CIFE CENTER FOR INTEGRATED FACILITY ENGINEERING

Automatic Selection of Components (ASCO)

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Hannu Lehtimaki from DPI and Ellen Tauber, a Stanford student, developed and implemented the final working prototype. I would like to thank them for their great contribution to this component selection project.

KEYWORDS

- power plant
- component selection
- expert system
- valve selection

1. INTRODUCTION

The selection of components for construction, buildings, and process plants is made by experts today. The selection of components for power plants, for example, is a very important task because the cost of components is half of that for the whole power plant and because the reliability of a power plant depends greatly on the reliability of the single components. The selection methods currently used by experts has worked well within the structure of a conventional design process. The few experts have had time to do the selection during the long design time. However, today several universities and companies are developing new methods to design and build process plants more efficiently. This means that the components have to be selected early in the preliminary design stage of the project. Using current procedures, it is difficult for the various experts to select components and produce all the paperwork needed. In this paper I suggest that Expert System Technology be applied to component selection and that component selection be more tightly integrated into the preliminary design process.

In the second section of this paper I describe the requirements for component selection. The selection of components today is time-consuming team work; I present how it takes place today in the third section. Next, I suggest a new selection method based on Expert System Technology. In Section 5, I show how the Automatic Selection of Components (ASCO) method will be run in the computer environment. The last section presents conclusions and suggestions for future research.

2. REQUIREMENTS FOR COMPONENTS

In this paper the word "component" stands for different kinds of subcontracted parts of process or power plants -- from a bolt to a desulfurization plant. In this section I consider what kinds of requirements I set for subcontracted components (also shown in Figure 1). The chosen component has to fulfill the performance demands and nowadays, when controllability of plants is becoming more important, the performance has to be acceptable and efficient at different load points. Other important questions are how environmentally friendly the component is and how safe its operation is. The reliability and maintenance properties of the components are also very important. The comparison between different options occurs today by using a lifetime-cycle cost method. For example, the cheapest flow control method is throttling, but compared to the rotation control of a pump or a fan, throttling causes such a big pressure and energy loss that the use of the throttle as a continuous control is actually extremely expensive.

The selection of the components is a part of the design process and in the selection the overall project has to be given great importance. In the power plant there are several fans for forcing air or gases. For the maintenance it is necessary to choose the fans so that at most two subcontractors are allowed (one for axial fans and one for radial fans). The choice has to optimize in such a way that the whole power plant works optimally with the chosen set of fans. The components should be optimized by thinking about customer needs and the main contractor's strategy and policy.

3. THE SELECTION OF COMPONENTS TODAY

The process of selecting components consists of the following steps:

1. Performance calculations.
2. Inquiry about the components to the vendors or subcontractors, including commercial and technical specifications.
3. Offers by subcontractors.
4. Technical discussions with subcontractors.
5. New offers.
6. Comparison of offers.
7. Final discussions and selection.
8. Preparation of final technical and commercial documents.
9. The execution of delivery.

Some parts of this work can enhance the end results. For example, during the discussion with the subcontractors it is possible to incorporate new solutions and also to get information about competitors. The negotiating of the price is an exciting experience. However, a big part of this work is the processing of information: sending, receiving, and modifying it. Today this work is done by a team consisting of a project manager, a process designer, a purchase engineer, and a layout designer. Knowledge outside of the team members' expertise is gained by using consultants or other employees serving as consultants. Sometimes the customer is also added as a member of the team.

Because the work of the team members is much wider than just selecting the components, they often feel that the selection work is inadequately performed. One problem is that sometimes the people who have the best knowledge about a particular component cannot give their expertise because they are involved in other projects.

The selection process of components has received very little research. People who have researched machine design have worked mainly to combine machine elements and manufacturing aspects into the concurrent design process. Construction research has been more building-related than process-plant-related. However, the emphasis in the design process and design-tool development is in the beginning of the project, e.g., in the conceptual design stage [1, 2]. This means that the component selection system described above is no longer acceptable. It is so time-consuming that it becomes a bottleneck in project execution.

4. DESCRIPTION OF THE NEW SELECTION METHOD

4.1 Statement of Purpose

My goal in developing this component selection system is to handle it as a part of the design process. I want to acquire knowledge and organize it so that it is used efficiently.

The integration of the component selection into other systems, like scheduling and cost estimation, will be very valuable (Table 1).

I formulate my goal as a statement, as suggested by Kunz [3]:

The automatic component selection system:

Statement of purpose:

The purpose of the system is to organize the component selection of the process plant so that optimal components fulfilling the customer and main contractor demands are selected. The selection process will be automated, the paperwork will be reduced to a minimum, and the selection system can exchange information with other systems such as scheduling, cost control, design, etc.

References [1] and [2] describe how important conceptual design is in thinking about end results. Reference [2] describes how component selection is combined with other systems (presented in this paper in Figure 2). The principles of automatic selection of components are presented in Figure 3 and are described in the following sections in the order presented in Table 2.

4.2 Overall Strategy

The first step to start the component selection is to ensure that the customer's requirements will be fulfilled. Some of the customer's requirements result from the high-level strategy of the customer. These requirements are common for all projects of the customer. Normally, the customer does not want to change them, even if they increase the price. Let us take some examples: Safety requirements are typical ones; the products have to be asbestos-free. Many times the customer lists the standards that should be used, such as ASME-Code, ANSI, etc. The language used in the project and its documentation can be determined. The origin country of components and sometimes also the list of acceptable manufacturers are important to the customer for maintenance purposes. In the future, the customer often needs many kinds of project information in a particular form for their own information system. An example is that the drawings have to be in a particular CAD-system format and the drawing file organized according to the regulations of the customer.

