Routine Design for Mechanical Engineering

Axel Brinkop, Norbert Laudwein
Fraunhofer Institute for Information- and Data-Processing (IITB)
Fraunhoferstr. 1, D-76131 Karlsruhe, Germany
bri@iitb.fhg.de, lau@iitb.fhg.de

Rüdiger Maassen
EKATO Rühr- und Mischtechnik GmbH
Käppelemattweg 2, D-79650 Schopfheim, Germany

Abstract

COMIX (COnfiguration of MIXing machines) is a system that assists members of the sales department of EKATO in designing a mixing machine which fulfills the requirements of a customer. It is used to help the engineer design the requested machine and prepare an offer that's to be submitted to the customer. COMIX integrates more traditional software techniques with explicit knowledge representation and constraint propagation. During the process of routine design, some design decisions have to be made with uncertainty. By including knowledge from process technology and company experience in the mechanical design, a sufficiently high degree of flexibility is achieved that the system can even assist in difficult design situations. The success of the system can be measured by the increase in quantity and quality of the submitted offers.

Introduction

The system described in this paper is currently working in the field at the sales department of EKATO, one of the world's most successful manufacturers of industrial mixing machines. It was developed in close co-operation between EKATO and IITB during a three year period. COMIX (COnfiguration of MIXing machines) is a system that assists members of the sales department in designing a mixing machine which fulfills the requirements of a customer. Since mixing machines have to be tailored individually to meet a customers requirements, this design process is time consuming. COMIX is used to help the engineer design the requested machine and prepare an offer that's to be submitted to the customer.

COMIX integrates more traditional software techniques like data bases, algorithmical computations and iterations with explicit knowledge representation and constraint propagation. During the process of routine design, some design decisions have to be made with uncertainty. Therefore, the process is guided by a combination of several strategies to help resolve the conflicts. For instance, variable ordering, dependency directed backtracking and knowledge guided backtracking are used. Nevertheless, all main design decisions are left to the user.

By including knowledge from process technology and company experience in the mechanical design, a sufficiently high degree of flexibility is achieved that the system can even assist in difficult design situations.

The success of the system can be measured by the increase in quantity and quality of the submitted offers. On one hand, the average time needed to prepare a sales quote for a mixing-machine was reduced by two hours. This reduced design time will lead to an amortizing of the investment in COMIX within 2.5 years of being in the field. On the other hand, the amount of offers that lead to contracting rose 20 %. These measures show that the use of COMIX has been beneficial for EKATO.

The Domain

Industrial Agitators

Industrial mixing machines, better known as agitators, are widely used in industrial manufacturing. They are especially useful for the chemical and pharmaceutical industries, food production and biotechnology. The basic structure of an industrial agitator is shown in figure 1.

The following aspects of the domain are important. First, agitators are individually tailored to meet the special requirements of a customer, so they cannot be mass-produced. Deciding whether a given agitator can perform a special mixing task can only be solved by comparing the new task with previously solved mixing tasks. Second, the space of possible configurations is large.

The basic structure of an agitator is quite simple, but each component can be constructed using a variety of different parts. For example, there are not only

