ABSTRACT

DEVELOPMENT OF AN EXPERT SYSTEM TO FACILITATE A PUMP MANUFACTURING/WAREHOUSE FACILITY

by
Muhammad M. Ghauri

The objective of this study is to evaluate the effectiveness of utilizing an expert system technology as it relates to manufacturing. It appears that our industries are still uncertain about this technology. In the first phase of this study, procedure for deployment of this technology is discussed. Secondly a knowledge-based expert system is developed, using a VP-Expert microcomputer shell. The system is made of three modules, inventory module, cost analysis module, and decision making module (for the selection of pumps).

A warehouse was selected for the analysis, which carries the finished product in the form of pumps. The quantities and parameters of the pump are maintained in the two database files.

The system is user friendly and most of the data required for maintaining inventory and cost calculation is retrievable from the database files and the user is asked to input very little information.

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by
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DEVELOPMENT OF AN EXPERT SYSTEM TO FACILITATE A PUMP MANUFACTURING/WAREHOUSE FACILITY

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This thesis is dedicated with love ...
to my parents and sister Farah

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CHAPTER 1

INTRODUCTION

Over the past decade, the field of artificial intelligence has had many important advancements. The most important of these has been the realization that " in the knowledge lies the power". This realization lead to the development of new computer systems known as "expert or knowledge-based systems". The newly developed rule-based expert systems are designed to solve problems by applying factual knowledge of specific areas of expertise. The effectiveness of knowledge-based system can be felt having system which diagnose disease, configure computer systems, and understand natural language. This success in the field of artificial intelligence is the result of the combined efforts of human experts and system developers.

The potential of knowledge engineering is emerging in all over the world and will have an impact on all areas of human activity where knowledge provides the power for solving important problems.

1.1 What is an Expert System ?

An expert system is traditionally defined as sophisticated computer programs that manipulate knowledge to solve problems efficiently and effectively in a narrow problem area. These system use symbolic logic and heuristics to find solutions.

The system is stored in IF-THEN rules and the acquired information is provided to user who is seeking advice. Expert knowledge is source of power for a knowledge based system which is coded into facts, rules, heuristic, and procedure. Expert system simulates an expert thinking by merging facts and heuristics and thus strengthen human knowledge via computer power, in solving problems. In addition the capacity of expert system to deal with challenging real world problem distinguishes it from traditional computer applications through the application of processes that reflects human judgment and intuition.

One of the advancements of the knowledge engineering is that expert systems are showing up as software applications in large software systems. With the introduction of embedded heuristics in many commercial packages (that constitute expert system components of the packages), it has been proved that this new technology is now really paying off, and even some operating systems now contain embedded expert system to provide systems monitoring and troubleshooting.

1.2 Expert Systems and Engineering Problems

The emergence of expert system technology is playing a vital role in solving many decision related problems encountered in business and every engineering field. It has been observed that expert system technology have become one of major tool and choice for technical community to compete in the global market.

Most of the companies are using expert systems as a major tool in inventory control, diagnose processes breakdown, scheduling operations, machine routine maintenance, troubleshoot equipments, process control and production control etc. The expert technology is proving as a drastic decision improvement and problem solving tool for most of the major companies and this was made possible by the integrated efforts of human experts and system developers.

1.3 Internal Structure of Expert System

Computer can retrieve and effectively use heuristic knowledge by format which distinguishes between data, knowledge and control structure. Hence an expert system can be organized around the following structure.

- Knowledge Base
- Working Memory
- Inference Engine

1.3.1 Knowledge Base

A knowledge base plays a role of nucleus for the expert system structure. It is actually a software program that contains solving rules, methods and data relevant to the problem domain.

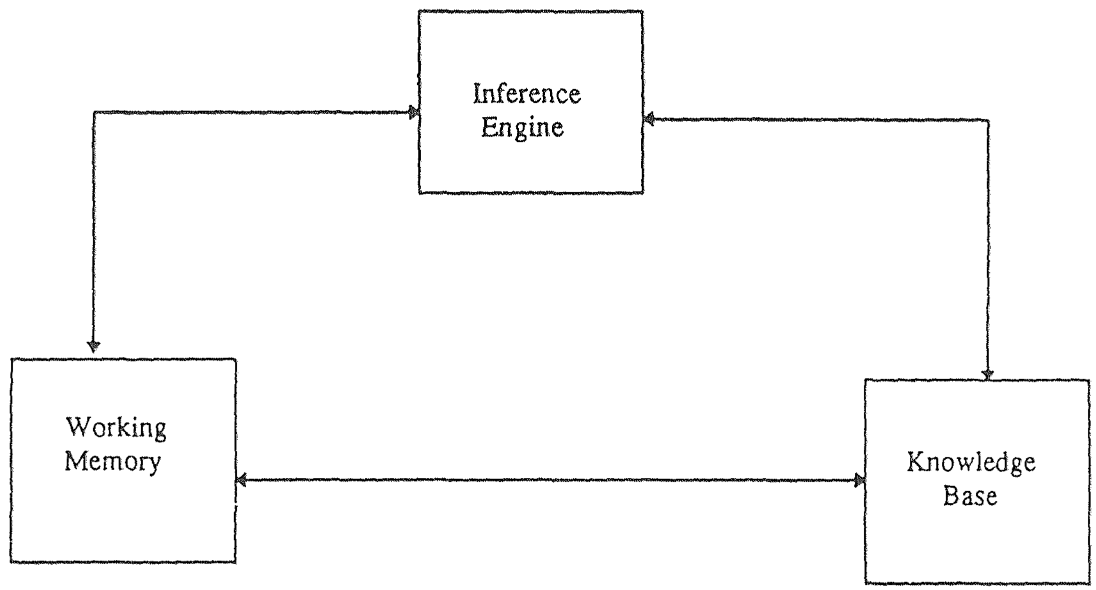


Figure 1. Expert System Organization and Structure

All the information given by real human expert is translated into rules and strategies by knowledge engineers thus creating a knowledge base. The knowledge involve represent the rule of thumb, educated guesses based on experience and expert's good judgment.

1.3.2 Working Memory

The working memory represent the data structure of the problem being solved, this data structure changes as per condition requirement of the problem and kept updated. It is the most dynamic part of an expert system.

1.3.3 Inference Engine

The inference engine is the most control mechanism that organize the problem data structure and searches through the knowledge base for application rules. An inference engine is composed of an interpreter and a scheduler.

Knowledge engineering has wide area applications, such as interpretation, prediction, control, instruction, repair, design, planning, monitoring, debugging. Such a system is based on two major components the inference mechanism and knowledge base, the first one deals with the problem solving component and the second deals with the number of knowledge bases.

The implementation of an expert system is good in situation where it promises greatest potential for success. For example where repeated processes have to be performed

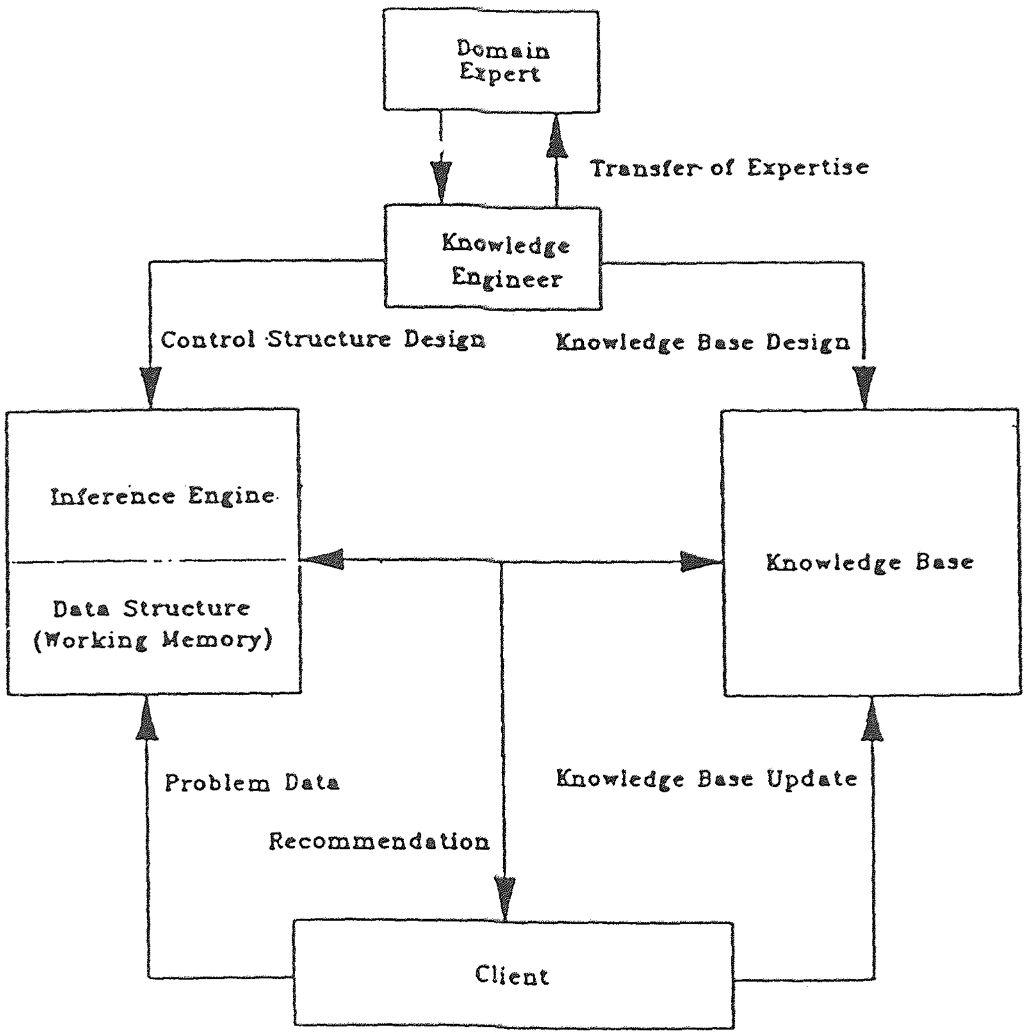


Figure 2. Functional Integration of Expert System

such that if management requires the answer of the same problem every day, week, or in a given time sequence to make any decision. These situation also includes strategic requirement, tactical necessity, time saving, economical consideration or conflicts avoidance.

1.4 Building an Expert System

An expert system can be developed by performing following activities

- Decompose the problem in as many parts as possible
- Reconstructing the problem into computer compatible languages
- Inserting the problem into the computer

Expert systems are 100% effective in subtle areas of improvement such as inventory control, more accurate decisions, better resource utilization, better product, effective service delivery, reduction in rejected product and better machine time for productive use.

An expert system is assumed to be successful if it is accomplishing all the requirements for those it was designed and giving the desired results which are acceptable to user.

CHAPTER 2

ARTIFICIAL INTELLIGENCE AND INDUSTRIES

2.1 Importance of Expert System in Industries

Expert systems are playing an important role in industries and providing support for decision makers such as managers, designers, maintenance personnel and operators. The expert system program will be different for each of these application since the task involved will comprise different knowledge sources and structure. The basic difference between the tasks is theoretical knowledge and practical knowledge. The theoretical knowledge is used by designers and maintenance whereas the practical knowledge is used by operators.

2.1.1 Design of Knowledge-Base System

It is believed that different knowledge base are designed for design activity since there are different types of design activities such as computer aided design to floor layout.

The knowledge base system for designers and personnel management can be build by utilizing the knowledge sources such as reference literature, technical support material, handbooks, and special requirement. The one good aspect of knowledge base design system is that it has no time constraint.

2.1.2 How to Make Expert System Technology Successful in Industry

To make an expert system technology successful in industry, it is important to know that how it works in terms of system operation. It provides support to all processes which are being performed in parallel on the industrial floor such a flexible automation and machining and may provide support for operators, fault diagnosis, future predictions, and results. Hence this technology is time critical and challenging to implement in industry. To develop these knowledge base number of knowledge sources are required such as working conditions and implementation procedures.

An expert system for predicting the consequence of technical failure requir not only engineering knowledge for procedural support, diagnosis and heuristic control modules but also require operational knowledge and engineering knowledge both.

2.1.3 Recognizing the Objectives

To develop the knowledge base system it is important to identify the goal, functionalities and their interdependencies at the initial stage. It should be noted that knowledge base system can not implemented in all industrial requirements. For instance existing numerical supervision and control system are based upon thorough engineering methodologies and its replacement by expert technology will considerably drop the performance graph.

It must also be noted that acquiring knowledge and conceptualization for industrial applications is much more difficult than an ordinary application because of the complex industrial requirements and it may take years to develop full process.

2.2 Knowledge Acquisition

The knowledge acquisition can be divided into two classes, elicitation and machine induction. It is generally believed that there is a continuum between human-human elicitation and automatic induction.

2.2.1 Principles for Knowledge Acquisition

There are three principles for knowledge acquisition.

- In order to capture important domain concept defined by the expert, task level should be designed. This principle based on separating out acquisition from implementation for describing information, hypothesis, relations and actions, in the domain expert language these task levels primitives must be naturally constructed.
- For procedural descriptions explicit declarative representational primitives are most appropriate as the most expert more easily understand the declarative representations. Formulating procedural aspects in this way can facilitate acquisition explanation and maintenance.

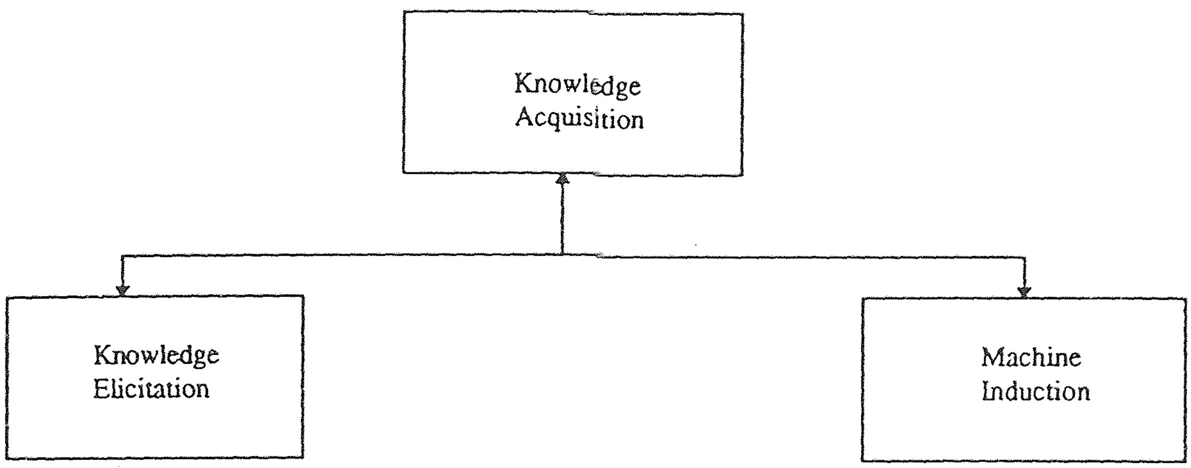


Figure 3. Relationship between Knowledge Engineering Terms

- The third principle says that representation should be at the same level of generalization as the expert knowledge. The main idea of this principle is that an expert should not be forced to generalize unless it is when absolutely necessary and they should not be asked to specify information not available to them. To classify a process variable as high, medium and low there would be an example of oversimplified generalization, when an expert need to differentiate between many more steps and or even a full range of numbers.

2.2.2 Techniques for Knowledge Elicitation

The techniques for knowledge elicitation involve the collection of information from the domain expert either explicitly or implicitly. The following are the techniques now being used.

- Interviews
- Questionaires and rating scale
- Observations
- Protocol analysis
- Teachback interview
- Walkthrough
- Time lines
- Formal techniques

It is generally believed that knowledge elicitation methodologies have more in common with the field work orientation anthropology and qualitative sociology than with the experimental orientation of many in the cognitive sciences. It is also believed that knowledge engineers use the literature, experience and data gathering methods such as face to face interviewing etc.

For interviewing, knowledge elicitation has some drawbacks such as obtaining data verses related to the expert as a person, fear of silence and failure in listening, difficulty in asking questions and interviewing without a record. Conceptual problems, such as, treating interviewing methodology as unproblematic or blaming the expert are also the drawbacks for interviewing techniques. There are two types of interview

- structured interview
- unstructured interview

In a structured interview, the knowledge engineer acts as a control. Such interviews are useful for obtaining an overall sense of the domain.

In an unstructured interview, the domain expert is usually in control; but one problem is that the results are inconsistent collection of domain knowledge which needs to be analyzed and conceptualized. It is helpful for the knowledge engineers to have some prior knowledge of domain through books, technical data, manuals and other sources, before meeting an expert.

Questionnaires can be used by itself or in addition to an interview. An interview can be structured around question-answer methodologies or questionnaires can be applied in a more formal way. It is suggested that questionnaires should be handled in such a way that a atmosphere of confidence could be built without bothering the expert in actual work environment.

Rating scale techniques are used for evaluating single item of interest by asking to expert to cross-mark a scale. As a reference for an expert, scales such as very low to very high or very simple to very difficult are used. The construction, use and evaluation of rating scales is described very well in the psychological and social science literature. Rating scales can be used in combination with interviews and questionnaires.

Another technique used for knowledge elicitation are observation. A feature of this technique is that it involve no or very little participation of the expert. Knowledge engineer is completely responsible for making all the recordings of actions and activities by observing an expert as accurate as possible. An appropriate blend of interviews and observations technique is called "observation interview". A series of activities are observed and questions about causes, reasons and consequences are asked by the knowledge engineer during these observations. The combined technique is very powerful because the sequences of activities can be observed. In addition decision criteria, rules, plans, etc are elicited in addition through what, how, and why questions.

Protocol analysis are useful for obtaining detailed knowledge. It is composed of verbal protocol and motor protocol. In verbal protocol an expert thinks aloud while carrying out the task, and a time-stamped recording is made out of his pronunciation. In motor protocol, the physical performance of the expert is observed and recorded often on a video tape. An example of motor protocol is eye movement. However they are useful when used in conjunction with verbal protocols.

In verbal protocol, an expert should not be allowed to include retrospective utterance. An expert should be conscious of theorizing their behavior and should report all the information and intentions within the current boundary of conscious awareness. The verbal protocol technique is broken down into short lines corresponding roughly to meaningful phrases. The verbal technique can collect the basic objects and relations in the domain and establish casual relationships. From these results a domain model can be built.

It is important to note here that any proposed expert system technology should not be allowed when using the transcribed method.

The teachback technique belongs to the interview family. In this technique knowledge engineer teaches back an expert the whole procedure which he has already explained to him, until the expert is satisfied.

The walkthrough technique is more powerful than protocol analysis. It performs each and every analysis in an actual environment which gives the better memory cues. This technique can also used in a simulated environment, where more questions can be asked.

The time lines technique uses tables which are composed of columns carrying the several items of knowledge. It is important to mention here that left column must be filled with time of occurrence of important events such as failures or operator actions. The information about the times is recorded in different columns (such as behavior of technical process, the automatic system and human operators) based on how much information required.

2.2.3 Machine Induction

Machine Induction is another broad technique for knowledge acquisition based on heuristics for generalizing data types, candidate elimination algorithms, methods for generating decision trees, rules sets, induction function and procedure synthesis. For describing such techniques a structure has been developed to abate an evaluation of the usefulness of any technique to particular engineering problems.

The inductive approach depend on the fact that though an expert does not understand their own reasoning mechanism but they would be able to supply enough examples to make the problem understandable. These examples are analyzed by an inductive algorithm and rules are generated automatically by using these examples.

It is a fact that experts develop the procedures based on assumptions and beliefs which they do not clearly define and as a consequence get surprised when results are pointed out. This whole situation reveals that expert are having problems in defining the pros and cons of the problem.

The inductive approach technique requires an expert to use a checking process to make sure that the rules designed were valid or not. This is because of the fact that rules are based upon a set of examples and the inductive algorithms. It is a common practice to get knowledge base refined by the domain expert through the induction process.

2.2.4 Guidelines for Using Inductive Techniques

- The inductive technique is useful where documented examples can be obtained easily, but not in the situation where unpredictable observations drives the system.
- There is no explanation for the rules developed. All output must be examined critically.
- The process assume that the example set is complete and current.
- Result should not be sensitive to small changes in the training set.

- The technique is consistent, unbiased and is suitable for domains where rules form a major part of knowledge representation.
- Induction provides the knowledge engineer with question, results and hypothesis which forms a basis for consulting an expert.

This is very helpful under the situation where data is available for the process but the rules are not known. Hence the induction can be used in industrial plants where great collection of data is available in order to induce the rules for its operation. Once the rules are known the process can often be optimized.

It has been found that inductive technique is very useful for diagnosing plant disease, symbolic integration, improved debt collection, weather forecast, predicting the behavior of chemical compounds, and designing gas oil separators.

Another interesting use of inductive techniques which will have a wide application in industrial control is its use in conjunction with a qualitative model of the process. This was first carried out in the analysis of electro-cardiograms. A qualitative model of the domain is built. Then, components are failed and the consequence on measurable parameters are determined for this failure. The process is repeated for each component and this build up a complete set of examples of failure. The examples are used as an input to the algorithm and the rules governing the failure are induced. These form a basis for a diagnostic expert system.

2.3 Knowledge Acquisition Tasks

Knowledge acquisition tasks are described as bottom-up or top-down. The basic assumption about bottom-up approach is that an expert system is based upon a large body of domain specific knowledge and that there are few general principles underlying the organization of the domain knowledge in an expert's mind. It should be noted that existence of underlying principles and casual relationships may be an indication that expert knowledge is more domain independent. The bottom-up basic aim is to prise data and concepts out of the expert and then iteratively refine it.

Hayes-Roth et al. (1983) claims that the building of an expert system is inherently experimental and is therefore characterized by rapid prototyping which is essentially a bottom-up process.

The reason to support the top-down alternative is that there is a crucial step missing in the prototyping approach between the identification of the relevant characteristics of the domain and selection of solution methods. This can be interpretation of the data into some coherent framework, a model schema or canonical form.

2.4 Levels of knowledge Analysis

There are five levels of knowledge analysis usually recommended

- Identification
- Conceptualization
- Formalization
- Testing
- Implementation

The development of these ideas in knowledge acquisition methodology is called KADS (Knowledge Acquisition and Documentation Structuring).

One of the feature of the KADS is that it support both top-down and bottom-down approaches. The bottom-up approach is supported by a hypertext protocol editor and hierarchies are developed and manipulated by a context editor whereas top-down is supported by a set of interpretation models each describing the meta-level structure of a generic task.

The KADS structure is based upon the following principles

- expert problem solving should be expressed as epistemologies knowledge.
- the analysis should be model driven as early as possible
- before the design and implementation formalism, knowledge and expertise should be analyzed.
- all collected data and interpretations should be documented.

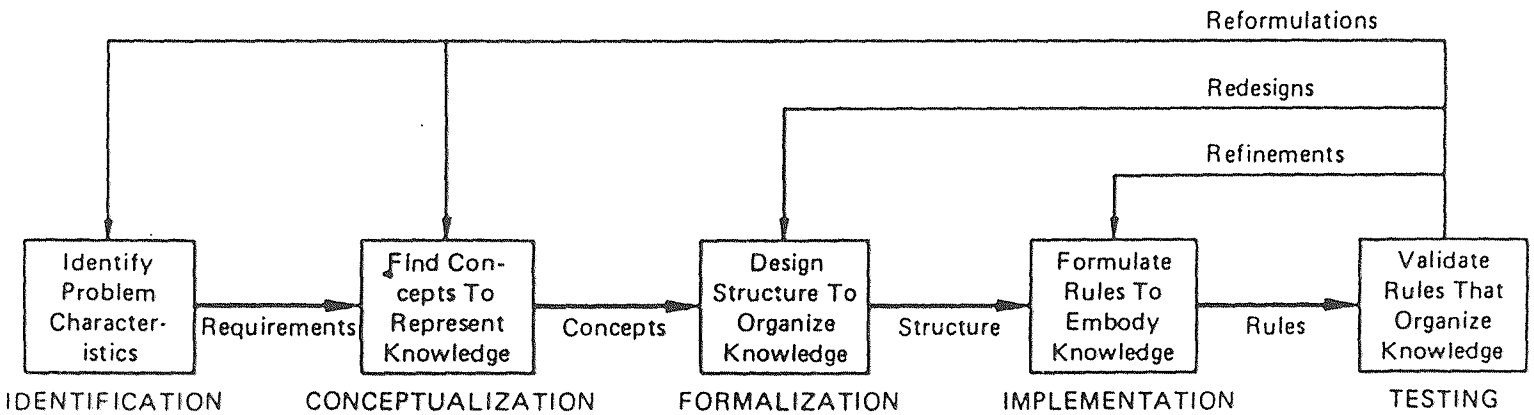


Figure 4. Levels of Knowledge Analysis

- new data should only be elicited when previous data has been analyzed
- the analysis should be breadth-first allowing incremental refinement

To produce a four layer model of expertise (Hayward et al., 1988) following steps are require.

- definition of the domain concept and their static relationships
- definition of relations arising in a task context which are concerned with dynamics and are expressed in the interference structure
- specification of how the available inferences can be used to undertake a particular task
- definition of how the task level may be controlled.

This is the least developed part of the model.

2.5 Multiphase Approach for Task Analysis

This approach basically deals with the controlled experiments designed to reveal the knowledge and processing strategies utilized by domain practioners, from initial informal interview techniques, to more structured knowledge elicitation technique.

The first phase develop the basic structure for further analysis. It is important that for specific rules get an expert to provide an overview. Once the semantics of the application have been developed more structure techniques can be used.

The second phase emphasize on observation and analysis of actual task performance in order to see that how the practioners perform their task. The techniques involved in performing these tasks involve, critical incident review, discussion of past challenges, or the construction of test cases on which to observe the expert at work.

In the third phase the practioners give the verbal explanation over the problem solving strategies of the expert, observed under the control conditions. It should be noted that the task can be deliberately manipulated, for instance, by forcing the expert to go beyond reasonably routine procedures. It is common practice that either an expert control the information gathering or an observer. The information provided by the expert includes data on the diagnostic search process and the information provide by the observer includes analytical report on expert interpretations. Another important technique is to isolate what factors really account for superior performance so as compare the performance of the experts with different levels of expertise.

2.6 Tools for Knowledge Acquisition

A large number of tools have been developed for knowledge acquisition process. The general idea to develop all these tools is to achieve less number of iterations for the knowledge acquisition process by bridging the gap between the problem domain and the implementation. The function of some of the tools are as follows

KRITON; support the idea of bottom-up knowledge acquisition. It has pre-stored set of procedures such as interview, incremental text analysis, and protocol analysis. Repertory grids are used to pull out declarative knowledge. An intermediate knowledge representation system is suggested for supporting the knowledge elicitation techniques. The knowledge presentation technique involves a propositional calculus for representing transformation during the problem solving process and a descriptive language for functional and physical objects. This is then translated semi-automatically into the run time system but this commit the knowledge engineer to a particular representation.

KEATS-1; provide a cross reference editing facility (CREF) and a graphical interface system (GIS), to support data analysis and domain conceptualization. CREF organizes the verbal organize text into segment and collection and GIS allows the knowledge engineer to draw and manipulate domain representations on a sketch pad. In KEATS-2, these have been replaced by ACQUIST, a hypertext application for structuring the knowledge from the raw text data. ACQUIST provides a support for both the bottom-up and top-down approaches. One of the feature of this tool is that the knowledge engineer uses predefined abstract model to guide the knowledge acquisition process. It has been observed that the use of these models can dramatically improve the knowledge acquisition process. In this approach fragment from the data are collected around concepts, concepts are factored into groups, and groups into meta-groups. Links can then be defined between any of these entities. The emerging structure is displayed graphically. The coding sheet is a set of hypertext cards.

CHAPTER 3

INFLUENCE DIAGRAM A TOOL FOR DEVELOPING AN EXPERT SYSTEM

3.1 Analysis of Decision System

Decision analysis is a concentration that permits the decision makers to analyze complex, dynamic, and uncertain decision problem. The main feature of the system is that it facilitate a structure and the principles which are helpful for decision makers in focusing their attention on the problem that are most relevant to the decision being made. The power of decision analysis lies in its ability to effectively interact the many factors that commonly effect a decision. Such an integrating capacity makes decision analysis a very successful means of facilitating the decision making process. Two criticism of decision analysis are that the amount of efforts and time spent on modeling a problem are is too burdensome and the resulting model is applicable to only one specific problem. Thus, it would be useful that the information learned in one decision problem is utilized in other similar type problems.

