also been studied including using a relational data base management approach. Wang and Walker [3] presented a framework for the creation of an intelligent process planning system within the relational data base management system.

Automating the CAD / CAM link has been the topic of considerable research and development efforts. Madurai and Lin [4] provide a discussion on the automatic extraction and recognition of part features directly from a CAD database. The objective of the study was to develop an intelligent feature extraction methodology and to implement it using currently available CAD software. Wang and Wysk [5] consider that an expert system technique for CAPP may replace traditional generative CAPP methods for various reasons. These include 1) the organization of knowledge in an expert system (i.e., facts, rules, and control strategy) provides for much easier modification when compared to traditional computer systems, 2) decision trees and decision tables, which are often used in traditional generative CAPP systems, work effectively only for simple decision making processes, and 3) expert CAPP systems may be designed so that knowledge can be accumulated as time passes, which is not a capability of current variant and generative systems. Wang and Wysk [5] discuss an intelligent process planning system called Turbo-CAPP which has the ability to 1) interpret and extract surface features in a wireframe-based CAD database, and 2) perform intelligent reasoning for process planning.

Automated assembly planning is an important activity in implementing an integrated manufacturing system. As such, Lin and Chang [6] presented a algorithmic methodology for automatic generation of assembly plans for three-dimensional mechanical products. The intent was to develop an efficient method to describe and plan the assembly of mechanical products. The method uses a two state planning scheme which considers only the geometric constraints first and then considers sequence constraints derived from non-geometric properties. The system infers mating and collision information from the assembly solid models and uses a frame-based representation scheme to explicitly represent the assembly non-geometric information. using expert system rules.

As discussed above the vast majority of research in the area of automated process planning (including machine parameter and sequence planning and assembly sequence planning) has focused on the use of expert systems, traditional generative process planning techniques, or other approaches, such as the use of relational database technology. Recently some emphasis has been placed on implementing neural network technology in the development of automated process planning systems. Knapp and Wang [7] formulated an approach for the automated acquisition of process selection and within-feature process sequencing knowledge using neural networks. The authors in this reference cite several reasons why the use of neural networks are a preferable alternative to expert systems for process planning: 1) the expert system knowledge acquisition process is time consuming, costly and error prone, 2) the systems can not adapt to change in manufacturing practice and technology, 3) the expert systems are brittle in nature (i.e., with sharp boundaries of application), and 4) expert systems cannot generalize from past experience to handle new cases. Knapp and Wang [7] used a back-propagation network to map spur gear attributes or features into feasible machining operations, and the selection of only one machining operation at a time was forced using a MAXNET network. The network used a recurrent input to keep track of the previous machining operation. Chen and LeClair [8] presented another neural network approach to process planning. In this reference the authors discussed the use of an unsupervised neural network in machine setup generation. Intersecting and non-intersecting features within a setup are identified and classified using an associative memory.

Chen and Pao [9] presented an approach to the design and planning of mechanical assemblies using an integrated neural network and rule-based system. The system first uses an unsupervised neural network learning algorithm in the design stage to cluster similar conceptual designs which provides the input interface to the design cluster memory. The rule-based portion of the system then accesses this design cluster memory as required while performing its role in the generation of assembly plans (i.e., performing the functions of pre-processor, liaison detection, obstruction detection, and plan formulation). The system attempts to utilize the strengths of both neural network and rule-based modules to provide a more powerful single system, which is similar to approach taken in work presented herein.

3. Project Objectives and Scope

The objective of this project was to develop a tool which could perform process planning and process time prediction functions automatically. The result was intended to be a user friendly software package which utilizes expert system and neural network computing methods in a fashion which is transparent to the user. The prototype system was developed for a metal furniture manufacturing environment to ensure that the problems and difficulties associated with a real manufacturing environment would be factored into the system and to illustrate that an integrated system is implementable.

3.1. Project Scope and Manufacturer

Haskell of Pittsburgh was selected as the test case for the prototype system. Haskell produces metal office furniture including pedestals, desks, file cabinets etc. and is considered representative because of its mainstream product line. Due to the extensive line of products produced at Haskell and the significant product variations possible, the prototype system was limited to only a small subset of the products manufactured there. It was determined that the Cube Pedestal product line would provide a good test case for the prototype system. This product line provided a manageable subset of products while still introducing significant variation, resulting in a non-trivial yet manageable problem.

