ETM
ENGINEERING & TECHNOLOGY MANAGEMENT

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Abstract: Here we examine the possibility of automating the component selection process used for configuring the Westinghouse PC 2000 industrial controller. The use of this tool will allow novice sales engineers and negotiators to configure a system without errors such as omission of expensive components or inclusion of incorrect components. In addition to the expected benefit summary and proposed system development schedule, this report contains the knowledge base representation, samples of the input and output, and sample sessions. A discussion of knowledge sharing as an acquisition tool is included as well as an illustration of what a knowledge base update session would look like.

EXPERT 2000

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EMP - P9037

Expert 2000 Executive Summary

This project examines the possibility of automating the component selection process used for configuring the Westinghouse PC 2000 industrial controller. The use of this tool will allow novice sales engineers and negotiators to configure a system without errors such as omission of expensive components or inclusion of incorrect components.

The expected benefits are:

Reduction in time spent by sales and support staff doing repetitive configuration tasks
Increase in consistency and correctness of configurations
Individualized on the job training
Differentiation from Siemens in customer service abilities.

The use of an expert system is possible but not necessary for this project. The knowledge base is very well structured and would prove tractable to other methods. The use of expert system technology is considered for several reasons. The first reason is the built in explanation ability of expert systems. The user can ask for information on why a component was selected and receive an answer in plain English. This ability to communicate can also be utilized for training sales engineers that are new to the product.

The second, and perhaps more important reason has to do with system maintenance. The group that would be using this tool does not have access to a computer staff that would be required to maintain a computer program. Even if the system was implemented using a database program, system maintenance would rely on the availability of someone who understood the organization as well as the database package. Expert systems have the ability to allow knowledge base maintenance by interaction of expert users answering questions put to them by the computer. This ability is exploited in knowledge sharing systems where humans and computers interact cooperatively to accomplish a task.

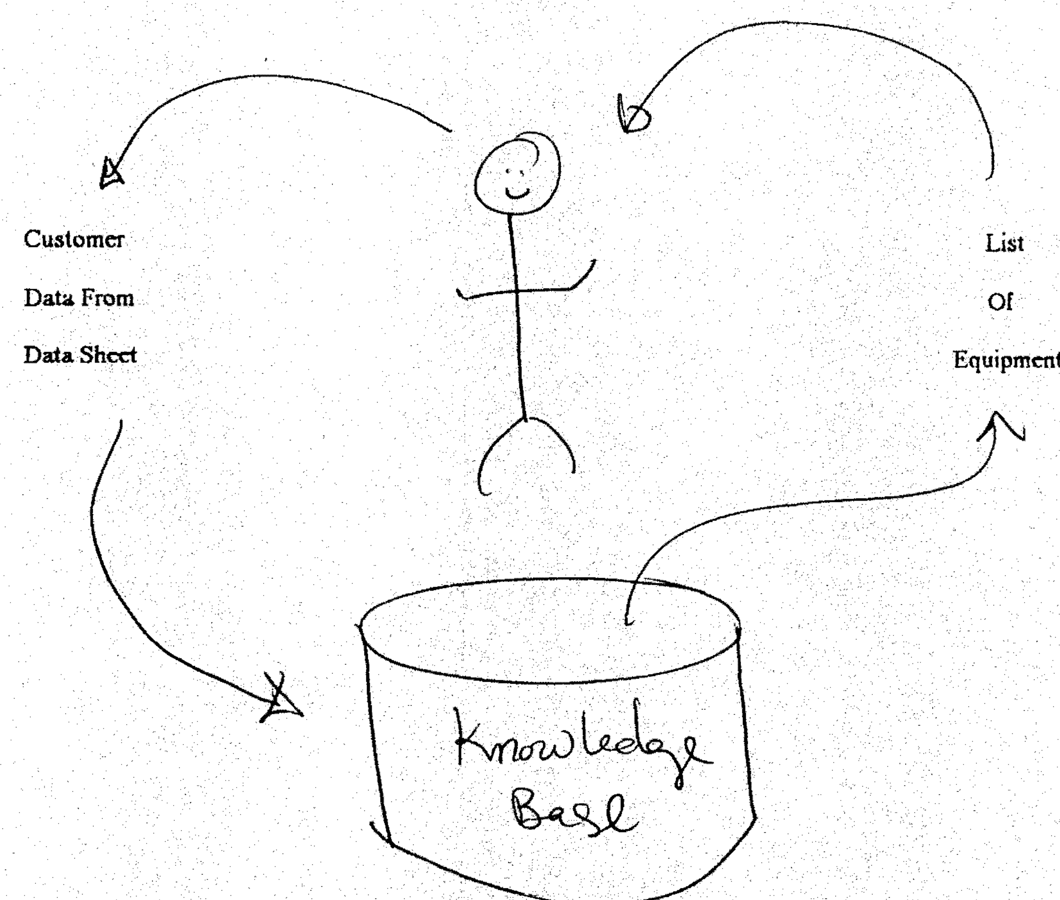
In addition to the expected benefit summary and proposed system development schedule, this report contains, the knowledge base representation, samples of the input and output, and sample sessions. A discussion of knowledge sharing as an acquisition tool is included as well as an illustration of what a knowledge base update session would look like.