All this effort is being done to reduce the margin of uncertainity under uncertain condition, as decisions results in certain consequence. As for example we can consider the theory of individual consumer, who choose a particular consumption bundle. Thus, it is proved that under uncertainty the consequences of a particular decision are not known until the uncertainty is resolved by the passage of time. Decision making under uncertainty involves taking account for all the possible consequences of our actions. The ultimate level of utility we achieve will not only depend on the decisions we make but also on the way in which uncertainty is resolved.

The greatest breakthrough of the last decade is the advancement in the field of artificial intelligence. Now this technology has become a worthwhile tool in solving decision making problems, which can be thought as an expert system. As it referred to as a knowledge-based decision system (KBDS) or intelligent decision system (IDS). It provides with a substantial amount of domain-specific knowledge to user. Therefore, a knowledge-based decision system provides a means for decision makers to take advantage of this rule-based technology in a relatively simple and inexpensive way.

3.2 Influence Diagram for Decision Analysis

An influence diagram is a data structure that can be used in solving the decision problems. Therefore influence diagram work as a natural representation of knowledge-based decision system. Influence diagrams are useful tool for decision analysis as the variables of decision process and their relations are displayed graphically. The development of an influence diagram is a direct result of the need to communicate with computers about the structure of the decision problems. It is important to mention here that part of knowledge-base helps in structuring the influence diagram for the given decision problem. The knowledge base, together with a powerful facility for manipulating and evaluating influence diagrams, constitute a knowledge base decision system. The following are some of the examples of decision systems which are using influence diagram as a tool

RACHEL, is an intelligent decision making tool that helps to infertile couples and their physicians in selecting a alternative medical treatments for infertility. Rachel guides users through dialogue that eventually creates a tailored influence diagram reflecting patient's decision problems and outcome preferences. One of the drawback of Rachel is that its user interface is character based and does not graphically displays the current influence diagram to the user. To overcome this problem another system based on the Rachel, VESPER was designed. The system was capable to draw graphically the influence diagram at any point in time. One of the problems with the VESPER is that it uses goal directed reasoning process, therefore if the goal is not known the system can not be used.

This research develops a methodology for the design and implementation of a knowledge-based decision system. As a prototype, KIDS was developed using Hypertalk on the Macintosh. HyperTalk, the language in HyperCard, offers object oriented programming, inheritance and properties and message-driven programming. KIDS was used as a raw material buyer decision tool, to decide an importing country and an importing volume of each raw material. As the raw material are of different types and contracts are made with diverse business connections, slightly different decision problems of a similar domain are repeated. The decision analysis class of this type can be effectively solved in a knowledge-based decision system.

- KIDS can solve specific decision problem as well as other similar type of problems.
- The HyperCard environment supplies many user friendly facilities, such as graphics, buttons, fields, cards, and stacks.
- KIDS uses an influence diagram as a representation language of decision problem. A rule-typed domain specific knowledge is used to build or modify an influence diagram.
- The decision making through KIDS needs not to follow given problem-solving procedure, because it can be implemented on an objected oriented based program, not as a flow program.
- One of the features of the of the KIDS is that if the decision maker is not satisfied with the model, it can always be modified, because of the fact that it provides a reason why the model was constructed.
- If the model is changes, the knowledge acquisition process is also performed.

- KIDS increase the acceptance of decision analysis as a useful tool, because it decrease the amount of time the decision maker spends in formulating and analyzing decision problem.

3.3 Computer Based Decision System

knowledge engineering and decision analysis share a common interest in developing knowledge-based decision systems. Decision analysis has developed several systems to automate parts of the decision analysis process. Similarly many expert system have provided their users with recommendations for various actions. The important advantage of the expert system approach is an attempt to make right decision under uncertain situations. The advantages of the decision analysis arise from its clear separation of domain knowledge obtained from an expert and its general methods for inference under uncertainty. It would be important to note here that inspite of much efforts from knowledge engineers and decision analyst, evolving a complete structure of decision system which can assist decision makers in all circumstances of decision making process is not achieved. This consequence of all these efforts is because of the lack of interaction between knowledge engineers and decision analyst. Another drawback of the decision-analysis approach is the quantity of numerical judgments needed for processing the probabilities.

The concept of analyzing a class of decision is an attractive and natural way to merge decision analysis and knowledge engineering. Knowledge-based decision system were developed to implement decision analysis to work on similar sort of problems. The knowledge-based decision system was developed to represent the knowledge of decision analyst and one or more experts in the decision domain. This knowledge-based together with powerful decision models constitutes a knowledge-based decision system.

3.3.1 Advantages of Knowledge-Based Decision System

There are three advantages of knowledge-based decision systems

- normative power
- ease of representation and use of uncertainty
- clarity in the knowledge acquisition process

One of the main features of the knowledge-based decision system is that it performs great in decision contexts where references and circumstances are complex, dynamic and uncertain.

3.4 Use of Influence Diagram in Decision Systems

In the decision science variety of representation for the decision basis have been developed. The components of decision basis represent the alternatives, states, preferences, and relationships in decision situations. For the decision problem, decision tree is the best language representation which is consist of nodes and branches. The drawback of a decision tree is that the formulation of uncertain decision problems is usually a combinatorially explosive task, which accounts for complex and sometime subtle relations between model elements. From a technical standpoint, decision tree often do not allow independence relation to be exploited.

Influence diagram are useful tools for decision analysis and a graphical representation language represents decision basis. It uses decision, chance and value nodes to represent variables and influence between them. The graphical representation consist of nodes and arcs. One of the main advantage of influence diagram is that it gives a clear understanding by graphically representing the variables of a decision problem and relationship or influences between these variables. When the influences are perfectly used, influence diagram focus decision makers attentions on only those parts of the problems which are currently relevant to the task. In the construction of influence diagram, the irrelevant information should be excluded to save the decision maker time as there will be fewer number of variables to be interpreted.

3.4.1 Structure of Influence Diagram

The structure of influence diagram can be understood by the figure 5. In this diagram decision maker is the one who

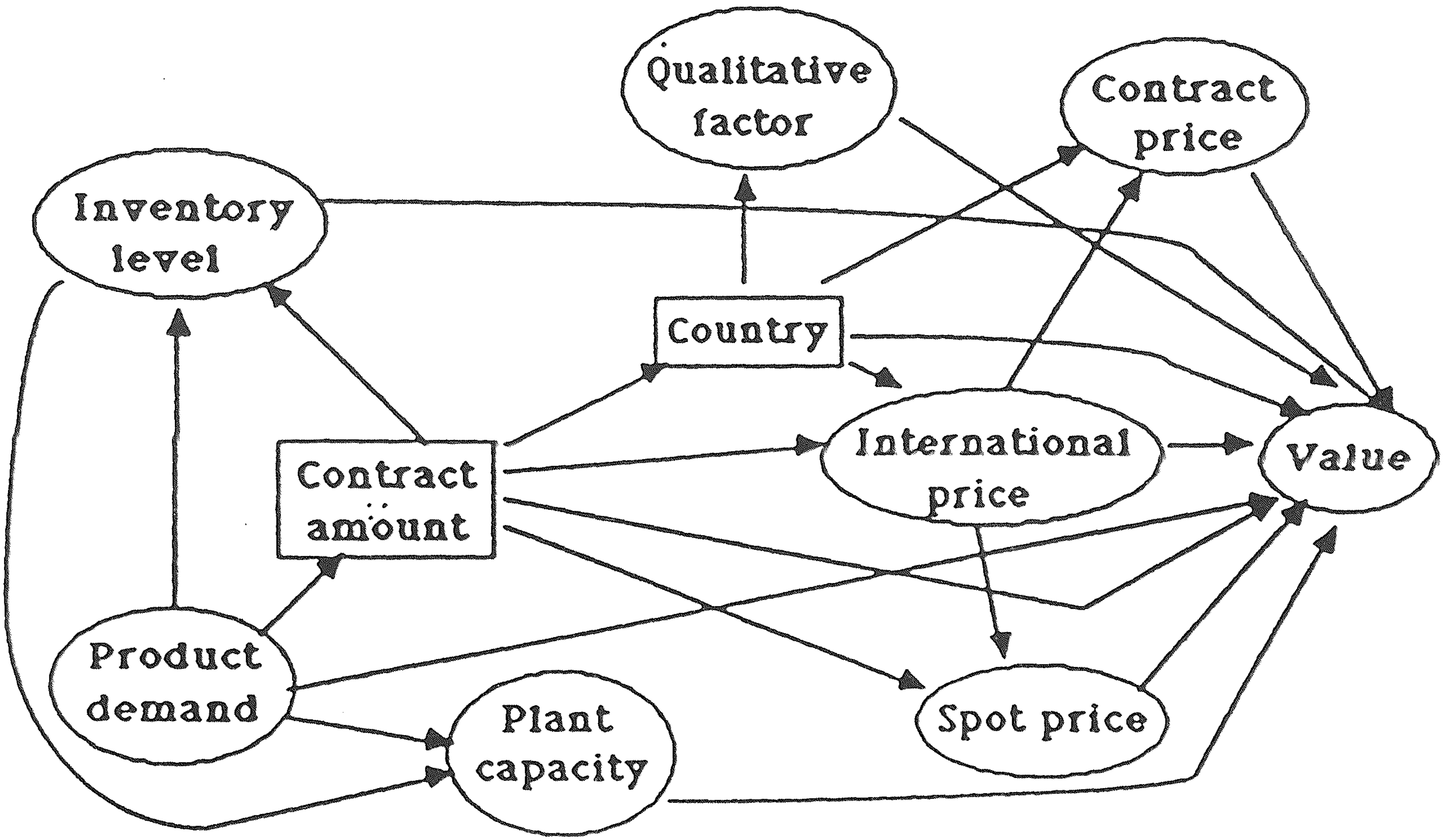


Figure 5. Influence Diagram for an Expert System

decide about the import volume of the next period and an importing country to buy a raw material of ethylene glycol.

In this figure country and contract amount are decision nodes. Decision nodes represent decision options that are available to a decision maker. The arcs of a decision node represent information available at the time the decision is made. Each decision node denotes variable under the control of decision maker. It has branches to represent the possible decisions.

Each chance node has an underlying probability distribution to quantify the uncertainty for the variable that node represents. Arcs into chance nodes represent information effecting the probability distribution for that node. Chance nodes are generally represented as a cycle or an oval in influence diagrams. In figure 5 "contract price" is an example of chance node.

Value" is a value node. It summarizes the preferences of the decision maker for the decision outcome. A mathematical function associated with this node calculate a numeric value representing the trade-offs among attributes of the problem. Direct predecessor nodes of a value node indicate attributes included in the evaluation of the preference. The value function or utility function is constructed by the domain expert reflecting the decision maker's preferences.

It would be interesting to note here that, when a decision maker modify value of a certain node, the corresponding values of the influence nodes are changed automatically. As each node in the influence diagram is made of buttons, the decision maker can click a certain node with a mouse to see branches constituting the node. When each value and uncertainty of chance is updated, the value of a value node are also updated.

CHAPTER 4

TECHNIQUES TO DEVELOP AN EXPERT SYSTEM FOR INDUSTRIES

4.1 Introduction

Expert system is relatively a new technology that can have a great impact on the advancement of productivity and improved quality. Expert system can play a vital role in the solution of industrial decision making problems and can provide them with a competitive edge. Expert systems appear in many forms, sizes, and structures. They can be integrated with other computer based information systems or they can stand alone. The first problem in the implementation of this technology in industrial environment is, when and how to introduce this technology in an organization. The foremost problem with the expert system is its developmental cost and unsure rate of success. It has been observed that if the organization is provided with some sort of guidance, planning or strategy, the success rate of this technology is very promising.

On the other hand it is necessary to identify the potential application of this technology in an industrial environment. To identify the potential applications someone in the company will play a champions role within the organization who understand this technology. Champion would be able to present the technology within the various departments of the company. The presentation will be based on the fact that how this technology can benefit the people in terms of their decision making, time and cost reduction.

Other objective of this introduction is to make operational people motivated to make use of this new technology. Specially in the field of manufacturing where people are encountered with many immediate problems. The major problem for the operation people is to visualize the technology that how it would be able to work in urgency.

To overcome this problem champion need to learn user operational activities and then relate these activities in the form of an expert system. Another way to conveyance the user is to describe how the other competing firms benefiting from this technology which is definitely very effective way or explain the potential areas of expert system technology which are similar to the user activities.

One important point to note here is that champion should be a person who firmly believe that expert system can really benefit an organization and willing to know its application for the end user. It is also the responsibility of the champion to relate the application domain to expert system technology, understand requirement of the user and how to approach them about working on an expert system. It is also assumed that champion has very good relationship with the users and they respect the suggestion of the champion so that the implementation of expert system become easier.

4.2 Identifying Application of an Expert System

To achieve the greatest success and reduce the failure, the potential applications of an expert system should be identified. The following should be the objective of an expert system

4.2.1 Goal of an Expert System

- To provide answers to a problem when an expert is not available and to reduce the demand on an expert.
- Increase the accuracy of a job by examining many alternatives.
- To reduce the time needed to achieve a task.
- To train the inexperience and new employes.
- To reduce the cost of project by using expert system as a decision making tool.

Beside these objectives, there are also some reasons to introduce the expert system technology in industrial environment. These may be called strategic objectives since the ultimate pay-off is indirect and usually long term.

4.2.2 Objective of an Expert System

- To demonstrate that how effective the expert system technology is in the industrial environment.
- To achieve a competitive edge in the global market by introducing high technology.
- To base the foundation of expert system in an industry for future.

- To relieve the dependence on an human expert.
- To reduce the impact of an expert through retirement, job transfer and leaving the company.

4.2.3 Getting Out of an Objective

The identification of each objective used in two ways, one is to determine the value of doing the application and the second will be to focus the development work such that the objectives are meet.

One important point to observe is that what is the extent of benefit of each application. The main goal of this assessment should be to reduced to only quantitative benefit for most of the objectives. The number obtained after financial gain of improvement can be used to justify the development costs and to assess which applications provide the largest impact on the organization. It should also be evaluated that the non-quantitative benefits to the organization are useful or not. The sale of this type of application is based on long-term impact.

4.2.4 Priorities for Selecting a Project

When defining the goal of the project for the selected application, two criteria must be met

- The length of the project must not exceed to the developer capability to reduce the failure risk.
- The expert system designe must solve the problem of the user.

It is advisable to solve the part of the problem first, to overcome the problem of project length and complexity. The advantage of doing like this is that it narrow the breadth of the problem but contain the full depth of knowledge for the selected part. On the other hand the solution of this part of the problem works as a model for the entire project. It shows that how successful and beneficial could be using of knowledge-based system in solving everyday decision making problem in the industrial environment.

Among the other priorities which should be considered when selecting a project is the project visibility. If the potential of the project is highly visible, then there are great chances that the technology would have a great impact on the overall industrial environment. However it should be kept in mind that the first project may have less success because of the pitfall encountered during the developmental process of the knowledge-based system.

The success of this new technology also depends on the attitude of the user organization. The willingness of this group to accept the new technology will impact greatly on the success of the project. Another factor toward the success of the project is the availability and participation of an expert. It is advisable to get the commitment of an expert before starting the project to avoid any uncertain circumstances.

When building an expert system, the efforts needed to maintain the system must be considered in order to update the system as the requirement arise.

4.3 Construction Plan of an Expert System

The construction of an expert system should be based on the following steps.

- Feasibility report
- Development techniques
- Commitments to the project
- Financing

4.3.1 Feasibility Report

The feasibility of the project must be checked in the development phase. The main result required in the feasibility report are based on the facts that how much project is practically successful and does it provide a useful solution of the problem or not. If these two objectives are not met the efforts must be stopped toward further developments. It is difficult to judge the success chances of an expert system at an early stage but an effort must be made. The best way to achieve these results is to hire an expert at an initial stage who can monitor the whole process from the start. After that a small model expert

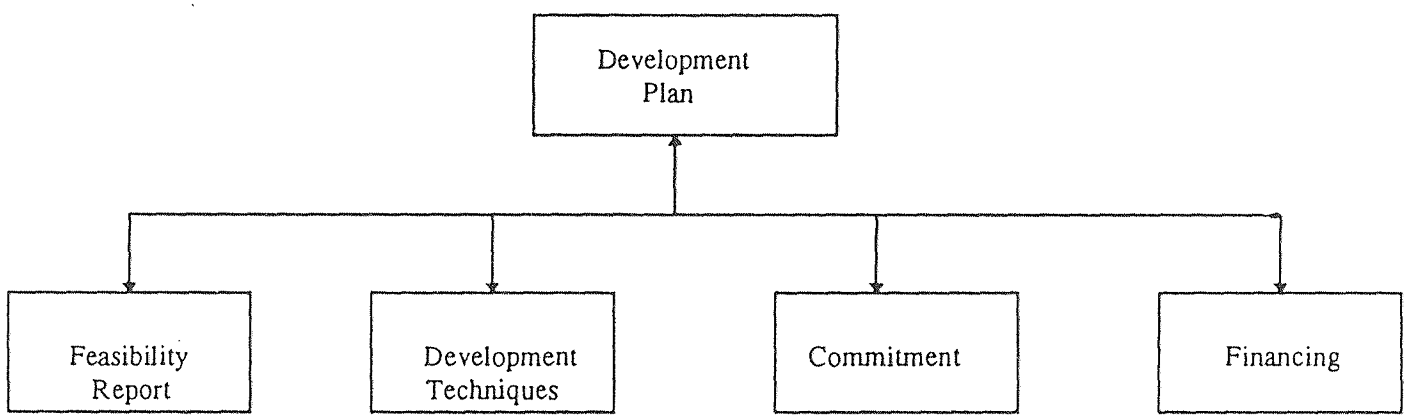


Figure 6. Development Plan for an Expert System

system should be made, once the target is met then it could be expanded according to actual plan.

4.3.2 Development Techniques

The development of an expert system should be based on maintenance and program updating. The development can be performed in three different ways as follows.

- Internal sources
- External sources
- Domain expert

The procedure to use these sources is given below

The easiest way to develop an expert system is to train the people who are already performing computer programming. The advantage of doing like this is that they can pickup the concept of knowledge engineering very quickly. Secondly it saves the time and money as well, though in the initial stages it may take little longer because of the lack of experience.

Another way to develop an expert system is to contract the outside resources. The fact is that it may be very costly but the good secret hiding behind this approach is that these people are very experienced professional in their field. A good aspect to hire these people is that internal programers learn and get exposure of the technology. To apply this technique it must be remember that these professionals are not familiar with the functioning of the company. Hence to overcome this problem a permanent manager should be appointed, who would be able to provide the necessary information to the contracting professional.

The third approach to develop an expert system is to let an expert develop the program. This requires from an expert to be motivated and responsible in achieving tasks. It is better to keep the problem as simple as possible to generate the interest for the domain expert. The important point to note in this approach is to select an expert system shell which is easy to use and learn. It is advantageous to have internal training and support available to domain expert. One of the features of this approach is that if the problem is easy it works well and increase the enthusiasm in the domain organization which results in more better ideas.

4.3.3 Commitment to Project

For the successful development of an expert system it is necessary that the expert, programmer and the user make the commitment before the start of the project.

It is also important to have an expert who is member of the organization to avoid any complication in the process of development. Expert is the one upon which the program knowledge is based and hence the success of the project. One of the advantages of local expert is that the programmer and expert can develop the good understanding between them which may become a major factor for the success of the project.

Users are responsible to test system that if it is working fine or not. Therefore it should be make sure that they have the necessary knowledge of computers or not. User should be trained for the testing of the system and they should be given a good part of involvement in the design process of the system so that they can develop the basic logic of the system development.

4.3.4 Financing

The financing of an expert system is little more complicated than a conventional software development. The reason for this is that only the expert know the development structure of the project, but he is unaware what it takes to develop the software of the system. The nature of the knowledge base engineering is such that the complications does not open until some development work has been done. Precisely speaking, the likelihood of inaccuracy in budgeting is very bright.

To overcome this problem following steps could be taken

- Get funding to develop a demonstration prototype.
- Make an estimate of the effort to do the work up through the development prototype and commitment by the sponsor.
- Estimate and get commitment for the remainder of the project.

4.4 Structure of the Development Process

The structure of an expert system based on many factors and steps. The most important are given below

4.4.1 Planning

Planning involves every step from start to final accomplishment of the project. In this phase the feasibility and budgeting of the project should be carried out. The important resources needed must be identified in this developing phase.

4.4.2 Prototype for Demonstration

Prototype for demonstration plays a vital role for the success of the project as it capture the attention and develops the interest of user and sponsor in the expert system technology. The purpose of the prototype is to provide a good user interface with the minimum knowledge. The objective of the prototype is to demonstrate the concept and the use of end system, with the sufficient knowledge. Also how the expert system would be used and benefit the organization

4.4.3 System Design

In this step the whole design procedure of the system should be set. The emphasis should be put on user interface, acceptance by the users, availability and cooperation of the expert, integration with other systems/software, target hardware and knowledge-based software tools with the same issues as in conventional software development.

4.4.4 Development Prototype

The task during this step is to define the knowledge needed to solve the problem and model this in a computer program. It is important that the development prototype demonstrate the depth of the knowledge needed in the delivery system. The refinement of the knowledge continues as the process develops further and further. However the prototype must provide the correct solution of the problem to be solved. Refinement of the user interface and development of interfaces to other software or system can be deferred to later development work if these are well understood techniques.

The development prototype should be done with the tools and the environment of the delivery system if possible. This is to reduce development effort and time and because it may not be feasible to translate the knowledge coding approach into another environment.

4.4.5 System Development

After the prototype is demonstrated successfully, the development of the rest of the system should be performed. This include the interface of the knowledge-based code to other software, the user interface, the data base and other system software, and development of any other hardware or software that is essential for the delivery system.

4.4.6 Testing

During the development various type of testing must be performed prior to putting the system into the operation. The first test is performed by expert who verifies that the knowledge in the system is accurate and according to objective. These tests are carry out several times in order to develop the process in the right direction. The process of testing and recording continues until the accurate knowledge in the expert system is achieved.

The second series of the test should be conducted by the users. These tests are carried out when the project is near completion. At the same time the user interfaces should also be developed and tested with the users. The purpose of the user test is to verify that the user interface provides the user with the information the users need in an easy to use form. Knowledge is identified on the basis of how effective it is for the users.

4.4.7 Knowledge and Data Maintenance

Expert system maintenance is very important in the field of knowledge-based engineering. One of the reason for maintaining the expert system is that knowledge gets old with the time and may not remain useful for the user.

Therefore it is very important to update the system as the need arise.

To update the expert system, an organization should have a permanent coordinator. It is not necessary that this person should be expert, but he/she could be any who can coordinate the activities of the user, expert and programmer. so that the maintenance take place. It would be a great help if the coordinator is from the organization as this person is always available and can take care of the system at the right time.

The commitment of the expert for the maintenance is very important as he/she is the only one who has the knowledge to update the system. The situation could be very complicated if the expert or the original expert is not available with the organization. To overcome this problem a substitute must be found or the organization should have a group of knowledgeable people in the application domain review the knowledge at appropriate times.

4.5 Different Approaches to Develop an Expert System

To develop an expert system an organization can use the different techniques. Following are some of the techniques which can be adopted

4.5.1 Be Your Own Boss

This technique is good for the organizations who have necessary resources available to develop an expert system.

Also the important feature of this technique is that the organization can control the sensitive knowledge if they have any.

The major attraction of this technique is that it provides a low cost and almost risk free entry into the field of expert system technology. One problem with this technique is that it does not provide a way to develop medium to large scale expert systems, which usually require more knowledge engineering training and specialized computer resources unavailable to most end-users. one of the good aspects of this technique is that all expert system projects are centralized in a special unit or department. Also an organization can use the existing information centers as the vehicle for disseminating expert system.

4.5.2 Use of Outside Resources

This technique work good for the organizations who don't have any previous setup or resources available for the development of an expert system. As a matter of fact, if the company knowledge is not sensitive the organization may allow an outside developer for using the company as a test site.

An organization who do not have knowledge engineers can hire a consulting firm for the development of their knowledge-base system. This technique provides a chance to inner resources to get know how about the knowledge engineering, expert system development, and maintenance. The negative aspect of this technique is that the use of outside resources may complicate the procedure of doing and may be very costly too.

4.6 Keys to Transfer Technology to an Industry

Followings are the important keys to remember when for introducing the expert system technology to an industries.

Develop the good understanding to top level management in order to get their full support for the successful implementation of the technology. Conveyance them to accept the risk involved in introducing the new technology and brief them for the effectiveness of the technology by the demonstration of working prototype to remove the misunderstanding.

Identify champion of expert system technology within the company and obtain the commitment from experts, knowledge engineers and operational groups. Expert provide the heuristic knowledge. Knowledge engineer develop and maintain the system. Operational groups use the system, provide information to estimate the benefits and determine the ultimate success of the system.

The key for the success of any expert system is the selection of right problem. The basic ingredient of the problem domain are limited and deep. The use of heuristic knowledge is the main component in the problem solving process. The committed expert should be able to determine the solutions methods.

To obtain the support of financial department, it is necessary to provide them the information regarding cost, benefits and return on investment. once the related authorities are satisfied the task would be easier for the people who are involved in developing an expert system.

Management of the expert system, will be responsible to handle and solve all incoming problems such as scheduling of the project, participants conflict and providing a motivation within the working team.

Select right tool to develop an expert system considering the cost, upgrading abilities and effectiveness of the tool.

CHAPTER 5

EXPERT SYSTEM FOR DECISION SUPPORT IN MANUFACTURING

5.1 Introduction to DSS

A DECISION SUPPORT SYSTEM is an information system application that helps in decision making. It can also be defined as a collection of tools designed and developed to assist decision maker in their decision-making process. Another definition of DSS is that it is a computer-based system that help decision makers in confronting ill-structured problems through direct interaction with data and analysis models.

There are three main elements of DSS software

- Data base
- Model base
- User interface

The components of this tool are data management, analytic modelling, report writers and visual displays. Decision support system can be used in planning, analyzing alternatives, and solutions. There are several DSS are available in the market. A good DSS should have three features.

- User Friendliness
- Tools Integration
- Domain Independence

5.1.1 Difficulties in DDS

It is true that the DSS technology has some problems because of the complexity of the managerial domain. Several features characterize a managerial domain, such as problem type, varying bases of knowledge in solving the problem, the broad range of expertise needed, stability of solution, problem type and problem solving orientation.

One of the reason of problem complexity in managerial domain is more than one expert to work with. These expertise are from different functional areas within the organization. Because of this reason the solution of the problem becomes instable and organization specific rather than domain specific.

Having a comprehensive solution for a problem in the managerial domain is a challenge. The reason behind is that because the approach of the solution is formulated and planning oriented instead of the classification oriented. The fact which further complicate the situation is that the result is obtained in stages rather than in one effort.

The fact which forces to build a DSS with more advance features is that the traditional DSS relies on the user understanding of the problem, his formulation strategy to obtain a solution and its execution. Hence a need arises to add new modules to handle the characteristics of a managerial domain.

5.2 What is a Decision Support Process

Decision Support Process is an approach to decision support that uses a programming environment to aid the decision maker. Decision making include four phases

- Intelligence
- Design
- Choice
- Review

Also there are four Stages of a Decision Support System

- Problem Definition
- Solution Planning
- Tools Integration
- Model Execution

In the problem definition stage we find out what the problem is and what is its scope? The solution plan set a procedure for the process capable of carrying out a set of goal states. Tool integration simply define a set of tools. In order to make things easier these tools should communicate with each other and with the database. For example if the problem need the use of two tools simultaneously, then these tools should be able to communicate with each other. Model execution is merely a execution of the plan and its interpretation. The next step in model execution is the analysis of the output and validation of the activities
taking place within.