The above-mentioned facts are strong constraints. In the ASCO system, I suggest they be processed under the title of overall strategies. The strong constraints are basically easy to handle in the selection process, but they are very important when thinking about the profit of the project.

The selection system should be intelligent enough to transfer the strong constraints to the component level. Overly strict constraints are avoided if the component expertise includes the determination of how strong constraints should be adapted to the selection process.

4.3 Delivery Strategy

The main contractor sets the business strategy. In the process and power plant industry, this includes, or should include, the component-delivery strategy because the components have such a big influence on the profitability of projects.

In Table 3, I present two subcontracting principles: centralized and decentralized. The centralized strategy means that the main contractor determines which components a subcontractor can use in the subproject. This strategy demands excellent project management by the main contractor, but it also offers possibilities to organize the after sales to be a growing, profitable business, because the main contractor has all component business in hand. The decentralized strategy means that the business of the main contractor is more focused on the construction of new plants.

The determination of the delivery strategy will give a more powerful view of the after sales business.

4.4 Different Types of Suppliers and Components

For the component selection it is necessary to classify the types of suppliers who will understand the opportunities and risks of subcontracting. For example, one factor in the car industry's success has been well-organized subcontracting. I am proposing four classes of suppliers (Table 4). I suggest that suppliers on different levels be used inside the boundaries of the delivery strategy.

The innovations and superiorities of small companies are opportunities in the power plant business to gain a leading edge. However, the reliability demands are so strict that a risk analysis must be performed.

I suggest the same kind of classification of component suppliers. The six different classes shown in Table 5 will help me organize the data of components to the database so that it is manageable. In the classification of the project components and services, the classes 1 and 6 are intended more for specification for inquiries than for really choosing a particular component or service.

4.5 The Project Constraints

The project-specific constraints are determined in the main contract. There are the following requirements:

- warranty
- reliability
- penalties and compensations
- patents
- force majeure, etc.

The constraints in the contract agreement have to change to be component-specific. For example, delivery-time compensation should be shared with subcontractors; however, it should be shared so that it improves the delivery of crucial components. The adaptation of constraints from the main contracting agreement to the component level should be done by preparing the project guide and rules. The expertise for both of them will become more profitable when they are well organized.

An important adaptation work is to do the project financing plan. It gets information from the agreement with the customer, from component knowledge, and from the financing sources. This financing plan should be updated during the lifetime of the project.

The product documentation also has to be determined by the customer. Interpreting these requirements for each type of component will produce better results. Today, documentation specifications are sometimes unclear and illogical.

4.6 The Technical Determination of Components

The technical determination was stated in the strategy and delivery-strategy sections of this paper. In this section I suggest how to combine process design with the expertise of the component-selection team.

The process design starts by stating a few performance demands, such as electricity MWs in the power plant. After that, the process design is made by using company-specific programs, combining project-specific, set performance values and expertise. This process generates the first performance values for components.

In the ASCO system I suggest organizing component-specific knowledge in the slots of the expert systems. This knowledge will be organized as libraries. The libraries can include formulas, such as the viscosity of fluid is equal to f(p,t). This knowledge can determine what kind of gaskets are needed for a particular fluid under certain pressure (p) and temperature (t).

It is locally possible to combine the performance values with the expert knowledge about components and analyze the subsystem by using a process-related plant design system like Plexsys [4]. Companies are also developing the connection between the plant-layout design system and the process calculation (Figure 2). The real-time connection between the process calculation, component selection, and the plant layout is of significant value when the optimization of the subsystem is made.

After the local iteration, the selection process continues combining all formed constraints as a requirement list for a particular component; hence, I have a component specification.

4.7 The Selection of All Acceptable Components to the Option List

I suggest that a RDB (relational database) be used as a place where the data about manufacturers and components are stored. However, I want to use the ASCO system for the selection of different kinds of components. In RDB the components have to be organized as different groups, when I want to get the system working fast. I suggest the groups shown in Table 5. In Table 5, I have six groups, from standard components to the project components. Project components are small process plants and they include the components.

In the future, it will hopefully be possible to get the RDB-tables of standard components in digital form. The project components have to design, so the ASCO system gives the design criteria and can evaluate what is the optimal choice of project components designed and offered by subcontractors.

When I have the specification of a particular component I will compare it with those of real products in the RDB. This comparison occurs so that all the properties of the real component are similar to the properties of the designed component. All those components that fulfill all the requirements of the specification will be listed in a list of options. These lists are stored for the forward processing.

4.8 The Selection of the Real Product from the Option List of Possible Products

The option list of possible products gives us the opportunity to search for the components that are the optimum in terms of the product. The optimum criteria might be set on the project level, but it is possible that is might also come from component expertise, if the component is important in thinking about operation, reliability, etc. Other optimization criteria could be the small size of the plant, low cost, the shortest possible delivery time, or a combination of some of them.

The choice of a component that is used in large numbers in the plant has to be done so that only one or two manufacturers are accepted for one project. If the results of the automatic selection are not sufficient, the project manager can change the criteria of the optimum or he can do what-if analysis by changing the optimum criteria and constraints. Therefore this system is a design tool that will be used under the control of the project manager.