Molly Olson
March 15, 1991

DOMAIN PROBLEMS

Task List	KBS Function
A. Form list of User requirements	0%
B. Configure list of hardware	100%
C. Layout components/addressing.......	0% (Future)
D. Troubleshoot PC faults..............	0% (Future)

Expert 2000 is solely designed to address the problems associated with component selection. Although the knowledge base is highly deterministic, expert system technology was suggested in order to allow easy human interface and computer explanation of selections as well as growth of the system to include layout, addressing schemes, and troubleshooting.



System Function

System User Requirements

Expert 2000 will act as an expert configuator tool for sales engineers and the High Tech Support Group.

A sales engineer is usually located in the field sales office some distance from the expert in Pittsburgh. This centralization of expertise is exacerbated by the three hour time difference between Pittsburgh and the west coast field sales offices. As mentioned earlier, these sales engineers have responsibility for the entire line of distribution and control equipment sold by Westinghouse and, in general,are not willing to spend the time required to become experts in this area.

The High Tech Support Group is located in Pittsburgh in the same building as the experts. Access to the expert is also limited due to the amount of travel the expert does in his role as product marketing manager. This group is responsible for supporting several product lines other than the PLC product lines. and has also experienced a fair amount of turnover.

The use of this tool will allow novice sales engineers and negotiators to configure a system without errors such as omission of expensive components or inclusion of incorrect components.

The interactive process of developing a system will teach a novice sales engineer the types of questions they must ask their customers and give them some familiarity with the technical jargon that is used in this field.

This tool will allow experienced users to decrease the time it takes to price a system, allow more consistency, and avoid rework.

In addition to the initial configuration this system must allow editing of previously entered systems as customer needs are clarified.

Finally, the system must be maintainable allowing the addition of new relationships or production rules between the existing components as well as the addition of new components and their associated production rules. This is particularly important because this is a new product line and the experts are still on the learning curve.

Knowledge Base Organization

Structure

This application lends itself to a structured production system approach. The equipment being configured has an organized structure physically. This structure allows many of the production rules to be categorized as applying only to a specific part of the system.

Example:
(Please see PLC Configuration Decision Process Flow)

Flow

The order of selection of parts is also important. Selection of an item to meet one criteria will often result in the limitation of possible items to meet other criteria.

Example:

IF (a communications processor is required)
THEN (the PC2000-11 cannot be used).

The search will be more efficient if the rules for communication processors are executed before the rules for CPU selection. In the process of acquiring the knowledge base this flow became clear.