The Cube Pedestal is a stand alone, desk high, filing cabinet. There are significant variations available within this product line including two different heights (executive and typing), three depths (20, 24, and 30 inches), various combinations of drawer types (four drawer types are available: tray, box, file and EDP) and configurations (i.e., eight standard drawer configurations for a executive height pedestal and three standard drawer configurations for a typing height pedestal), various drawer handle and filing accessory options, several lock and support options, and many paint color choices.

Within the Cube Pedestal product line additional product variations are feasible which are not currently available and which would not require changes to the basic components which make up the assembly. Specifically, many different drawer combinations which are currently not a standard option are feasible via altering only the quantity of parts required and the assembly process. Altering the process plan to accommodate these special order cases is a good test of the process planner's ability to generalize.

The scope of this project was further limited to the final assembly area which includes the weld, paint, assembly and packaging processes. The final assembly processing sequence is divided into 14 sub-processes as shown in Figure 1 and is briefly described below. There is only limited flexibility in the sequencing of these major sub-processes due to the inherent nature of the assembly process (i.e., certain processes must necessarily precede others). Haskell was interested in development work in this area for two reasons; 1) no written process plans currently exist for the final assembly area and 2) only limited time studies have been completed in this area.

3.2. General Approach

Once the project scope had been sufficiently limited and defined the following five step general approach was followed:

3.2.1. Document The Current As-Is Process

As stated above, no written process plans exist for the final assembly area. Currently the specific processing steps completed for each of the 14 major sub-processes are determined by an experienced operator. A brief description of each of these 14 sub-processes follows:

MIG WELD NUTS TO BOTTOM CHANNEL - Two bottom channels form the support base for the Cube Pedestal. In this process two nuts are MIG welded to each bottom channel. These nuts are used to attach the glides to the bottom of the pedestal. Three lengths of bottom channel exist to support the three available pedestal depths.

FORM WRAPPERS - In this process the pre-cut sheet metal blank is bent to form the outer surface or covering for the pedestal (i.e., the sides and back of pedestal). The tabs which are used to weld the top cap to are also formed in this process. Five different sheet metal blank sizes are available to support the different pedestal sizes.