5. PROTOTYPE OF THE ASCO METHOD

5.1 The Choice of the Expert System Shell for the Prototype

Above I have determined the properties of the selection system. From those I can derive the demands for the expert system shell. The shell has to be connected to other engineering systems, such as cost estimation, design, and analysis system. Another demand comes from the database. I suggest that all product and manufacturing data should be stored in the RDB and therefore the expert system shell should support this interface. The user interface has to be comfortable for engineers to use. This kind of an expert system is described in source [1] and shown in Figure 4, where the system is called the Integrated Boiler Plant Design (IBPD). The development of the IBPD system has continued so that P&ID's expertise has been included in it.

The IBPD system fulfills all the demands for prototyping, except connection to the cost estimation. The prototype was made at Stanford University where it is possible to use the commercial expert system shell named Design++. It is based on the framework of IBPD. Design++ is a software built on KEE expert system. Autocad is included for geometry presentation. The hardware is a Sun Sparc station.

5.2 Functioning by Using ASCO

The knowledge will be represented in the system in the following way:

- library component hierarchy
- the attributes of a component
- parts and assemblies

When my system is connected to the design knowledge, e.g., other engineering systems, I have to add only the component-selection-specific knowledge. This addition of knowledge also improves the knowledge of other systems. The reason for this is that the knowledge should formulate the thinking for the whole subsystem. The knowledge will be formulated mainly as design rules.

When the knowledge is in the libraries, the product structure will be created. By using product structure, I will design the requirements list for each particular component, as shown in Figure 3.

5.3 The Valve Selection as an Example

Let us take a real problem as an example for the prototype. In the power plant there are 500–1000 valves. I want to use the valve selection as an example because it is a huge, time-consuming task. It includes a lot of knowledge that may be formulated as design rules.

First I describe the problem in Figures 5 and 6. I continue creating rules for black liquor valves. The attributes are presented in Table 6 and Table 7 shows some design rules used in the valve selection. The result -- the list of options -- may be separated by using the reporting tool of the Expert System Shell. This option list is in Table 8.

For the final selection I made the optimum clause that is in Table 9. This particular optimum-valve-list is based on reliability. The final valve list is in Table 10.

6. CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

The component selection is one key issue in process and power plant realization. The prototype in this research shows that an automatic and optimal selection is possible. During prototyping I realized that acquiring the knowledge for the selection process is an interesting and motivating task. Getting needed data from valve manufacturers in digital form is impossible today, but when I can show the benefit of selection and the demand, I believe that manufacturers will be willing to make digital data and update them.

When the ASCO system is in use, the project manager and designer, as well as others needed in the selection process team, can concentrate more on setting the constraints and optimizing, and less on the writing, reading and modifying of papers as traditionally occurs. The requirements for valves and for the delivery process will be determined by a more exact and knowledgeable process when using ASCO, because it can use the best available knowledge and the knowledge can be updated with experiences from every project. This is a big advantage compared to the traditional way; until now it has only been possible to use the knowledge of a human and increase it mainly from his own experiences.

In the near future the process and power plants should be realized in a reduced delivery time [2]. This means that the component selection has to be done during the conceptual design. This will be possible by using the ASCO system, because it can complete the selection as a part of the conceptual design project.

Future research should be headed in two directions. The first is to enhance the integration of the process calculation, P&IDs, layout geometry, and the component selection as a modular system. The tools for each of the above-mentioned functions are now demonstrated, but the integration will be weak until the modularization of the plants is developed.

The second part is to develop knowledge-manipulation methods on how to change the information from the main contract agreement to the constraints of the selection system. It will demand interaction between different knowledge sources, such as law, business, and engineering. In this research I have suggested that the integration of the construction industry needs the automatic selection of components.

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TABLE 1

SYSTEMS TO WHICH THE COMPONENT SELECTION SYSTEM IS RELATED

1. The Cost Estimation (as a part of the business study tool)
2. The Modular Power Plant Design System
3. The Project Planning System
    - Scheduling
    - Cost Control
4. The Design Feedback System

TABLE 2

THE COMPONENT SELECTION SYSTEM

---

1. Overall Strategies (from customer standards)

2. Delivery Strategy (from manufacturer's point of view)

3. The Hierarchy Level of the Purchasing Component

4. Different Types of Suppliers

5. The Constraints Coming from
    - The Main Contract
    - Project Financing Plan
    - Project Guide
    - Project Customized Documentation
    - Schedule

6. The Technical Determination of Components
    - The Process Design of Components
    - The Analysis of the Components
    - The Relationship with Other Components and Systems
    - Requirements for Components

7. Selection of All Acceptable Components from Database and Determination of the Option List

4. Selection of the Real Component from the Above-Mentioned Option List by Using Optimizing Criteria Set at the Project Level

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TABLE 3

DELIVERY STRATEGY

STRATEGIES CHOSEN FOR COMPONENT SELECTION

1. Centralized

- Component Selection: All components are chosen by the main contractor
- Prerequest: Project management has to be excellent
- After Sales: Management centralized, store places can be decentralized
- Quality: Strict quality control in the workshop of the component manufacturer

2. Decentralized

- Component Selection: Only the suppliers of subprojects are chosen
- Prerequest: Subcontracting manual should be advanced
- After Sales: The main contractor has no direct business with component suppliers, so the main contractor can sell only know-how and high-level work
- Quality: Quality control is made by the supplier; the main contractor reviews results

TABLE 4

DIFFERENT TYPES OF SUPPLIERS

1. Main Process (Gas Turbine)
   - The Series of Products
   - Turn-Key Delivery into the Ready-Made Building
2. Subcontractor
   - The Individual Delivery for Each Project
   - Nested Component Selection
   - The Price, Sales Conditions, etc., Depend on the Actual Situation in the Market
3. Component Companies
   - Worldwide Operations
   - Constant Operating Way
   - Products and Their Properties Are Known
   - Constant Documentation Is Needed and Obtained
   - Own ID-Codes Are Used
   - Generally, the Same Kind of Competitor Is in the Market
   - An Existing History of Deliveries
4. Small Company
   - The Product Can Include Superiorities
   - The Service Can Be Great, Flexible
   - Can Be the Competitor of Big Companies
   - Lack of Data of Reliability and Other Properties