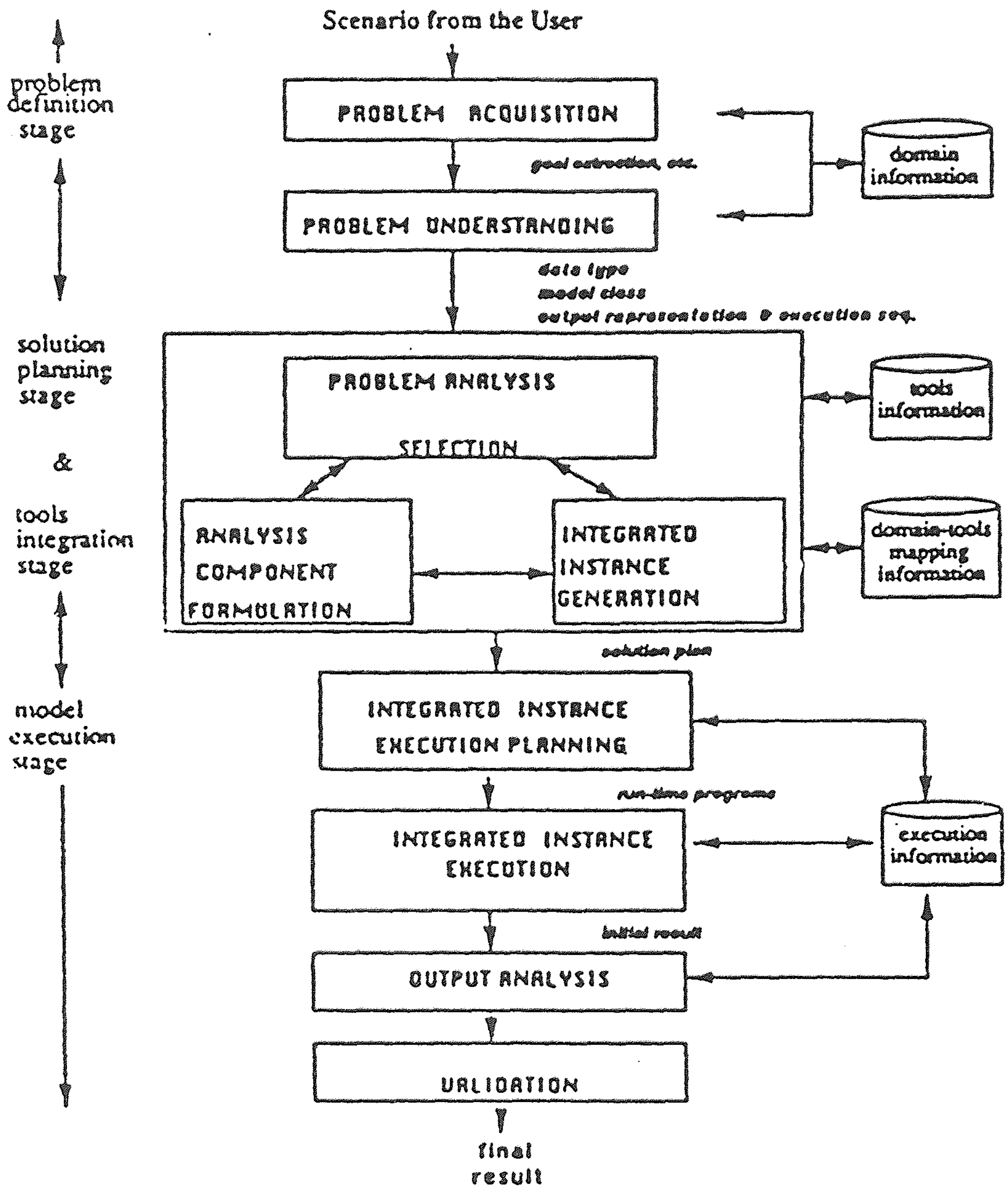


Figure 7. Different Stages of DSP Activities

5.3 Framework for DSP Activities

There are four kinds of information to support DSP activities

- Domain Information
- Tools Information
- Domain Tools Mapping Information
- Execution information

Domain information involves the theories and concept of a particular domain. For example in production planning domain, domain information include knowledge about the planning horizon, forecast of future demand and production center capacity. Tools information includes among other data, knowledge planning models, mathematical programming techniques, simulation models needed to solve the problem, and tools integration knowledge. The integration knowledge describes how a tool should be used, how it should be connected to any other tool. Domain tools making information makes it possible to map a problem definition to collect tools, needed for the solution. Execution information helps the user to execute the needed computer software.

The stages of DSP are shown in figure 7.

The basic purpose of the problem definition is to isolate the problem and its characteristics from the rest of the scenario. This problem contains two basic steps

- problem acquisition
- problem understanding

5.3.1 Problem Acquisition

In the problem acquisition step, the system uses the domain information base prompt the user with questions to define the problem and establish the goals of the analysis. The problem understanding step first involves isolating problem attributes and then establish the general and specific cause for the problem.

5.3.2 Problem Analysis

The problem analysis step use, the problem attributes and causes in conjunction with the tool information to select a class of analysis needed to solve the problem. The system then sends this output to the analysis (component formulation step. Here, problem formulation and reformulation occur. Using both the outputs of the analysis component formulation and problem analysis steps and the domain-tools mapping knowledge), the system develops an abstract representation of the entire analysis for the problem. This step is called integrated instance generation and the process is called integrated instance.

In the model execution stage of DSP, executed information transforms the instance into a sequence of execution steps. Execution information is needed because user may not always be proficient in using various packaging. The integrated instance is automatically executed and results are stored in the predefined structures. Since user may sometimes be unable to interpret the results, these results may be analyzed to validate the model.

5.3.3 Advantages of Multistage Approach to DSP

The advantages of using a multistage approach to DSP address the shortcomings of current DSS. These advantages are maintability, transportability and flexibility. Maintainability and flexibility allows quick incorporation of new technologies into the existing DSS. Transportability ensures that the DSS remains problem-domain independent.

5.4 Architectural Framework for DSP

The architectural frame work provide automated assistance to DSP and for this reason it is called XDSP. It is generally believed that XDSP should support all four stages of DSP, but because of the complex task it supports only first three stages of DSP. The first three stages of DSP are

- Problem definition
- Solution planning
- Tools integration

Following components should be included in the first three stages of DSP

- Problem decomposition
- Incremental solution planning
- Hybrid approach
- Integration of tools
- Multiple knowledge or information sources

5.4.1 Design Concept of XDSP

The design concept of DSP is based on three assumptions

- DSP is a planning effort
- People make decisions at different levels of abstraction
- The levels of abstraction have functional significance in the planning process

5.4.2 Planning in Artificial Intelligence

There are four approaches planning in artificial intelligence

- non hierarchical planning
- hierarchical planning
- script-based planning
- opportunistic planning

The hierarchical planning is most suitable for XDSP because of the fact that it provides a most detailed and concise plan. The advantage of hierarchical planning is that the plan is developed at a stage at which the details are not computationally overwhelming.

5.4.3 Levels of XDSP

XDSP requires a three layer knowledge abstraction.

- Axiomatic level
- Median Level
- Instantial Level

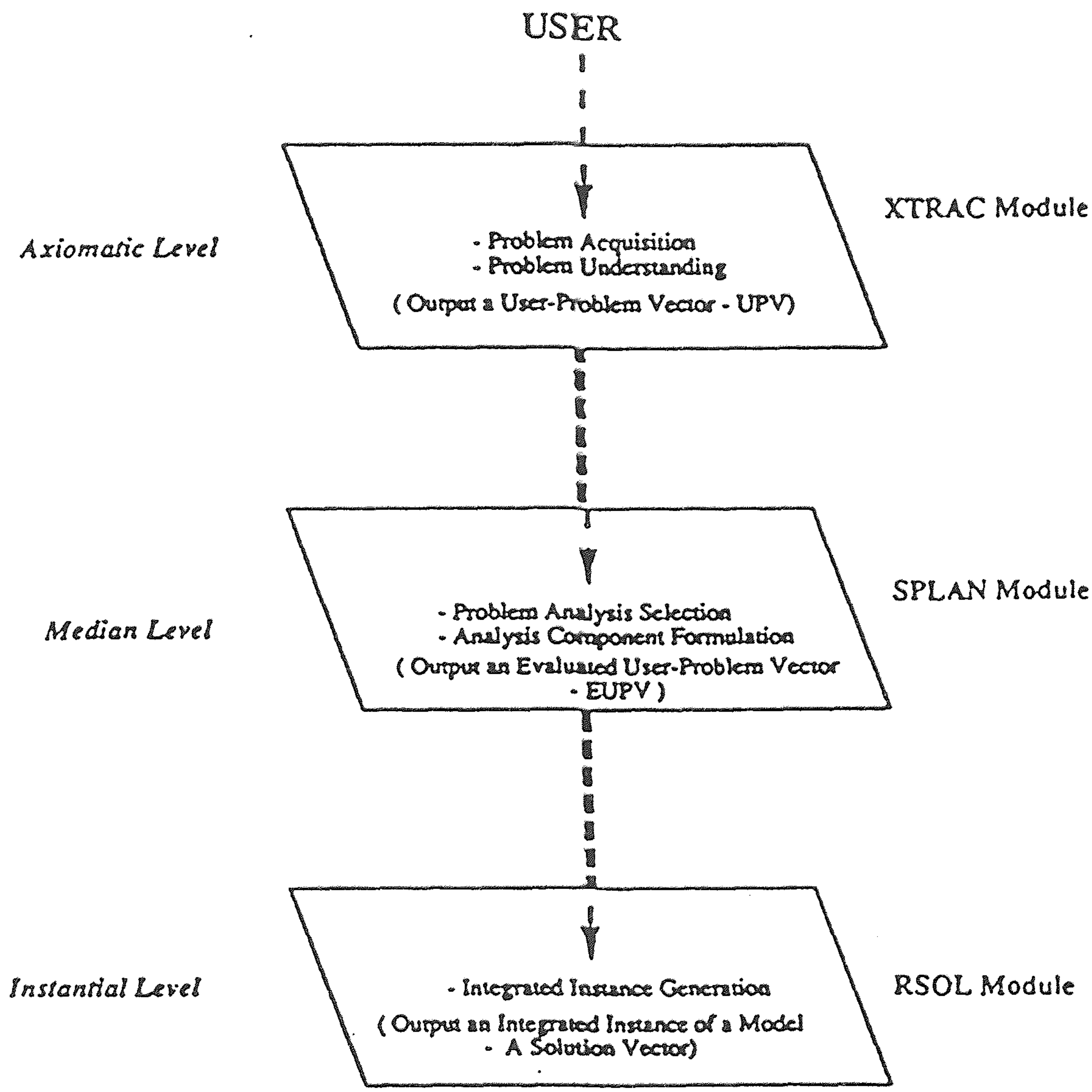


Figure 8. Levels of XDSP

At the axiomatic level the system knowledge is focused on related sets of elements, properties, functions and relationships defining the problem attributes. For example problem attributes such as "production of electronic motors," may be extracted at this level. Axiomatic knowledge deals primarily with the problem attributes to determine a formal model for the stated problem.

At the median level knowledge is used to analyze the components of the problem formulated at the axiomatic level. The goal required is to describe possible intermediate states of problem refinement by applying heuristics, probability distribution, policy and preference structure to the various identifiable parts of the problem.

At the instantial level higher level attributes are converted into specific identifiable instances. Instantial level knowledge also includes the ability to identify patterns in the problem statement

5.4.4 Features of XDSP System

Following are the features of the system that use knowledge at different levels of abstraction.

- Refinement of the models at upper level in the system.
- Lower levels inherit features and attributes from upper levels, however this inheritance is selective rather than comprehensive.

- The lower the level the less abstract of the model and more descriptive the observable phenomena.
- Sublevels for each of the three identified levels of knowledge must exist.
- The lower the level the more detailed the data specification.
- Completeness and consistency of the upper levels determine the completeness and consistency of models at the lower level.

5.5 Categories of Knowledge

5.5.1 Support Knowledge

Support knowledge means, different models, data and solution sets which can help in establishing the base of the system. It tells what the system can do and cannot do.

5.5.2 User Knowledge

The development of a profile of the user and the use of stereotype and user models built from user profiles facilitate an improvement in the solution of problem. Because the resulting solutions take into account both objective and subjective considerations, users appreciate them more highly. The users of XDSP are assumed to have different knowledge and skills levels. At one extreme the system may be used only to substantiate the user beliefs regarding a particular solution, and at the other extreme, the user may have only abstract ideas about the nature of the decision. For this reason the user may require a more involved dialogue. In any case the program assumes users know their requirements and are able to communicate to the symptoms that need addressing.

5.5.3 Preference Structure Knowledge

The preference structure knowledge is used to select the solution set. For the system to provide the optimal solutions, the preference structure should provide a form of weighing structure included in the overall analysis.

5.5.4 Probabilistic Knowledge

The probabilistic knowledge in any decision system is very important. The use of probabilistic knowledge is reserved for chance nodes in the decision model. Acceptable probability distributions, and appropriate parameters, will be based on the problem class that the system addresses.

5.5.5 Selection Process Knowledge

The selection process needs to consider proper weighting of the various decision criteria. Such criteria may include user requirements, preferences, existing polices, and the accepted heuristics in a given context.

5.6 Components of Decision Support System

There are three components of decision support system

- The Problem Extraction

- The Solution Planning
- The Problem Resolution

5.6.1 The Problem Extraction

This component is used for initial problem definition and profiling of the user. The system focuses on the user conception of the task in defining the problem, and the definition includes a description of goals and possible actions considered. The user is profile to define the skills and biases that he or she can bring to the problem. In addition the user profile includes descriptions of available resources and potential constraints. The outcome of the problem extraction reflects an initial classification of both the user and the problem.

After completing the user/problem definition the user will receive a description of the system understanding of the problem addressed. At this point the user may change any of the problem characteristics and repeat the process until the user approves the problem definition. Once satisfied with the problem definition, the user passes control to the problem formulator to check for consistency, completeness, and logical accuracy of the attribute values. The outcome expected from user interaction with problem extraction is

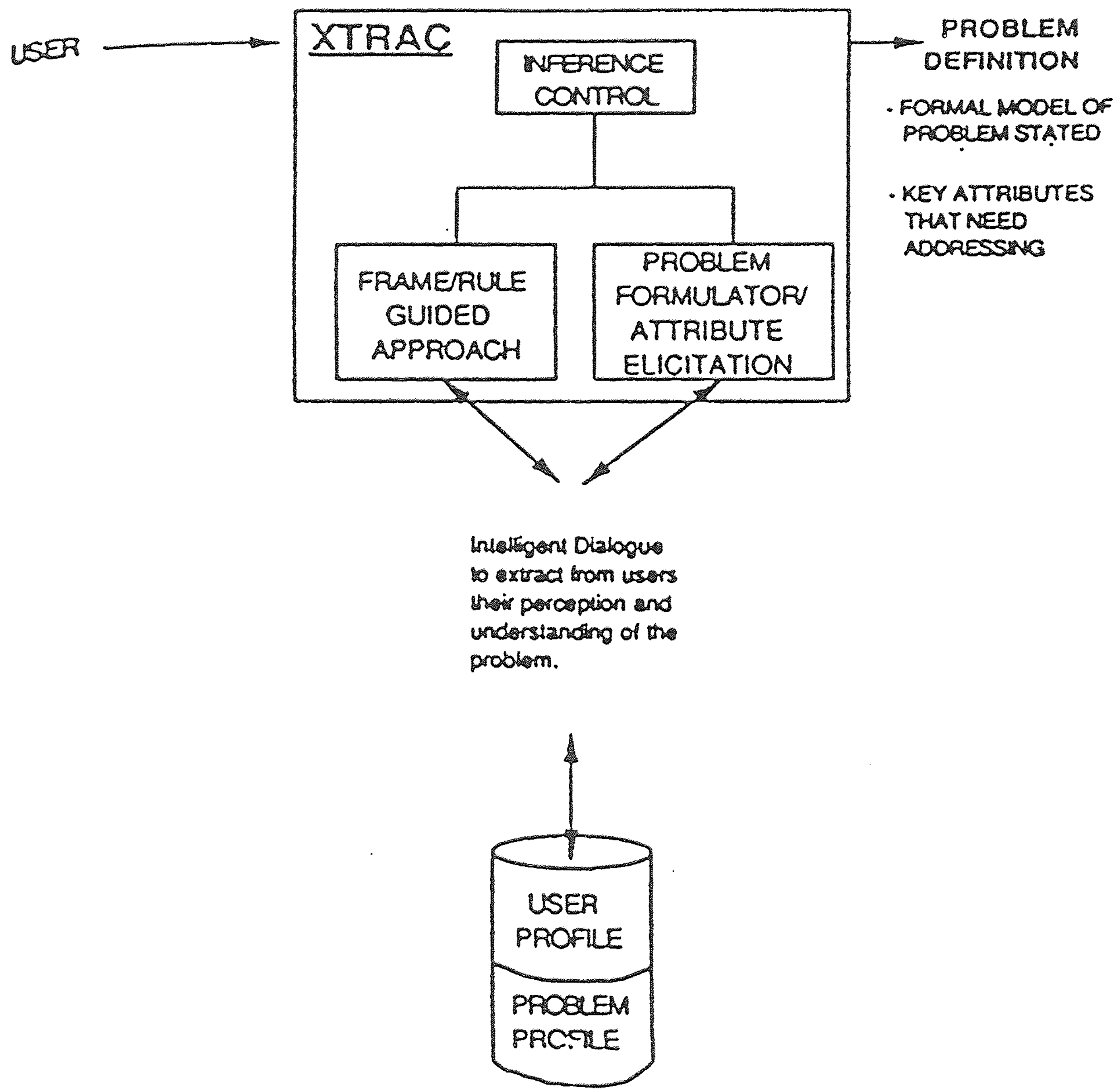


Figure 9. Problem Extraction Phase

the generation of the formal model of the decision problem being addressed.

5.6.2 The Solution Planning

The solution planning deals with refining the problem developed by problem extraction. Problem refinement at this level needs to use knowledge that is partly heuristic and partly probabilistic. In solution planning the user plans to represent the problem symbolically in order to generate potential solutions. The user interaction with problem planning focuses on the criteria the planner wishes to impose on the solutions and define the evaluation criteria that will be used to evaluate the prospective solution. In addition to user interaction, the problem component analyzer in solution planning uses heuristic knowledge, organization policy knowledge, user preference knowledge, and probabilistic knowledge to help refine the problem. Based on either preference or the probabilistic models that are applied, information provided in the latter part of the user-system dialogue can alter the analyses of the problem components, making solution planning iteration. The proposed outcome of solution planning is a detailed evaluation of the problem/decision. i.e, a clear definition of the user intentions and a detailed problem assessment. The basis for the evaluation will be the experts, domain knowledge, user preference and applicable probabilistic knowledge. The model

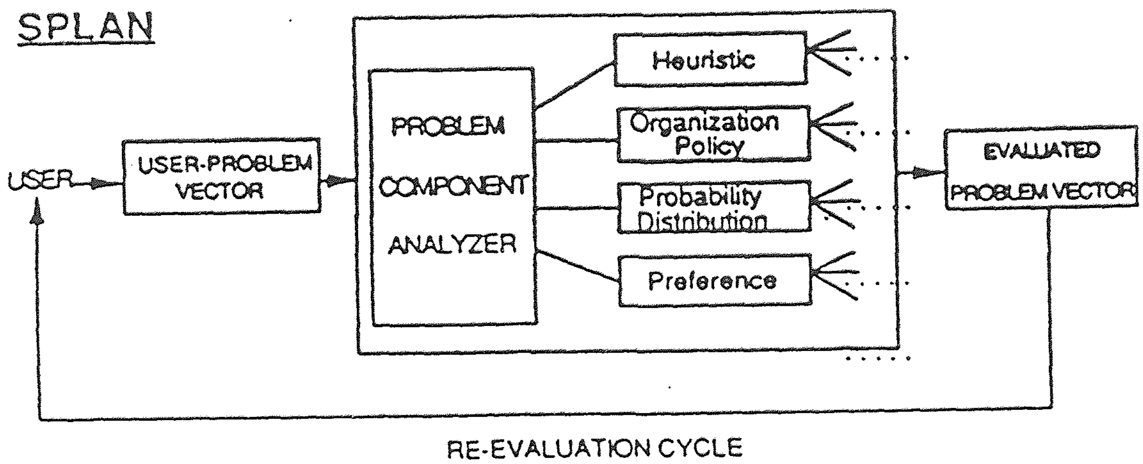


Figure 10. Solution Planning Phase

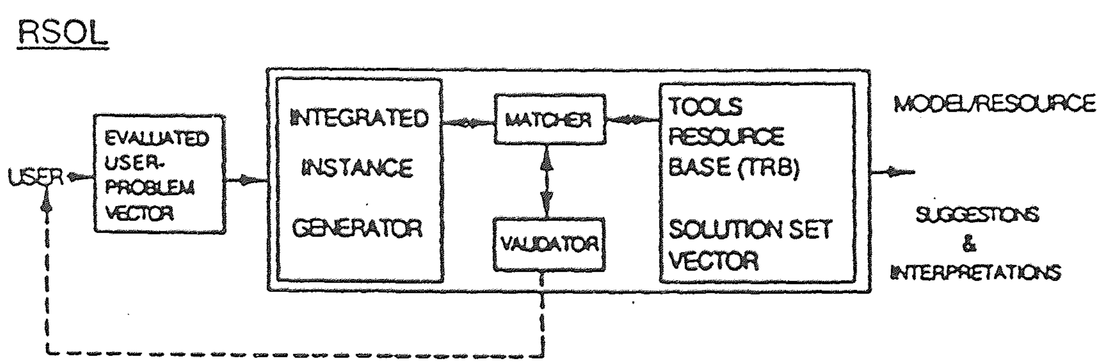


Figure 11. Problem Resolution Phase

developed and its logical implications will then be presented to the user.

5.6.3 The Problem Resolution

The purpose of the problem resolution component is to integrate different perspective of the problem as they relates to the objects and relationships of the problem environment. This component deals with more detailed level and looks at specific attributes. These attributes of the known problems in an attempt to pattern match attributes that define the user decision/problem with the attributes of the considered solution/models/resources. The outcome of the problem resolution is a satisfactory solution of the problem, solutions with caveats and a statement why the problem is or is not solvable given by the constraints.

This process results in the specification of a solution or a set of solutions. These results will be accompanied by probability/certainity values attached to the recommendations. The system will also provide interpretations of the formal recommendations.

5.7 Decision Support and Manufacturing

The use of decision support system is becoming more and more demanding in the field of manufacturing to stay alive in the global competitive market.

It has been observed that the companies which are using expert system for their decision making process are achieving targets more precisely than the companies who don't have this facility yet. Also the use of expert system technology saves time and avoid many decision related conflicts within the organization.

5.7.1 Objectives of Expert System Technology in Decision Making

For the successful implementation of expert system technology for decision making following aims should be achieved.

- Investigate the current practices in the company about the software tools and up to what extent decision support tools and expert system packages are being utilized.
- Design an integrated system of software tools that will utilize decision support, expert systems, simulation, and flexible manufacturing methodologies within the organization.
- Try to obtain the company people for the development software in order to reduce cost and get the confidence of management.
- Consult outside resources if any problem arises or the persons within the organization are having some problem in achieving the tasks.

5.7.2 Decision Criteria to Implement DSS

For the successful implementation of decision support system, the following design criteria must be meet.

- Analyze the computing techniques which are currently available to manufacturing management, with the scheduling and resources available within the medium-sized engineering establishment.
- Specify design and implement advance software tools to coordinate the components of flexible manufacturing system and to schedule and monitor the work within an flexible manufacturing system.
- Develop real-time simulation software and associated database management software, that will help in decision making in the areas of resource utilization and shop floor production.
- Integrate these tools within an overall decision support/expert system that will both coordinate their operation in real time and provide management with- up to the minute detail about the current state of the plant.
- Construct a user-friendly interface layer around this software system that will enable it to use efficiently and effectively by the management.

5.7.3 Application of Decision Support System in Manufacturing

The decision support system/expert system technology is proving very effective in the field of manufacturing. Following are some of the glimpses how it is providing help in the real manufacturing world

- Cost estimation for the tender is time consuming and difficult task. Sometimes after all efforts achieving the task is not possible which really hurt the company. Presently an expert system is being used in many companies as a consultant tool for tender estimation.
- An expert system for laboratory data handling is being currently used which is able to process and responsible to make decisions for approximately 1000 tests on a daily basis.
- Storing tons of information on computers and its easy access the user is some time create great deal of difficulty. To overcome this problem methods are being designed on the basis of what information user precisely require which would be accessible to user in an easy format.
- Inventory control plays an important role for the success of the business, specially when the market is more competitive. An expert system is currently being designed for the companies that would be able to make decision for production procedure and planning.

- Most of the manufacturing companies runs their production 365 days a year and consequently the machines. If the problem occur at any time in any of the shift it should be fixed immediately which some times creates great amount of problems. To overcome this difficulty an expert system was developed which and is presently working in some companies. The expert system is responsible to give advice to shop floor management that how to control the each and individual machine and consequently the whole production line.
- The problems related to machine maintenance and their scheduling were big issues for many companies. Expert system packages are really proving worthwhile and are available in the market for this purpose. These tools are being utilize in many companies and providing desired results.

CHAPTER 6

METHODS TO ESTIMATE COST FOR AN EXPERT SYSTEM

6.1 Importance of Expert System in Businesses

Expert systems are the induction of new source for the business community to solve their business related problems based on decision making. Expert systems are being developed and implemented by increasing number of businesses. The characteristics expert system like user friendly, intelligent decision making tool and time saver has attracted business community and encouraged many organizations to develop and implement their own expert system tool.

It is true that the expert system is a new sensational breakthrough in the world of computer technology which would supplement traditional methods of decision making, but like other projects which involves company capital, an expert system must be analyzed for its economic and strategic worth to the organization. Each and every aspect should be clearly defined in terms of money involved. The critical factors which must be considered are methods of development, cost and benefit data, analysis of the project worth, results and recommendations.

6.2 Methods of Evaluating Investment Alternatives

Different organizations use various methods to measure the project worth. The ultimate goal of analyses is to select a small but comprehensive method, which would be most suitable for the organization. Engineering economy and capital budgeting focus on cash inflows and outflows over the study period as traditional measures. According to analysis it is very obvious that these methods lack the ability to effectively include irreducible factors, they are widely accepted as a standard measures for decision makers who can have both intuitive and quantitative feel.

These methods measures different aspects of a project with some consistency, but some create conflicting results. To avoid this controversy most companies use combinations. All are based upon for future determination of cost and saving of a project. The discount rate is the minimum attractive rate of return of a project and is the opportunity cost to the company of the money to be spent. The discount rate should be equal or greater than the capital cost. To overcome the problem of risk involved, a risk adjusted discount rate is used and for this purpose risk undertaking is inflated to reflect that risk.

6.2.1 Payback Method

This method is popular because of concern with risk and short term profitability. It says that the net revenues derived from an investment should pay back the investment in a certain period of time. It can be calculated in either a discounted or non-discounted format.

6.2.2 Rate-of-Return Method

This method also called Internal rate of return. It measures the inflows verses the outflows over time to arrive at a rate of return. Means that if the calculated rate is greater than the criterion rate of return, the investment is acceptable. One of the assumption about rate of return which is not often true is that cash inflows can be invested at the rate of return, instead it has inspire variation of this method. These modified internal rate of return often ask the analyst for an interest rate for both cash outflows and cash inflows.

6.2.3 Present Worth Method

The present worth method uses the equivalent present value of all current and future cash flows to evaluate the investment proposal. This is found by calculating the Net Present Value of a project and dividing by the Present Worth of Annuity factor for the number of years of the life.

6.2.4 Benefit to Cost Ratios

This method is also called profitability ratios. It measure the sum of the discounted inflows divided by the sum of the discounted outflows, and gives consistent results with Net Present Value or Equivalent Annuity.

There are many software packages are available for measuring purpose including spreadsheets, and also can be calculated by calculator.

6.3 Comparison of Investment Alternatives

Any of the four methods described above can be used to compare investment alternatives. Each method has its own advantages and disadvantages. The advantage of rate of return method is that it brings the all project at common level, no assumed rate of return, and easy to understand concept. With these advantages, the drawback of this method is that it assumes reinvestment at same rate.

Present worth method is more common than other methods. It maximize value for unconstrained project selection. The disadvantage is that the projects of equal size cannot be compared.

The payback method ignores flows after payback is reached and assume standard project cash flow profile. The advantage of this method is that it may be discounted or non-discounted.

Benefit to cost ratio method is conceptually familiar and brings all projects to common level. One of the drawback of cost to benefit ratio is that it is difficult to classify outlays between expense and investment.

