CIFE CENTER FOR INTEGRATED FACILITY ENGINEERING

Reduced Delivery Time for a Customized, New-Type of Power Plant, Through the Use of AI Technology

by
Asko Riitahuhta and Jean-Claude Latombe

TECHNICAL REPORT
Number 35

June, 1990

Keywords: integrated gasification combined cycle power plants, integrated life cycle process, expert system, reduced delivery time

Reduced Delivery Time for a Customized, New-Type of Power Plant, Through the Use of AI Technology

If you would like to contact the authors please write to:

c/o CIFE, Civil Engineering,
Stanford University,
Terman Engineering Center
Mail Code: 4020
Stanford, CA 95305-4020

1. INTRODUCTION

Process plants are changing significantly in response to the needs of customers. The most important demand will often be that the process plant must be environmentally clean. **The changes in process plants and the industrial environment requires that the methods used to design and build process plants must change.** The methods must be:

- highly automated
- fast
- flexible
- integrated
- related to R&D efforts

so that the latest results can be implemented immediately. In this paper we take a power plant as an example of process plants and we present **what must be changed in the power-plant-manufacturing industry in order for the customer to get the needed services.**

In the first section we describe how the needs of customers in the power-plant business are changing. These changes are caused by problems in nuclear power plants, environmental damages, and the long-term shortage of fuels like oil, natural gas, and even uranium. According to the *Conference on Technologies for Producing Electricity in the Twenty-First Century* [1], coal is in the long term the most important fuel because of its availability. However, the use of coal demands new clean coal technologies. Because of these changes, the power-plant realization methods are not efficient any more and we describe the main problems.

In the next section we suggest a way in which the power-plant business should operate and the tools that will be needed. We describe the power-plant project in seven stages, starting with the development of the power-plant project and going to the last stage of maintenance. For each stage we suggest realization methods and tools to make them more integrated and efficient compared to today's practice. We also estimate the results of the suggested changes.

In the final section we consider how well the research work conducted in the Center for Integrated Facility Engineering (CIFE) at Stanford University supports the "grand view" presented in this paper. We also suggest new research projects for power-plant construction.

2. PROBLEMS IN POWER-PLANT CONSTRUCTION

2.1 New Technology--Integrated Gasification Combined Cycle

The main energy source in the 21st century will be coal since nuclear energy and natural gas cannot come into consideration, because the amount of them is so limited [1]. However, **new technology must be developed to deal with the accompanying problem of increased CO_2 and acid rain, and a major environmental protection effort is required, including not only air-pollution control but also waste disposal and wastewater management.** That kind of technology can be found in the **Integrated Gasification Combined Cycle (IGCC) technology**, whose process is diagrammed in Figure 1.

The IGCC process is a major step toward the above-mentioned requirements. Its efficiency is 5 to 10 percent higher than that of the conventional process and, correspondingly, the CO_2 emission is lower. The SO_x and NO_x emissions, as well as the dust emission, are only one tenth that of the conventional technology (Figure 2). **The power plant itself is different**, since the gasification process takes place under pressure and includes different types of components than earlier processes, for example hot-gas cleanup and more pipe work.

The development work of the IGCC process is ongoing; the first demonstration plants will be ready during the next five years and the commercial plants will operate by the end of this decade.

However, by the development of the IGCC technology alone, the needs of the customer are not fulfilled. The realization of power plants must also be different from that of today. Tables 1 and 2 summarize how the power plant business is changing.

The suitable size of the demonstration plant will be 150 MW. The size of commercial IGCC plants can consist of different amounts of units, such as gasifiers, gas turbines, and steam turbines. This flexible configuration also allows building the needed electricity capacity, step by step, unit by unit.

2.2 Realization Problems

Engineering companies have been the main contractors in power-plant projects and each main process has been delivered by a specialized company. This situation has made it **difficult to maintain consistency of the design**. The only way to maintain consistency has been by means of a large amount of drawings sent from one company to another. This method of consistency maintenance has not worked well, because many times the lack of professional conceptual design has caused a series of low-level, time-consuming modifications.

2.2.1. Design of traditional power plants

The design of traditional power plants starts with the determination of a few performance values such as the amount of electricity and steam needed, as well as the pressure and temperature of steam. After that the process calculations are made. The design continues as a conceptual design and detail design that require several design disciplines.

Figure 3 shows the different disciplines used in design of the boiler plant, which is a major part of the traditional power plant. Figure 4 shows how these disciplines are connected. It is easy to imagine that **the design process can be very iterative**. Usually the iteration is increased because preliminary and detail designs are not clearly separated and they are concurrent.

The good progress that has been made in the mechanical engineering CAD has been applied to plant design, but a couple of years later. CAD plant design has the possibility of drawing process and instrumentation diagrams (P&IDs) at the start of the design. The P&IDs can include process knowledge, identification information, and list of materials. That information can be efficiently processed automatically. This information processing should bring high productivity. According to our experience, productivity gains are rarely achieved, because **in a real time frame it is impossible to implement all the information required for such a large project within the P&IDs.**

The next stage after the P&IDs is to do **a three-dimensional geometric model of the process plant.** The lack of the systems is **that most of them do not support the conceptual design.** But when the spatial design of the plant is clear, the computerized model is accurate and many programs produce shadowed color views and are capable of replacing the plastic design scale model. The big CAD-plant users, as well as manufacturers of nuclear power plants and oil rig platforms, have accepted the working procedure of these programs, because the basic concept of these plants does not often change. The accuracy of the model has the benefit of avoiding mistakes such as collisions of different parts. In power plants, the situation is different, because they are individual. **The impact of conceptual design to the end result is significant.**

The next stage in plant design is to produce documentation for the realization. Typically this has meant creating drawings. In CAD-systems the good capabilities of the three-dimensional model and the efficient production of drawings have not gone hand-in-hand. The software developers, who have created good systems for three-dimensional design, have not had enough resources with which to develop drawing production.

More advanced tools, such as **process simulators, are rarely used in the industrial environment.**

2.2.2. Manufacturing and construction stages

The realization of process plants is not very advanced. The use of automation is low compared to that of the car industry. Let us take one example, that of automatic welding. It has been rarely used at the construction site because its investment cost is high, and it demands that the pieces to be joined are accurate. This accuracy can be reached today using CAD-systems the design can be made precisely. Also the accuracy of manufacturing can be high enough using CNC-technology, if the construction site demands it. The higher investment cost can be covered by the better quality. For example, in the beginning at the site, it appears that one fourth of the manual welding has to do with repair. In the workshop, the repairing work for welded pipe joint work is only one hundredth that of manual work. By developing automatic welding methods and constructions, so that automatic welding can be used at the site, the reduced repairs can give a good return on the investment. This example shows that even today possible enhancements are not being applied, although the profitability would be excellent.

Another example of the extensive manual work at the site is the insulation against heat losses. In the power plant, all hot pipework, ductwork, and the furnace are covered with insulation, which is made manually at the site. This manual work comprises over 20 percent of the site labor costs.

The reason for the low automation stage is that the power-plant construction industry is fragmented, like the construction industry in general. It has been nobody's business to develop an integration of site operations. Of course, site automation is a difficult task, because there are many temporary facilities, many tasks are going on at the same time on different levels, and the ground to move on can be unstable.

2.2.3. Operation and maintenance

Operating the power plant is a demanding task, because the power plant consists of many complicated, controllable circuits and parts. The training of operators is mainly done during the commissioning of the power plant. **To learn to operate a complicated power plant takes a lot of time. This has meant that the commission period has become longer during the last few years, from two months to half-a-year adding extra costs.** Untrained personnel can cause shutdowns of the plant. The shutdown and restart of the plant are very expensive.

Power-plant owners have had their own personnel for the daily maintenance of the power plants. The larger maintenance efforts are sometimes performed partly by manufacturers and partly by smaller, local, low-cost service companies under supervision of the owners. **This has meant that the owner has had to employ many people working on maintenance and the maintenance work has been strongly competitive.** Today utility companies are reducing costs and they are willing to transfer more responsibility for maintenance to other companies. The maintenance business will change. Many companies are making business plans to improve maintenance by using automation, design information, improved control systems, predictive maintenance etc.

3. GRAND VIEW OF POWER-PLANT DESIGN AND CONSTRUCTION

3.1 Setting of Goals and Reaching Them

From Table 2 we get the goals, which we can crystallize into two main goals, as follows:

1. Values -- what the customer needs, must be reached.

2. Delivery time must stay under half of today's best one.

The first goal determines performance and business-related values, and the second goal the way of realization. The above-mentioned goals include very challenging subgoals. **Setting the delivery time goal such that it is impossible to reach with today's methods, we ensure that the operating processes will change.**

In this paper we divide a project into the following parts:

a. Development of the power-plant project

b. Plant design of the project after the investment decision

c. Detail design

d. Manufacturing

e. Site operations

f. Operation

g. Maintenance

For each part, our model shows how the project data grow and become more complete. Even here, we want to emphasize that at the same time that the systems are developed, the product itself -- the power plant and its components -- must be researched and developed.

3.2 Development of the Power Plant Project

In most cases today the investor wants the main process suppliers to commit to the project by investing in it. This is called the "build, own, and operate" system. Therefore, the manufacturer must also learn the power-plant-owner business more deeply, or the new business may not be profitable. The utility companies study many possibilities when they start to plan a new power plant. In these studies, the size of the plant is a variable, as are the fuel used, the operation time per year, and the operation ratio from the full capacity of the plant. The outcomes depend on the power consumption of the serviced areas, but the profit depends on investment and operational costs. Conceptual design is needed to determine investment and operational cost. We propose **that a knowledgeable application team under the direction of the sales management, functioning together with the customer, can develop a profitable project by using the Business Study Tool (BST).** The BST system described is shown in Figure 5. The BST consists of software, which will be connected to the manufacturer's computer network, enabling it to get more knowledge from the host computer.