TABLE 5

TYPES OF COMPONENTS (SUBCONTRACTING THINGS)

1. Project Components
   - No Ready-Made Solution
   - The Inquiry Made by the Main Contractor -- Offers from Component Suppliers
   - The Component Selection System Has to Evaluate the Optimum of All the Offered Options

2. Standard Components
   - The Lists of Components (Bolts, Pipe-Supporting Parts, etc.) in Digital Form Made by Suppliers
   - The System Chooses According to Specifications

3. Preselected Components
   - The Lists of Suppliers, Sizes, Standardized Components (Made by Power-Plant Main Contractor)
   - The System Chooses from This List

4. Series Products That Are Made for a Particular Project (High-Pressure Valves, etc.). The Component Selection System Can Handle These as Standard Components

5. The Tubes

6. Services

TABLE 6

THE ATTRIBUTES OF A VALVE

<0> VALVE Slots

member:
ACTUAL_COST (local)
ACTUATOR_TYPE (local)
ALLOWABLE_VALVES (local)
ALLOWABLE_VALVES_FOR_DELIVERY
ALLOWABLE_VALVES_FOR_QUALITY (local)
ANSI_CLASS (local)
BODY_MATERIAL (local)
CONNECTED_TO (local)
CONNECTION_TYPE (local)
CONTROL_TYPE (local)
FLOWRATE
GASKET_TYPE (local)
GEO_TYPE (local)
HISTORY
ID_NUMBER
INPUT_COMPONENT1 (local)
LINE_NUMBER (local)
NOMINAL_SIZE (local)
OBJECT_TYPE (local)
OUTPUT_COMPONENT1 (local)
PRECEDING_PUMP (local)
PRESSURE
PRESSURE_RATING
PRODUCT_ID
RDB_ATTRIBUTES
RDB_IN_USE
SERVICE (local)
TEMPERATURE
TEMPERATURE_RATING
VALVE_ID_NUMBER
VALVE_SPECIFICATION
VALVE_TYPE (local)
WANT_ACTUATOR
WANT_RECOMMENDED_ACTUATOR