6.4 Cost of an Expert System

For the wide area application of an expert system an organization may need to buy other software packages such as expert system shells, spreadsheets, database managers, and language compilers to support the expert system and achieve

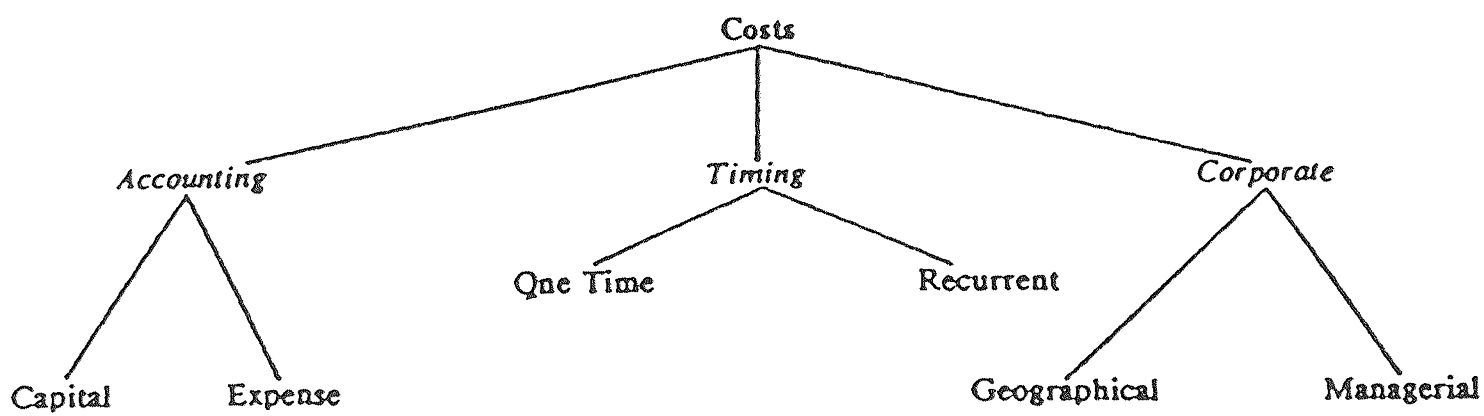


Figure 12. Categories of Cost

the desired tasks. One of the method to break the cost is that divide it among all the projects which will use them.

Knowledge engineering and programming are used to develop an expert system. This part is the result of human effort who charge the money for their time spending. Usually this is the largest cost of an expert system.

The estimation of the cost of hardware is relatively simple as it is the purchased from the outside market and the prices can be obtained in advance from these sources. Leasing of hardware is a common practice, the terms of lease or a capital lease and the cash flows can be treated accordingly.

Miscellaneous cost is also a major part of the total cost. It includes the cost of printers, furniture, office space, communication lines and devices, measuring instruments, documentation training costs and others related costs.

6.5 Benefits of an Expert System

The benefits of an expert system technology are beginning to showing up as the technology is advancing day by day. The most benefited areas are prediction, design, monitoring and interpretation. The following are some of the important benefits of expert system are

- It is estimated that the use of an expert system can increase the speed of professional and semi-professional work by the factor of tens to hundreds.

- The use of an expert system is very useful where the task have numerous solutions and hence consuming time, in such circumstances it works as a useful decision time saving tool.
- An expert system is also a useful decision making tool. One of the advantages of an expert system is the explicit representation and recording of the knowledge and procedures.
- It works as a consulting tool for any one who want to make decision about any problem. The consistency and quality of decision making satisfied the customers, faster the response times, and improves the quality.
- Expert system allows workers to perform new tasks previously done by others or not done at all. This can increase employee fulfillment and enlarge job market.
- The technology of expert system is the source of opening the new markets, improving the competitiveness, advancing the technology, and positioning the company for the future.

6.6 Preparing a Documentary Report for Justification of an Expert System

A documentary report should discuss the ways and means of justification of an expert system. It should justify in detail that why an expert system is necessary for the company and how beneficial it can prove for the company over the next three years. The other question which should be answered in the report are

- Whether expert system should be developed in house or outside resources should be utilized.
- What kind of tools are required to develop an expert system such as software, hardware, database and spreadsheets etc.
- What kind of people should be trained from the company
- What would be the cost in order to update the system as per need.
- Estimate the total cost that would be involved in the project.
- What is the organization loss if the worse happens and the project is a total failure for the company.

Answer of these questions provide a good look and judgment before any work is done practically.

A good report is that which is supported by perception interpretations and reasonable recommendations. The most suitable people who can provide this insight are those who has the prior knowledge of the technology and are familiar with the importance of the project.

Developing an executive summary is a vital component of any report. This should be no more than a page long and highlights the reasons for the system, the major cost and benefits, the study methods and the important results and recommendations.

Another important component of the report is the sensitivity analysis, specially if it yields less than encouraging results. The most important and attractive part of the project is that the management is interested in the amount of risk involved in the project and its outcomes. This component should cove the contingency plans, worst case scenarios, and fallback positions.

Expert system is still an emerging technology, still new improvements are being made to make the technology as simple as possible. It would be a good idea for delaying a project if knowledge engineering and software development anticipate a significant near term improvement.

CHAPTER 7

FUTURE OF AN EXPERT SYSTEM

7.1 Areas and Design of Application

Expert systems is defined as an interactive computer based decision tool that use both facts and heuristics to solve difficult decision problems based on knowledge area from an expert. The combination of computer power and human intelligence, expert systems enhance the value of expert knowledge by making it readily and widely available. This capability of an expert system has been demonstrated in the fields of medicine, law education, finance, manufacturing, and operational military problems.

There are numerous application possibilities of an expert system application such as network management, image processing, collection, manipulation, monitoring storing, sensing, counting, actuating and transmitting of data or information.

The followings are the four information technology growth areas are

- Intermediate and final demand of industry
- Government purchases
- Private household demand
- Infrastructure investment

Because of the global competition in the industry, the demand of more technically advanced equipment, systems and servicing is increasing. The reason for this is to achieve targets of productivity and flexibility to meet ever changing economic circumstances as well as consumer demand. It is expected that in the near future the use of expert system technology will be broaden to agriculture, forestry and fishery industries farm management to achieve the optimum production. One of the features of the expert system will be to determine the procedural needs when working in combination of robotics and automatic/remote control systems.

In the field of manufacturing such as automated handling and manipulation, automated packaging and dispatch, intersite communications automated testing and quality control, computer aided planning, scheduling and management. The use of expert system is also very fruitful in the service sector for providing intelligent-based database search and retrieval systems.

7.2 Interaction of Artificial Intelligence With People

Currently work is being done to make the artificial intelligence interactive with the people and to facilitate the reasoning about information. It is expected that in the next decade the information technology based equipments will be remote control such as infrared switches, leading to multicontrol remote, user friendly such as voice control, more informative output displays, voice synthesize messages, Programmable (i.e offering increase options to fit current user requirements, and automatic control which takes into account energy tariffs) Informed (i.e memory to recall previous programming and data input) portable (smaller, more personal devices such as cordless devices for convenience of use) Safety featured (warning indicators, automatic fail safe controls) Breakdown featured (diagonostic and easy repair), Power conserving (more energy efficient devices), integrating different items of equipments around common monitoring and control systems.

The major reason to use this equipment will be to improve the person to computer interface to encode expertise for use by others. The software which will perform these activities will be expert system. The expert system has the promise for the management of future networks by the integration of information technology.

Another reason to develop this equipment is that the future knowledge worker will have a primary job of decision making and this equipment will be responsible to provide many facts and opinions available. Expert system tools which allow for conversion, enhancement combination or correlations of graphics or animated presentations, will increase information movement and management. For this reason the implication for integrated services digital networks (ISDN) is the parallel development for the higher level languages for application specific functions.

Based on the analysis and observations it has been proved that the expert system technology is the greatest breakthrough of the last decade and its capability as a decision making and problem solving tool will make it worthwhile for the companies of the future.

7.3 Integration of Information System and Expert System Technology

In the early days the expert system technology couldn't grow because of the lack of knowledge acquisition and knowledge modeling.

To overcome this problem a new approach was adopted by applying knowledge engineering methodology to expert system projects. Structural knowledge engineering provide which is based on academic research, provide the facility to knowledge engineer to recognize the business problems.

The role of structural knowledge engineering is to recognize and solve the different issues such as knowledge acquisition and knowledge modeling, verification and validification of knowledge, justification and prototyping aspects.

Another problem is that the information technology is not capable to handle all the data related processes. It is the responsibility of information engineer to recognize that the particular process can be formalized or not. Once the system analyst recognize, the knowledge engineer would need to fix it. It would be good for an organization, if the information engineer and knowledge engineer work together to get the optimal information supply.

7.4 The Role of Inference in the Development of Expert System Technology

Inference is playing an important role in the field of expert system technology by developing new tools. One of the new product of Inference is Automated Reasoning Tool, which was Lisp-based. The effectiveness of Automated Reasoning Tool is available in VAX\VMS, UNIX workstations, PC's and IBM mainframe. The ART is very popular because of the reason that it can be interface with all computer environments and languages which make the technology a greatest breakthrough of the last decade. Inference is committed to provide innovative tools for building knowledge bases, user interfaces and data interfaces. Inference is currently involved in the development of knowledge-based software reuse assistant, real time expert systems and case based reasoning. The ultimate goal of this research is to transfer technology to product developers.

7.4.1 Shortcomings of Current Expert System

Though in the last ten years the expert system technology has many advancements, but some applications produce great amount of difficulties that stretch the current technology. The most common are the followings

- The combination and unification of the knowledge of many experts when no prior standardization has occurred.
- The application of broad bodies of knowledge quickly, as may arise in real time command and control problems.
- The incorporation of the knowledge that is hard to represent, which often arises when it is required to reason with spatial or temporal problems.
- Flexible and general natural language understanding, which may arise when user need to exercise initiating in directing the activities of a knowledge system.

CHAPTER 8

GENERAL FEATURES OF THE PUMPS

8.1 Introduction to Pumps

The pumps generally used for heating system and cooling system are the centrifugal pumps.

The centrifugal pumps recirculate hot water in heating system and chilled water in cooling system. The purpose of the recirculation is to predetermined rate of flow between the boiler/chiller and the space conditioning terminal units.

Other pump application on hydronic systems include

- Condenser water circuits to cooling towers and water source heat pumps
- Boiler fed
- Condensate return

Pumps are required with boiler feed and condensate return only if a stream boiler is included in the system. In such cases, the boiler manufacturer defines the specific pumping requirements. When a cooling water rejects heat for a chilled water plant, the condenser water pumps are selected on the basis of the flow rate specified by the refrigeration equipment manufacturer and location of the tower relative to the condenser.

In centrifugal pumps a driver converts part of the output torque into pressure energy by centrifugal force, which is a function of the impeller vane peripheral velocity. Impeller rotation add a energy to a liquid after it enters the eye of the impeller. The casing collects the liquid as it leaves the impeller and guides it out of the discharge nozzle. The pressure energy added by the pump overcome the friction caused by the flow through heating and air_conditioning equipment i.e piping, valves, coils, chillers or boilers and raises the water to a higher elevations such as to the to the top of the cooling tower.

8.2 Types of Pumps

Most centrifugal pumps used in hydronic systems are single stage with a single or double-entry impeller. Double suction pumps are generally used for high flow applications, but either form is available with similar performance characteristics and efficiencies. Selection can be based on installed cost and personal preferences.

These pumps have either volute or diffuser types of casings. The volute types include all pumps that collects the water from impeller and discharge it perpendicular to the pumps shaft. Diffuser type casing collects the water from impeller and discharge it parallel to the pump shaft.

Pumps can be classified by method of connection to the electric motor and can be closed coupled or flexible coupled. The close coupled pump has the impeller mounted directly motor shaft extension, while the flexible-coupled pump has an impeller shaft supported by a frame or bracket that is connected to the electric motor through a flexible coupling.

Pumps are also classified by their mechanical features and installation arrangement. Circulator is a generic term for pipe-mounted, low pressure, low flow units, and may be either wet rotor or conventional flexible coupled open-type motor driven. In addition to their application in residential and small commercial buildings, circulator recirculate flow of terminal unit coils to enhance heat transfer efficiencies and improve the management of large systems.

One horsepower and larger pumps are available as close coupled and base mounted. The close coupled pumps are end suction for horizontal mounting or vertical inline for direct installations in the piping. The base mounted pumps are end suction frame mounted or double suction horizontally split case units. Double suction pumps can also be arranged in a vertical position on a support frame with the motor vertically mounted on a bracket above the pump unit.

Pumps are identified by their vertical or horizontal position. The types of pumps used in heating and air-conditioning are

- Circulator
- Close coupled, end suction
- Frame mounted or flexible coupled end suction

- Double suction, horizontal split case single stage
- Horizontal split case, multistage
- Vertical in-line
- Vertical turbine

The following table lists these pump types and summarizes their design features.

Table 1 Mechanical Features of Centrifugal Pump

Pump Type	Impeller Type	Number of Impellers
Circulator	Single suction	1
Closed-coupled, end suction	Single suction	1
Frame mounted, end suction	Single suction	1
Double suction, split casing	Double suction	1
Vertical in-line	Single suction	1
Vertical Turbine	Single suction	1 to 20

Table 1 Mechanical Features of Centrifugal Pumps (Continued)

Casing	Motor Connection	Motor Mounting Positions
Volute	Flexible coupled	Horizontal
Volute	Close-coupled	Horizontal
Volute	Frame coupled	Horizontal
Volute	Flexible coupled	Horizontal
Diffuser	Flexible coupled	Vertical
Volute	Flexible or close coupled	Vertical

8.3 Construction of Centrifugal Pumps

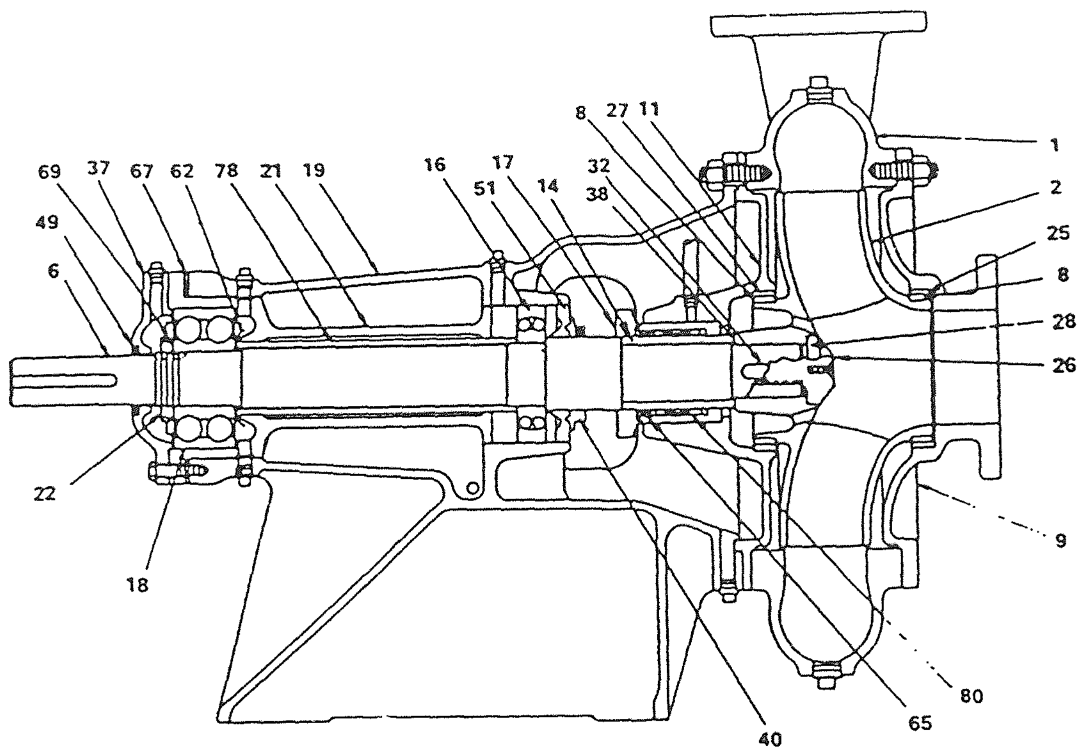
Followings are the features of centrifugal pumps

8.3.1 Material

Material of centrifugal pumps is generally offered in bronze-fitted, all bronze, or iron-fitted construction. In bronze fitted construction, the impeller, shaft sleeve, and wearing rings are bronze, and the casing is cast iron. These construction material referred to the liquid end of the pump.

8.3.2 Stuffing Box

Stuffing Box, is that portion of the pump where the rotation shaft enters the pump casing. To seal leak at this point a



1 Casing
2 Impeller
6 Shaft, pump
8 Ring, impeller
9 Cover, suction
11 Cover, stuffing box
14 Sleeve, shaft
16 Bearing, inboard
17 Gland
18 Bearing, outboard
19 Frame
21 Liner, frame
22 Locknut, bearing
25 Ring, suction cover
26 Screw, impeller
27 Ring, stuffing box cover
28 Gasket, impeller screw
32 Key, impeller
37 Cover, bearing, outboard
38 Gasket, shaft-sleeve
40 Deflector
49 Seal, bearing cover, outboard
51 Retainer, grease
62 Thrower, oil or grease
65 Seal, mechanical, stationary element
67 Shim, frame-liner
69 Lockwasher
78 Spacer, bearing
80 Seal, mechanical, rotating element

Figure 13. Cross Section of End Suction Pump

mechanical seal or packing is used in the stuffing box.

8.3.3 Mechanical Seals

Mechanical Seals are used predominantly in hydronic applications. Inside seals operate inside the stuffing box, while outside seals have their rotating element outside the box. Pressure and temperature limitations vary depending on the liquid being pumped and style of seal.

8.3.4 Packing

Packing is used where abrasive substances included in the water are not detrimental to system operation. Some leakage at the packing gland is needed to lubricate and cool the area between the packing material and shaft.

8.3.5 Wearing Rings

Wearing Ringsthese are used for the impeller or the casing. They are replaceable and prevent wear to the impeller or casing.

8.3.6 Ball Bearings

Ball Bearings are most frequently used, except in circulators, where motor and pump bearings are of the sleeve type.

8.3.7 Balancing Ring

Balancing ring is placed on the back side of a single-inlet, enclosed impeller to reduce the axial load. Double-inlet impellers are inherently axially balanced.

Nominal operating speeds of motors may be selected in the range between 600 and 3600rpm.

8.4 Pump Affinity Laws

The followings tables lists terms and equations for pumping and the affinity laws for pumps. These laws describe the relationships among the changes of the pump impeller diameter, speed, and specific gravity. Without knowledge of the system curve, the laws should not be used to predict the pump performance of a hydronic system.

Figure 14 describes pump performance at 1750 and 1150rpm, in accordance with the affinity laws for constant impeller diameter and viscosity.

8.5 Pump Performance Curves

Performance of a pump is most commonly shown by graphs, which relate the flow, the head produce, the power required, the efficiency, the shaft speed, and the net positive suction head required for pumps with various impeller diameters. Pumps curves present the average result obtained from testing several pumps of the same design under standard test conditions.

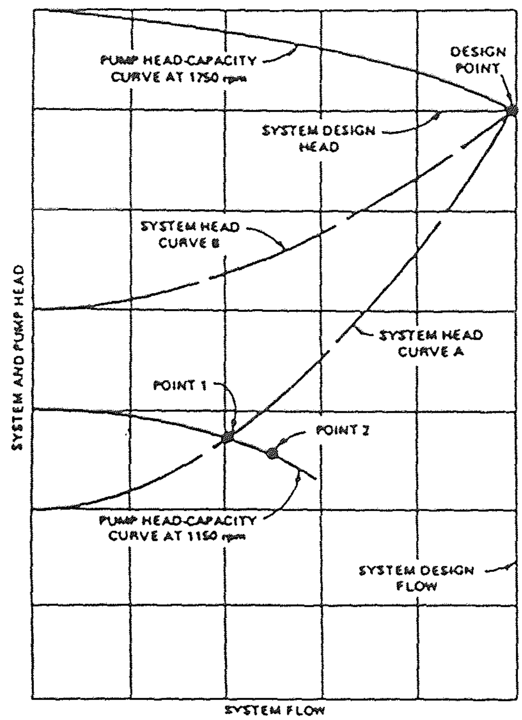


Figure 14. Application of Affinity Laws

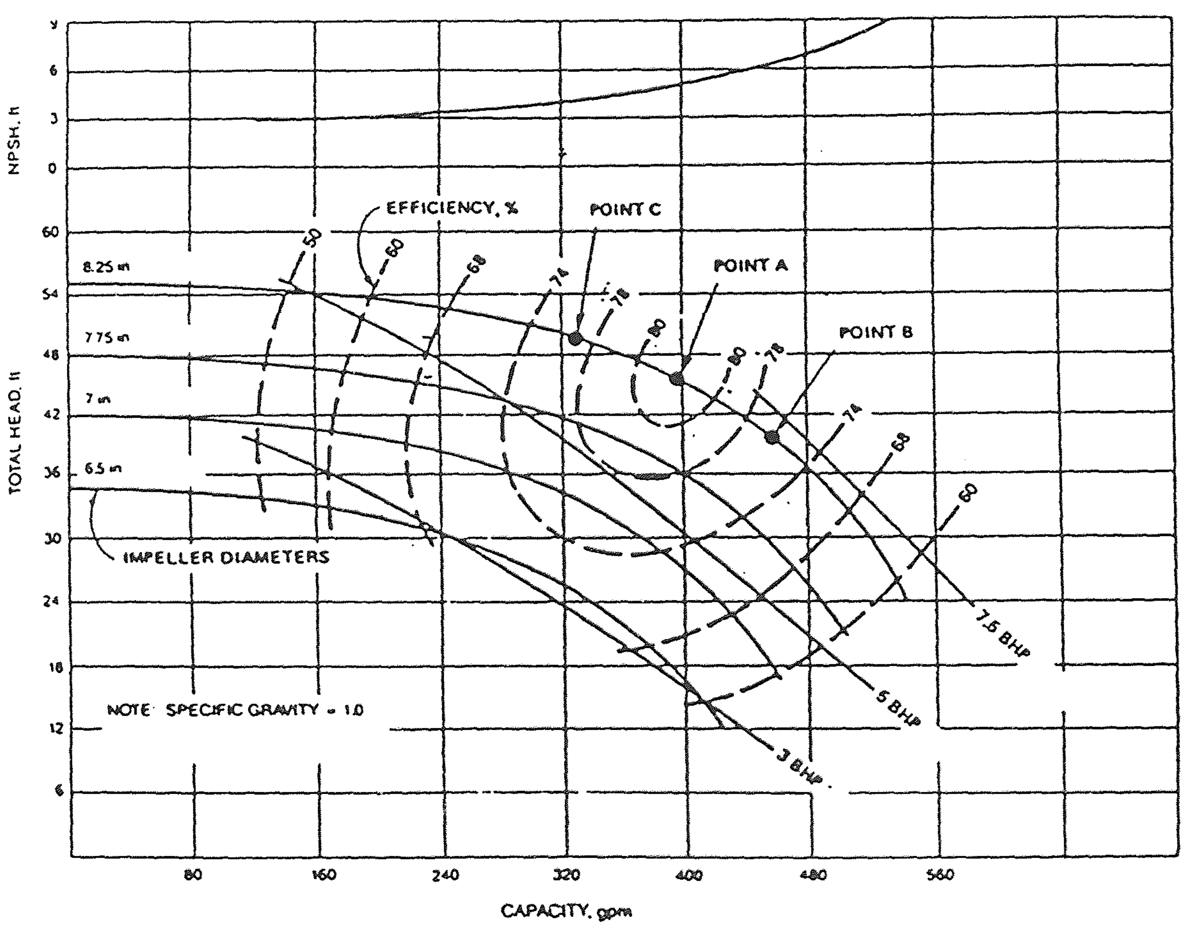


Figure 15. Pump Performance Curves

8.6 Pump Suction Characteristics (NPSH)

If the absolute pressure on the liquid at suction nozzle approaches the vapor pressure of the liquid, cavitation occurs, and vapor pockets form in the impeller passages. The collapse of the vapor pockets could progressively damage the impeller.

The amount of pressure in excess of the vapor pressure required to prevent the formation of vapor pockets is the net positive suction head required (NPSHR). NPSHR is a characteristic of a given pump, and varies considerably with pump speed and flow. NPSHR is determined by testing individual pumps, it increase rapidly at high flows, as shown in figure 15.

8.7 System Curves

The friction loss of a piping system depends on the flow rate through it. If one set of friction pressure/flow rate data is available, as characteristic curve may be developed for the system by using the principle that friction pressure varies directly with the square of the flow.

After the appropriate temperature difference is determined, the design flow rate is established. The form of the piping circuits and their sizes are developed next, and the design friction loss is calculated. When these two values are known friction losses corresponding to other flow rates are calculated using the formula $H1/H2 = (Q1/Q2)$.

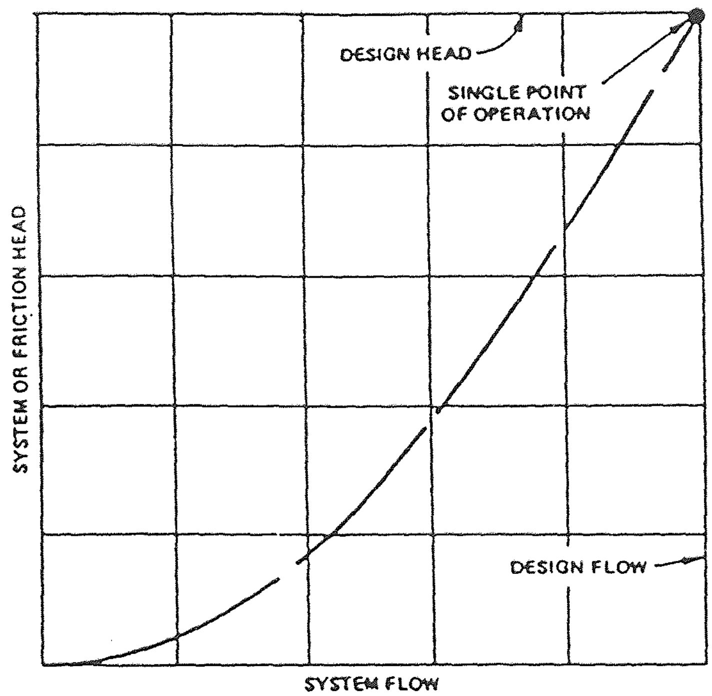


Figure 16. Constant Flow System Curve

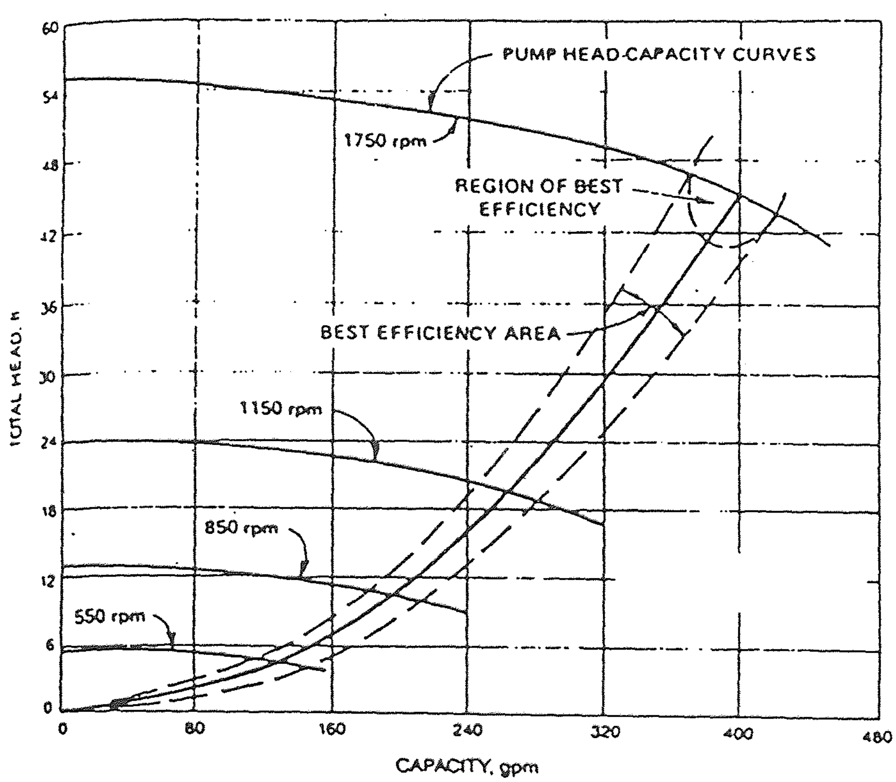


Figure 17. Pump Best Efficiency Curves

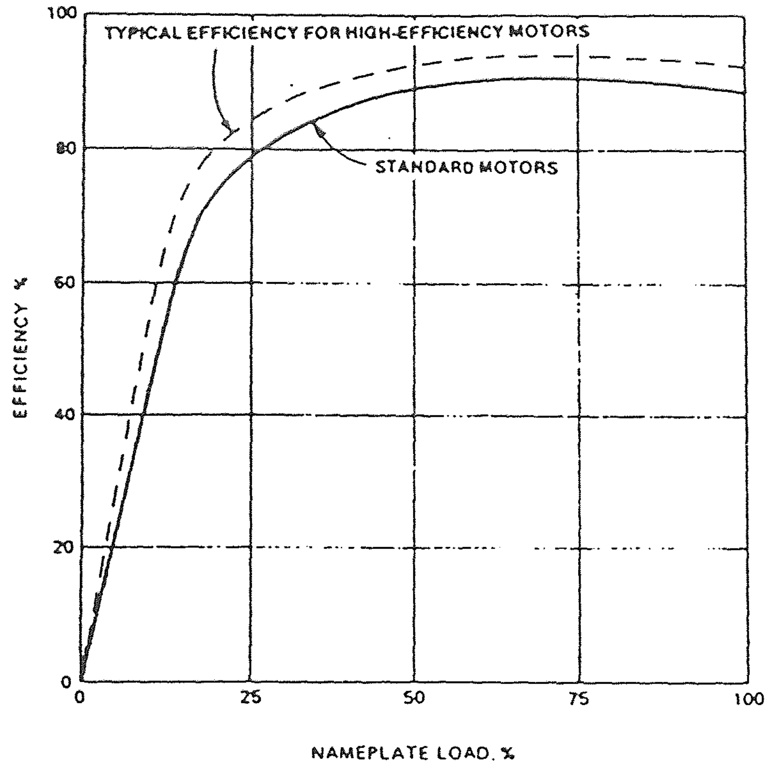


Figure 18. Efficiency Curve for Induction Motor

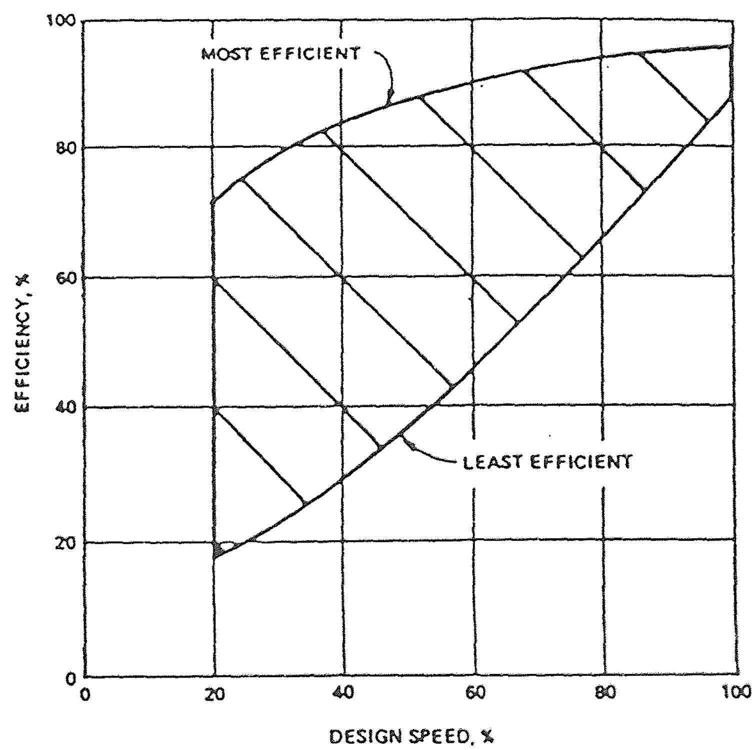


Figure 19. Efficiency Range of Variable-Speed Drives

Plotting the known and calculated points generates the system pressure curve as shown in figure 16.