Rule Samples

System Topology :
ST1
If Number of I/O cards > 34
THEN Remote I/O is needed.

General I/O Requirements
GIO1
IF number of analog inputs > 64
THEN ask user if multiplexing inputs is ok.

I/O Card Selection
DI2
IF voltage is not specified
THEN use 115/230VAC

Identify I/O Accessories Required
IOA3
IF NLIM-2304 is used
THEN add one NLC-2304B for each NLRE-2007.

PLC CONFIGURATION

Decision Process Flow

System Topology (Remote I/O)	Number of clustered I/O locations. Operator panel ergonomics.
Computer Interface Requirements	Number and types of computer or LAN interfaces.
Identify I/O Requirements	Determine traits by cluster: Discrete, analog, voltage, current, etc.
Identify Future I/O Requirements	Immediately available spare I/O points. Bus slots available for future growth.
Identify Special I/O Requirements	High speed monitoring or control needs.
CPU Selection	Number of I/O points, RAM, scan time, number of comm. ports, memory backup.
Power Supply and Rack Requirements	Selection based on number of racks and number and types of cards per rack.
Programming Tool Selection	Hand held or Personal Computer based.

__Input to system__ consists of information about the users equipment requirements. Please see the data collection sheet on the next page. Expert knowledge of what to assume is captured in defaults shown. Minimum required information to produce a budgetary estimate is highlighted in block A on the form. The ease with which a user can get started in using the system is important.

Examples of the types of input information follow and a filled in sample sheet is attached.

__Output from system__ consists of a detailed bill of material that meets the user's needs as portrayed on the Data Collection Work Sheet. Initially this BM will be printed without list prices. Enhancements will include list prices and graphical layout.

__Example:__

PC 2000 System for Weyerhaeuser Longview Trimmer #4
February 20, 1991
By JoAnn Smith, Sales Engineer, 503-624-4013

Item	Description	Part number	Qty	Price
1	CPU	PC 2000-11	1	$840.00
2	Memory Module	NLB-2000	1	$ 40.00
3	Power Supply	NLPS-2703	1	$390.00
4	Digital Inputs	NL-2005	2	$670.00
5	Assoc Hardware	NL-2924	2	$ 60.00
6	Digital Outputs	NL-2020	1	$564.00

.
.(etc.)
.

Total $2358.00

Please also see completed Bill of Material related to example from Data Sheet attached.

DATA COLLECTION WORK SHEET FOR the SALES ENGINEER

EXPERT 2000 PLC CONFIGURATION SYSTEM

Name of Data Collector: ____________ Job Name: ____________

NOTE TO THE ANALYST: Fill in the information sheet as completely as possible. If limited information is available or, if only a quick budgetary quote is desired, fill in **BLOCK A**, otherwise proceed with collection details. Circle the correct choice or fill in the blanks.

Defaults are shown in *italics*.

BLOCK A - Minimum Required Data:

1. Number of digital inputs in system: 130
2. Number of digital outputs in system: 93
3. Number of analog inputs in system: 20
4. Number of analog outputs in system: 16

BLOCK 1: GENERAL

Are any of these required?

Battery Backup (yes) no

Non volatile memory backup (yes) no

EPROM ✓ EEPROM ____

Specific scan time requirements? yes *no*

If yes enter the required scan time ____ K words/ms.

BLOCK 2: LINE VOLTAGE

Line voltage for the system (is *115 vac*) or 24 vdc.

BLOCK 3: DISCRETE INPUTS

___ 24vdc ___ 24-48vdc 130 *115vac* ___ 230vac

Percentage of additional spares 0 %

BLOCK 4: DISCRETE OUTPUTS

___ 5-24vdc ___ 48-115vac 70 *115vac/230vac*

Percentage of additional spares 0 %

BLOCK 5: RELAY REQUIREMENTS

(Show quantity of each type required and spares.)