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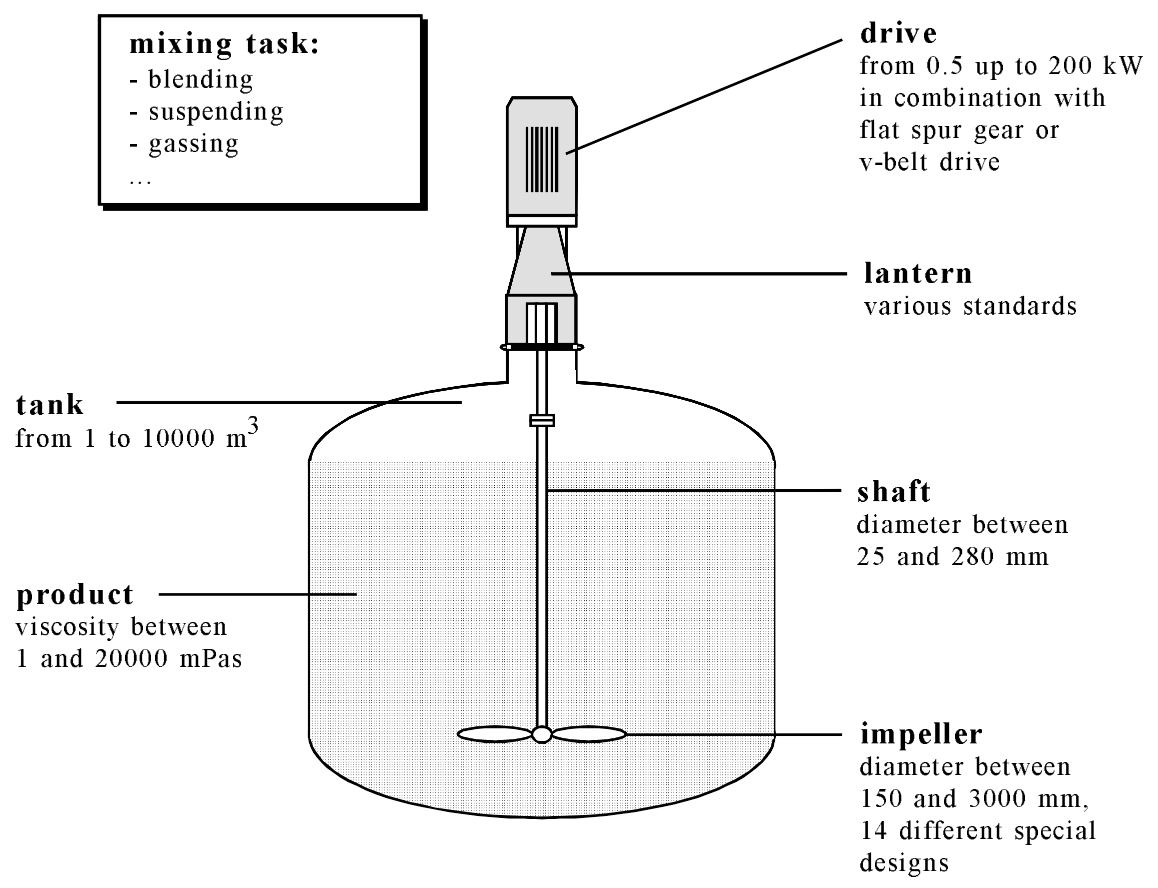


Figure 1: Basic Structure of an Agitator

propellers, but various special forms of impellers; different shafts are available and thousands of direct motors providing power from 0.5 kW up to 200 kW produced by several manufacturers can be used. The direct motors can be used together with flat helical gearboxes, with v-belt drives, or combinations of them both. There are also some optional components, such as a sealing between lantern and tank or an additional bearing at the bottom of the tank. It is also possible to add some additional fixtures, called baffles, to the tank.

In addition to the wide variety of parts for each component, the design task also has to cope with several different mixing tasks, such as blending, i.e. making a homogeneous liquid out of two different solvable liquids, or suspending, i.e. achieving a relatively uniform distribution of solid particles in a liquid, a mixing task very common in lacquer production. Another task is bringing gas into liquid, a well known problem in the field of waste water treatment or fluegas desulfurization.

Main Objectives

For a long time, EKATO has used computers to aid in the design of the mechanics of the agitators. About 15 years ago, the first programs were developed at EKATO to assist in the mechanical design of agitators. These programs have been in continuous use since then and have been repeatedly revised and extended to reflect changes in manufacturing and process technology. But, recently, the maintenance of these systems was determined to no longer be possible. Thus, a new system was needed with configuration knowledge explicitly represented so that maintenace would be easier.

Analysis of the strengths and weaknesses of the elder system led to an expanded functionality:

- integration of process engineering knowledge,
- high flexibility,
- assistance even in difficult design situations, for example when the number of revolutions of the configured machine meets the frequency of natural oscillation.

By including industrial process engineering knowledge, two objectives could be achieved. First, knowledge from different experts of the company could be conserved. Second, the software used by the sales staff for designing the machines could be run on a standard platform.

More flexibility in configuration enabled the reduction of the variety of parts of some of the key components. This reduction lead to the use of a higher number of premanufactured parts, which in turn lead to considerably reduced manufacturing costs.

Assistance in difficult design situations, such as conflicting number of revolutions and natural oscillation, saved design time and increased the quality of the design.

Tasks

COMIX has to perform a set of different tasks depending on user requirements and information given by the customer. In the "agitator" domain, it is a hard problem to decide whether a given agitator fulfills a given mixing task. The main problem is the design of the impeller system. The phenomena in agitated vessels defy a description by equations in an exact physical way. So, the problem can only be solved based on experience and by comparing the task with previously solved mixing tasks. If the mixing task is somehow new, experiments with scaled down mixing machines have to be done.