The BST must provide the conceptual design of the plant and must, of course, be powerful enough to create business scenarios for a particular power plant. Other necessary data are the performance and emissions rates for the permit applications and the model and specifications for the customer.

The tool must be very reliable and powerful, because at this time the customer will choose the partner; if his business determinations are good, the manufacturer has a maximum possibility of getting the project.

3.3 Plant Design of the Project after the Investment Decision

The power plant that will be built has been determined very well in the business-study stage by the use of BST. Once the investment decision has been made, the project personnel are chosen. The project management takes the first initial budget and other data from the BST. The plant design chart is shown in Figure 6. **The goal at this stage of the project is to get as a result the design model, all specifications, and the project plan.**

The project management typically will contribute on four levels: the whole project, the main processes, the work packages, and the specific tasks. An example of what is involved in the latter three levels is shown in Table 3 [2].

The time schedule will be so tight that the different teams need design tools that are automated.

The design model and specifications produced will be meant as a set of requirements for the detail design of the manufacturing. The interesting question is, what should be the boundary between the plant design and the detail design and how much detail design knowledge will be needed at the plant-design stage? The strategy should be that the detail design be done as close as possible to the manufacturing. On the other hand, the process knowledge at the plant-design stage is strong, but that is not so in the manufacturer organization, where the detail design is made. **We propose that at the plant-design stage, the components must be so clear that the local layout is possible to do inside the modules, but in the detail-design stage the joints of components and more accurate measurements are determined.** By doing so, the needed knowledge is available where the design is made.

In the plant-design stage, it is necessary to get the customer personnel to commit to the decision made. Let us go through Figure 6. **When the power-plant supplier designs the process, the customer starts to do process simulations.** This means that the power-plant simulator must be so advanced that it is possible to start to use it with only limited data about the project. As the simulator works more and more accurately, the technical specifications are made and transferred to it. A check of the specifications is made by using the simulator.

A significant influence on the project comes from how well the components were selected. The main process of the power plant consists of the different kinds of components: some of them are as complex such as a hot-gas cleanup system, some may be only an on–off valve. The power-plant engineering vendor will choose the components, but the customer will be involved in the work.

Module design is possible after the process and components are determined. The design tools must be flexible so that they allow the module design from top–down and bottom–up, e.g., starting with module constraints or components. **Many disciplines of the design are made simultaneously; therefore, teamwork is mandatory.** The module design will be accomplished either at the main process level or at the work package level, as described in Table 3. **The module design and automatic routing, as well as the**

process design and component selection done earlier, are key issues insuring that this design stage will be dramatically enhanced.

The result of the plant-design stage is the approved project data and the design model.

3.4 Detail Design

Today the tools for the detail design are quite advanced. Many companies are doing the detail design of the project almost 100 percent by using 3D CAD-systems and further developments in this area are coming fast. **For this project stage we want to integrate project management.** At this time, the project management schedule will be made for the task level (Table 3). When the modules from the plant-design stage have been obtained, they will be designed at this stage, so they can be easily manufactured and constructed.

Detail design will be mainly made inside the modules defined at the previous plant-design stage. Therefore the constraints set in this process and plant design must be followed. **However, the feedback link between these two project stages will allow for the necessary modifications.** Thus the project stage will produce the final design data of the project. The data flow of the detail design is shown in Figure 7.

3.5 Manufacturing (Construction)

Unlike the situation on site, the manufacturing performed today in workshops is automated. Consequently, we propose that many manually performed tasks at the construction site be transferred to the workshop, as shown in Figure 8. **That means that in the workshop, where nowadays only metal works are made, whole modules should be assembled in the future.** The manufacturing of modules possibly will include concrete foundation beds for machines, steelwork, pipe work, installation of components, heat insulation, electrical wiring, etc. **This manufacturing of modules also will make quality control and testing of the modules possible in the workshop.** Thereby the modules can be placed in the plant already connected and started up.

The change in product design by the IGCC process does not need today's manufacturing facilities so much, but the change in manufacturing strategies demands a whole new type of facilities.

The project data will be maintained, combining the manufacturing and quality-control data and updating the design model, as modifications made during the manufacturing.

3.6 Site Operations

During the duration of the whole project, the time schedule of the project will be developed and refined. On the other hand, a lot of the work will be moved from the site to the workshop. **The site operations will consist of the assembling of modules and routed objectives, such as pipe work, duct work, etc. Robotics will be used extensively.** The changed operating model demands that the site have excellent project management tools and communication with a comprehensive database.

The use of robotics allow a new accuracy level for the installation. That will be possible by using new types of laser measurement systems at the construction site. These measured data again will be transferred to the project database.

Temporary facilities and transportation to the site are very costly today. The temporary site layout will be optimized. The key issues of site operations are shown in Figure 9.

3.7 Operation

The personnel of the customer will be trained to operate the plant by using the simulator. They will be involved throughout the realization of the plant, so the commission will be mainly a test of the communication and information links. **The operation of the power plant will be supported by the simulator in such a way that the simulator suggests the actions to the operator.**

3.8 Maintenance

The database coming from previous project stages will be stored in the computers or on optical disks. **These are given to the customer, enabling the customer to organize the maintenance by himself, but based strongly on the database.** Use of the database is most economical, if it has been organized by the main contractor.

3.9 Expected Results

3.9.1. Delivery time

Will it be possible to reduce the delivery time of the plant to half, when the above-described systems are used? In Figure 10 are shown the construction time for today's power plant and the construction time when the new system is used. The diagram shows that it will be possible to reach the delivery time goal. **The reduction in delivery time will be the sum of the enhancements made in every stage of the project.** The most important improvements will come from BST, component selection, advanced manufacturing, and comprehensive commission.

3.9.2. The low-cost plant and its operation

How much more cost-effective will the plant be when we operate according to the new system? Possibilities for making the plant most cost-effective are:

(i) Development of the project

- finding the right time and place
- finding the right fuels
- finding a configuration that is flexible enough to allow future changes

(ii) Design

- clarifying the concept
- choosing the right components
- insuring that only minimum modifications are needed
- choosing the smallest possible plant size that allows efficient operation and maintenance
- insuring that the smallest amount of man-hours will be needed in the short term

(iii) Manufacturer

- executing work in the right place; integrated manufacturing
- minimizing the amount of material
- implementing new, advanced methods, for example EB-welding
- making inspections and tests in the workshop

(iv) Transportation

- distributing information and material
- using the modules

(v) Site

- minimizing work and transportation at the site
- automation of the manual work
- modules

We have included all the above-mentioned possibilities in our grand view.

We have previously studied how much the costs of a normal power-plant boiler can be reduced [3]. That study showed that using methods in the above list effected a cost reduction over 20 percent. So here we have set a goal of achieving at least 30 percent.

The total costs of the typical power plant project consist of 10 percent engineering, 54 percent components and materials, and 36 percent construction costs. In Figure 11 we show how costs will be structured when we realize the power plant through the use of the new methods. **We expect that all functions, such as design, manufacturing, etc., can reduce the costs, but an especially strong influence is from site operations, because we suggest that the work will be transferred to the workshops and there it will be made by using automated machines instead of today's manual work.** Based on the research made by Tatum et al. [4] concerning the influence of prefabrication, preassembly, and modularization, as well as our own research in the fields of AI, robotics, design and power plants, we believe that the goal of a 30 percent cost reduction is realistic. We estimate that 5 percent in savings will be obtained, because the development of the project is made by the customer and main contractor together.

However, the new way of operating does not only give a reduction in time and costs, it will also increase the profitability for the following reasons: **The business study has been done in such a way that the solution is optimum, using the best existing knowledge from the customer and the main contractor. The design is based on strong R&D work, and the manufacturing takes place in the workshop under good conditions, so that the quality of the plant will be excellent. This good quality means that the reliability of the plant will be improved, both during the commission and throughout all the phases of the life cycle. A more compact plant means that the pressure losses are smaller and the efficiency is better. In addition, more trained personnel can operate at a better efficiency level. Profitability could be raised by some percentage points.**

The other aforementioned needs of the customer have been reached because the project is developed in cooperation with a customer who plays a very strong role and because the chosen product technology fulfills these needs.

3.10 Tools Needed to Obtain These Results

To obtain the new way to operate and accomplish the results described above will require a lot in the choice of tools. The need for these kinds of tools has been found at Stanford University where the Center for Integrated Facility Engineering (CIFE) has been established. CIFE is an industry affiliate program that combines the resources of the Civil Engineering and Computer Science Departments with those of industry affiliate members in order to pursue a research program directed toward the following goals:

1. To improve the cost effectiveness, productivity, and quality of the planning, design, construction, and facility management functions by developing computer-based tools that will facilitate the **integration** and **automation** of these functions. This **integration** will be accomplished through computer tools

(database, AI, communications) and industry standards for exchanging and sharing data. **Automation** refers both to engineering, design, and management systems that are "smarter" and field automation using robots and machines that reduce manual labor and increase safety and quality. CIFE will emphasize the software rather than hardware requirements of field automation.

2. To better understand the non-technical problems that hinder the adoption of advanced technology within the design, construction, and facility management process and to suggest approaches to overcome these problems.
3. To introduce into the educational curriculum at Stanford and elsewhere the technology and ideas developed from research efforts so that graduates will have the advantage of powerful design and analysis tools and a better understanding of how technology can contribute to the facility over its life cycle.