8.8 Hydronic Applications

There are four major types of hydronic systems that use centrifugal pumps

- Chilled Water and Hot Water Pumps
- Condenser Water
- Condensate or Boiler Feed Water System

8.8.1 Chilled and Hot Water Pumps

Chilled water and hot water pumps are used in closed recirculating systems. Hot water pumps, particularly hot water units, require special pumps features such as high temperature seals and thermal expansion means. The hydraulic application is similar for chilled and hot water pumps.

Figure 20 illustrate a typical system curve for a variable volume, chilled or hot water system. Flow is regulated through the heating or cooling coils by two way valves. The independent pressure, as shown is the pressure drop of the heating and cooling coils and their control valves. The system friction pressure is much greater than the coil and valve loss, resulting in a steep system curve. Such a system lends itself to multiple pumps, two-speed motors, or variable speed drives on the pumps to avoid overpressuring the system.

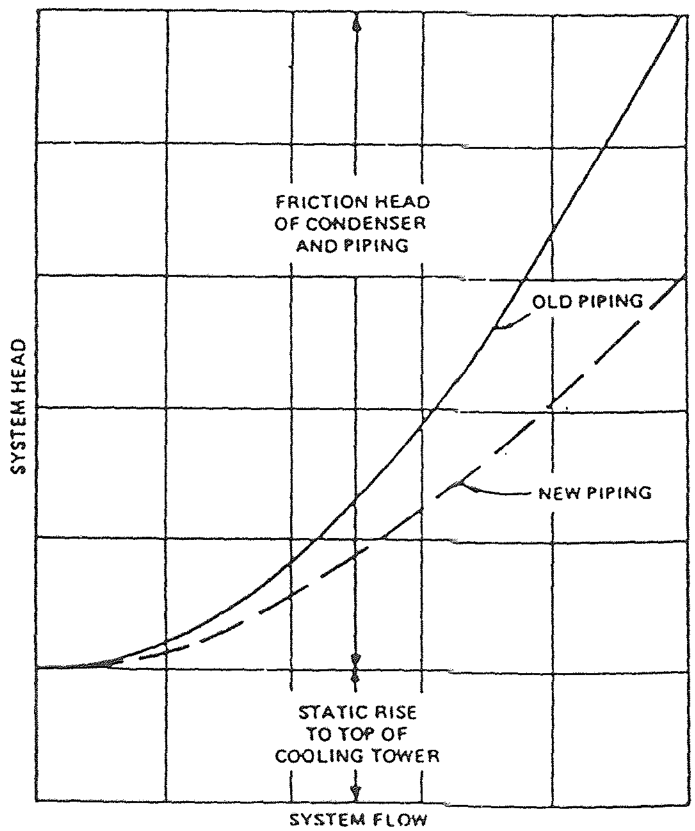


Figure 20. System Head Curve for Condenser Water System

8.8.2 Condensate Water

In cooling towers, the independent head is the static pressure rise to the top of the cooling tower, as shown in figure 14. The suction condition of condenser water pumps must be considered to ensure that the NPSHA from the system is always greater than the NPSHR by the pumps. To avoid the negative effects of the suction, turbulence and friction, the condenser protection strainer should be placed on the discharge side of the pump. Also condenser water pipes may become rusted, eroded, or coated with material, thus pipe friction must be evaluated on a new and old pipe basis.

8.8.3 Condenser and Boiler Feed System

Condenser and boiler feed systems have flat system curves as compared to the chilled, hot, or condenser water systems. The boiler pressure is the independent head and in most cases is much greater than the system friction head. These system lends themselves to parallel pumping and seldom require two speed or variable speed pumps. Because these units pump hot condensate from open tanks, care should be taken to ensure that the NPSHA from the system is always greater than the NPSHR by the pumps.

The reason to provide this all information about pumps is that whenever someone want to make advancement in the pump warehouse expert program he/she can get the necessary information.

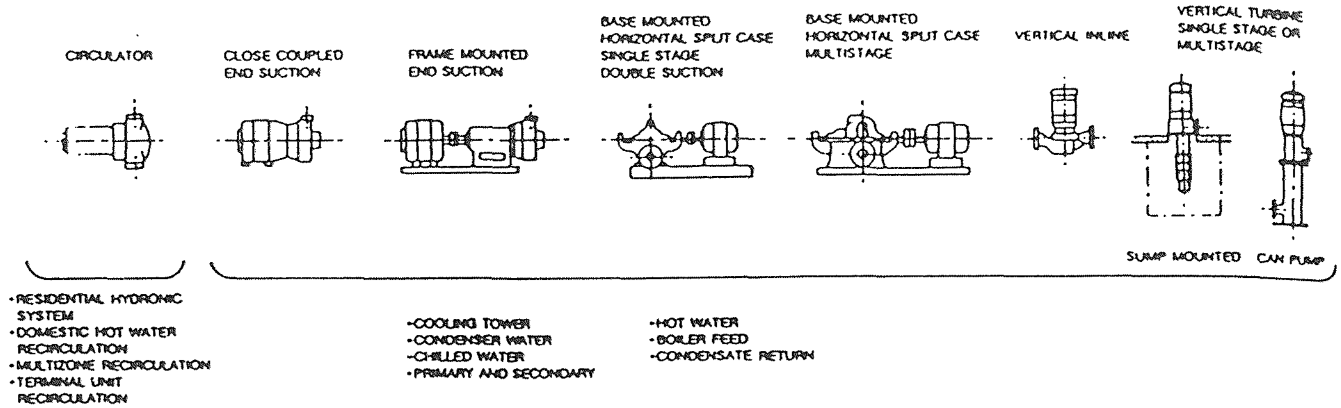


Figure 21. Applications for Centrifugal Pumps Used in Hydronic Systems

The discussion about types of pump, its general construction, and hydronic applications gives a broad concept of centrifugal pumps to readers.

CHAPTER 9

OBJECTIVES AND METHODOLOGIES OF PUMP WAREHOUSE EXPERT (PWE)

9.1 Introduction to PWE

The primary purpose to develop this program is to reduce the gap between theory and practice of the expert system technology in the field of manufacturing systems engineering.

Recent years have seen major changes within the manufacturing industry in the united states. One of the factors which contribute most to these changes is to the lesson termed by the decline in automobile business and loosing consumer market to foreign countries specially to Japan. This factor has given grater awareness to Unites States industry to introduce more efficiency and flexibility to manufacturing environment.

Many companies are now convinced to the effectiveness of expert system technology and want to integrate this technology with each and every function of the manufacturing environment such as inventory, cost analysis, decision making and quality control etc.

Pump warehouse expert is a model program to show how this technology is an asset for the American Manufacturing Industries.

The following three modules are designed in the PWE.

- Module for Inventory Analysis

- Module for Cost Analysis
- Module of Decision Making for the Selection of Pump

The purpose to develop inventory analysis module is to maintain the inventory level in a pump warehouse. The module for cost analysis gives the option of cutting the cost of the final product by introducing discount and the third and last one shows the effectiveness of expert system technology in decision making.

9.2 Features of Pump Warehouse Expert (PWE)

- This system consist of a knowledge base system containing rules for controlling the modules, two database files contain the record of all the critical characteristics of the pump. These characteristics of the pump provides technical details of the pump to customer.
- Database file can be updated any time if some or all of the variables have to be change for some reason or whenever information about new incomings have to be put in the database file.
- The cost analysis module provides an option of discount rate depending on the number of pumps customer he/she buying.
- The selection module provide all the technical information of the pump.

- The inventory module helps in making the right decision at the right time for maintaining the certain inventory level in the warehouse.
- This system is user-oriented and ask for an input data to user in simple English.
- The output from the system can be provided in such a way that it can be easily understood by the user.

9.3 Ten Design Rules for an Expert System

Endosowan (1987) suggested the following ten design rules for the system designers.

9.3.1 Obtain the Right Knowledge Base

The knowledge base must be constructed by collecting accurate information from history, experience and expert judgment, that has been tested in an adequate environment with demonstrated successful results.

9.3.2 Form Knowledge Base Procedure

The knowledge base procedure should include consistent and correct methodology for solving the problem being addressed. The designer of the expert system must ensure that the procedure is based on streamline useful information from Rule 1.

9.3.3 Provide Adequate Structure for Systems Prompts and Human Socialization

Expert system prompts should be designed to emulate the human phrases which they are expected to represent. Prompts that are not clear to users causes problems. This can create limitations and dislike for the system. Expert system designers must endeavor to use program statements which are clear and concise.

9.3.4 Provide Adequate Response Time

Every expert system should be geared toward increasing productivity. Human waiting time for the system must be kept to a minimum if it is going to be productive. Unnecessary iterative procedures, rules and loops in programing should be avoided.

9.3.5 Provide Adequate Documentation for Variables

System designer should provide the ability for the users to query and interface with expert systems in a friendly manner. The documentation process involved in the use of the expert systems can be made simple through the use of illustrative flow chart and graphical displays and symbols.

9.3.6 Provide Adequate Time-Sharing Options

In order to increase productivity and utilization of an expert systems, the system must have adequate provisions for simultaneous use by several workers.

9.3.7 Provide Adequate User Interface on Expert System

An expert system should allow workers an opportunity to learn new skills or enhance existing knowledge bases. The control options provide in the system must be free from psychological and stress problems. The expert system work station must be ergonomically feasible for workers to use.

9.3.8 Provide Inter-System Communication Ability

The effectiveness of an expert system is greatly enhanced if its various system can communicate with each other under a system network. The ability of the various expert system to understand the same natural language is of equal importance.

9.3.9 Provide Automatic Program Ability and Controls on Expert System

Automatic programming and control will minimize system downtime and increase efficiency of an expert system. The various controls should have the capability to alert end users to potential events.

9.3.10 Provide Flexibility for Ongoing Maintenance and Update of the Expert Systems

New techniques, approaches and methodologies for solving problems arise periodically. Expert system design must allow a flexibility in updating the experience base of the system, procedures and options.

The adherence to these ten rules in developing and designing of an expert system usually results in a successful and practical expert system.

9.4 Definition of Important Parameters Used in PWE

- GPM, is the unit of flow rate, in gallons per minute
- Net Positive Suction Head, is the minimum pressure required by the pump to avoid cavitation. It is measured in feet.
- Horsepower, is the unit of the power of motor.
- Impeller, is a rotating part of the machine, which is able to rotate continuously and freely in the fluid, allowing an uninterrupted flow of liquid. Its dia is measured in inches.
- Head, is the total (pressure, kinetic, potential) energy per unit weight. It is measured in feet.
- RPM, is the speed of the motor.
- Efficiency, is defined as ratio of the power output of a machine to the power input into it.
- Model Number, is the assigned code number by the company to a pump for their own recognition of pumps.

9.5 Description and Development of PWE

The PWE is a VP-Expert based microcomputer Shell, developed by Brian and Sawyer 1989 for paper back software international. It is written for IBM and compatible microcomputers. This shell works under DOS environment with

512K RAM or more. The version of this shell can be 2.0 or higher.

Vp-Expert is a powerful educational tool and it is equally helpful for the beginner and advance level programers. It provides to the user a good dictionary of commands which can be used to develop variety of programs. It should be noted here that among the number of commands only those commands are used which are helpful for the developmental structure of the program.

The structure of the program revolves around an analytical approach, database file, and a set of intelligent rules for modules.

This program contains the following three files which must be in one diskette in order to run the program.

Project.Kbs

Pumps.dbf

Cash.dbf

The project.kbs is the expert programing file. It contains all the rules for the program and runs all the modules of the program. The pumps.dbf and cash.dbf are the database files which are used for data input. Some commands used in expert system programming make the project.kbs capable of retrieving and updating the data from the database files.

The followings are the important commands which governs the program.

ACTIONS COMMAND, an action block contains the system's strategic plan. It tells the inference engine what to look for. Inside an action block is a list of one or more clauses which the program will execute during a consultation. Clauses in an ACTIONS block are executed in order.

The ACTIONS block must begin with a key word ACTIONS. It will contain one or more clauses and a semicolon must be used at the end of the entire block. The two most common clauses used in the ACTIONS block are FIND and DISPLAY.

FIND must be followed by the variable name which you have chosen for your goal.

DISPLAY is used to supply text whenever a goal value is displayed.

RULES COMMAND,the RULE represent the actual expertise of the system. They contain the domain expert knowledge. Each rule is written in IF and THEN form. As a group the RULE should include all the knowledge which might be needed during a consultation. RULES may be written in any order, but their sequence may have an effect on the results of a consultation.

Each RULE must begin with the key word RULE, followed by a space and then a label. This label can be a name or more commonly a number which serves to identify the RULE. Also a RULE must have premise and a conclusion. The premise must begin with the key word IF and the conclusion with the key word THEN. Optional clauses in the conclusion can begin with ELSE and BECAUSE. A RULE must end with a semicolon. For reference see the example.

WHILEKNOWN-END command,the WHILEKNOWN-END is a loop. The first word of the loop is WHILEKNOWN and the last word is END. WHILEKNOWN-END loop provides that the variable used to control the loop has a value other than UNKNOWN whenever END is reached. Only one WHILEKNOWN loop can be active at one time.

WOPEN, is used to create a window on the consultation screen. It requires six integers parameters (1, 2 & 3, 4, 5, 6). The meaning of these integers to VP-Expert is as follows

1 is used for the number of window being opened.

2 & 3 are the row and column coordinates of the upper left-hand corner of the window.

4 is used for the number of rows window occupy.

5 is used for the number of columns window occupy.

6 is used for the color of the window background.

ACTIVE is used to activate the window. It is used in conjunction with WOPEN command. ACTIVE is followed by a single integer 0 to 9, which means that number of window has to be opened.

CLS is used to clear the consultation screen.

Color is used to give window background color and blinking color of text. 0 to 15 are background colors and 16 to 31 are blinking colors.

9.5.1 Function of Rules

All the rules are interlinked with each other based on influence diagram. An influence diagram is explained in detail in chapter 3. The basic concept of influence diagram is that, "it is the data that can be easily transformed to solve similar type of problem".

All the rules work according to some logic, which is explained below.

The basic function of rule 1 is to update the database file, "pumps". The logic of this rule is that GET command retrieves the pump variables from the database file, when the values are assigned to each variable the APPEND command update the database file. MRESET clause frees up the memory automatically allocated to the memory generated by the last menu clause.

The function of rule 2 is to list the pumps one by one to check the inventory level. The GET command retrieves the most current data from the database file and simply display it. The variable "C" was used to assign the number to each type of pump.

The logic of the rule 3 is same as the rule 2 other than different variables were used to retrieve the database file "pumps".

In the rules 4 and 5 three works are being performed. Firstly is the calculation work for the quantity of pumps and motors and their cost. Secondly the display of all variables and third is updating the database file "cash".

In rule 6 the get command was used to retrieve the database file cash.dbf. Once the data is retrieved it is used for calculating the total numbers of pumps and motors sold and grand total of sale on a particular day.

9.6 Reason to Choose Pump Warehouse for Problem Analysis

A pump warehouse was considered to analyze all the modules of the program.

The warehouse was designed more than twenty years ago, when both the product and the production system were completely different from the present situation. Thus, the warehouse represent a macroscopic imperfection of the logistics system, that's why the warehouse was made the target of analysis for the problem.

The warehouse of any manufacturing industry is the critical factor on the financial performance of the company. There are many questions related to the warehouse i.e whether to keep the in-process inventory in the warehouse or not, how to reduce the cost of the inventory, and what level of finished product should be maintained in the warehouse, etc.

The following modules of the program were designed to maintain the finished product inventory, and cost analysis and making decision for the selection of the product which is pump.

To make the problem easy a basic concept of the terms like inventory, cost analysis and decision making is provided with the discussion of the each module.

9.7 Module for Maintaining Inventory

There are two parts of this module, the fist one update the new incoming and the second one shows the inventory level of a particular model with other parameters of the pump. Before going into the further detail about the structure and working of the module the author would like to discuss and give a basic concept of the term inventory to make the problem easy for the readers.

9.7.1 General Concept of Inventory

Broadly speaking the term inventory can be interpreted as any unutilized asset awaiting for sale or use. It can include any tangible asset such as equipment, machine parts, tools, personnel, vehicle, cash or support equipment.

The term inventory is still debatable for many industries up to now, because of the question whether to keep the level of inventory high or low. In the manufacturing industry there are two types of groups who have two different opinion about the level of inventory.

One group believes that buffers between the station cause problems in terms of money but inventory is not the reason, rather it is scrap, downtime, and variability which cause production problems. This group also believes that the presence of high inventory tends to attract more customers and decrease in the level of inventory results in the decrease of sale.

The second group believes that keeping the inventory level high is not the solution of the problem. In the opinion of the author this group is more moderate group than previous and because their thinking is more flexible and broad.

They suggest that the inventory should be removed gradually to expose the problems because high inventory hides the production problems. By lowering the level of inventory gradually problems exposed one by one and hence it is easier to remove them permanently from the manufacturing process. This group also believes that the sincerity and maturity of the workers immensely help in cutting the inventory.

9.7.2 Types of Inventory

There are three kinds of inventories, raw material, in-process and finished goods. Supplies to an organization also count as a kind of inventory which include pencils, paper, and other organization necessities.

Raw material are items purchased from suppliers to be used as inputs into the production process. This raw material is transformed into finished goods. The example of raw material in a plastic manufacturing company are resins, inserts, and screws etc.

In process goods are those which are partially completed final product which are still in the production process. The example of in process inventory in a plastic manufacturing industry is cover, back and lenses, laches, key, pivots, gears and other components which will be used in the assembly of a dispenser.

Fished goods are the final product ready for shipment or storage. The typical example of finished goods in a plastic company are dispensers, bottles, toilet seat covers, and other plastic products.

The kinds of inventory also vary from company to company i.e if the responsibility of a particular company is only to mold the car handles, then it is the finish product for that company, but it is in process inventory for the company (GM) who is involved in assembling the car handles in a car.

9.7.3 Type of Inventory for Pump Warehouse

The pump warehouse carry the fished product inventory only, which are pumps ready to storage and sale on an order from customers.

9.7.4 Level of Inventory Maintained in PWE

The level of inventory maintained in PWE is 500 units of pumps and motors for each model based on 10 days of lead time period. It is the responsibility of the user to check the level of inventory at the end of each day and order as per required units to production department.

9.7.5 Function of Inventory Module

As mentioned above there are two parts of inventory modules. The first part "inventory update", takes care of all the incomings in the warehouse. One of the feature of this module is to update the inventory with other characteristics of the pumps i.e that head, GPM, Impeller Dia, efficiency, Net Positive Suction Head, Model number of the pump, horsepower, and unit cost of the pumps and motors. (all of these parameters are defined in section 9.4).

The purpose to provide this technical data into the database file is that all the modules are interconnected to each other. This information is needed in the "selection module" of the pump to check the performance of the pumps, provided on the base of some known parameters which will be discussed in that module.

The advantage of entering all this information with updating the inventory in the database file is that whenever the user check the inventory in the part two of the module, he/she can get the technical information of the pump if needed.

Whenever the user select update inventory module program, a series of inquiries runs on the screen. To update the incomings, user have to provide the required information by simply giving the answers of all the inquiries. The inquiries of this module are as follows

- Enter the model number of the pump.
- Enter the flow rate in GPM.
- Enter the speed of the pump in RPM
- Enter the required head of the pump in feet.
- Enter the horsepower of the pump.
- Enter the efficiency at part load.
- Enter the impeller dia of the pump in inches
- Enter the NPSH of the pump at part load.
- Enter the quantity of pumps.
- Enter the unit cost of pump.
- Enter the quantity of the motors.
- Enter the unit cost of the motor.

Once the user provide the answers of all these inquiries and hit enter all the information is updated in the database file "pumps" automatically. In this way all the incomings are updated in the program.

The purpose of the second part of the module is to check the inventory level of any particular or all the pumps and motors available in the warehouse. The user is responsible for maintaining a certain level of inventory, if the inventory falls below that level he/she are responsible to make an order in order to maintain the given level of inventory.

When the user select this part of the module all the information about each pump is retrieved from the database file "pumps" and display on the screen one by one in the following format.

Model:-	{Model}	=	2AC
GPM:-	{GPM}	=	100
HEAD:-	{HEAD}	=	100
RPM:-	{RPM}	=	3500
HP:-	{HP}	=	5
EFF:-	{EFF}	=	65%
IMP-DIA:-	{IMP-DIA}	=	5
NPSH:-	{NPSH}	=	8
QMOTORS:-	{QMOTORS}	=	51
CMOTORS:-	{CMOTORS}	=	$65
QPUMPS:-	{QPUMPS}	=	51
CPUMPS:-	{CPUMPS}	=	$200

All these parameters are given in table 3.

One of the feature of this module is that if the user has, had any wrong characteristic of the pump in the update module by mistake, he/she can consult the database file "pumps" to make the correction. Similar procedure can be used for the errors detected later on.

9.8 Module for Making Decision for Selection of Pump

In this module author design a simple decision system based on the selection of pumps to justify the effectiveness of expert system technology in decision making.

9.8.1 General Description of Decision System

Decision making is a process decipline that allows decision makers to analyze complex, dynamic and uncertain decision problems. It provides a framework of principles useful in focusing a decision maker's attention on only those problem feature that are most relevant to the decision being made. Much of the power of the decision analysis lies in its ability to effectively integrate many factors that effect a decision. Such an integrating capacity makes decision analysis a very successful means of facilitating the decision making process.

Two criticism of decision analysis are that the amount of effort expended and the time spent on modeling a problem are too burdensome and the resulting model is applicable to only one specific problem. Thus it would be helpful to use information learned in one decision problem to solve other similar problems. Therefore, a knowledge-based decision system provides a means for decision makers to exploit the normative power of decision analysis in a relatively simple and inexpensive way.

9.8.2 Function of Decision Module

Every decision system is based on some sort of data. This module was also designed by using some data of the pump parameters.

The data used in the selection of pump is important, to ensure that an adequate, reliable, efficient pump is selected. The following is some of the information required in the selection of pump. It should be noted that specific application may have conditions that require further information and an economic evaluation.

- Maximum and minimum flow in system
- System pressure at maximum and minimum flows
- Continuos or intermittent operation
- System operating temperatures and pressures
- Pump environmental conditions, including ambient temperature
- Number of pumps required and percent of standby required for emergency operation
- Electrical current characteristics
- Electrical service starting limitations
- Special electrical controls
- Water chemistry that may effect material selection

In this module only some important parameters of the pump were used to make the decision about the selection of pump. i.e model number, impeller dia, horsepower, NPSH, RPM, GPM, and efficiency of the pump. (The definition are provided in section 9.4).

It is the common practice that the pumps are ordered by their GPM and HEAD. Hence a need was felt by the author to develop such a decision module which would work according to standard business environment.

This module works around these two standard parameters of the pump. When the user select this module the following enquiries run on the screen.

- Enter the GPM of the pump.
- Enter the HEAD of the pump.

As the user answer this inquiries, all the characteristics of the pump appears on the screen in the following format.

Model:-	{Model}	=	2AC
GPM:-	{GPM}	=	100
RPM:-	{RPM}	=	3500
EFF:-	{EFF}	=	65%
IMP-DIA:-	{IMP-DIA}	=	5.5
HP:-	{HP}	=	5
NPSH:-	{NPSH}	=	8
QPUMPS:-	{QPUMPS}	=	1000
CPUMPS:-	{CPUMPS}	=	$200
QMOTRS:-	{QMOTRS}	=	1000
CMOTRS:-	{QMOTORS}	=	$50

The advantage of this module is that it provide all the important information about pump without going into the complex paperwork.

The feature of this module is that it provides all the information about the pump characteristics and cost of motors and pumps needed.

9.9 General Concept of Cost Analysis

It has been observed that in traditional manufacturing environment, the manufacturing engineers and accounting managers always have conflicting concept about the cost of the product. These conflicts occur because of the facts and data, which never agrees with respect to cost and revenues expectations. However, it does not mean that sets of data they get are wrong but problem occur because of the perspective they were derived from.

One of the method to overcome this problem is that the fictional differentiation should be replaced with product teams. These product teams should be consist of a representative from manufacturing engineering department, accounting department, and marketing department.

Once this team is made they should be held responsible for cost analysis of the product and getting a final cost of the product.

Some time it is helpful that the companies have permanent team members for this purpose which results in better understanding and harmony in the team.

The major portion of the analysis should be devoted to final cost of product and risk in terms of cost variation. The following are the advantages of using this approach.

- Causes of risk and reasons for their impact on cost are described.
- Significant problems and risks that should be addressed are acknowledged.
- Contingencies that would effect revenues or cost are considered.
- Possible effects of different risk can be compared.

- Areas where control effort should be concentrated are highlighted.
- Quantitative information is provided to give a raealistic view of what might happen, for instance how likely a product is to achieve targets set for it and what the probability of cost overruns is.
- Employees are shown that a possible outcomes exists, depending on the measure they take.

9.9.1 Module for Cost Analysis

There are three parts of this module one gives the final cost of the product and cost of product after discount, while the other one gives the total sale of the product on a particular day.

The reason to select the final product as a cost analysis target is that whenever the product has to be marketed, the first question to ask is, "How much does the product cost the customer?"

In the recent manufacturing environment most of the manufacturing process are often determined at the conceptual design phase. Therefore the most appropriate time to control the final product cost is during the analysis and developmental stage, even though most of the cost are not incurred until much later.