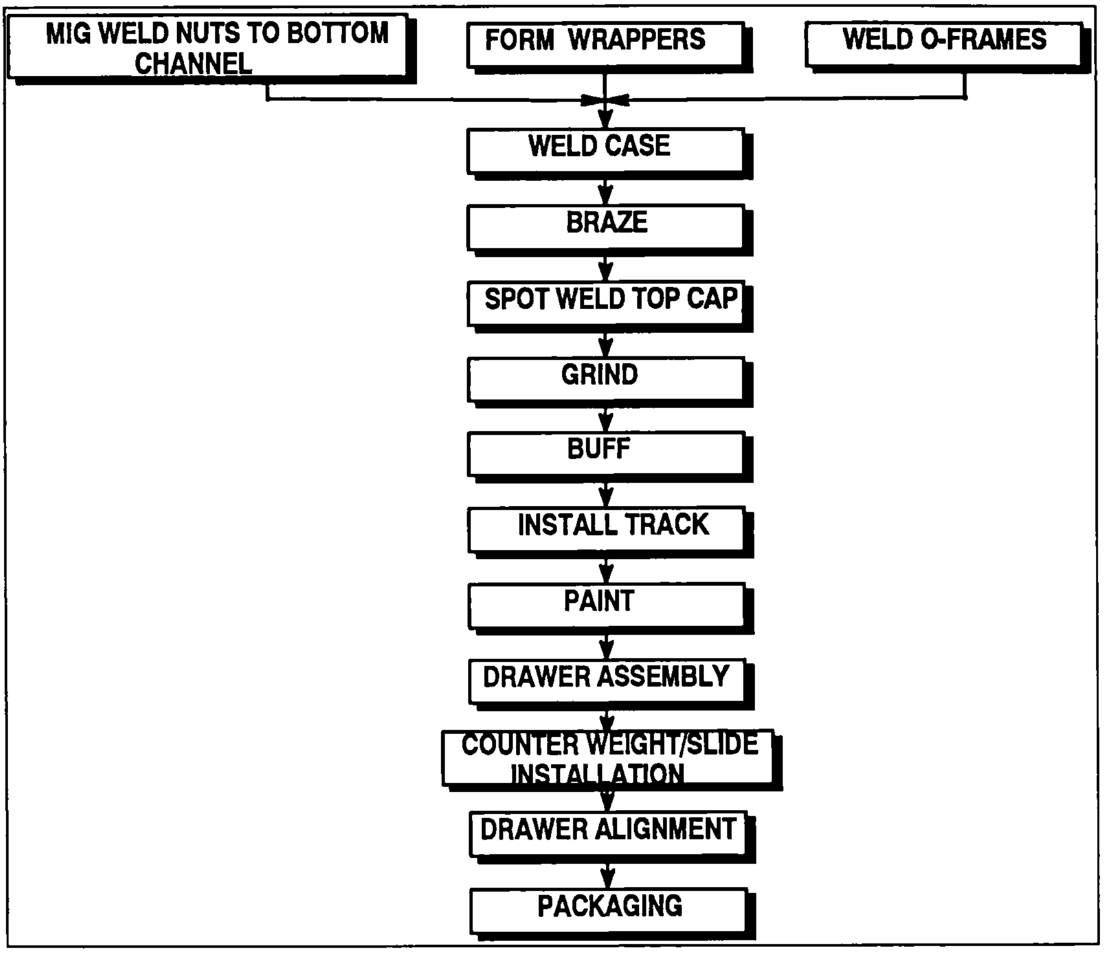

Figure 1. Overview of Cube Pedestal Process.

WELD O-FRAMES - The o-frames provide the inner support structure for the pedestal. There are two o-frames in each Cube Pedestal assembly, one near the front and the other near the back. The o-frame is a rectangular structure formed by spot welding two vertical stiffeners to two horizontal stiffeners. All four stiffeners are loaded into an adjustable fixture and the welds are made simultaneously by machine. Two sizes of o-frame are available to support the two pedestal heights.

WELD CASE - In this process the wrapper, o-frames, bottom channels, and other stiffeners and plates are welded together to form the shell of the Cube Pedestal. An appropriate assembly fixture is used to obtain the proper alignment between the piece parts for the particular product variation being built.

BRAZE - In this process the top cap (i.e., top of the pedestal) is positioned on the pedestal case and brazed in all four corners. Some additional brazing of support structures and the bottom front corners of the pedestal is also completed.

SPOT WELD TOP CAP - In this process the top cap is spot welded along both sides and the back of the pedestal shell. The quantity of welds depends on the particular variation in size of the product being built.

GRIND - The grind operation removes excess braze from all the externally visible brazed locations. This is a cosmetic operation to ensure the final pedestal surfaces are smooth.

BUFF - The buff operation is also a cosmetic operation to prepare the surfaces, which have been spot welded, for the painting operation.

INSTALL TRACK - In this operation the runners (i.e., which support the pedestal drawers) and the lock bar(s) are installed. This installation requires proper positioning of the parts based on the product variation being built, making hook and slot connections, and installing holding screws.

PAINT - The pedestal case and drawers are painted in this process. Due to the in-accessibility of this process it was not documented in detail and is not supported by the process planning and standard time prediction system.

DRAWER ASSEMBLY - When the drawers reach this process they are in the general configuration of a drawer, i.e. they are built elsewhere. In this operation various options are added to the drawers, such as the hanging mechanisms for file folders. Also the drawers are cosmetically touched-up to remove excess paint and to touch-up areas missing paint.

DRAWER SLIDE AND DRAWER INSTALLATION - In this operation the casters or glides, drawer counter weight, drawer roller mechanisms, and various bumpers and sound deadeners are installed. Subsequently, the drawers are installed.

DRAWER ALIGNMENT - In this operation various adjustments are made to ensure that the pedestal shell is square, that proper spacing exists around all edges of the drawers, and that the drawers move in and out smoothly.

PACKAGING - The completed product receives a final inspection and is packaged for shipment in this operation.