The above goals are applicable to a wide variety of architectural, civil engineering, and infrastructure areas, including: buildings of all types, heavy civil works, chemical plants, power plants, waste treatment, transportation, etc. CIFE research is distinguished by efforts that allow improved **integration and automation during all phases of the life cycle** as opposed to efforts that study only one aspect of the facility life cycle in greater depth.

The following list shows what systems we have envisioned for the enhancement of power-plant delivery, and next to them are shown the projects that are ongoing in CIFE at Stanford University.

a.	Project Database	KADBASE, Flagship project #1
b.	Project Planning	SIPE, OARPLAN, Integrated Project Management System
c.	Business Study Tool	None
d.	Technical Specification and Component Selection	None
e.	Module Design and Module Layout System	Sight Plan
f.	All Routing Disciplines	Pipe-routing System
g.	Detail Design Tool	Partly Commercial
h.	Manufacturing Automation	Robotics, Pipe manipulator, Assembly project
i.	Measurement and Quality Control System for the Workshop and the Site	None
j.	Operating System	None
k.	Maintenance System	IRMA-Project, IRTMM-project
l.	Video-communication in all stages of the project	Developed

4. RESEARCH IN CIFE AT STANFORD UNIVERSITY AND WHAT THE NEW SYSTEMS NEED

4.1 Overview of Some Aspects

In this section we suggest what kind of emphasis we want to give to CIFE's research project for enhancing the development of tools and methods needed in the above-described power plant system.

The basic function of process plants is the process itself. Around it the whole process plant is constructed. In the same vein, all facilities have their main functions. A good start for research in the process field is Intelligent Real Time Control on Monitoring Project. But a good understanding of P&IDs is necessary for process plant research.

The automation of Technical Specification and Component Selection gets information from the P&IDs. It is a very important task, because today the only tool used is spread-sheet programs, but the needed expertise seems suitable to process by using Expert Systems like the one described in Ref. [3]. However, the following fields need to be studied:

a. Acquiring and maintaining knowledge of all components needed.

b. Organizing this knowledge so that it is useable.

c. **Choosing the subcontractor strategy. Is the cooperation model better than today's tender competition?**

In source [5], Dr. Teicholz has shown how the productivity of the construction industry is going down. A possible way to increase the productivity and profitability is to enhance the conceptual design and the business plan of the project. The Business Study Tool is suggested for this purpose. The BST needs information of the database of the main contractor, the customer, and the environment.

In the next section we will present some interesting research projects that are enhancing the methods of process and power plants significantly.

4.2 Stanford CIFE Projects

4.2.1. Knowledge Aided Database Management System (KADBASE)

In our vision of the power-plant realization, the database management systems is a very important component. The KADBASE system [6] has been developed, because many existing engineering applications are restricted to limited amounts of data and have no facility for sophisticated data management. KADBASE is a knowledge-based interface in which multiple expert systems and multiple databases can communicate as independent, self-descriptive components within one integrated, distributed engineering computing system.

KADBASE is divided into three basic components as described below and shown in Figure 12.

- The **Knowledge-Based System Interface** (KBSI) is a part of each knowledge-based system. It formulates the queries and updates sent to the network data access manager and processes the replies from the network data access manager. The KBSI possesses knowledge about the schema of the KBS context (data space) and uses that knowledge to perform semantic (and syntactic translations) for the queries, updates and replies.

- The **Knowledge-Based Database Interface** (KBDBI) acts as an intelligent front-end for a basic Database Management System DBMS. It accepts queries and updates from the network data access manager and returns the appropriate replies. Like the KBSI, the KBDBI possesses knowledge about the local database schema and the local language for data manipulation requests. It uses that knowledge to perform semantic and syntactic translations for the queries, updates, and replies.
- The **Network Data Access Manager** (NDAM) provides the actual interface. It receives requests (queries and updates) expressed in terms of the global schema from the knowledge-based systems (through their KBSIs). Using information associated with the global schema, the NDAM locates sources for the data referenced in a request and decomposes each request into a set of subqueries or updates to the individual *target* databases. The subrequests are sent to the corresponding knowledge-based database interfaces (KBDBIs) for processing. The replies from the KBDBIs are combined to form a single reply to the original request and sent to the requesting application through its KBSI.

The NDAM receives queries and updates expressed in terms of the global schema from the knowledge-based systems (through their KBSIs). Using the global schema, the global data source mapping, and the global integration mapping, the NDAM locates sources for the data referenced in a request and decomposes each request into a set of subqueries or updates to the individual *target* databases. The subrequests are sent to the corresponding KBDBIs for processing. The replies from the KBDBIs are combined to form a single reply to the original request and sent to the requesting application through its KBSI (Figure 13).

KADBASE is a prototype, but it will be developed agressively during the next few years. The prototype has been tested by two types of problems: a structured component design system and a knowledge-based cost estimator for detailed building designs.

The process plant design is a multiple-discipline problem. There are several expert systems for design purposes. For example, the structural design of steel work, modules, pipe work, cable trays, etc. This means that the task of maintaining consistency of the design data is very important. In KADBASE development this multidisciplinary problem has not been sufficiently studied. So it is **necessary to use a broader example, for example a power plant, where KADBASE definitions are made after the first prototype.**

We consider another example made by Computervision, that of a division of Prime Computer. **Here a lot of development work has been done to control who can change data and to track what kind of revisions can change the database.**

The KADBASE project has been selected a flagship project of CIFE and offers opportunities to collaborate with other database management developers, so that the multidisciplinary problems can be taken into account with the proper emphasis.

4.2.2. Sight Plan -- a system for site layout design

Sight Plan [7] positions temporary facilities, such as parking lots, construction office trailers, and material-laydown areas. These facilities remain on the site for periods ranging from a few days to several months, or even years, depending on whether they support a single construction activity, a construction phase, or the entire construction enterprise. There are many factors that influence what facilities are needed on a given project and how they should be laid out. Sizing requirements may be satisfied before any layout is generated. Other requirements affect the location of facilities on the site.

The goals of Sight Plan development were the following:

a. Build a model to reproduce the problem-solving strategies employed by human experts in designing site layouts.

b. Test the power and generality of BBI, a generic blackboard architecture on this design problem.

c. Explore the potential of computer-based strategy and interactive graphics to integrate the bookkeeping and computational strengths of a computer system with the spatial perception and reasoning strengths of a person engaged in this spatial layout task.

The limitation of Sight Plan is that it would locate approximately 50 predefined temporary facilities of rectangular shape in a 2-dimensional space.

The postponed commitment strategy, implemented in the final computational strategy, strikes a balance between heuristically pruning the solution space and flexibly generating alternatives.

In conclusion, the research group for Sight Plan initiates the development of a system to perform architectural space layout of rooms and designing the layout of the permanent facilities of a power plant.

The goals of Sight Plan are the same as those of Scema software and IPBD-design system [3] The realization is different. In Scema the product hierarchy and advances made in the modeling work determinate the layout. So the idea is that research and standardizing work made in the modeling stage are alone with the wide scope of covering the concerns that appear. The model that has been made should provide an optimum one because it is possible to change the design interactively. Instead of it, **Sight Plan can produce different possibilities inside the set boundaries.** The user of the system can decide and choose the best one.

In the best-case scenario, Sight Plan can produce innovations and produce more economical results, but it demands that the user be very knowledgeable.

Regardless of which system we choose as a Module Layout System, the system must have the following characteristics:

a. The power plant has been split into three modularization levels; the system uses the two upper levels (an example of modularization is shown in Table 3).

b. The modules are determinated according to the process; the first domain comes from P&I diagrams.

c. The specifications and components are the second domain comprising the modules.

d. The modules include constraints

e. The users can add their own constraints

f. The system has to operate three-dimensionally.

g. The plant can be divided into zones

h. The modules in this stage can be composed of orthogonal space elements.

i. The optimal result is reached when the plant is as small as possible within the boundaries of the constraints.

When the spatial reasoning is made, the system must change the P&IDs into the three-dimensional form corresponding to the power plant and thereafter the check of process calculations should take place. The module layout using P&IDs comes within the domain of the Automatic Routing System.

4.2.3. <u>The Automatic Routing System</u>

One of the authors has developed Automatic Pipe Routing System [8]. The idea is that the routing takes place as motion planning. **The system is based on an hierarchical approximate cell decomposition method for motion planning**, composed of two main steps:

1. Decompose the space into rectangular regions called cells and label them empty, full, or mixed, depending on whether they are completely outside of any C-obstacles, completely inside some C-obstacles, or neither.
2. Construct an adjacent graph of the cells and search for a sequence of empty and/or mixed cells that connect the initial and coal configurations.

The implementation of the approach is efficient, because of

1. constraint reformulation techniques using bounding and bounded approximations of C-obstacles to generate a decomposition of the space, and
2. divide-and-conquer techniques allowing construction of a separate subgraph for each retuned mixed cell and searching for a subchannel.

The drawback of the sequential routing is that the nets routed may first take up the "wrong" space, preventing the routing of other nets. The solution to this is a parallel router based on

"Constraint Propagation" techniques. The router is extended to take into account optimality criteria, additional constraints on the geometric shape of the pipe, and branching (Figure 14).

The pipe router described above is working in the university environment now, but the plan is that it will be transferred to the industry in the near future. The router operates now using two design levels.

The automatic routing tool that we want to use in the power-plant design should also be able to include **other shapes in addition to just round, such as ducts, cable trays, beams, maintenance, and operation corridors, as well as staircases.** The size of routing shapes can vary a great deal, from 10-mm small pipes to 5- × 20-m flue gas ducts.