TABLE 7

SOME DESIGN RULES USED FOR THE SELECTION OF COMPONENTS

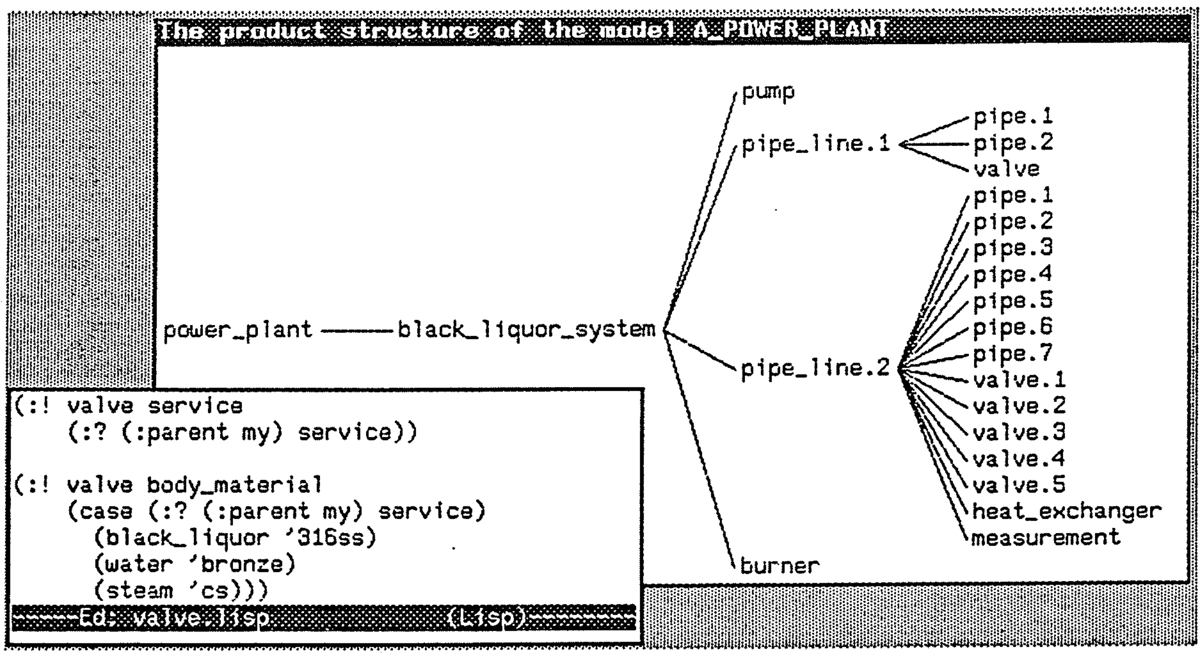

TABLE 8

THE OPTION LISTS OF ALLOWABLE VALVES

```
||| Component: POWER_PLANT
Attribute: QUALITY_VALVE_LIST from POWER_PLANT.S220
   ValueClass:
               (LIST.OF LIST)
   Design.Rule:
                (! SELF QUALITY_VALVE_LIST
                  (LET ((VALVES (:? MY VALVE_LIST)))
                       (LOOP FOR
                             V
                             IN
                             VALVES
                             COLLECT
                             (LET* ((PRICE-LIST
                                      (:? (EVAL V)
                                          ACTUAL_COST))
                                    (QUALITY-LIST
                                      (:? (EVAL V)
                                          ALLOWABLE_VALVES_FOR_QUALITY))
                                    (QUALITY-PRICE
                                      (LOOP FOR
                                            PAIR
                                            IN
                                            PRICE-LIST
                                            WHEN
                                            (MEMBER (CAR PAIR)
                                                    QUALITY-LIST
                                                    :TEST
                                                    'STRING-EQUAL)
                                            COLLECT
                                            PAIR)))
                               (MIN-FROM-LIST-OF-LISTS QUALITY-PRICE)))))
   Rule.File: "optimization"
   Values:
           (("MR3" 1800.75) ("MR7" 1727.25)
                            ("MR6" 294.0)
                            ("MR8" 7644.0)
                            ("MR5" 205.8)
                            ("MR7" 1727.25))
```

```
||| (Output) Component: POWER_PLANT
Own slot: LEAST_EXPENSIVE_VALVE_LIST from POWER_PLANT.S220
   ValueClass:
               (LIST.OF LIST)
   Design.Rule:
                (! SELF
                   LEAST_EXPENSIVE_VALVE_LIST
                   (LOOP FOR
                         V
                         IN
                         (:? MY VALVE_LIST)
                         COLLECT
                         (MIN-FROM-LIST-OF-LISTS (:? V
                                                     ACTUAL_COST))))
   Rule.File: "optimization"
   Values:
           (("MR3" 1800.75) ("NJ7" 1501.5)
                            ("NJ6" 259.35)
                            ("NJ8" 6893.25)
                            ("MR5" 205.8)
                            ("NJ7" 1501.5))
```

TABLE 9

A CLAUSE USED TO OPTIMIZE THE SELECTION OF VALVES

```
(:! flow_control_device allowable_valves_for_quality
   (let ((valves (:? my allowable_valves))
         (plant_qlevel (:? power_plant minimum_qlevel))
         (type (:? my valve_type))
         )
     (comr:flatten
      (loop for v in valves
            collect
            (let* ((manuf (:std (eval v) manufacturer prices '(product_id))) ;FROM RDB
                   (valve_qlevel (:std (format nil "~A$~A" manuf type)      ;FROM RDB
                                       quality_level mnf_ratings '(manufacturer valve_type)))
                   )
              (when (<= valve_qlevel plant_qlevel)
                v))))))
-**--Ed: optimization.lisp      (Lisp)------------------------------------------------
```

TABLE 10

THE FINAL VALVE LIST

```
cmdtool - /bin/csh

VALVE INFORMATION

   Users' optimum valve set based on QUALITY:

   MR3 1800.75
   MR7 1727.25
   MR6 294.0
   MR8 7644.0
   MR5 205.8
   MR7 1727.25

   Total price of this valve set: $13399.05

List of all allowable valves and their cost:

    VALVE                 MR3 1800.75
   VALVE.1                MR7 1727.25 MS8 1754.4 NJ7 1501.5
   VALVE.2                MR6 294.0 NJ6 259.35
   VALVE.3                MR8 7644.0 NJ8 6893.25
   VALVE.4                MR5 205.8 MS7 244.8 NJ5 218.4
   VALVE.5                MR7 1727.25 MS8 1754.4 NJ7 1501.5
```

FIGURE CAPTIONS

Figure 1. Requirement areas of components.

Figure 2. Plant design of the project after the investment decision.

Figure 3. Flow chart of the automatic selection of components.

Figure 4. Interaction of numerical and graphical programs with expert systems [4].

Figure 5. Sample product structure for part of a power plant.

Figure 6. Sample power plant pipe-line for selecting valves.