Each of the processes was documented via detailed interviews with the operators and observation of the process. It was observed that the operators based their decisions concerning which processing steps were required on their past experience and on basic written instruction detailing the type and quantity of final product required. During this documentation phase it became evident that each of the 14 major sub-processes consisted of a core or standard process, which was the same for all variations of the product line, plus a small number of key processing steps, which were dependent on the specific product variation selected. The specific processing steps and the reasoning or rationale behind the decision to perform that particular processing step was documented for all the major sub-processes. For example, in the Weld Top Cap process the operator determines the required number of spot welds to make on each side of the top cap based on observing the depth of the pedestal (i.e., 20, 24, or 30 inches) or by referring to a computer output for the pedestal depth. Knowing the depth of the pedestal is sufficient information to determine the required number of spot welds. This type of reasoning/action process was extracted from the operator interviews.

3.2.2. Develop Standard or Core Process Plans

Based on the documentation acquired from the operator interviews a set of core process plans was developed, one for each of the 14 major sub-processes. These core process plans consisted of the detailed processing steps common to all product variations within the Cube Pedestal product line plus key words which identified where the process plan required modification for specific product variations. The types of information that is specific to the product variation selected includes machine settings, appropriate fixtures, and number of welds. Each of these core process plans were stored in a separate text file. The word *VARIABLE* were used as key words for a process and indicate that a manufacturing step must be inserted in these locations which is specific to the product variation under consideration.

3.2.3. Develop Knowledge Base Rules

A set of rules was developed which conclude the appropriate processing steps to be inserted into the core process plan for a specific product variation. In general the core process plan is updated with the specific processing steps appropriate to the product variation under consideration. The rules determine the correct processing step to be inserted based on the attributes of the product variation under consideration. It was found that simple rules were sufficient to correctly select the product specific processing steps. Rules were developed which could correctly determine these product specific processing steps for two cases, 1) when the product selected was a standard or currently available product variation and 2) when the product selected was a non-standard or currently unavailable product variation.

It must be noted that new products (i.e., non-standard or currently unavailable products) must be within the physical constraints of the available piece parts. Specifically, any new combination of drawers could be selected with the constraint that the overall dimensions of the pedestal are not changed. For example an executive height Cube Pedestal with 8 tray drawers, which is a non-standard product variation that is not currently available, could be generalized by the system because the 8 tray drawers would fit in the executive height Cube Pedestal. However, specifying a typing height Cube Pedestal with 8 tray drawers is not acceptable to the system because the 8 tray drawers physically will not fit into the typing height pedestal. Thus any product variation can be generalized by the system provided it does not alter the basic piece parts required for the assembly and is physically feasible.

3.2.4. Evaluate Standard Processing Times

Recent time studies completed at Haskell provided timing data for 8 of the 14 sub-processes. Evaluation of this data and discussions with Haskell personnel indicated that most of these sub-processes had relatively static processing times across all product variations. Specifically, there is minimal or no variation in the time required to complete the processes as a result of the specific product variation being considered. The variation in the time data is attributable to such things as operator, equipment and part variability. Thus, for most of the sub-processes the standard processing time is applicable to all product variations. For these cases the development and use of standard processing times is a straight forward look up table.

In general, standard processing times do not behave as nicely as those noted above. The standard processing time required to complete a given operation is typically highly dependent on the product variation selected. This is the case for the Install Track sub-process of the Cube Pedestal assembly operation. Depending on which product variation is selected, the type, quantity, and installation positions of the piece parts involved in this process are highly variable and thus the associated time required to complete the process is highly variable. Haskell had not performed time studies on this process for this reason. Timing studies performed on one variation of the product line are not in general applicable to other product variations. Thus if accurate time data is desired, then time studies of all the product variations would be required. When significant product variations are involved this can become a very time consuming and impractical task.

Use of a neural network to generalize the standard time data from a small subset of the possible Cube Pedestal products to all the remaining Cube Pedestal products could greatly simplify the determination of standard process times for the Install Track process. This method would require that time studies be performed on only a limited number of representative product variations. Also for non-standard products the neural network could be used to estimate standard process times for products which had not yet been built. This was the approach taken in this study. As discussed in more detail below, a neural network model was developed and tested utilizing a training and test set of simulated data. A similar neural network model is planned using actual data collected by Haskell.

3.2.5. Develop Software System

A software system was developed which consists of an interactive expert system that acts as user interface, procedural data base, inference engine, and system integrator. Exterior to the expert system are the neural network component and external data files. Figure 2 provides the system architecture. The expert system utilizes both forward and backward chaining reasoning together with developer designed procedures to accomplish the specified system tasks. The expert system development software used was Level 5 Object version 2.5, running under Windows 3.0, and the neural network development software used was BrainMaker, version 2.0.