The router should be capable of working at all three modularization levels. While the router is created within one domain, it must be capable of giving feedback to the other domains. For example, pressure drop calculations must be repeated using real pipe shapes and lengths.

The layer technique can be very good, but two levels at one time are not enough. It should be possible to select 50 layers for routing and about 20 layers to refer. In a real power plant there are places where the uptake of pipes, cable trays, etc., from one level to another is preferable. The system should include sources to guide the router. When the router is looking to avoid obstacles, the source should be opposite the obstacle. This source system should make the router a real three-dimensional tool, particularly when the sources are different types for different routing objects; possibly, five different types are sufficient.

Another important feature of **the pipe work should be a pipe-supporting system and a component-adding system.** The component-adding system is necessary because the module system includes the main part of the components, such as fans, pumps, tanks, etc., but not all. Pipe-supporting is a very time consuming and expensive stage in the design of the plant, and thus, its automation can give big benefits, especially when it is automated within the pipe-support optimization system.

The corridor routing system is a new way to design operation and maintenance galleries. It reduces the size of the galleries to a minimum, and therefore the plant can be as small as possible.

4.2.4. Project management

The new operating system for the power plant business will be extremely demanding in terms of project management. We have described what is new in the system and must develop a new type of module system and manufacturing facilities for it, and the most informative systems must be capable of communicating much more efficiently. The capacity used to realize the project will also be different. We will have a high-quality design team that works very efficiently on the project, but the short time span and, of course, module assembly must also meet a new type of capacity. During the whole project the Just-In-Time (JIT) principle is in use. How well does the OARPLAN [9] project management system suit this operating way?

OARPLAN is a prototype planning system that generates construction project plans from a description of the objects that comprise the completed facility. OARPLAN is based upon the notion that activities in a project plan can be viewed as intersections of their constituents: objects, actions, and resources. Planning knowledge in OARPLAN is represented as constraints based on activity constituents and their interrelationships; the planner functions as a constraint satisfaction engine that attempts to satisfy these constraints. The goal of the OARPLAN project has been to develop a planning shell for construction projects that provides a natural and powerful constraint language for expressing knowledge about construction planning and generates a facility construction plan satisfying constraints expressed in this language.

To generate its construction plan, **OARPLAN must be supplied with extensive knowledge about construction objects, actions, and resources, and about spatial, topological, temporal and other relations that may exist between them.** The idea is that these come from databases. Activity dependencies are shown in Figure 15.

The project management programs traditionally are suited better to manage site operations as design stages of the project. OARPLAN also needs a ready-designed world. This feature is badly suited to a project, where design and component determination stages are very important. On the other hand, the OARPLAN system uses three different levels: executive levels, work package levels, and task levels. The use of these levels is adopted to our modular system.

Normal planning systems represent actions by defining their preconditions and effects, and use these to determine action inclusion and dependency. In OARPLAN, elaboration and dependency KSs that reason about activity constituents replace the need for preconditions and effects. **OARPLAN-like presentation is well suited to our system, which emphasizes the design.** OARPLAN should be developed as a system that grows with the project design and becomes more detailed when we conduct the detail design. In our system constraints should include design-related constraints.

The researchers' vision of OARPLAN is that it will include the **capability of replanning automatically in response to changes in a facility's design.**

5. BARRIERS TO ESTABLISHING AND USING THE SYSTEM DESCRIBED

Is it possible to establish the system described earlier? As we have noted, many expert systems and AI-systems are being built, and the goal of many software companies is for their programs to be integrated with the programs of other companies. Above we have suggested the grand view and the software systems related to this grand view. In this section we consider how a company's personnel will work efficiently in the relization of the IGCC power plants by using the system described.

5.1 Company Personnel

In the design office headed by one of the authors it has been found that a Master of Science degree in Technology gives a very good starting point for developing systems. The idea has been that Ph.D.s create strategies and M.S.s develop the technology of the integrated work package in their theses. In many cases the person who has developed the work package area has become the chief design engineer of it. The school background has been Mechanical Engineering. But the development of the integrated work packages has demanded knowledge of other disciplines as well. **In the future of the system development area we will need experts of the narrow area but also engineers who have more multidisciplinary backgrounds working as teams.**

To use our system we need some five to seven engineers on a multidiscipline team. How do we teach these teams and how do we maintain the interest of the team in working together? These people are very qualified. Normally we think that these kinds of people want to improve the designs every time. Are they willing to use the modules, or will they feel that the modules change makes the work too uncreative? These teams must operate under 100% project loads, or they cannot start projects fast enough. Is it possible to combine R&D work with slack times? These are the management problems that need to be solved.

The tight schedule brings with it the risk of delaying the project. The risk of delay at the site is not big, because a lot of work and sequential working procedures have been transferred to the workshop. The manufacturing time is not reduced that much today. The difficulty in the manufacturing is that it will include more different disciplines than today. It will be integrated into the manufacturing. The project planning and scheduling has to work as a real-time system. Good examples showing this can be taken from a look at the oil-rig platform industry.

The design, and especially the component-selection areas have been reduced considerably. **This will be possible by using the new operational ways suggested in this research. It will include a strong product R&D, a customer committed to the project, capable personnel, AI and expert systems-based information systems, and management that is willing to eliminate barriers to apply this system.**

Table 1

Traditional Way to Operate in the Power-Plant Business

CUSTOMER NEEDS:

- -- cheap electricity
- -- high reliability
- -- less pollution than the regulations permit

TECHNOLOGY:

- -- conventional pulverized coal-firing technology
- -- large power plant blocks
- -- large electricity-transfer network
- -- DESOX and DENOX technology

PROJECT MANAGEMENT:

- -- analysis method, such as PERT or CPM, computerized or manual
- -- based on the long expertise of the project manager

DESIGN:

- -- computerized process calculation
- -- two-dimensional CAD-systems for detail design
- -- three-dimensional CAD-systems are in use, but design methods are as before
- -- some advanced companies are developing Expert Systems
- -- design and drawing work are partially subcontracted

MANUFACTURING:

- -- core part of the boiler manufacturing is automated, but the other parts are made manually
- -- components are subcontracted

SITE OPERATIONS:

- -- core part of the boiler is preassembled
- -- the share of the manual work is big

Table 2

New Way to Operate in the Power-Plant Business

CUSTOMER NEEDS:

- -- low-cost electricity
- -- high reliability
- -- environmental friendly
- -- safety
- -- flexibility in every sense
- -- suitable to use in retrofits
- -- very short building time

TECHNOLOGY:

- -- Integrated Gasification Combined Cycle power plants

PROJECT MANAGEMENT:

- -- intelligent project management tools that use the common project data

DESIGN:

- -- modularization
- -- design made by customer
- -- motion planning and automatic routing
- -- expert systems for narrow area
- -- optimization

MANUFACTURING:

- -- modules
- -- highly automated and distributed
- -- robotics

SITE OPERATIONS:

- -- new ways, new orders, use of results of above

Table 3

Modularization Levels in the Power-Plant -- Some Examples

1. THE MAIN PROCESS LEVEL:
    a. gasification plant
    b. gas turbine
    c. water-steam process
    d. monitoring and controlling
    e. fuel handling
    f. waste handling
    g. service building
2. WORK PACKAGE LEVEL:
    a. gasifier
    b. hot-gas cleanup
    c. pipe work between the gasifier and hot-gas cleanup
    d. fuel-feeding to the gasifier
    e. ash-handling system
3. TASK LEVEL:
    a. controlling flow (valve)
    b. maintenance pump (gallerie)

FIGURE CAPTIONS

REFERENCES

[1] Session 1, Plenary Session, 1989, Conference on Technologies for Producing Electricity in the Twenty-First Century. EPRI, October 30-November 2, 1989. San Francisco, California.

[2] R. E. Levitt and J. C. Kunz, 1987. Using Artificial Intelligence Techniques to Support Project Management, *Journal of Artificial Intelligence in Engineering, Design, and Manufacturing*, **1**, 3-24.

[3] A. Riitahuhta. Enhancement of the Boiler Design Process by the Use of Expert System Technology. Dr.Tech. Thesis. *Acta Polytechnia Scandinavica*, Mechanical Engineering Series No. 92, 1988, p. 122.

[4] C. B. Tatum, J. A. Vanegas, and J. M. Williams. Constructability Improvement Using Prefabrication, Preassembly, and Modularization. Technical Report No. 297, Department of Civil Engineering, Stanford University, November 1986.

[5] P. Teicholz. Technology Trends in Computer Aided Design and Engineering. Presentation in CIFE Summer Course at Stanford University, August 1989.

[6] H. C. Howard. KADBASE: A Prototype Expert System -- Database Interface for Engineering Systems, Presentation in CIFE Summer Course at Stanford University, August 1989.

[7] I. Tommelein, R. Levitt, and B. Hayes-Roth. Sightplan: An Articifical Intelligence Tool to Assist Construction Managers with Site Layout, Sixth International Symposium on Automation and Robotics in Construction, 16th ISARC, San Francisco, California, June 1989, pp. 340-347.

[8] J.-C. Latombe. Motion Planning and Automatic Routing. Presentation in CIFE Summer Course at Stanford University, August 1989.

[9] A. Darwiche, R. E. Levitt, and B. Hayes-Roth. OARPLAN: Generating Project Plans by Reasoning about Objects, Actions and Resources, *AI EDAM*, **2**(3), 169-181, 1988.