24vdc: ___/___ 0.1A ___/___ 0.5A ___/___ 2.0A

115Vac: 3 /___ 1.0A ___/___ 1.5A ___/___ *5.0A*

BLOCK 6: ANALOG OUTPUTS

(Show number of each type required.)

___ ±10v or ±20mA 16 1-5vdc or 4-20mA

Percentage of additional spares ___%

BLOCK 7: ANALOG INPUTS

(Show quantity of each type required and spares.)

Differential ___/___

Single ended 20 /___

RTD ___/___ ±10vdc ___/___ ±5vdc ___/___

BLOCK 8: COMMUNICATION REQUIREMENTS

Will you be connecting to:

1. Operator interfaces (I/O Plus, Genesis) yes no
2. One other PC2000 or PC500 yes no
3. Modbus network yes no
   If yes: master or slave?
4. L1 network yes no
   If yes, as controller? yes no
5. Dumb terminal, printer, or other device requiring ASCII transmit and receive yes no

Example Usage

User and Problems

User

The user in this case is a sales engineer with novice status. Knowledge of novice status prompts the system to offer assistance with terms. This help is not offered to expert users although they can initiate a request for it.

Problem

The sample system is outlined on the Data Collection Worksheet attached.

Sample Session - Inputs and Outputs

The sample session below is representative of the type of dialog the user and computer would have. If a mouse interface is available then the user would have the ability to click on areas to fill in data and computer could prompt the user to select from a list of choices. It is important to design the system to allow it to run on a system without a mouse if possible since many potential users have older equipment.

Computer: Please key in the number of Digital Inputs in the system.

User: 130

Computer: Please key in the number of Digital Outputs in the system.

User: 93

Computer: Please key in the number of Analog Inputs in the system.

User: 20

Computer: Please key in the number of Analog Outputs in the system.

User: 16

Computer: Do you have more information on system requirements?

User:Yes

Computer:Is battery backup required?

User: Yes

Computer: Is Nonvolatile memory backup required?
(Type help for assistance with nonvolatile memory)

User: Help

Computer: Nonvolatile memory is used to keep a copy of the program in the PLC even if the power goes out. The default choice is yes. Press return for default.
Is nonvolatile memory backup required?

User:(return)

Computer: The default EMPROM memory cartridge will be used.

Computer: This is the input card selection section. Do you wish to specify spares as None(N), Percentage of actual (%), or specific number(#)? (Type help for information on spares.)

User:None

Computer: Do you know the voltage the inputs will be? (Type help for information on input voltage levels.)

User: Yes

Computer: Please enter how many voltage levels there will be.

User: 11

Computer: There are only 4 possible voltage levels.Please enter a number between 1 and 4.

User: 1

Computer: Please enter the first voltage level.

User: 115

Computer: Please enter the number of inputs required at this voltage level.

User: 130

Computer: Quantity 9 of NL-2005 will be used.

[Rule DI6: If Voltage = 115 Then use NL-2005.
Rule DI8: Number of cards =
(If NL-2005 Then Number of inputs/16 rounded up.)]

Please see attached data sheet and rule list for inference used to arrive at output bill of material. Note that, due to the deterministic nature of this knowledge base, the reasoning used is strictly forward chaining, exhaustive search.

The expert user will consider the interactive input of information a waste of time. A table format for data entry for both initial data and data changes would be useful. The interactive validation of the component choice is appropriate for the expert user and can be used as needed.