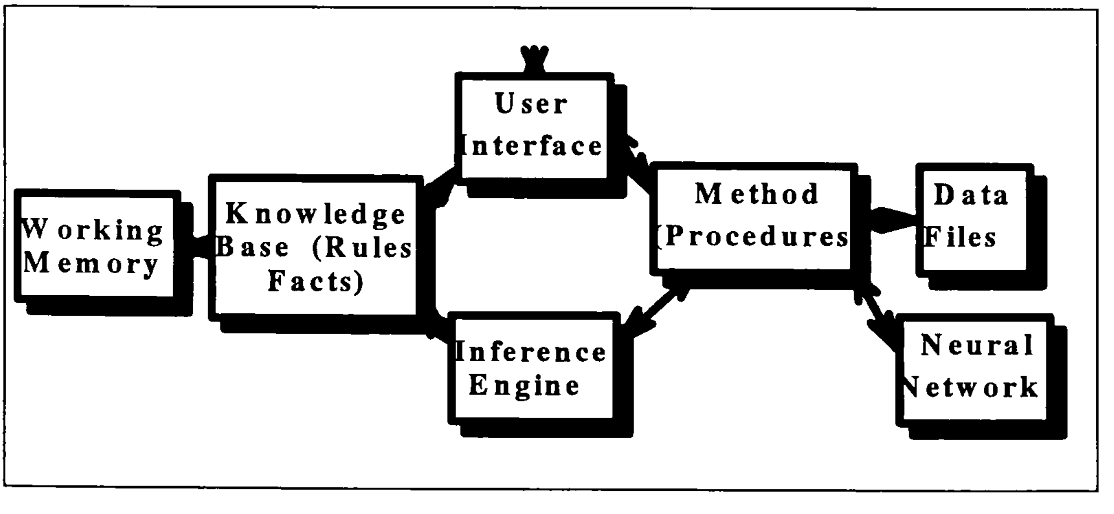

Figure 2. System Architecture.

4. System Description

4.1. System Architecture

The system has three primary functions 1) develop detailed process plans, 2) develop parts lists, and 3) determine standard process times for each major sub-process. Each of these functions are completed for the specific product variation selected. To perform these tasks the system utilizes an expert system, a neural network, and external data files. The User Interface, which is a user friendly set of input screens, can set current facts in the knowledge base or activate methods. Facts are simply attributes for which the current values are known with certainty. For example, when the attribute "height" of the Cube Pedestal class is selected by the user to be 24 inches this is stored as a fact in the working memory. The fact can then be accessed throughout the consultation when the value of that attribute is required. A method is a developer designed procedure which can perform various tasks and/or set attribute values based on a series of If-Then clauses. Methods may have loops and nested Ifs which make them different from basic rules. A simple example of a method is shown below.

```
WHEN CHANGED
        BEGIN
        IF drawer option OF cube pedestal = "Other" THEN
                ASK drawer option choice display
        ELSE
                ASK Cube Ped Process Flow display
        END
```

This example shows a WHEN CHANGED method. WHEN CHANGED methods are attached (or associated with) a given attribute; whenever that attribute changes value the WHEN CHANGED method is activated and it completes its procedure. The above method simply checks the value of a certain attribute to determine if it equals the string value "Other" and activates the appropriate display screen.

The Methods in this system perform four primary functions 1) access and read/write to external data files, 2) access, provide input vector, and run the neural network in recall mode, 3) activate the expert system Inference Engine, and 4) perform various tasks required by the system, e.g., print files etc. The Inference Engine is either activated by a Method to pursue a given attributes value via backward chaining or is activated in a forward chaining mode when certain attribute values are changed by the user. The knowledge base consists of a set of backward chaining rules (called Rules) and a set of forward chaining rules (called Demons). Finally the working memory keeps track of the current values for all attributes.