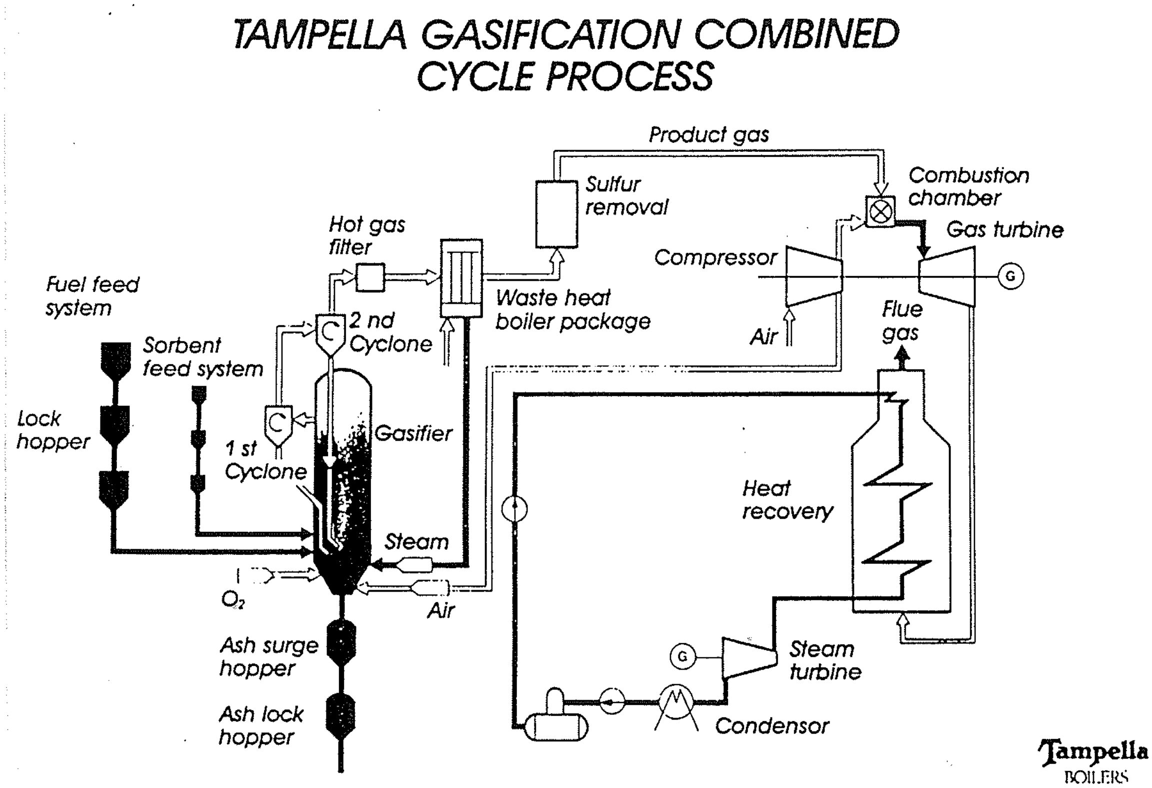


Figure 1. Tampella Gasification Combined Cycle Process

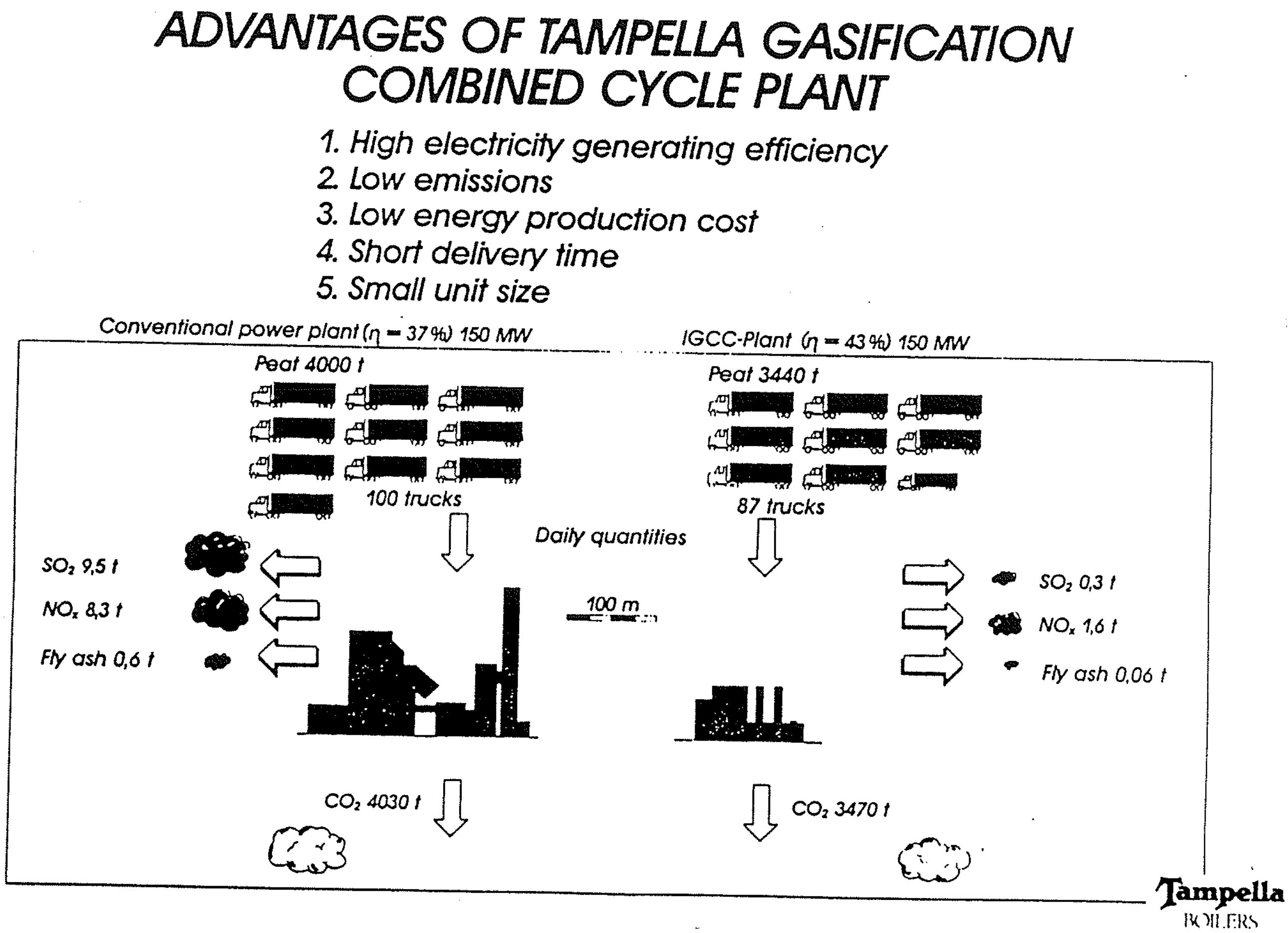


Figure 2. Advantages of Integrated Gasification Combined Cycle Plant

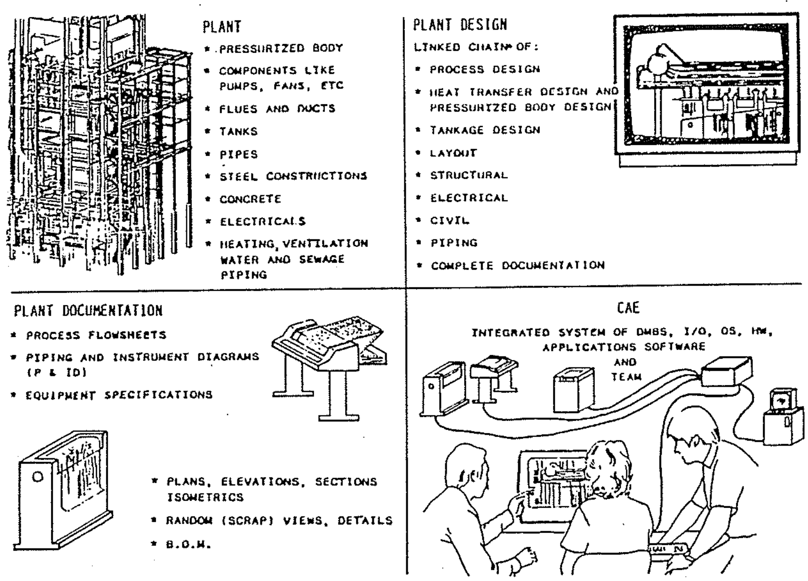


Figure 3. Boiler Plant Design

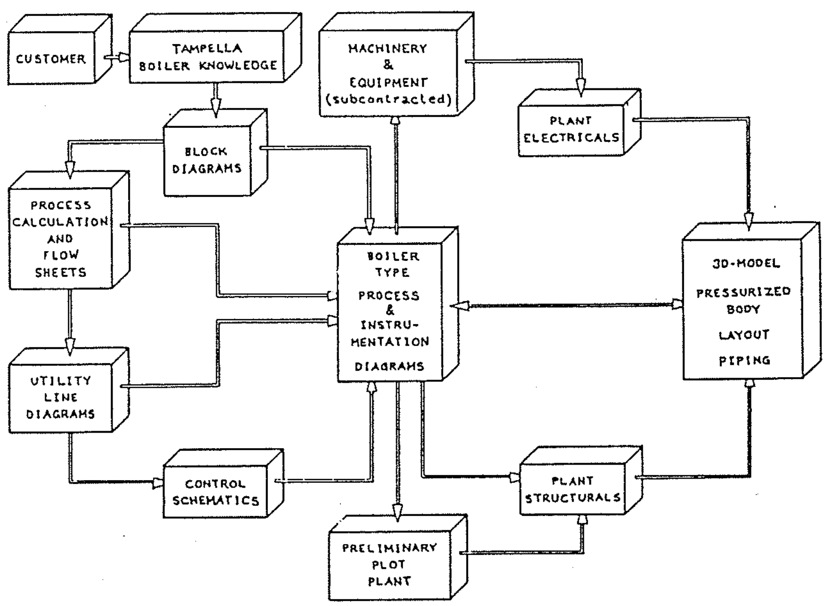


Figure 4. Data Flows in Boiler Plant Design