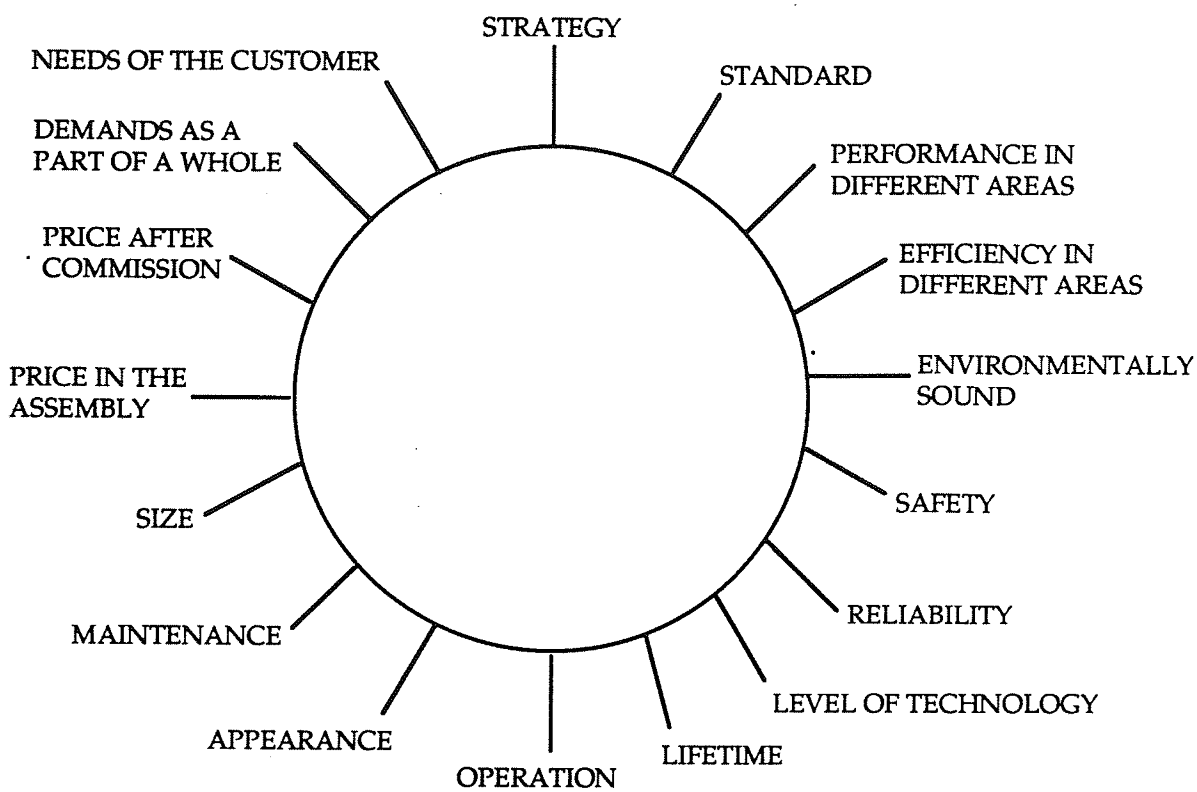

Figure 1. Requirement Areas of Components

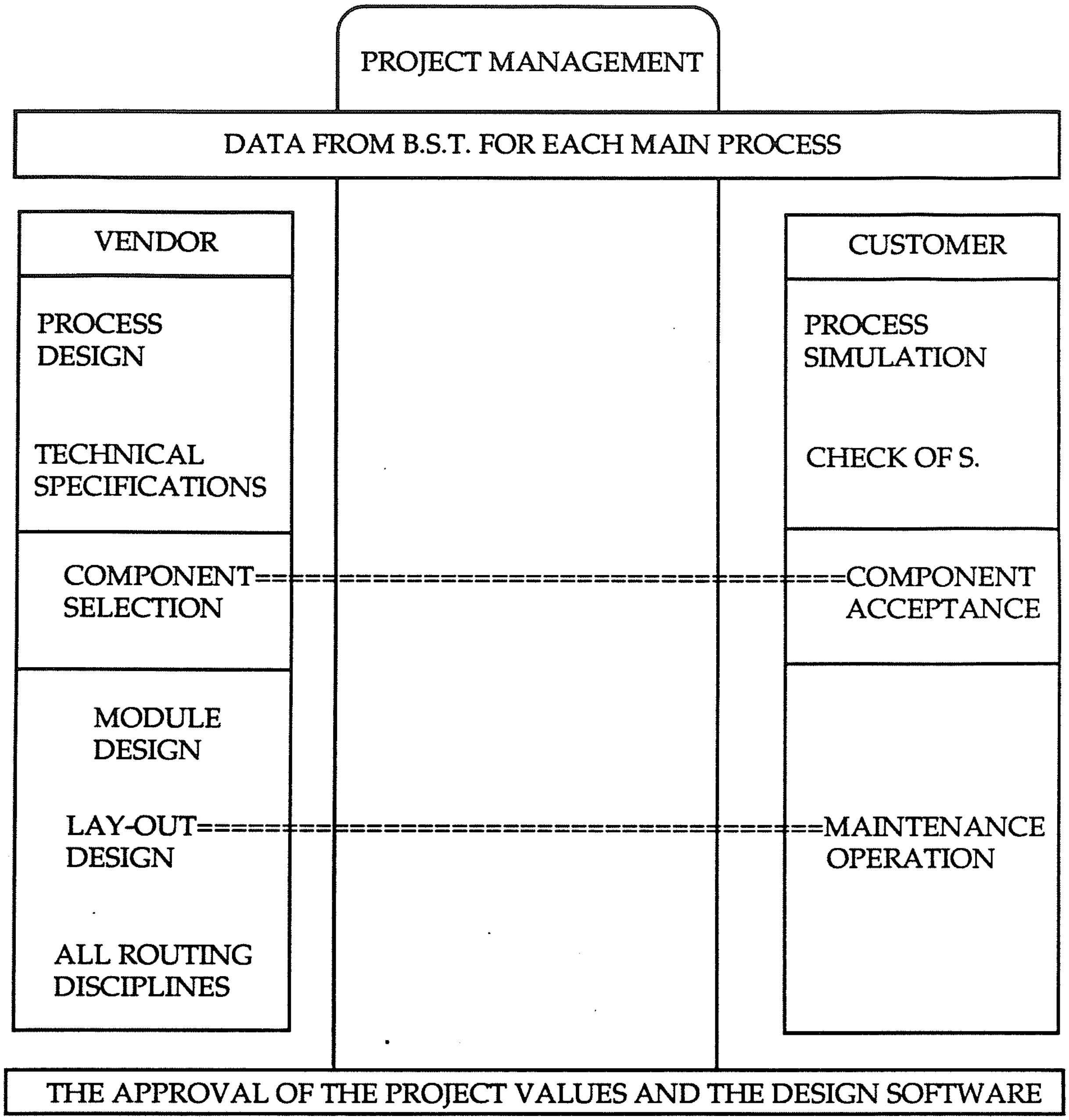

Figure 2. Plant Design of the Project After the Investment Decision