Example of inference chain to support attached data sheet and Bill of Material:

Item	Description	Part number	Qty
1	CPU	PC 2000-31	1
2	Battery Backup	NLB-2000	1
	Memory Module	NLEP-2516	1
3	Power Supply	NLPS-2707	1
	Fan	NLR-2300	1
	Mounting Hardware	NLR-2301	1
4	Digital Inputs	NL-2005	9
5	Assoc Hardware	NL-2924	2
6	Digital Outputs	NL-2029	1
		NL-2021	6
7	Analog Inputs	NL-2042	2
		NL-2052	8
8	Assoc Hardware	NL-2401	5
		NL-2946	2
		NL-2924	2
9	Com Processor	NLCP-2524	1
10	Com Accessories	NL-2900	1
		NLCI-2502	1
11	Main Rack	NLR-2107	1
12	Accessories	NLIM-2304	1
13	Expansion Racks	NLRE-2009	3
14	Accessories	NLC-2315	3
		NLIM-2306	4

Inference Chains

Examples of inputs directly (one rule) affecting outputs and inputs indirectly affect outputs are shown.

Input	Rule	Output
Block 1	CPU-9	add NLB-2000

If (Battery is required)
Then (add NLB-2000 to bill of material list)

Indirect affects:

Block 3	GIO-3	within bounds don't exit
	DI-6	Use NL-2005

If (voltage = 115) then use NL-2005

	DI-8	Use Qty 9 NL-2005

If (NL-2005)
Then (Number of cards =Numpoints/16 round up)

This number of cards is then used to figure the number of slots

LER2 Number of slots = qty of cards requiring slot space

, which in turn specifies the types and number of racks and cables required (LER3, LER4, LER5, LER6, and LER7).

In order to facilitate use of this knowledge base for troubleshooting the basic components would be given attributes (such as numpoints/card). The inference rules would then act on those attributes. The attributes could then be extended to include troubleshooting information.

Additional output in the form of explanation of choices is also an important part of the output. This system could be implemented in a database program environment but the requirement for demonstrating why the component was chosen in clear English is important.

This output would be generated interactively by the user after the above output had been given. The system would ask the user if any component selection should be justified. The user can then see the chain of logic that led to the component selection. Backward chaining could be used for this since there is only one solution (given the cost tie breaking logic). How this is implemented will be a function of the tool selected.

Example:

Computer: Do you wish to know the reason for any component selection?

User: Yes

Computer: Please key in the part number of interest.

User: PC2000-42

Computer: The following rules and input data were used in selecting the component:

1. Input data specified need for ASCII Interpreter.
2. Rule CPU2:
    IF ASCII Interpreter is needed
    THEN Use PC200-42.

Do you wish to modify the input data?

User:No

Computer: Do you wish to know the reason for any component selection?

User: No

Changing the Input

Once the system has been configured the User will be able to make changes and the system will reconfigure the hardware. Editing the entered input data is necessary as specifications often evolve and optional bids are sometimes required. If the user enters more than one area for change the computer will organize them in the order of most efficient flow.

Computer: Please key in the areas that need changing. If entering more than one number separate with commas.

1. Memory Backup
2. Line Voltage
3. Discrete Inputs
4. Discrete Outputs
5. Relay Requirements
6. Analog Inputs
7. Analog Outputs
8. Communications Requirements

User: 3

Computer: Please key in the number of Digital Inputs in the system.

User: 22

Computer: Please enter the number(s) corresponding to what needs changing. If entering more than one number separate with commas.
1.Voltage levels
2.Quantities

User:1,2

Computer: Please enter how many voltage levels there will be.

User: 3

Computer: Please enter the first voltage level.

User: 115

(Etc.)

Each section of the input data sheet has areas of the knowledge base that it is directly related to and areas that it is indirectly (through the inference chain) related to.

For example:

Data Sheet section Block A.1

Directly affects rules GIO3, DI8, DI9

Indirectly affect:

DI8 affects LER2, LER3, LMR7
DI9 affects CPU4, CPU5, CPU6

Due to the deterministic nature of the knowledge base one could evolve a meta-knowledge about the base knowledge that would cause only rules known to have a potential change in result due to input data changes. Using the example above:

IF (BlockA.1new .NE. BlockA.1old)

THEN (execute rules GIO3, DI8, DI9, LER2, LER3. LMR7, CPU4, CPU5, CPU6)

One could further increase the computation efficiency by maintaining a copy of past outputs from these rules. If the rule output remained unchanged then none of the inferred rules would require re-executing since the results will be unchanged.