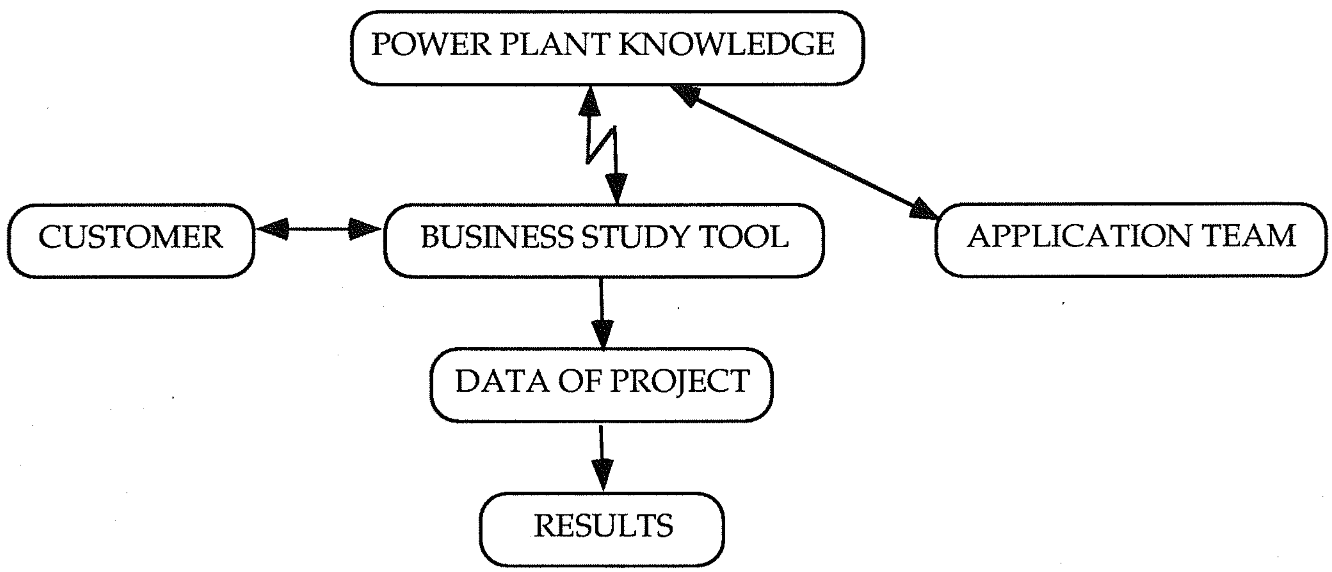


Figure 5. Development of the power-plant project

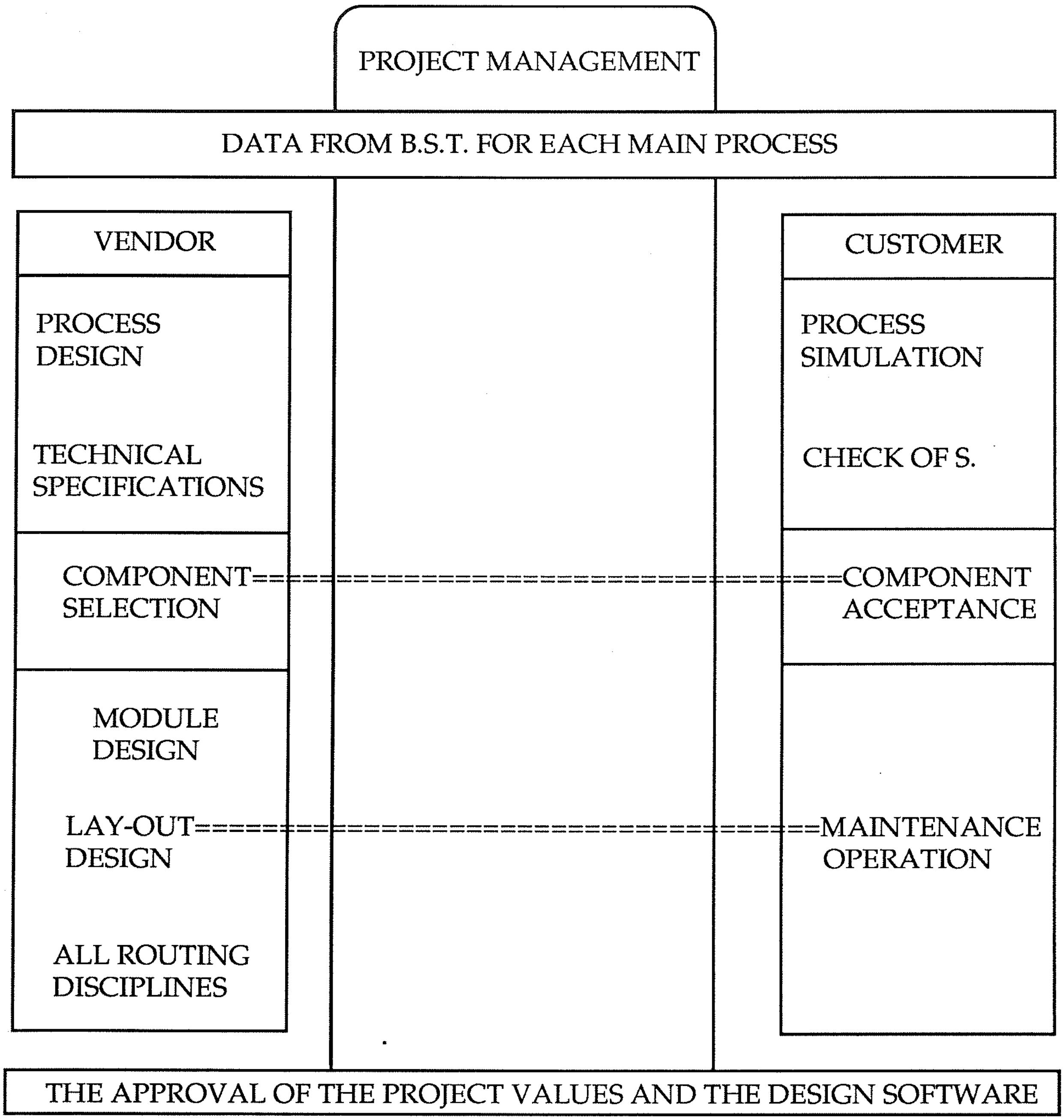


Figure 6 Plant Design of the Project After the Investment Decision

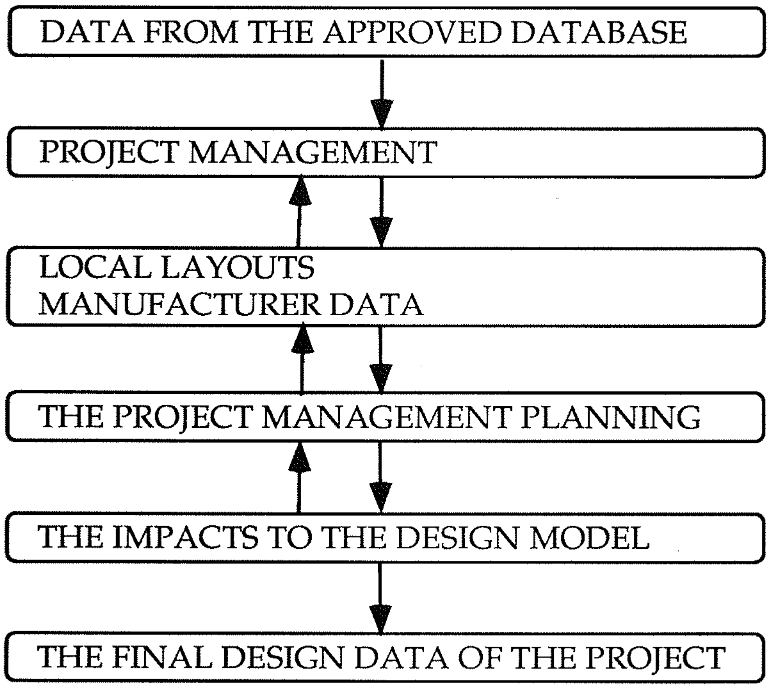


Figure 7. The Detail Design

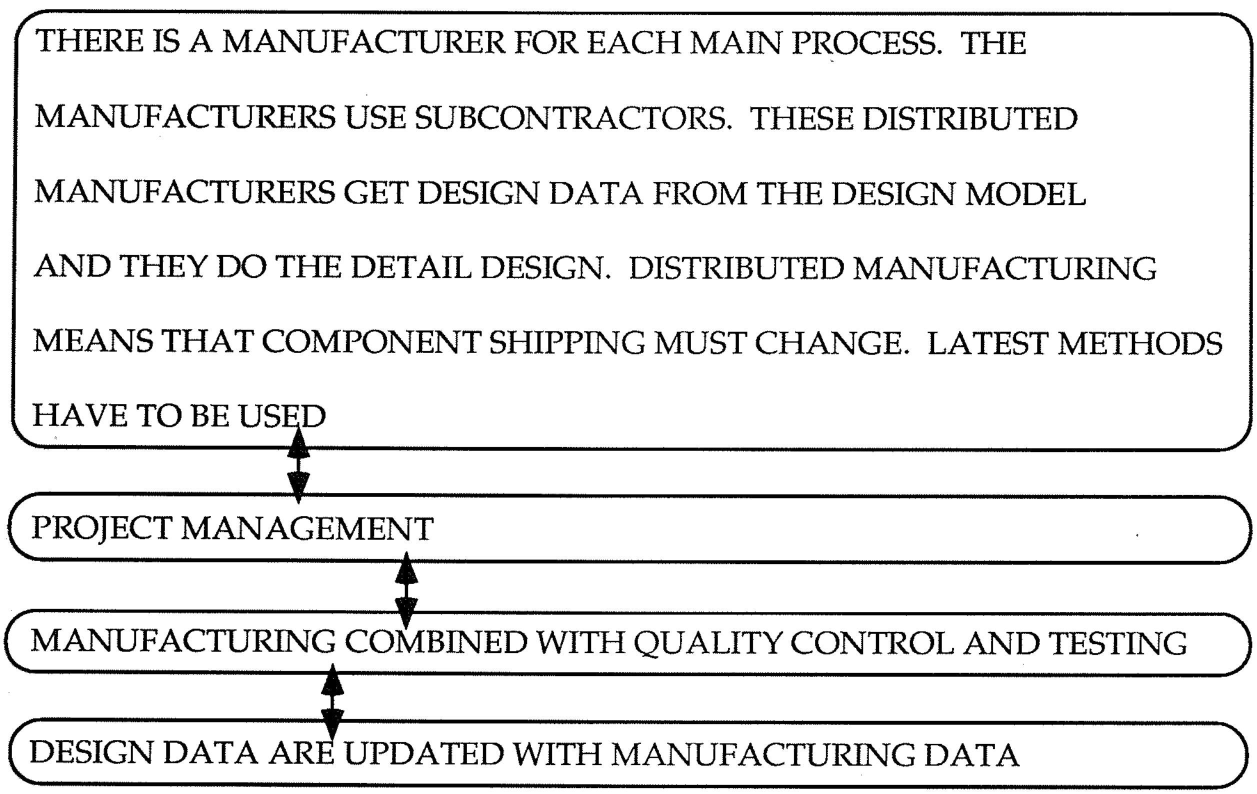


Figure 8. The Manufacturing Diagram

SITE LAYOUT