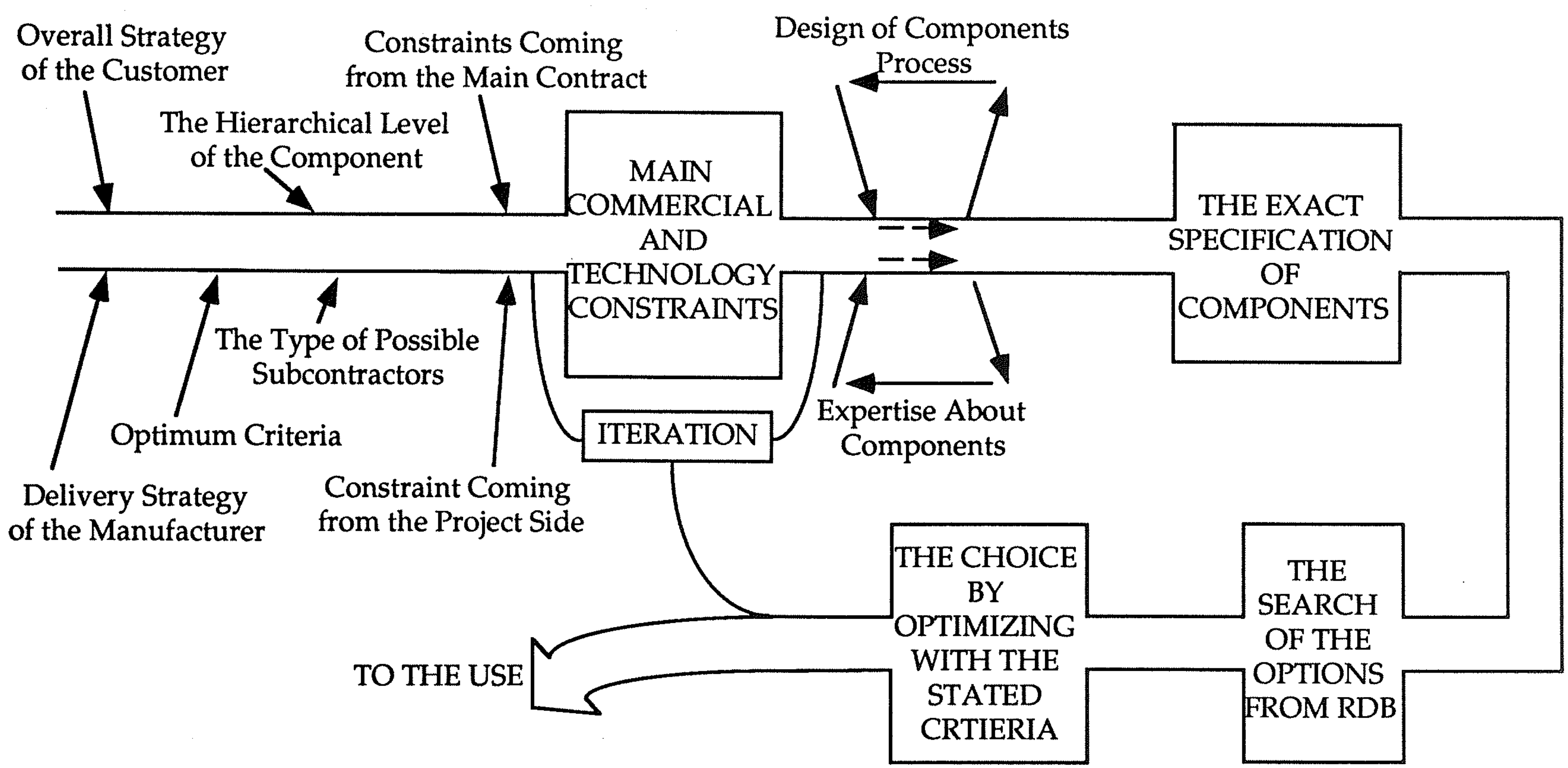

Figure 3. Flow Chart of the Automatic Selection of Components

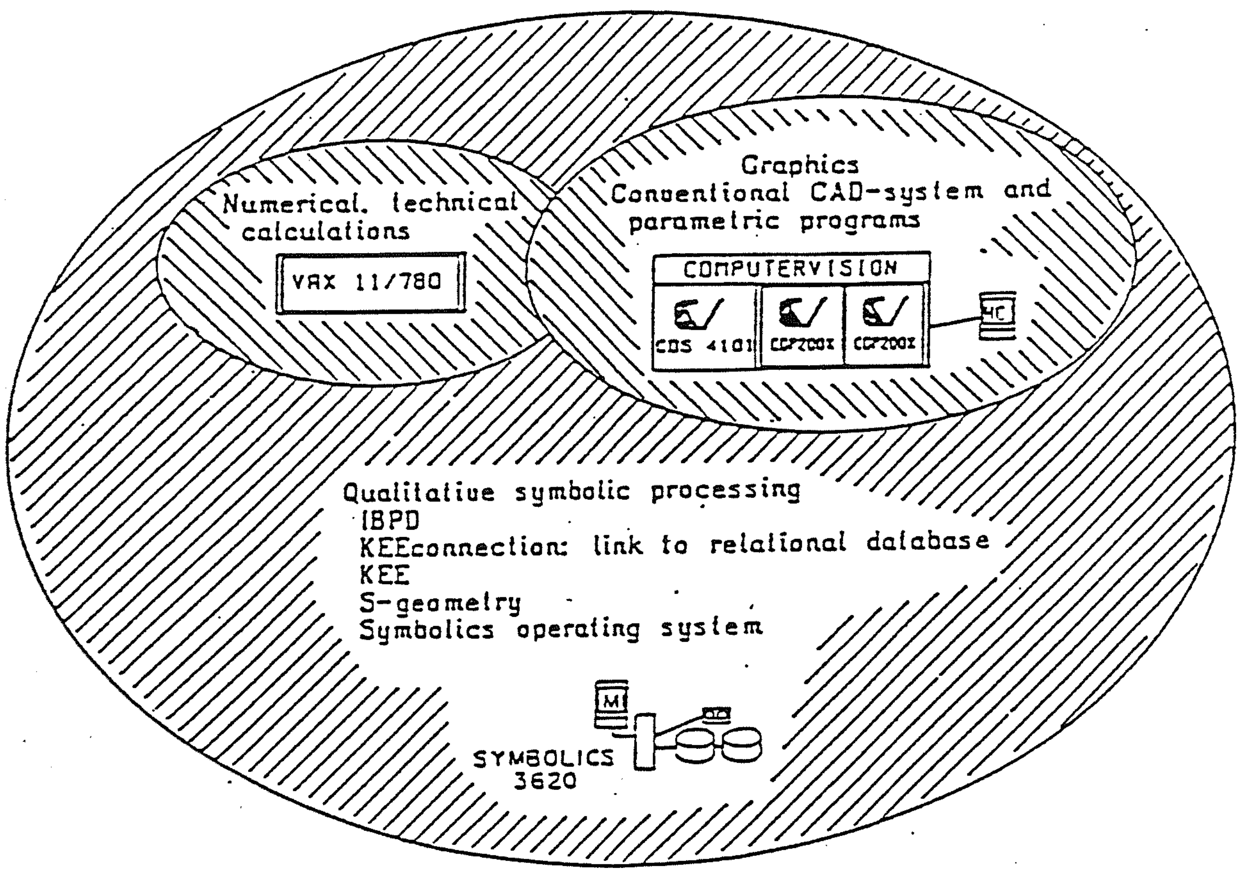

Figure 4. Interaction of Numerical and Graphical Programs with Expert Systems