4.2. Detailed System Description

Figure 3 shows the program flow diagram for the system. Upon starting a consultation the user is greeted with an introduction screen and is provided access to a system information screen which briefly describes the system. When the user continues, a prompt to select a product line is displayed. After the Cube Pedestal product line is selected a product specification screen is displayed. This screen is specific to the Cube Pedestal line and provides all its attributes with the corresponding possible values. These attributes are:

Series Option
Drawer Pull Option
Case Height Option
Case Depth Option

Lock Option 1
Support Option
Drawer Option
Paint Color Option
Filing Accessories Option
Lock Option 2

Via the use of radio buttons the user can select the desired value for each option. If incompatible options are selected for the various attributes, an error message is displayed and the user is required to modify the selection. The attribute values selected in this screen are set for this consultation in the system's Working Memory via firing a set of backward chaining rules. This product specification screen can be used for both standard products (i.e., currently available product variations) and non-standard products (i.e., special product variations which are not currently available).

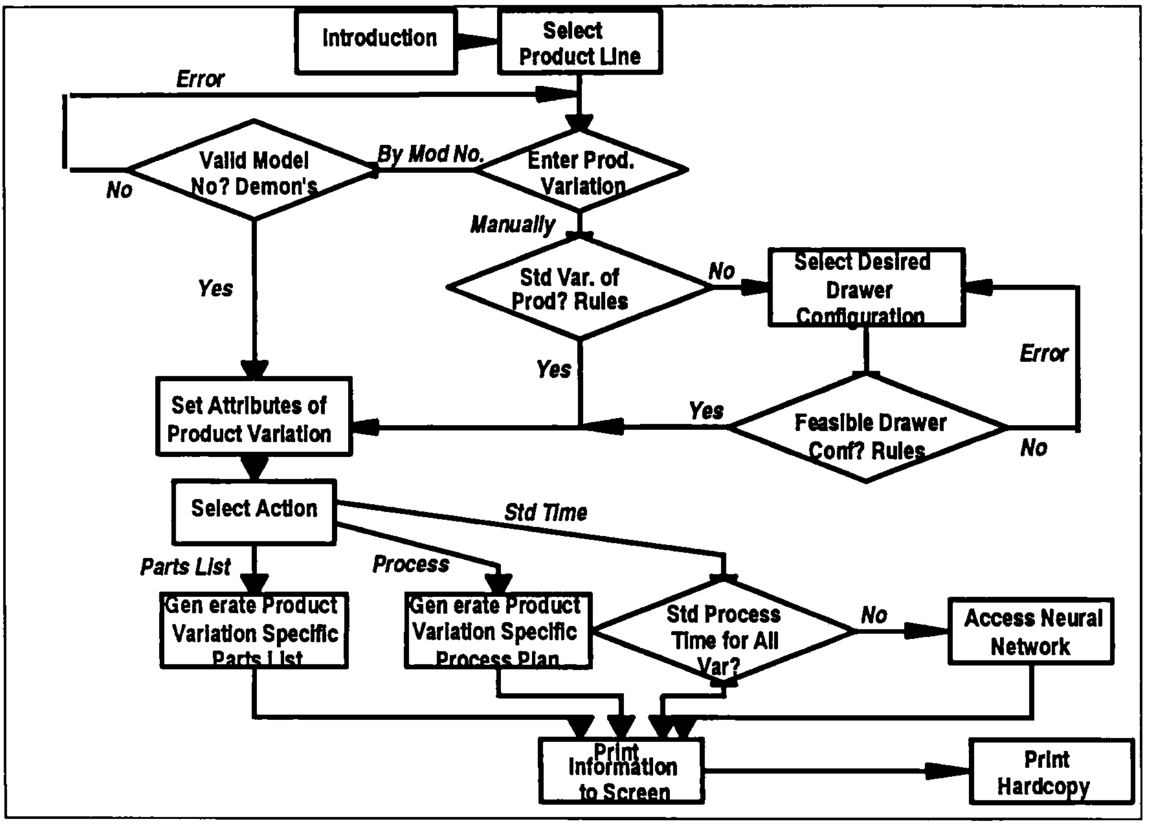

Figure 3. Flow Chart of User Consultation.

An alternative approach to specify the product variation is to directly input the product's serial number. This option is obviously only available for standard product variations. This selection calls another input screen which accepts the product's serial number. When the product's serial number is input a series of checks are run by the system to determine if the input is a valid serial number; if it is not valid, an error message is displayed and the user is prompted to modify the serial number input. When a valid serial number is input, a set of forward chaining demons is fired which translates the serial number input to the appropriate attribute values and sets these values in the system's Working Memory similar to the above.