MANAGEMENT FACILITIES TO THE SITE

MEASUREMENT SYSTEM AT CONSTRUCTION SITES

JOT, MODULES, ROBOTICS AND AT ONCE READY

SITE DATA TO THE DATABASE

Figure 9. Site Operations

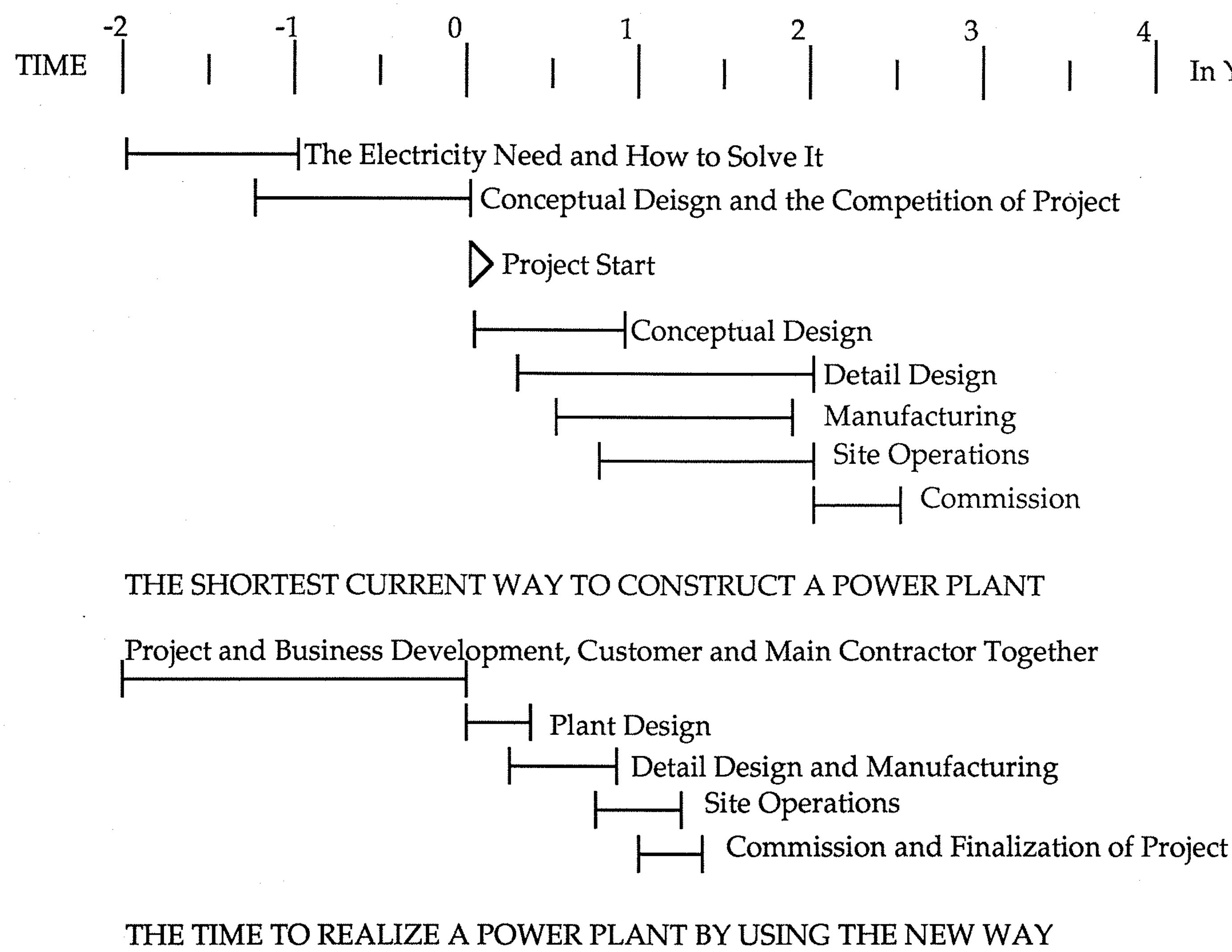
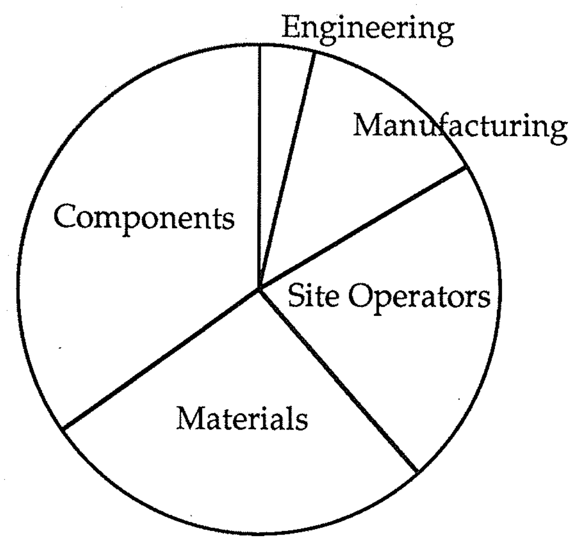
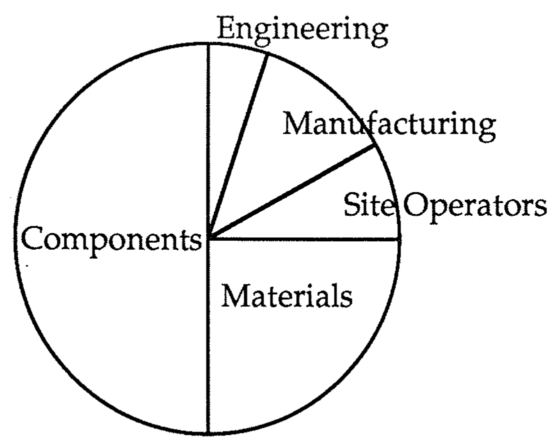


Figure 10. Delivery Times, When Operating According To The Traditional Way And The New Way