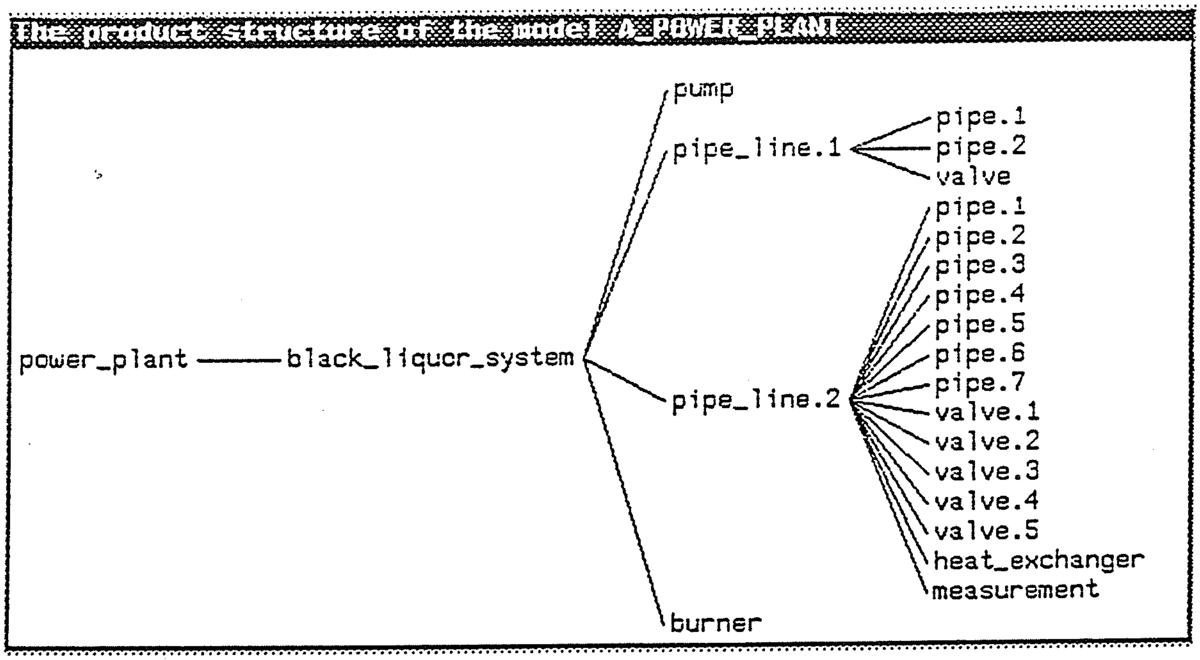

Figure 5. Sample Product Structure for Part of a Power Plant

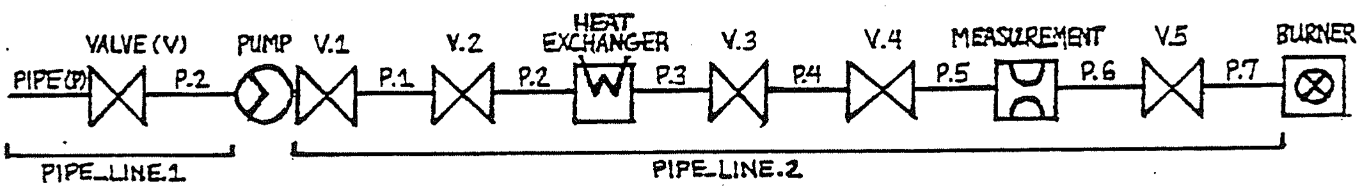

Figure 6. Sample Power Plant Pipe-Line for Selecting Valves