In this module to attract the customer the following options were introduced

- if the customer want to buy a less than fifty units he /she is paying more overall cost.
- if the customer is buying a more than fifty but less than 100 units he/she getting a 15% discount.

9.9.2 Functions of the Cost Analysis Module

This module is responsible for calculating the final and discounted cost of the pumps.

Whenever the user select this module, the following questions appears on the screen

- Enter the model number of the pump.
- How many pumps have to be purchased.
- How many motors have to be purchased.
- Enter he todays date in the format mm-dd-yy.

Once the user enter the answer of these question the following formulae calculate the final product of the pump.

It should be noted here that the APPEND command update the current number of pumps and motors, by subtracting the number of pumps and motors sold from database file "pump.dbf automatically. This is one of the main function of expert system technology here.

$$QPUMPS = (QPUMPS - QTYP)$$

where

QPUMPS are the number of pumps in the database file "pump.dbf"

QTYP are the number of pumps in "cash.dbf" which customer want to purchase.

AMT = (CPUMPS * QTYP)

TAX = Y

TOT = ((AMT * TAX) + AMT)

DISCT = (TOT * X)

where

AMT is the cost of pump

Y is variable for percent of tax

TOT is the total amount of pump of the pump

DISCT is the discount on total

X is variable for discount percent

Same logic was applied for the calculation of final cost of motors. The only difference is that the variables were named different since it is against the logic of the expert system technology to use the same variable name in the program. The use of same logic for the calculation of cost of motors is the use of new advancement in expert system technology called influence diagram.

The author want to mention here that it is the new research in expert system technology that same data can be used to perform different tasks. This technique is called influence diagram. Influence diagram is a data structure that can be profitably transformed in order to solve similar problems. The influence diagram is describe in more detail in chapter 3 of this thesis.

QMOTRS = (QMOTRS - QTTM)

SUM = (QMOTRS * QTTM)

TAX = A

TOTL = ((SUM * TAX) + SUM)

DISCONT = (TOTL * B)

Once this calculation is done, all the information is displayed on the screen. This information carry with it the cost of pumps and motors as well as all the mechanical features of the selected pump which is an added advantage of this module.

The other part of this program was designed to facilitate the analysis of the final product of cost for the product team during the marketing of the product. The product team is avoided to long and complex paper work and all the information they needed about the sale report of pumps and motors is provided instantly for the analysis.

The report display with model number of pump, unit cost of pump and motor, number of pumps and motors sold, and total sale of particular model.

This part also provide the information about the net quantity of pumps and motors sold and the grand total of sale for a particular day. In providing this information the module uses following formulae

NETQTY-PUMPS = (NETQTY-PUMPS + PQTY)

NETSALE-PUMPS = (NETSALE-PUMPS + COSTERND)

where

NETQTY-PUMPS is the net quantity of pumps

PQTY is the quantity of pump

COSTERND is the cost of pump

Same logic was applied for the calculation of the net sale of motors

NETQTY-Motors = (NETQTY-Motors + MQTY)

NETSALE-Motors = (NETSALE-Motors + CSTERND)

GRAND-TOTAL = (NETSALE-PUMPS + NETSALE-MOTORS)

where

MQTY is the quantity of motors

CSTERND is the cost of motor

9.10 PWE User,s Manual

In order to run PWE, the user must follow the following steps.

- Make sure that the following files are in the same diskette.
- PROJECT.KBS
- PUMPS.DBF
- CASH.DBF
- The software needed to run PWE is VP-EXPERT version 2.0 or higher.

- If you are using two disk drive system, place the program diskette containing VPX in drive A. Insert the diskette containing the knowledge-base PWE in drive B.

If you are using system with a hard disk containing VPX on it, then place the knowledge-base in floppy disk drive.

To start the program type VPX at the A> and then press <ENTER>.

When the main menu appears on the opening screen, select the path option by moving the cursor using the arrows keys.

You will be asked "what is the new path?"

- If you are using two floppy disk drive system type B: press <ENTER>.
- If you are using system with a hard disk, then type the drive name and press <ENTER>
- Choose consult from the main menu by moving the cursor and press <ENTER>.

You will be asked "choose a file"

Select PWE and press <ENTER>

- Choose GO from the main menu and press <ENTER>
- Answer the question asked during the consultation by selecting the choices displayed.

After making the selection press <ENTER>

- To quit the VPX system during the consultation type "/q" and after the consultation run press F8.

Table 2 List of Variables/Parameters Used in PWE

AMT	Price of pump in dollars
COST	Price of motor in dollars
CSTERND	Total cost of motor
FRIC	Pressure of pump
HP	Horsepower is the unit of pump
MQTY	Quantity of motors
COSTERND	Cost of pump
EFF	Efficiency of pump in percent
IMP-DIA	Impeller dia of pump in inches
NPSH	Net Positive Suction Head in feet
FLOW	Water flow in GPM
GTOTL	Grand total of pump and motor
CMOTOR	Cost of motor
CPUMPS	Cost of pump
FORCE	Horsepower of the pump
HEAD	Pressure of the pump
MODEL	Model number of pump
PERFOR	Efficiency of the pump

APPENDIX A

PUMP WAREHOUSE EXPERT (PWE) PROGRAM

```
ENDOFF;    ! Turn off the use of end key
RUNTIME;   ! Disappears the default rules and other windows
!EXECUTE;  ! Directly start the consultation


! ACTIONS BLOCK

ACTIONS

WOPEN 1,1,1,20,77,3
WOPEN 2,1,1,20,77,7


ACTIVE 1
COLOR = 20
     Display "
                              Pump Warehouse Expert Program"
COLOR = 5
     DISPLAY""
     DISPLAY""
     DISPLAY "     Presented By Muhammad Mutahir Ghauri"
     DISPLAY "    --------------------------------------"
COLOR = 0
     DISPLAY""
     DISPLAY""
     DISPLAY               "Synopsis of the program :-"
     DISPLAY              "---------------------------"
     DISPLAY"
```

The following program has been written to facilitate a pump warehouse manufacturing facility. The main function of the program is to maintain the inventory level of each model available in the warehouse, make decision for the selection of pump and finally make a cost estimation for the selected pumps. The specific description of each module is given at the begining of that module."

```
     DISPLAY""

WHILEKNOWN Switch
RESET Switch
FIND Switch
END

CLOSE 1

COLOR = 0

CLS
ACTIVE 2


!The following variable is the main variable which has been
!used in each of the five modules and drives the program all
!the way upto the end.


DISPLAY " New entry to the database file "
MENU Catalog,ALL,pumps,ALL


FIND Record

CLOSE 2
;

! Rules Block

RULE 1

     IF    data = update
     THEN  Record = add


! This part of the program adds data to the existing
database file


CLS
COLOR = 5
```

```
DISPLAY " DATA ENTRY MODULE"
DISPLAY " ----------------"

COLOR = 0

DISPLAY"
```

This module updates the database file and add new records of the pump to the database file. In order to enter the new records to the database file the user has to select this module. Once the module is selected, it ask certain questions about the incoming inventory, design and performance criteria of the pump. The user is responsible to answer these question in order to update the inventory."

```
DISPLAY""
DISPLAY""
DISPLAY""
DISPLAY " Press any key to continue ~"

CLS
WHILEKNOWN Model
GET Catalog = Model,pumps, ALL
MRESET Model
Find Catalog
Model = (Catalog)
MRESET GPM
FIND FLOW
GPM = (FLOW)
MRESET HEAD
FIND FRIC
HEAD = (FRIC)
MRESET RPM
FIND SPEED
RPM = (SPEED)
MRESET HP
FIND FORCE
HP = (FORCE)
MRESET EFF
FIND PERFOR
EFF = (PERFOR)
```

```
MRESET IMP_DIA
FIND SIZE
IMP_DIA = (SIZE)
MRESET NPSH
FIND SUCTION
NPSH = (SUCTION)
MRESET QPUMPS
FIND QUANTITY
QPUMPS = (QUANTITY)
MRESET CPUMPS
FIND COST
CPUMPS = (COST)
MRESET QMOTRS
FIND COUNT
QMOTRS = (COUNT)
MRESET CMOTRS
FIND PRICE
CMOTRS = (PRICE)

APPEND Pumps

WHILEKNOWN Switch
RESET Switch
FIND Switch
END

END;

RULE 2

          IF   data = list
          THEN Record = enlist

CLS


! This part of the program displays the data in the existing
database file


COLOR = 5
DISPLAY " PUMP RECORDS DISPLAY MODULE "
DISPLAY "----------------------------"

COLOR = 0

DISPLAY "
```

This part of the inventory module displays the records exist in the database file. The purpose of having this feature in the program is to enable the user to check the level of inventory periodically."

```
DISPLAY ""
DISPLAY ""
DISPLAY ""
DISPLAY ""
DISPLAY ""

DISPLAY " Press any key to continue ~"

CLS
C = 1

    WHILEKNOWN Model
     GET ALL, pumps, ALL

     DISPLAY "Pump No :{C}
              MODEL  :-    {Model}
              GPM    :-    {GPM}
              HEAD   :-    {HEAD}ft.
              RPM    :-    {RPM}
              HP     :-    {HP}
              EFF    :-    {EFF}
             IMP DIA:-     {IMP_DIA}in.
              NPSH   :-    {NPSH}ft.
              QMOTRS:-     {QMOTRS}
              CMOTRS:-     ${CMOTRS}
              CPUMPS:-     ${CPUMPS}
              QPUMPS:-     {QPUMPS}"
       C = (C+1)

DISPLAY " Press any key to continue ~"
CLS
END;

RULE 3

               IF data = Selection
               THEN Record = search
CLS

DISPLAY " PUMP SELECTION MODULE"
DISPLAY " ---------------------"

DISPLAY"
```

The decision for making selection of the pump is based on the GPM and Head required for a a particular system. Certain pump's data have been established in the database file from where decision for selection will be made."

```
DISPLAY ""
DISPLAY ""

FIND FLOW
FIND FRIC

CLS

C = 1

WHILEKNOWN  GPM
GET FLOW = GPM  AND
    FRIC = HEAD , Pumps, ALL

    DISPLAY "{C})
              MODEL  :-     {Model}
              GPM    :-     {GPM}
              HEAD   :-     {HEAD}ft.
              RPM    :-     {RPM}
              HP     :-     {HP}
              EFF    :-     {EFF}
             IMP DIA:-      {IMP_DIA}in.
              NPSH   :-     {NPSH}ft.
              QPUMPS:-      {QPUMPS}
              CPUMPS:-      ${CPUMPS}
              QMOTRS:-      {QMOTRS}
              CMOTRS:-      ${CMOTRS}"

 C = (C + 1)

DISPLAY""
DISPLAY ""
DISPLAY " Press any key to continue ~"

CLS

END;

RULE 4

          IF    data = purchase
          THEN  Record = sell

CLS

COLOR = 5
```

```
DISPLAY "                        COST MODULE"
DISPLAY "                        ------------"

COLOR = 0

FIND Catalog


C = 1

WHILEKNOWN  Model
GET Catalog = Model,Pumps, ALL

FIND QTYP
FIND QTTM
FIND DATE

      QPUMPS = (QPUMPS - QTYP)
      AMT = (CPUMPS * QTYP)
      TAX = 0.06
      TOT = ((AMT * TAX) + AMT)


      QMOTRS = (QMOTRS - QTTM)
      SUM    = (CMOTRS * QTTM)
      TAX = 0.06
      TOTL = ((SUM * TAX) + SUM)

CLS
      DISPLAY " Pump Warehouse       Hello : (516)732-8277"
      DISPLAY " PURCHASING DESCRIPTION OF THE SELECTED PUMP
Date:{DATE}"
      DISPLAY "-----------------------------------------"
      DISPLAY ""
      DISPLAY ""

DISPLAY " PUMP INVOICE                    MOTOR INVOICE"
DISPLAY " ------------                    --------------"

DISPLAY "


AMT          =     ${AMT}            SUM        =     ${SUM}
TOTAL        =     ${TOT}            TOTAL      =     ${TOTL}
QUANTITY     =     {QTYP}            QUANTITY   =     {QTTM}
Model        =     {Model}           MODEL      =     {MODEL}"

      GTOTL = (TOT + TOTL)

COLOR = 5
```

```
DISPLAY "
                              GRAND TOTAL    =     ${GTOTL}"
DISPLAY "                     ============================"
     PUT Pumps

COLOR = 0

   WHILEKNOWN PQTY
   GET Number = PQTY,Cash,ALL
   MRESET MODEL
   MRESET PQTY
   MRESET UNTCOST
   MRESET COSTERND
   MRESET MQTY
   MRESET UNTCOSTM
   MRESET CSTERND
   MODEL = (Catalog)
   Number = (QTYP)
   PQTY = (Number)
   UNTCOST = (CPUMPS)
   COSTERND = (TOT)
   MQTY = (QTTM)
   UNTCOSTM = (CMOTRS)
   CSTERND = (TOTL)

APPEND Cash

WHILEKNOWN Switch
RESET Switch
FIND Switch
END

END;

RULE 5

          IF    data = discount
          THEN  Record = concession

CLS

COLOR = 5

DISPLAY "                            DISCOUNT MODULE"
DISPLAY "                           ------------------"

COLOR = 0

FIND Catalog


C = 1

WHILEKNOWN  Model
```

```
GET Catalog = Model,Pumps, ALL

FIND QTYP
FIND QTTM
FIND DATE

      QPUMPS = (QPUMPS - QTYP)
      AMT = (CPUMPS * QTYP)
      TAX = 0.06
      TOT = ((AMT * TAX) + AMT)
      DISCT = (TOT * 0.15)
      NET = (TOT - DISCT)


      QMOTRS = (QMOTRS - QTTM)
      SUM    = (CMOTRS * QTTM)
      TAX = 0.06
      TOTL = ((SUM * TAX) + SUM)
      DISCNT = (TOT * 0.2)
      NET1 = (TOTL - DISCNT)

CLS
      DISPLAY " Pump Warehouse       Hello : (516)732-8277"
      DISPLAY " PURCHASING DESCRIPTION OF THE SELECTED PUMP
Date:{DATE}"
      DISPLAY "----------------------------------------------"
      DISPLAY ""
      DISPLAY ""

DISPLAY " PUMP INVOICE                    MOTOR INVOICE"
DISPLAY " ------------                    --------------"

DISPLAY "


AMT          =     ${AMT}          SUM          =     ${SUM}
TOTAL        =     ${TOT}          TOTAL        =     ${TOTL}
QUANTITY     =     {QTYP}          QUANTITY     =     {QTTM}
Model        =     {Model}         MODEL        =     {MODEL}
DISCT        =     ${DISCT}        DISCNT       =   ${DISCNT}"


      GTOTL = (NET + NET1)

COLOR = 5

DISPLAY "
                      GRAND TOTAL    =     ${GTOTL}"
DISPLAY "             ==========================="
     PUT Pumps

COLOR = 0

   WHILEKNOWN PQTY
```

```
   GET Number = PQTY,Cash,ALL
   MRESET MODEL
   MRESET PQTY
   MRESET UNTCOST
   MRESET COSTERND
   MRESET MQTY
   MRESET UNTCOSTM
   MRESET CSTERND
   MODEL = (Catalog)
   Number = (QTYP)
   PQTY = (Number)
   UNTCOST = (CPUMPS)
   COSTERND = (TOT)
   MQTY = (QTTM)
   UNTCOSTM = (CMOTRS)
   CSTERND = (TOTL)

APPEND Cash

WHILEKNOWN Switch
RESET Switch
FIND Switch
END

END;



RULE 6

          IF data = report
          THEN Record = show
C = 1
PQTY = 0
MQTY = 0
COLOR = 5

DISPLAY " PUMP's SOLD MODULE"
DISPLAY "-------------------"

COLOR =0

DISPLAY "
Model No    P QTY    Pump       Pumps      M QTY      Motors
Motors
            Sold     U.C.       Sale       Sold       U.C.
Sale"

     WHILEKNOWN PQTY
     GET ALL, Cash, ALL


DISPLAY "
```

```
{Model}          {PQTY}      ${UNTCOST}        ${COSTERND}
{MQTY}         ${UNTCOSTM}        ${CSTERND}"

     NETQTY_Pumps  = (NETQTY_Pumps + PQTY)
     NETSALE_Pumps = (NETSALE_Pumps + COSTERND)

     NETQTY_Motors = (NETQTY_Motors + MQTY)
     NETSALE_Motors = (NETSALE_Motors + CSTERND)

     GRAND_TOTAL = (NETSALE_Pumps + NETSALE_Motors)

 END
CLS
COLOR = 1
DISPLAY "           SUMMARIZE REPORT OF THE ITEMS SOLD"
DISPLAY "           =================================="
DISPLAY "


    Quantity of Pumps  :-    {NETQTY_Pumps}
    Sold

    Quantity of Motors :-    {NETQTY_Motors}
    Sold

    Grand Total        :-    ${GRAND_TOTAL}
                              ============"

DISPLAY""
DISPLAY""
DISPLAY""

WHILEKNOWN Switch
RESET Switch
FIND Switch
END
;


! STATEMENT BLOCK

ASK data : "Please choose any one of the following options";
CHOICES data: update, list, selection,purchase, report,
discount;

ASK Record : "What do you want to do";
CHOICES Record : add, List;

ASK Catalog: "Enter the model number of the pump";

ASK SPEED : "Enter the speed of the pump in RPM ";

ASK FLOW : "Enter the flow rate in GPM";
```

```
ASK FRIC : " Enter the required head of the pump in feet";
ASK SIZE : " Enter the Impeller dia of the pump in inches";
ASK FORCE: " Enter the horsepower of the pump";
ASK PERFOR : " Enter the efficiency at part load";
ASK SUCTION : " Enter the NPSH of the Pump at part load";
ASK QUANTITY : " Enter quantity of the pumps";
ASK COST : " Enter the unit cost of the pump";
ASK COUNT : "Enter the quantity of the motors";
ASK PRICE : "Enter the unit cost of the motor";
ASK Switch : " Press ? and hit enter to continue ";
ASK QTYP : " How many pumps have to be purchased";
ASK QTTM : " How many motors have to be purchased";
ASK DATE : " Enter today's date format mm-dd-yy";
```

APPENDIX B

```
                    Pump Warehouse Expert Program


               Presented By Muhammad Mutahir Ghauri
               -------------------------------------


Synopsis of the program :-
--------------------------

The following program has been written to facilitate a pump warehouse
manufacturing facility. The main function of the program is to maintain
the inventory level of each model of pump available in the warehouse,
to make decision for the selection of pumps, and finally make a cost
estimation for the selection of pumps. The specific description of each
module is given at the begining of each module.

 Press ? and hit enter to continue

Enter to select     ? & Enter for Unknown     /Q to quit
 1Help 2How? 3Why? 4Slow 5Fast 6Quit
```

```
 New entry to the database file
Please choose any one of the following options
 update                    list                     selection
 purchase                  report                   discount

↑ ↓ →     Enter to select   END to complete    /Q to Quit   ? for Unknown
```

DATA ENTRY MODULE

This module updates the database file and add new records of the pump to the database file. In order to enter the new records to the database file the user has to select this module. Once the module is selected, it ask certain questions about the incoming inventory, design and performance criteria of the pump. The user is responsible to answer these question.

Press any key to continue

```
Enter the model number of the pump
 2AF

Enetr the flow rate in GPM
 120

 Enter the required head of the pump in feet
 130

Enter the speed of the pump in RPM
 3500

 Enter the horse power of the pump
 5

 Enter the efficiency at part load
 65%
```

Enter to select   ? & Enter for Unknown   /Q to quit

```
65%

Enter the Impeller dia of the pump in inches
5

Enter the NPSH of the Pump at part load
10

Enter quantity of the pumps
500

Enter the unit cost of the pump
250

Enter the quantity of the motors
500

Enter the unit cost of the motor
100
```

```
Enter to select    ? & Enter for Unknown    /Q to quit
```

PUMP RECORDS DISPLAY MODULE

This part of the inventory module displays the records exist in the database file. The purpose of having this feature is to enable the user to check the level of inventory periodically.

Press any key to continue

```
Pump No :1
              MODEL :-     2AC
              GPM   :-     100
              HEAD  :-     100ft.
              RPM   :-     3500
              HP    :-     5
              EFF   :-     65%
             IMP DIA:-     5.5in.
              NPSH  :-     8ft.
              QMOTRS:-     500
              CMOTRS:-     $100
              CPUMPS:-     $200
              QPUMPS:-     500
 Press any key to continue
```

```
Pump No :2
          MODEL :-    2.5AB
          GPM   :-    200
          HEAD  :-    140ft.
          RPM   :-    3500
          HP    :-    15
          EFF   :-    70%
         IMP DIA:-    6.5in.
          NPSH  :-    10ft.
          QMOTRS:-    500
          CMOTRS:-    $50
          CPUMPS:-    $100
          QPUMPS:-    500
 Press any key to continue
```

```
Pump No :3
               MODEL :-    1.5A
               GPM   :-    60
               HEAD  :-    40ft.
               RPM   :-    1770
               HP    :-    1
               EFF   :-    40%
              IMP DIA:-    6in.
               NPSH  :-    10ft.
               QMOTRS:-    500
               CMOTRS:-    $50
               CPUMPS:-    $100
               QPUMPS:-    500
 Press any key to continue
```

```
Pump No :4
              MODEL :-    2A
              GPM   :-    120
              HEAD  :-    40ft.
              RPM   :-    1750
              HP    :-    1.5
              EFF   :-    55%
             IMP DIA:-    6in.
              NPSH  :-    25ft.
              QMOTRS:-    500
              CMOTRS:-    $100
              CPUMPS:-    $250
              QPUMPS:-    500
 Press any key to continue
```

```
Pump No :5
              MODEL :-    2.5F
              GPM   :-    140
              HEAD  :-    40ft.
              RPM   :-    1750
              HP    :-    2.5
              EFF   :-    55%
             IMP DIA:-    6.5in.
              NPSH  :-    7ft.
              QMOTRS:-    500
              CMOTRS:-    $75
              CPUMPS:-    $200
              QPUMPS:-    500
 Press any key to continue
```

```
Pump No :6
              MODEL  :-    1.25AC
              GPM    :-    80
              HEAD   :-    160ft.
              RPM    :-    3500
              HP     :-    7
              EFF    :-    55%
             IMP DIA:-     6.5in.
              NPSH   :-    10ft.
              QMOTRS:-     500
              CMOTRS:-     $50
              CPUMPS:-     $150
              QPUMPS:-     500
 Press any key to continue
```

```
Pump No :7
              MODEL :-     1.25AB
              GPM   :-     150
              HEAD  :-     160ft.
              RPM   :-     3500
              HP    :-     11
              EFF   :-     60%
             IMP DIA:-     6.5in.
              NPSH  :-     10ft.
              QMOTRS:-     500
              CMOTRS:-     $100
              CPUMPS:-     $200
              QPUMPS:-     500
 Press any key to continue
```

```
Pump No :8
              MODEL  :-     1.25AA
              GPM    :-     40
              HEAD   :-     15ft.
              RPM    :-     1750
              HP     :-     0.5
              EFF    :-     54%
             IMP DIA:-      4.5in.
              NPSH   :-     8ft.
              QMOTRS:-      500
              CMOTRS:-      $25
              CPUMPS:-      $50
              QPUMPS:-      500
 Press any key to continue
```

```
Pump No :9
              MODEL :-    2AA
              GPM   :-    50
              HEAD  :-    15ft.
              RPM   :-    1750
              HP    :-    0.5
              EFF   :-    55%
             IMP DIA:-    5.5in.
              NPSH  :-    4ft.
              QMOTRS:-    500
              CMOTRS:-    $50
              CPUMPS:-    $100
              QPUMPS:-    500
 Press any key to continue
```

```
Pump No :10
              MODEL :-     1AA
              GPM   :-     20
              HEAD  :-     10ft.
              RPM   :-     1750
              HP    :-     0.25
              EFF   :-     40%
             IMP DIA:-     4in.
              NPSH  :-     3ft.
              QMOTRS:-     500
              CMOTRS:-     $25
              CPUMPS:-     $50
              QPUMPS:-     500
 Press any key to continue
```

```
Pump No :11
              MODEL  :-    1.25AA
              GPM    :-    30
              HEAD   :-    15ft.
              RPM    :-    1750
              HP     :-    0.25
              EFF    :-    45%
             IMP DIA:-     4in.
              NPSH   :-    2ft.
              QMOTRS:-     500
              CMOTRS:-     $25
              CPUMPS:-     $50
              QPUMPS:-     500
 Press any key to continue
```

```
Pump No :12
             MODEL  :-    3AB
             GPM    :-    500
             HEAD   :-    110ft.
             RPM    :-    3550
             HP     :-    20
             EFF    :-    70%
            IMP DIA:-     6in.
             NPSH   :-    15ft.
             QMOTRS:-     500
             CMOTRS:-     $150
             CPUMPS:-     $300
             QPUMPS:-     500
 Press any key to continue
```

```
Pump No :13
              MODEL :-    4AC
              GPM   :-    800
              HEAD  :-    160ft.
              RPM   :-    3550
              HP    :-    45
              EFF   :-    81%
             IMP DIA:-    6.5in.
              NPSH  :-    20ft.
              QMOTRS:-    500
              CMOTRS:-    $150
              CPUMPS:-    $300
              QPUMPS:-    500
 Press any key to continue
```

```
Pump No :14
              MODEL :-     3E
              GPM   :-     500
              HEAD  :-     350ft.
              RPM   :-     3550
              HP    :-     50
              EFF   :-     65%
             IMP DIA:-     9in.
              NPSH  :-     10ft.
              QMOTRS:-     500
              CMOTRS:-     $100
              CPUMPS:-     $300
              QPUMPS:-     500
 Press any key to continue
```

```
Pump No :15
              MODEL :-     4E
              GPM   :-     1200
              HEAD  :-     320ft.
              RPM   :-     3550
              HP    :-     100
              EFF   :-     79%
             IMP DIA:-     9in.
              NPSH  :-     35ft.
              QMOTRS:-     500
              CMOTRS:-     $150
              CPUMPS:-     $300
              QPUMPS:-     500
 Press any key to continue
```

```
Pump No :16
              MODEL  :-    1.25AC
              GPM    :-    60
              HEAD   :-    40ft.
              RPM    :-    1750
              HP     :-    1
              EFF    :-    60%
             IMP DIA:-    6in.
              NPSH   :-    5ft.
              QMOTRS:-    500
              CMOTRS:-    $25
              CPUMPS:-    $50
              QPUMPS:-    500
 Press any key to continue
```

```
Pump No :16
              MODEL :-    1.25AC
              GPM   :-    60
              HEAD  :-    40ft.
              RPM   :-    1750
              HP    :-    1
              EFF   :-    60%
             IMP DIA:-    6in.
              NPSH  :-    5ft.
              QMOTRS:-    500
              CMOTRS:-    $25
              CPUMPS:-    $50
              QPUMPS:-    500
 Press any key to continue
```

```
Pump No :17
              MODEL :-     1.5AB
              GPM   :-     80
              HEAD  :-     40ft.
              RPM   :-     1750
              HP    :-     0.75
              EFF   :-     60%
             IMP DIA:-     6in.
              NPSH  :-     5ft.
              QMOTRS:-     500
              CMOTRS:-     $50
              CPUMPS:-     $100
              QPUMPS:-     500
 Press any key to continue
```

```
Pump No :18
              MODEL  :-     2AD
              GPM    :-     75
              HEAD   :-     40ft.
              RPM    :-     1700
              HP     :-     5
              EFF    :-     50%
             IMP DIA:-     5.5in.
              NPSH   :-     10ft.
              QMOTRS:-     500
              CMOTRS:-     $50
              CPUMPS:-     $100
              QPUMPS:-     500
 Press any key to continue
```

```
Pump No :19
              MODEL  :-     2AZ
              GPM    :-     80
              HEAD   :-     100ft.
              RPM    :-     1700
              HP     :-     5
              EFF    :-     55%
             IMP DIA:-      6.5in.
              NPSH   :-     10ft.
              QMOTRS:-      500
              CMOTRS:-      $35
              CPUMPS:-      $75
              QPUMPS:-      500
 Press any key to continue
```

```
PUMP SELECTION MODULE
---------------------

The decision for making selection of the pump is based on the GPM and
Head of a particular system. Certain pump's data have been established
in the database file from where decision for selection pump will be made.


Enetr the flow rate in GPM
 100

 Enter the required head of the pump in feet
 100

Enter to select    ? & Enter for Unknown    /Q to quit
```

```
1)
            MODEL  :-     2AC
            GPM    :-     100
            HEAD   :-     100ft.
            RPM    :-     3500
            HP     :-     5
            EFF    :-     65%
           IMP DIA:-      5.5in.
            NPSH   :-     8ft.
            QPUMPS:-      500
            CPUMPS:-      $200
            QMOTRS:-      500
            CMOTRS:-      $100

 Press any key to continue
```

```
          SUMMARIZE REPORT OF THE ITEMS SOLD
          ==================================

    Quantity of Pumps  :-    65
    Sold

    Quantity of Motors :-    65
    Sold

    Grand Total        :-    $19936.480469
                              ============


  Press ? and hit enter to continue

Enter to select    ? & Enter for Unknown    /Q to quit
```

```
PURCHASING MODULE
------------------
Enter the model number of the pump
 2AC

 How many pumps have to be purchased
 51

 How many motors have to be purchased
 51

 Enter today's date format mm-dd-yy
 12-12-94
```