COST SHARE IN THE TRADITIONAL POWER PLANT PROJECT



COST SHARE ACCORDING TO THE NEW WAY

Figure 11. Costs of Power Plants

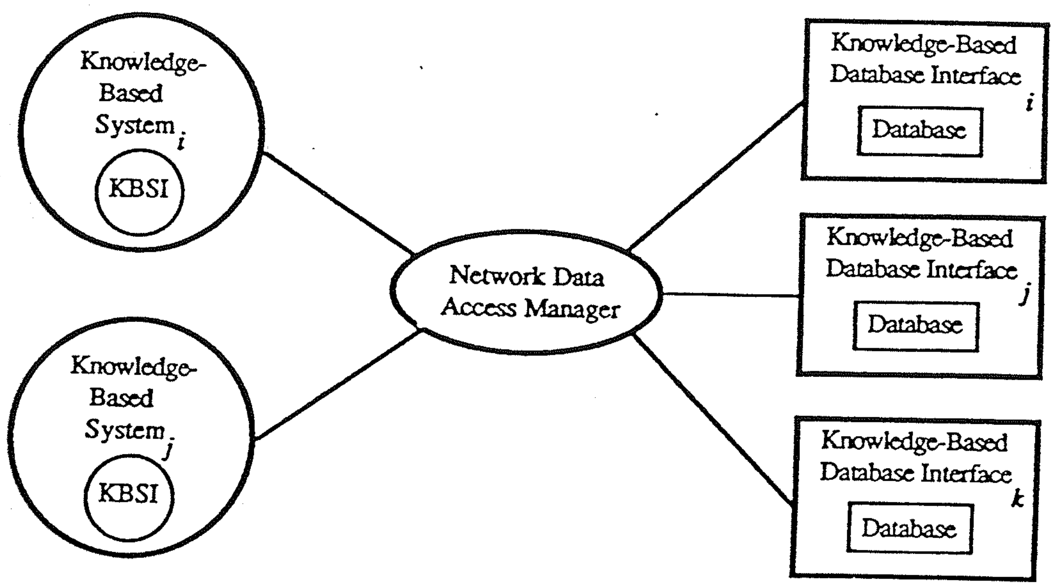


Figure 12. Overview of KADBASE Architecture

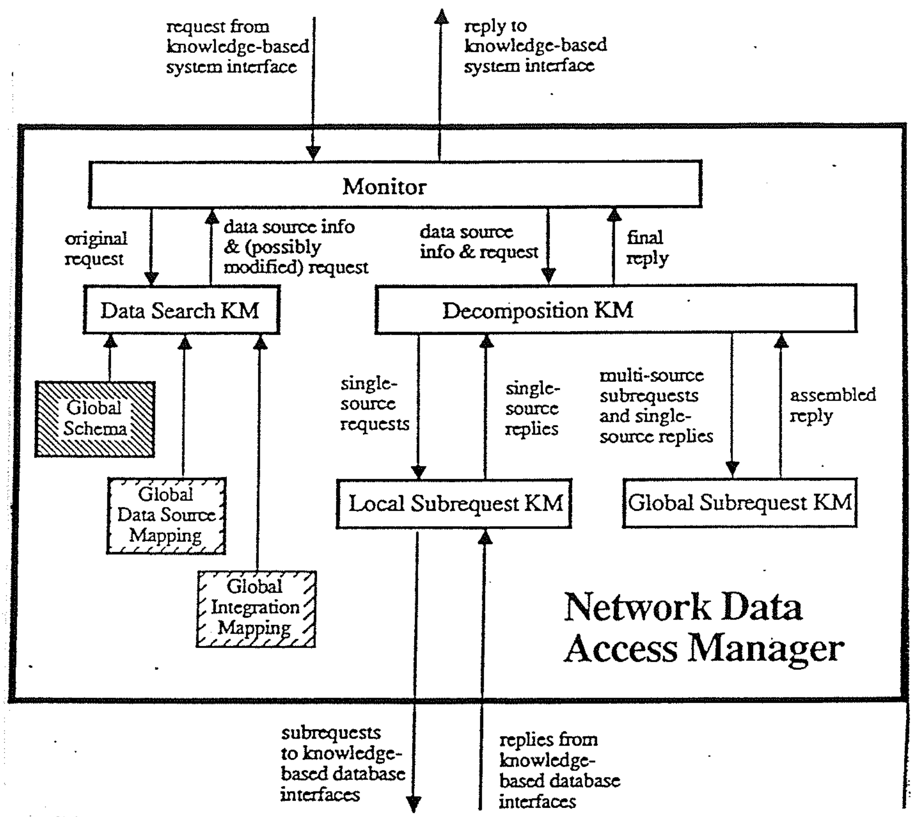


Figure 13. Dataflow in Network Data Access Manager

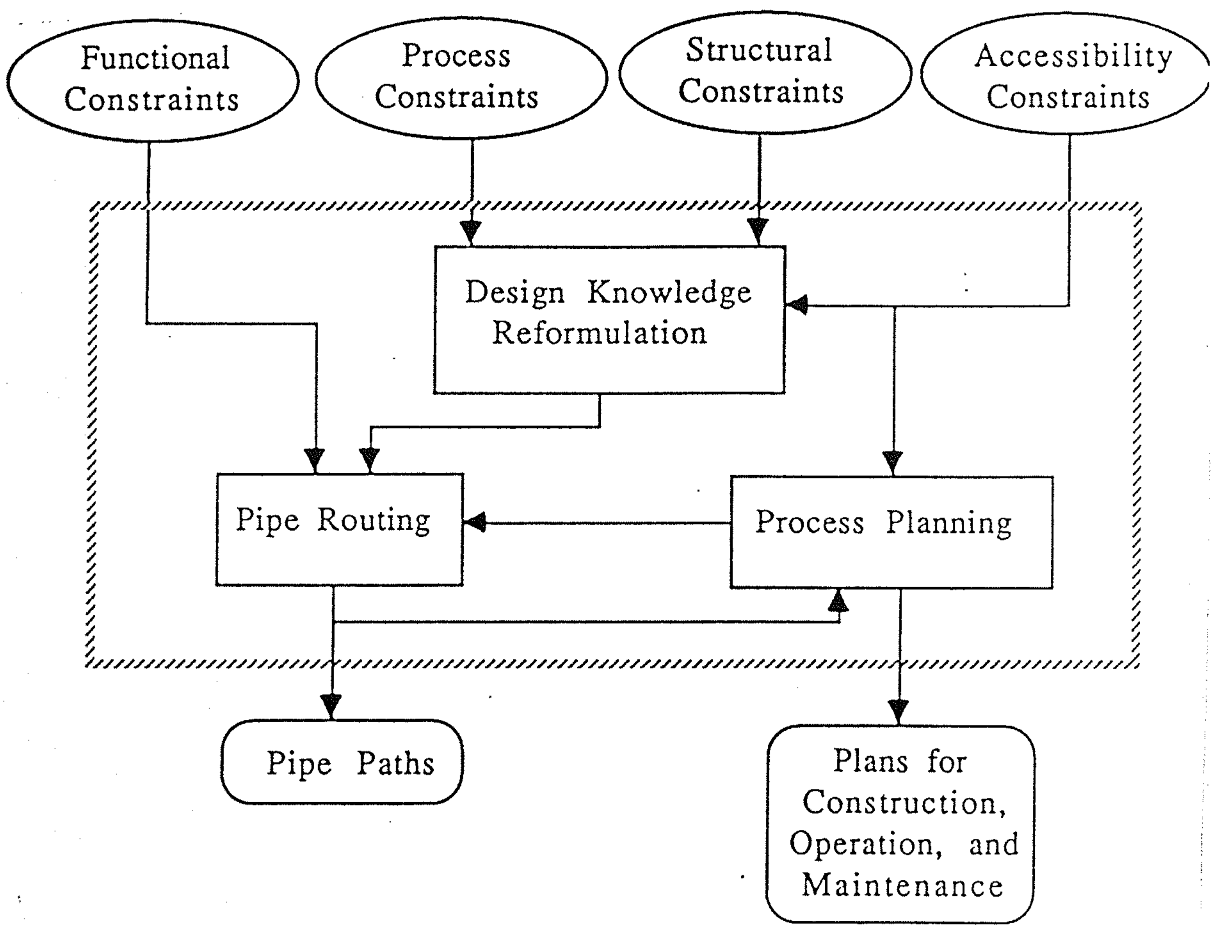


Figure 14. Automatic Design of Pipe System for the Ease of Construction, Operation and Maintenance

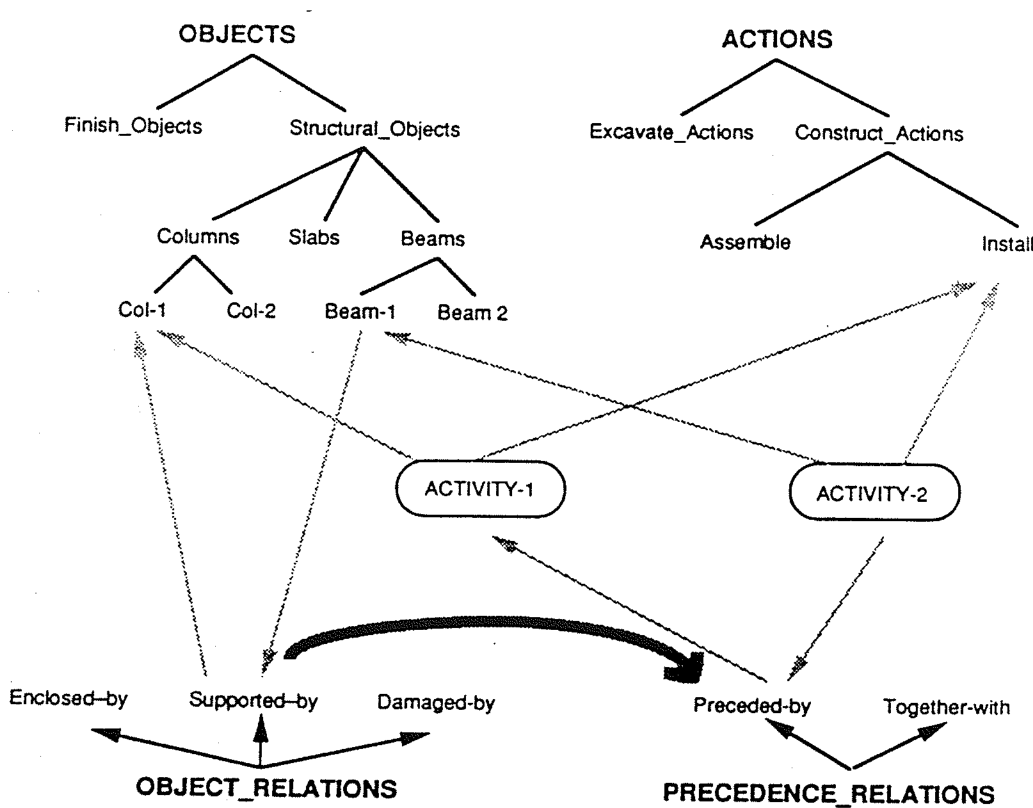


Figure 15. Activity Dependencies