A more general form of this would involve searching the rule base for all rules containing reference to the material changed, forming a list of these rules and implementing the list.

The size of the knowledge base and, more importantly, the fact that it would be implemented on a personal computer where storage and RAM memory would be at a premium would suggest that the simpler approach of re-application of all rules that follow any directly affected rule be executed.

This is computationally inefficient but may be a better solution given the small search space and hardware constraints.

The rules for this "brute force" approach would be:

If Block 1 has changed then enter rule base at CPU1 and execute all remaining rules.

If Block 2 has changed then enter rule base at PS1 and execute all remaining rules.

If Block 3 has changed then enter rule base at GIO3 and execute all remaining rules.execute all remaining rules.If

If Block 4 has changed then enter rule base at GIO4 and execute all remaining rules.

If Block 5 has changed then enter rule base at GIO4 and execute all remaining rules.

If Block 6 has changed then enter the rule base at GIO2 and execute all remaining rules.

If Block 7 has changed then enter the rule base at GIO1 and execute all remaining rules.

If Block 8 has changed then enter the rule base at CPUCOM1 and execute all remaining rules.

The subject of meta-knowledge is receiving a great deal of attention. There are many difficulties that are involved with its use. In this case, it is difficult to justify the additional complexity just for re-evaluation of configuration. This is not true of larger systems that require meta-knowledge in order to do the configuration in a reasonable amount of computer time.

There is however, a more compelling reason to add meta-knowledge to the program. This is discussed in the next section on system maintenance.

Knowledge Sharing as an Acquisition and Maintenance Tool

An additional enhancement of the expert's interaction with the system would be the implementation of a Knowledge Sharing System used as a knowledge acquisition tool. This system is new to the technical support group. As they become more experienced they will learn more production rule relationships that should be part of the data base. A Knowledge Sharing System provides a format for the system manager to collect this information in an automated format.

Another way of viewing this is as the semi-automation of knowledge acquisition and knowledge base maintenance. Successful implementation of any software tool requires timely maintenance. In an organization that does not have a staff of people trained in the skills necessary to do this the program will fail, unless the organization can afford to add another employee with the proper skills. Automation of this process makes the tool available to users that are less computer literate. In this respect it is much like the personal computer window interfaces of today. The benefit of the use of the tool must be balanced against the loss of system understanding and flexibility that automation brings.

It is difficult to anticipate rules that should be in the database but here is a "make-believe" example to illustrate what could happen. This example does not reflect actual domain knowledge.

Upon completion of the Bill of Material, the expert user can query the system as to why it selected a particular piece of equipment. The computer can respond with the rules that led to its selection. These rules can be generated from backward chaining or can be kept available using the blackboard approach. Implementation software will probably be the overriding factor in that decision.

Once the reasoning has been shown, the expert may want to ask, "Why not NLCP - 999?". The computer could respond with all the rules that lead to selection of NLCP999 (not a real component) and ask if any of the If-conditions apply. If none apply the computer can query whether the expert user has a new piece of knowledge to be proposed for addition to the knowledge base. If the answer is yes, the computer could provide a list of the areas of knowledge in the knowledge base. (System Topology, communication requirements, I/O general rules, I/O selection, etc.).

The expert could select the area that the new knowledge relates to. For example, in this case, the expert would select communication requirements. The computer would then display the taxonomy of the selected area. In this case:

C: Please select the area you feel the new knowledge is related to:
1. L1 Networks
2. Modbus networks
3. Ascii transmit and receive
4. 2 pc networks
5. number of communication processors
6. new network interface

H: 6

C: You wish to add a rule concerning new networks.
The rule format is :
IF(network type interface required is new network)
THEN (use quantity of cp-xxxx)
Please enter the new network type name:

H: Bailey Net-90

C: The network name entered was Bailey Net-90.
Do you wish to change this?