Enter to select   ? & Enter for Unknown   /Q to quit

```
Pump Warehouse                                    Hello : (516)732-8277
PURCHASING DESCRIPTION OF THE SELECTED PUMP          Date:12-12-94
--------------------------------------------


PUMP INVOICE                      MOTOR INVOICE
------------                      --------------

AMT            =    $10200           SUM           =    $5100
TOTAL          =    $10812           TOTAL         =    $5406
QUANTITY       =    51             QUANTITY       =    51
Model          =    2AC            MODEL          =    2AC

            GRAND TOTAL    =    $16218
             ===========================
Press ? and hit enter to continue
```

Enter to select   ? & Enter for Unknown   /Q to quit

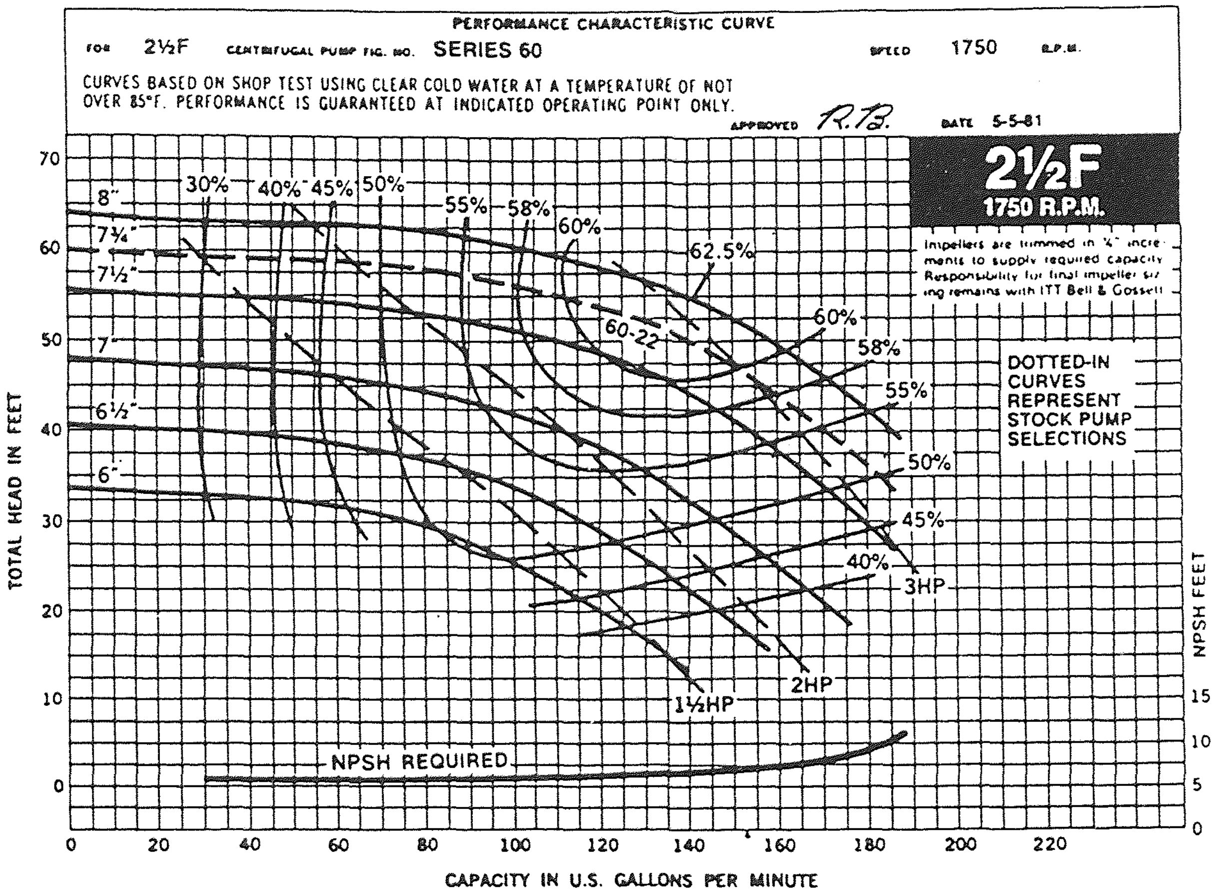
```
DISCOUNT MODULE
------------------
Enter the model number of the pump
 2.5F

 How many pumps have to be purchased
 51

 How many motors have to be purchased
 51

 Enter today's date format mm-dd-yy
 12-12-94
```

```
Enter to select    ? & Enter for Unknown    /Q to quit
```

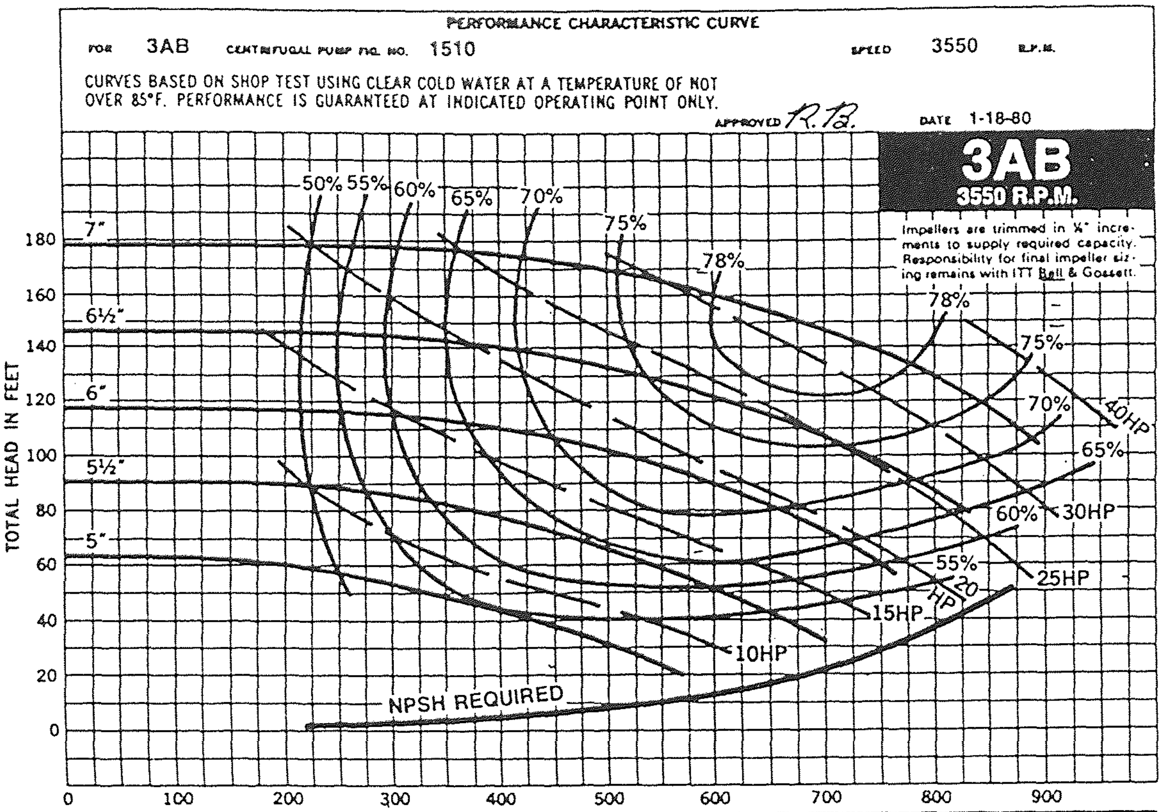
```
Pump Warehouse                              Hello : (516)732-8277
PURCHASING DESCRIPTION OF THE SELECTED PUMP     Date:12-12-94
--------------------------------------------


PUMP INVOICE                 MOTOR INVOICE
------------                 --------------

AMT           =    $10200          SUM          =    $3825
TOTAL         =    $10812          TOTAL        =    $4054.500000
QUANTITY      =    51           QUANTITY     =    51
Model         =    2.5F          MODEL        =    2.5F
DISCT         =    $1621.800049          DISCNT         =    $2162.400146

            GRAND TOTAL    =    $11082.299805
             ===========================
Press ? and hit enter to continue
█

Enter to select    ? & Enter for Unknown    /Q to quit
```

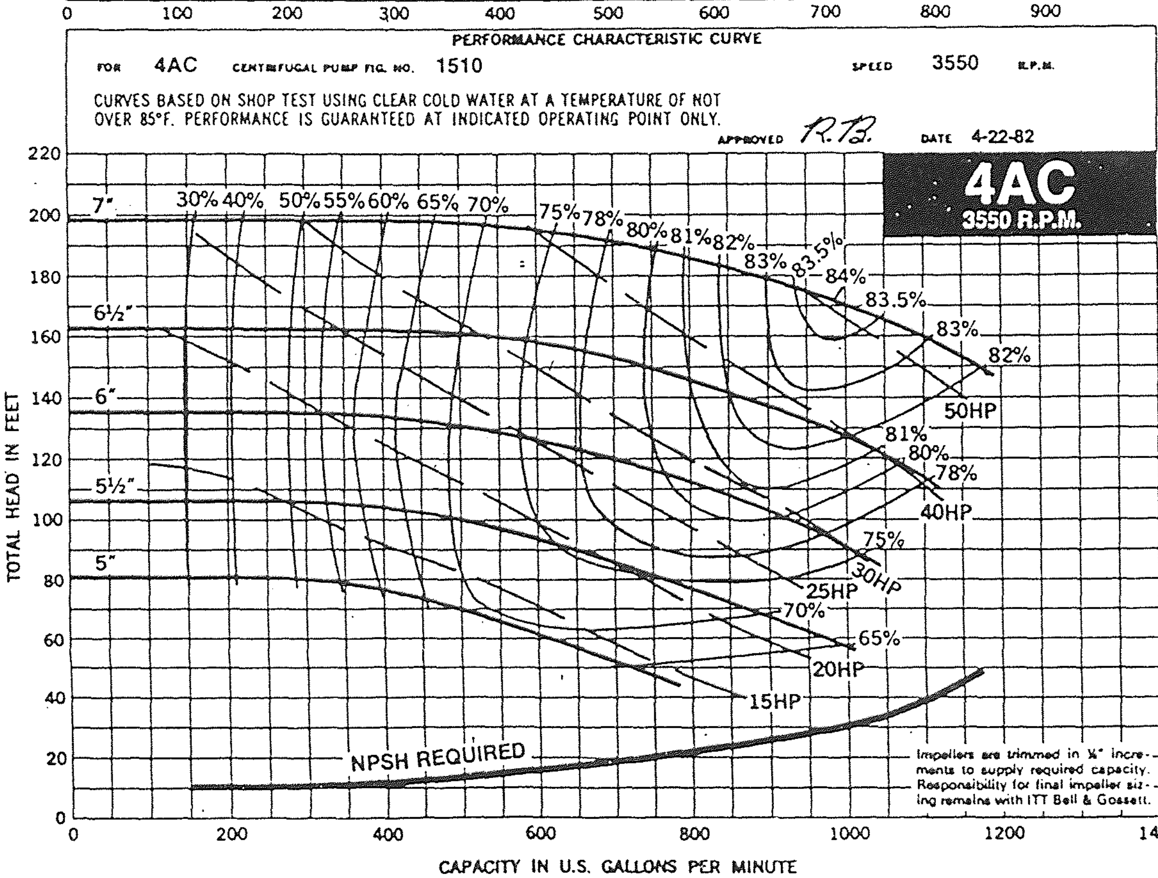
APPENDIX C

SERIES 60 BUILT-TO-ORDER PUMP PERFORMANCE CURVES



3500 RPM PUMP CURVES





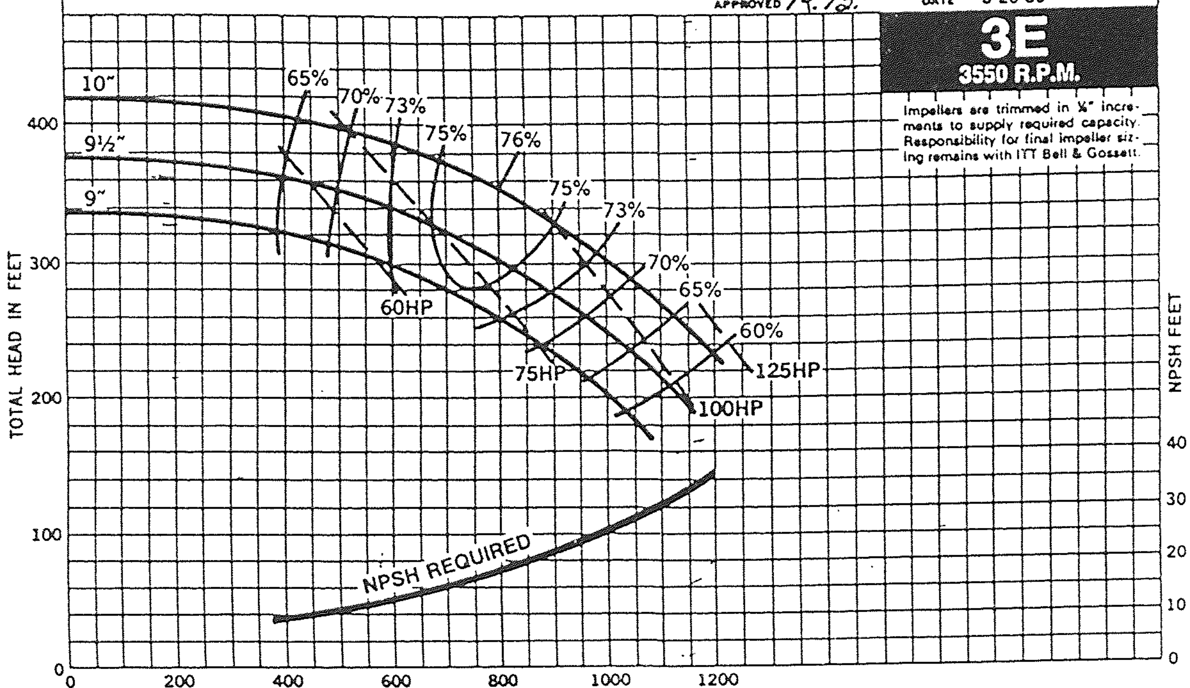
3500 RPM PUMP CURVES

PERFORMANCE CHARACTERISTIC CURVE

FOR 3E CENTRIFUGAL PUMP FIG. NO. 1510 SPEED 3550 R.P.M.

CURVES BASED ON SHOP TEST USING CLEAR COLD WATER AT A TEMPERATURE OF NOT OVER 85°F. PERFORMANCE IS GUARANTEED AT INDICATED OPERATING POINT ONLY.

APPROVED R.B. DATE 3-26-80

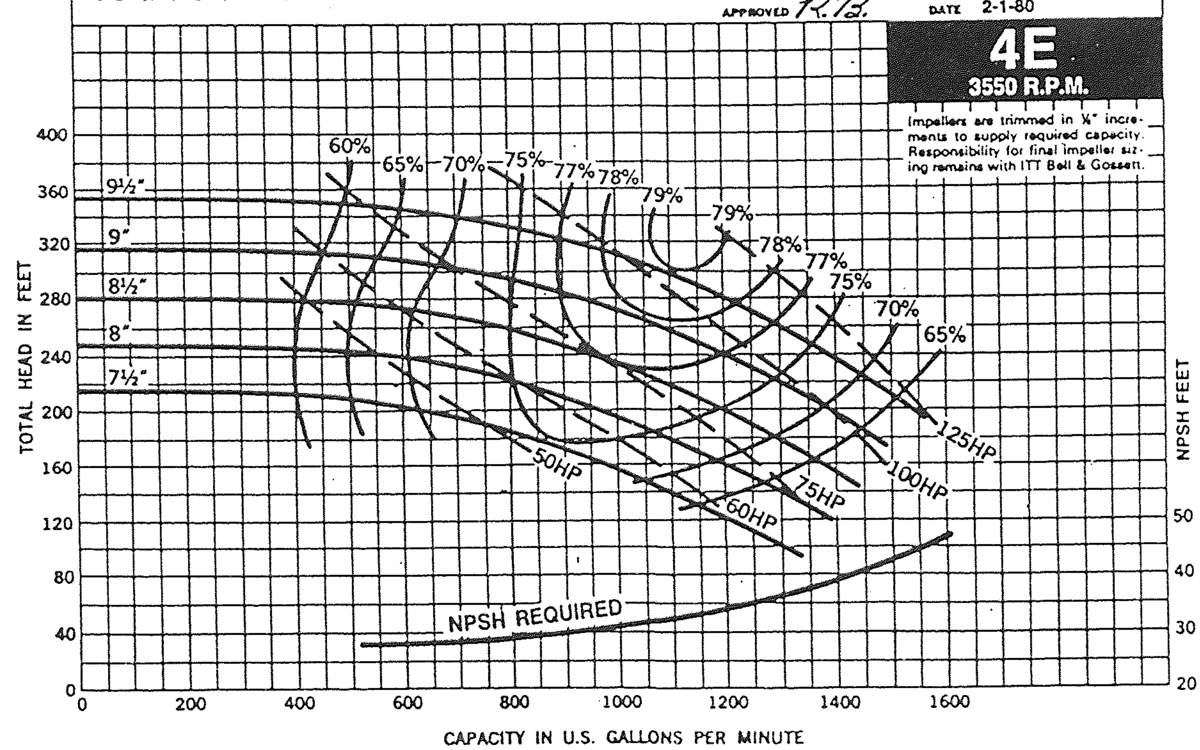


PERFORMANCE CHARACTERISTIC CURVE

FOR 4E CENTRIFUGAL PUMP FIG. NO. 1510 SPEED 3550 R.P.M.

CURVES BASED ON SHOP TEST USING CLEAR COLD WATER AT A TEMPERATURE OF NOT OVER 85°F. PERFORMANCE IS GUARANTEED AT INDICATED OPERATING POINT ONLY.

APPROVED R.B. DATE 2-1-80



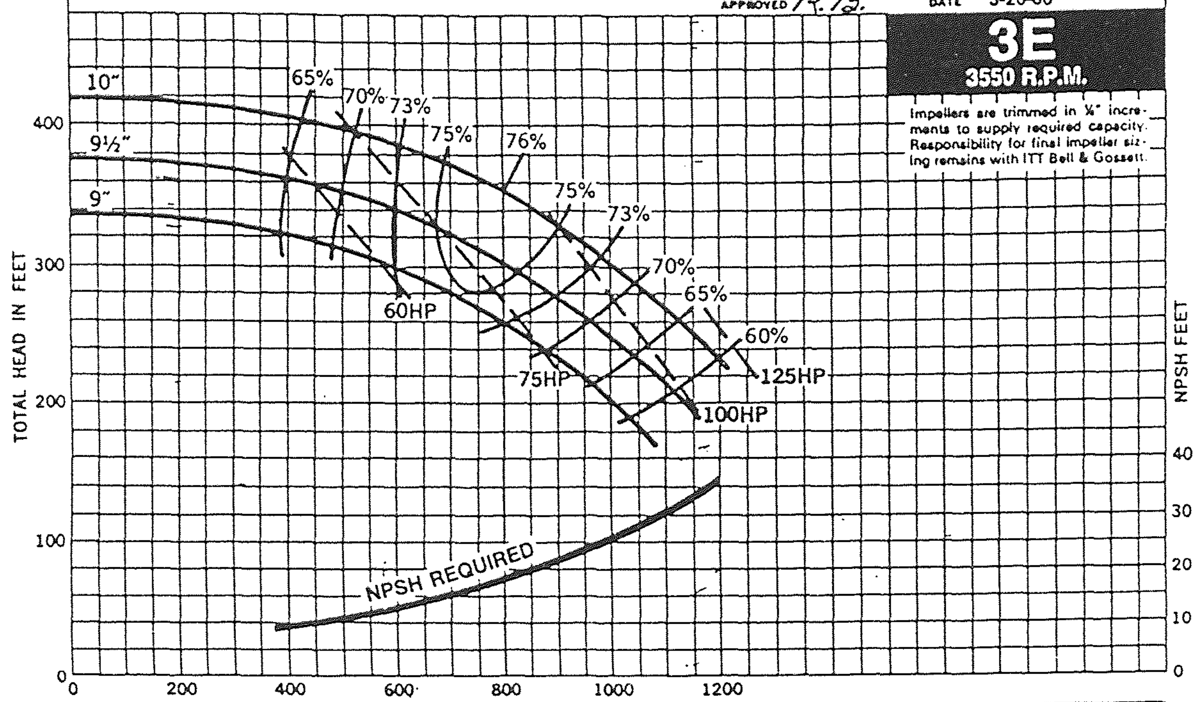
3500 RPM PUMP CURVES

PERFORMANCE CHARACTERISTIC CURVE

FOR 3E CENTRIFUGAL PUMP FIG. NO. 1510 SPEED 3550 R.P.M.

CURVES BASED ON SHOP TEST USING CLEAR COLD WATER AT A TEMPERATURE OF NOT OVER 85°F. PERFORMANCE IS GUARANTEED AT INDICATED OPERATING POINT ONLY.

APPROVED R.B. DATE 3-26-80

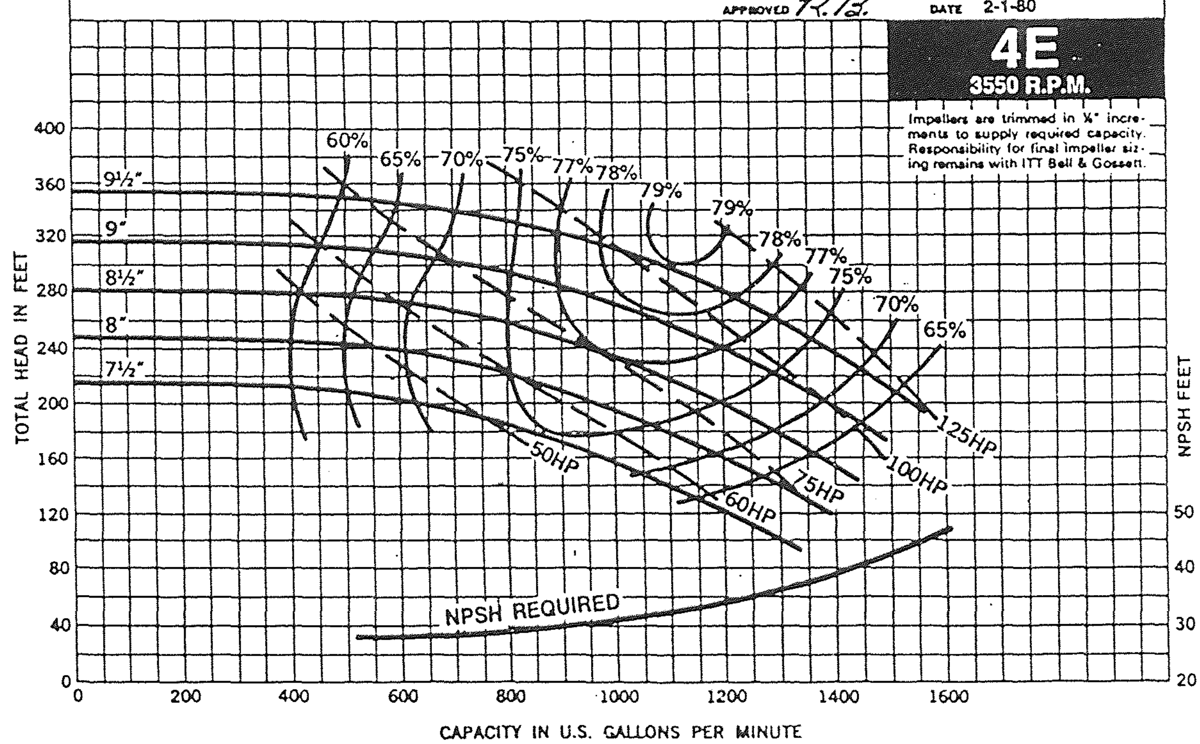


PERFORMANCE CHARACTERISTIC CURVE

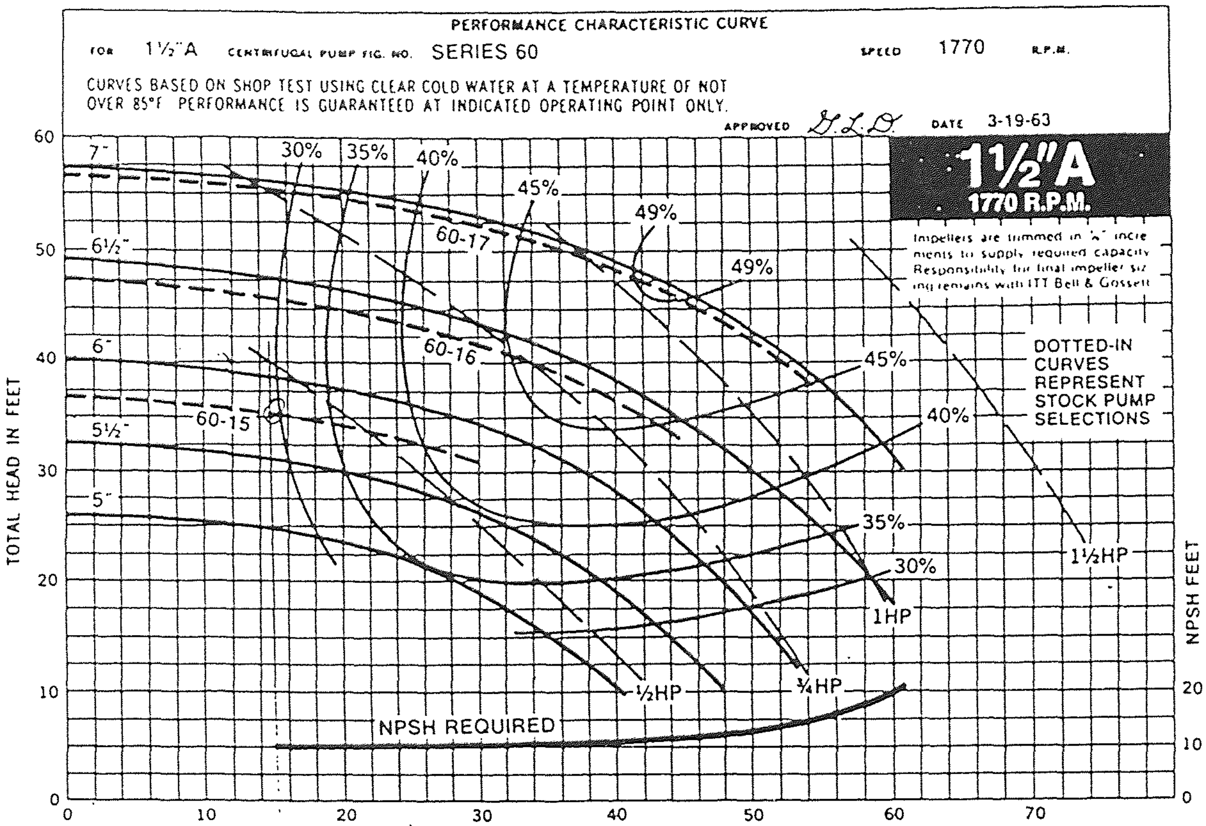
FOR 4E CENTRIFUGAL PUMP FIG. NO. 1510 SPEED 3550 R.P.M.