H: No

C: Please enter the type of Communications processor to be used to interface to the Bailey Net-90:

H: NLCP-999

C: The communications processor entered was NLCP-999.
Do you wish to change this?

H: No

C: Please enter the quantity required to complete the interface:

H: 1

C: The quantity entered was 1.
Do you wish to change this?

H: No

The computer would then implement a search for all likely areas of component rules.

C: I will now search the knowledge base for other rules affected by existing communications processors. Please answer the following questions about the NLCP-999.

C: All other Communication processors must be mounted in slot 1 - 6 of the main processor rack. (Rule COM8 and COM9)Is this true for NLCP-999?

H: Yes

C: All other communication processors required use of the 15A power supply with fan attached.(PS4) Does this rule apply?

H:No.

C: Do you wish to add comments to the request for knowledge base change?

H: yes

C: Please enter comments now.

H: New com processor is due into stock in 4th quarter. Don't add before in stock!! Also this component is being tested for use in ASCII transmit and receive. Test results are due by 1st quarter next year.

C: Your proposed change will be forwarded to system manager for review.

Changes are made by enlarging the areas already included in the organization of the knowledge base. A similar change would be the addition of new components as they became available and the removal of older components that have been obsoleted. Similar types of meta-knowledge rules based on the structure of the knowledge base could be employed.

Adding completely new rules could also be automated with cross-checking for conflicts and loops. This part of the automation procedure becomes extremely difficult in less structured knowledge bases. In the above example I still assume the existence of a system manager who would review the new rule and add completely new rules. This could be done by the developer on a contractual basis.

Expected Benefits

The expected benefits are:

Reduction in time spent by sales and support staff doing repetitive configuration tasks

Increase in consistency and correctness of configurations

Individualized on the job training

Differentiation from Siemens in customer service abilities.

The use of expert system technology to solve this problem is based on the usefulness of the special benefits that derive from this technology. The knowledge base occurs naturally in production rule form.making it easy to implement and maintain with this technology. Future enhancements such as layout and overlapping PLC lines also fit well into the technology. This technology is well suited to users that respond best to conversational interaction. This is the approach they currently use with the human expert. This type of technology automatically addresses the need for training and its ability to explain why it made the decision it did is important for the ability to interactively design a system that best meets the needs of the customer.

Strategic justification is as or more important than the reasons listed above. This industry must find a way to cope with the need for specialized expertise in a cost efficient manner. If one cannot afford the specialists then one must find technological solutions to the problem. The potential for growth of the above expert system into areas enhancing customer service are exceptional. Expert system trouble-shooters can be made part of every system sold. The benefits of communicating to a customer in "plain English", of training, and of always being available are requirements for staying in the control business.

System Development

The development of this system takes place in three parts. The first part of the project will turn the proposal into a working prototype that demonstrates the intended capability and interface mechanisms. The criteria for acceptance will be agreed upon at this stage. The second part will complete the working program and turn it over to a beta test site. The third part of the program will be use and maintenance training the support group responsible for the program.

The first portion of the project would require the following personnel:

1. System Engineer - full time 3 months

2. Programmer - 1 month

3. PC 2000 Expert - 2 months 20% time as consultant
   The time is short here because much information is already available.

The prototype will then be demonstrated to the expert and to typical users for evaluation and feedback.

The second portion of the project is the final programming of the working model. This will require further knowledge acquisition, revised interface requirements, and programming.

Once the program is complete, the beta testing site (Greentree) will be trained on the program and its use will determine any further clarification of knowledge or interface.

Training for use and maintenance will be done for 1 week upon completion of acceptance tests.

The following personnel will be needed:

1. Systems Engineer - Full time for 3 months

2. Programmer - Full time for 3 months

3. Expert and Users - 20 % time for 1 month