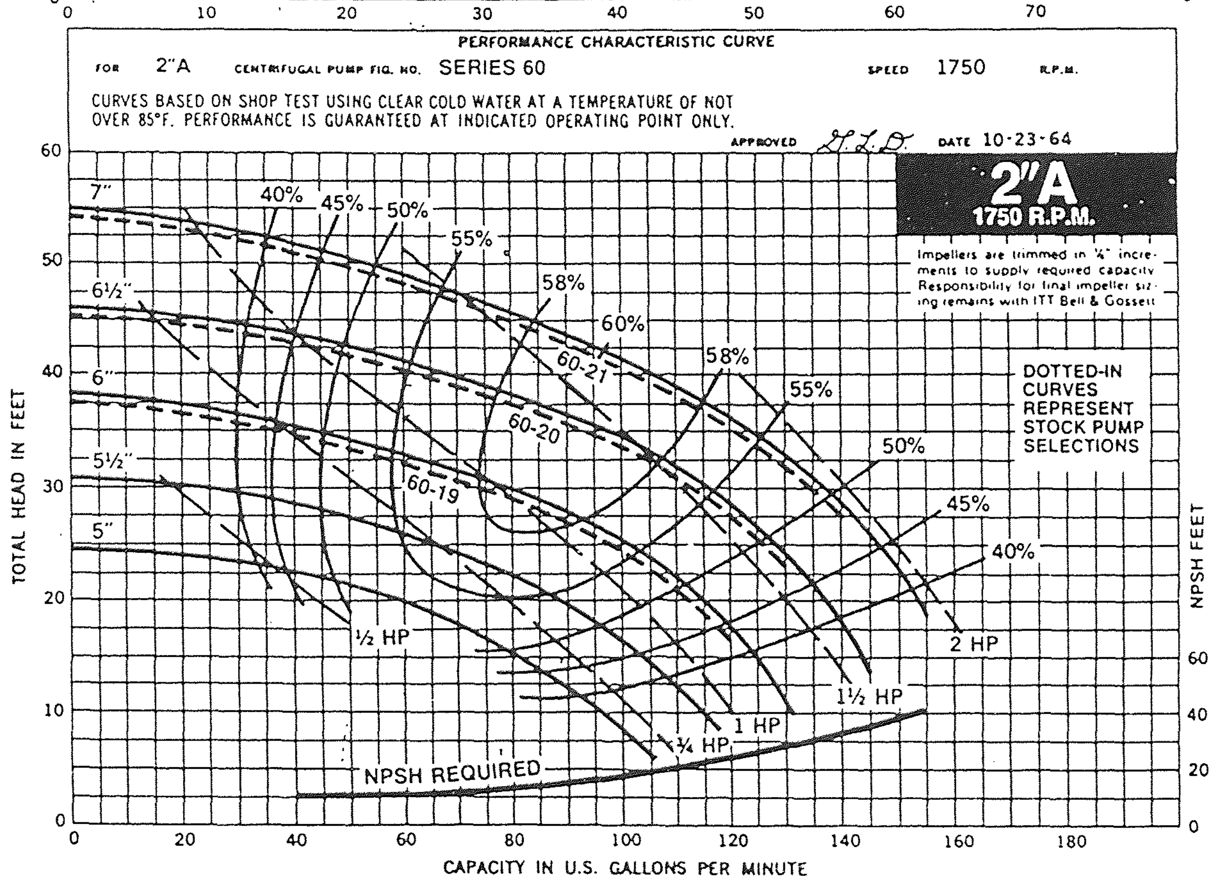
CURVES BASED ON SHOP TEST USING CLEAR COLD WATER AT A TEMPERATURE OF NOT OVER 85°F. PERFORMANCE IS GUARANTEED AT INDICATED OPERATING POINT ONLY.

APPROVED R.B. DATE 2-1-80

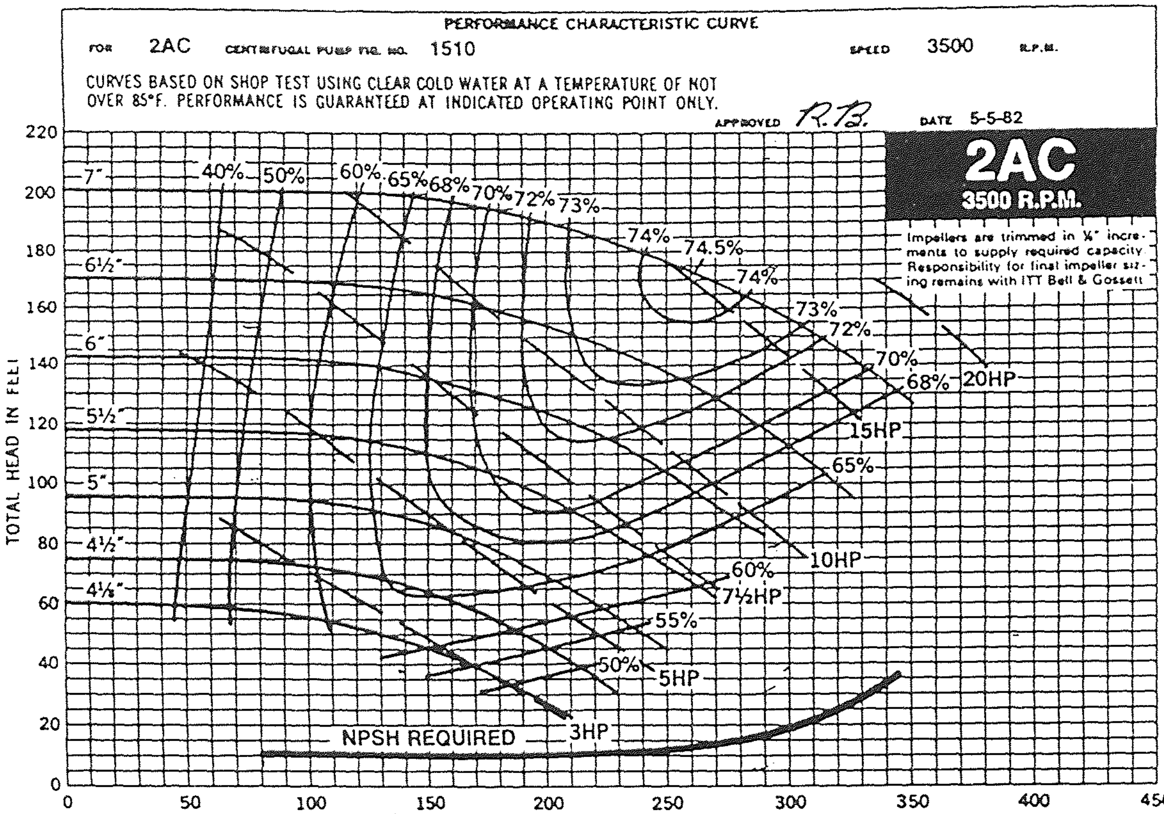


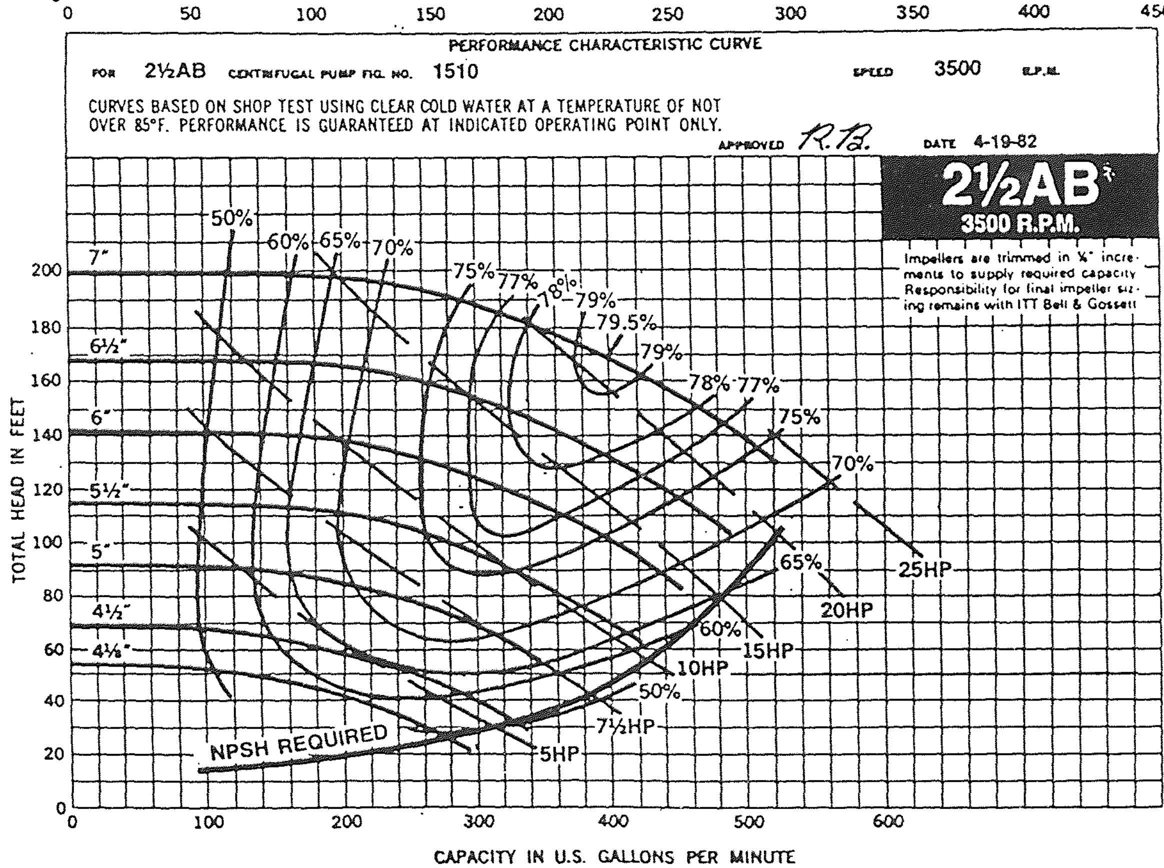
SERIES 60 BUILT-TO-ORDER PUMP PERFORMANCE CURVES



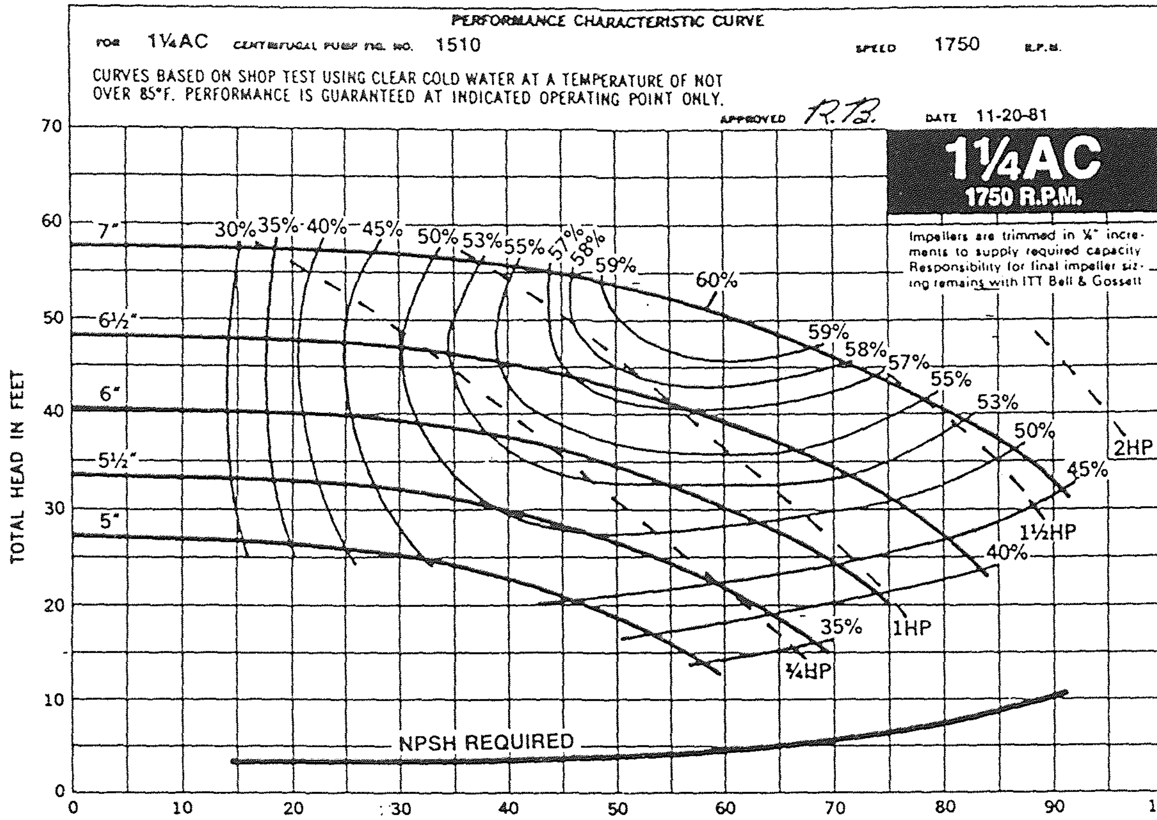


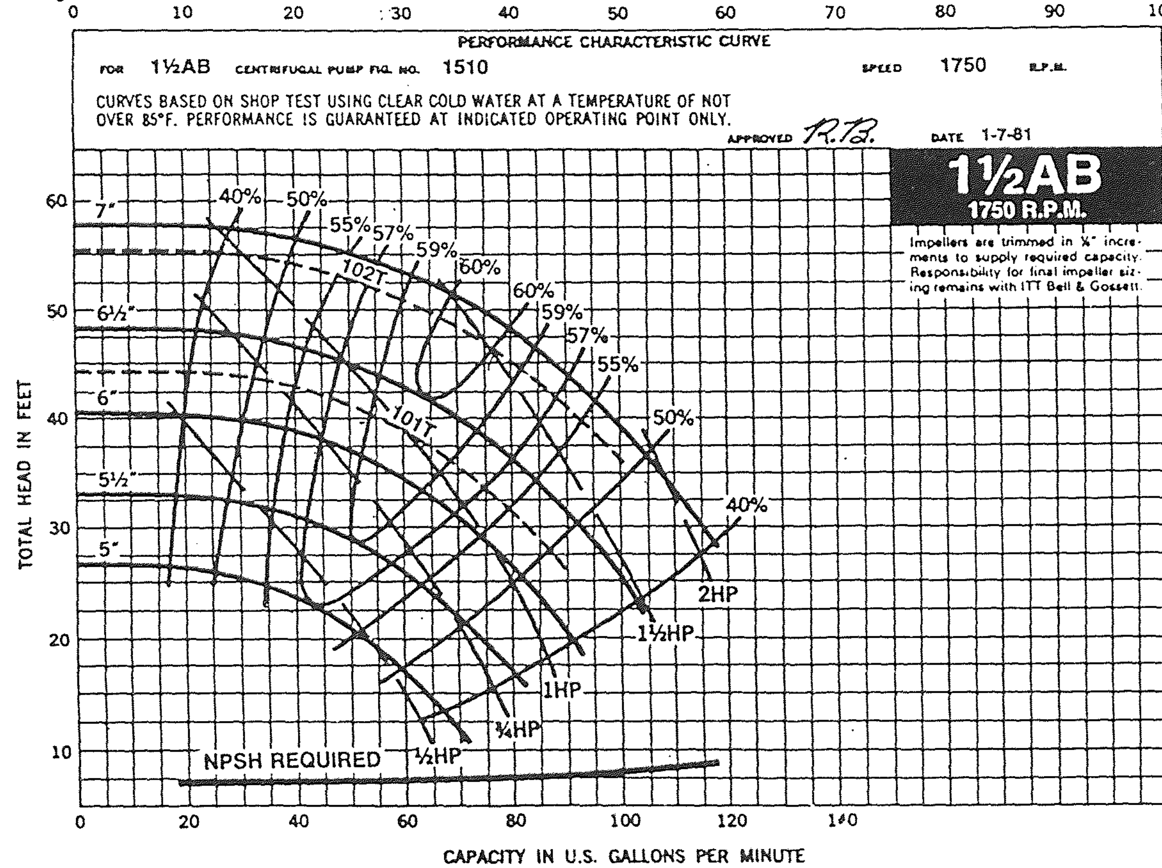
3500 RPM PUMP CURVES



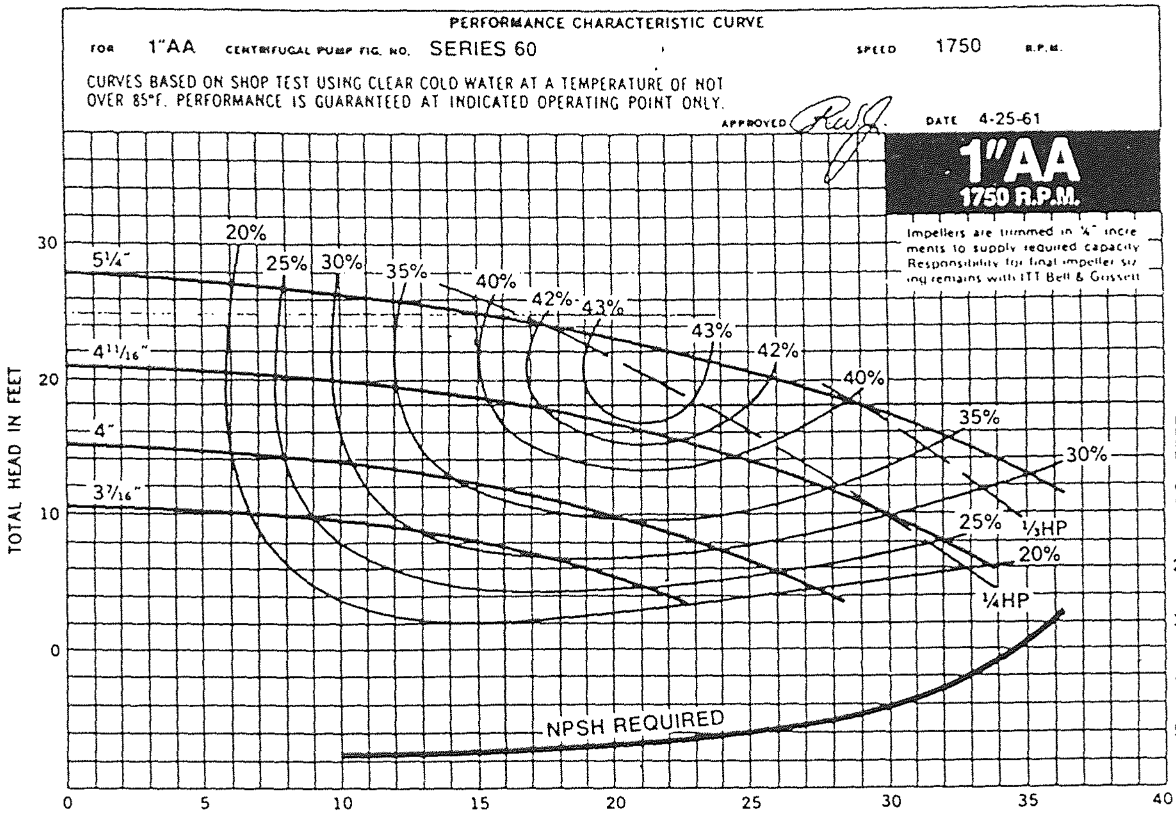


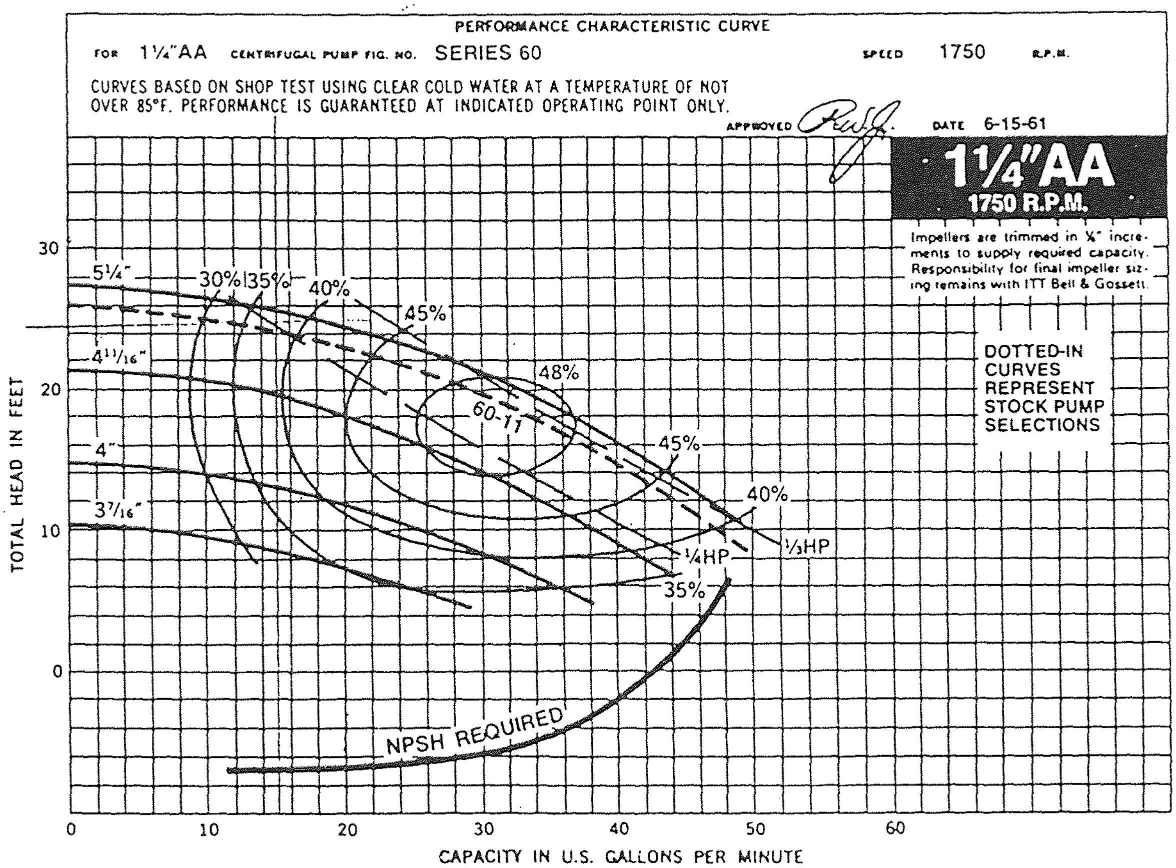
1750 RPM PUMP CURVES



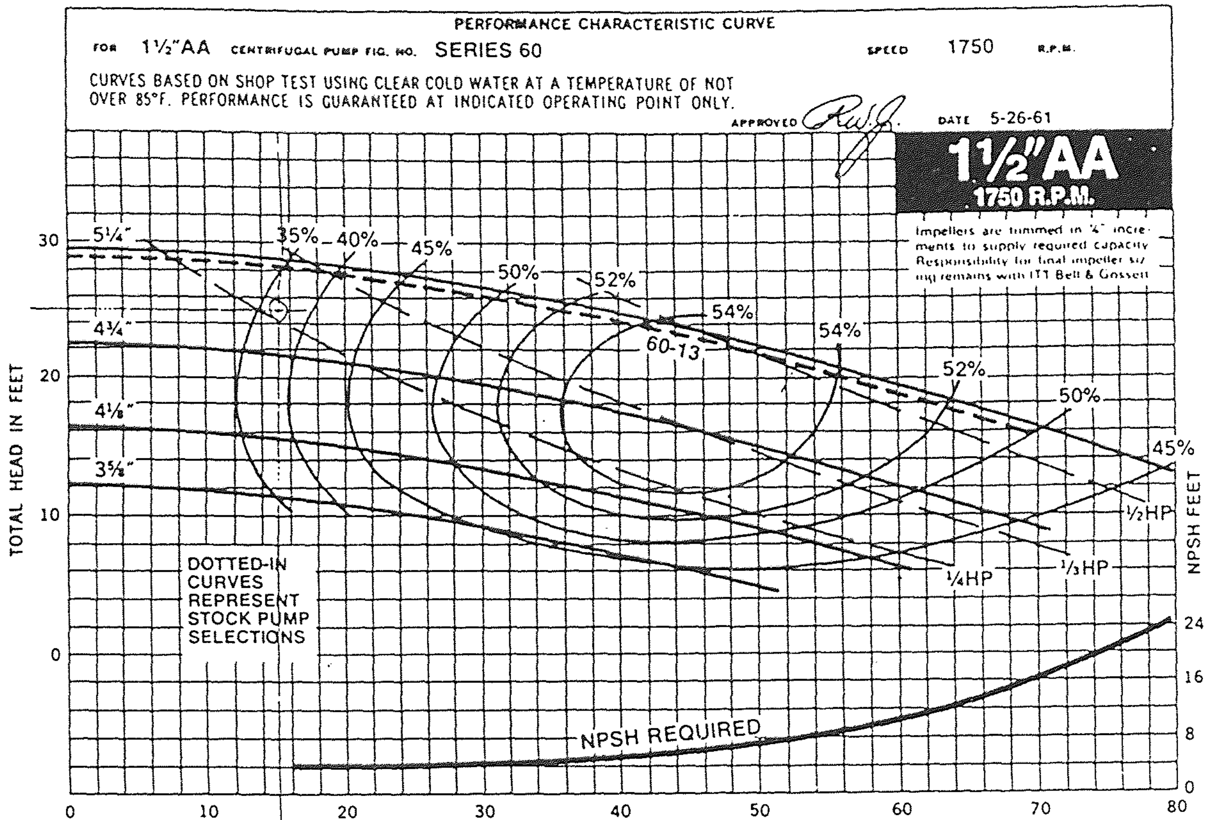


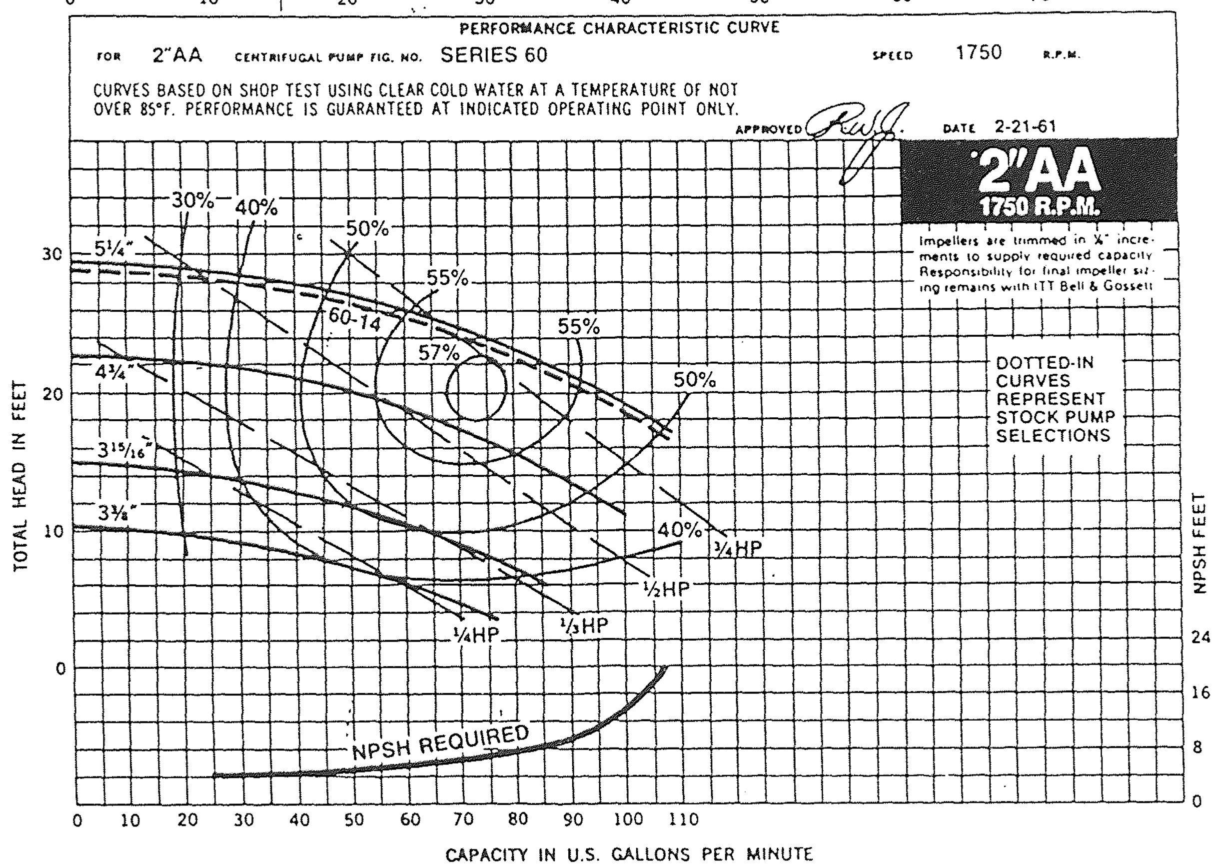
SERIES 60 BUILT-TO-ORDER PUMP PERFORMANCE CURVES





SERIES 60 BUILT-TO-ORDER PUMP PERFORMANCE CURVES





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