But, once the impeller system is specified, then the mechanical design of the agitator can be treated as a configuration problem. Given a well defined set of available components, the system only needs to find a combination of single components which will work together as intended.

COMIX performs the following tasks:

- given the user requirements, the system derives a specification of the impeller system for several basic process engineering tasks,
- given the specification of the impeller system, COMIX finds a correct and complete configuration of the agitator.

Deriving structure from function. Usually, a customer presents a set of requirements for an agitator and asks the manufacturer to submit a bid. A responsible engineer of the sales department has to design a mixing machine which meets the particular requirements of the customer. Given a desired functionality of the machine, the system has to derive a specification of a machine with the intended functionality. Based on knowledge from process technology and prior experience the system is able to handle the following basic process engineering tasks:

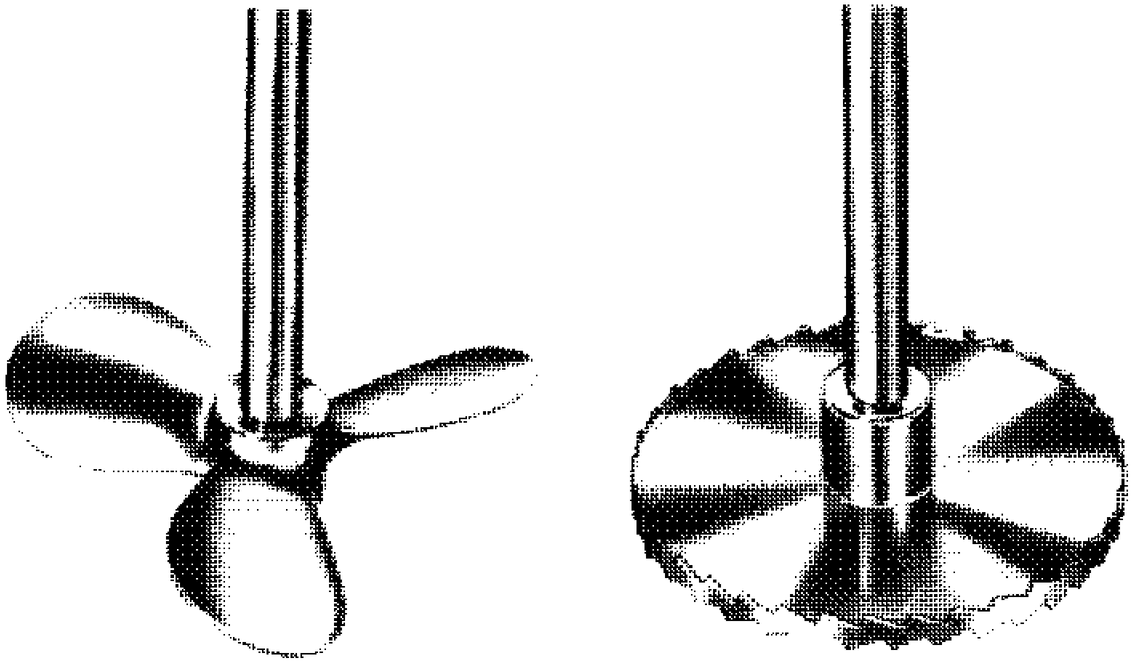
- blending of two different solvable liquids
- suspending solid particles in a liquid
- heat transfer, i.e. cooling down or heating up a liquid
- gassing, i.e. bringing gas into a liquid

The agitator is specified by the design of the impeller system, i.e. number, design and diameter of impellers, their positions in the vessel and the number of revolutions. This also includes the number and size of the baffles in the vessel. Given a specification of the impeller system, it is possible to derive the necessary components of the agitator.

Configuration. Given the specification of the impeller system, COMIX has to find a detailed and complete configuration of an agitator that will work as intended. The set of available components is well defined. For some types of components, there is only a small set available. For others, thousands of choices are available. Some parts even fall into a continuous definition set. Laws of mechanics, standards and quality guidelines of the manufacturer, and industrial standards as well as inter-component constraints have to be taken into account. Additionally, constraints from process technology have to be satisfied to guarantee the intended function. The result consists of a detailed specification that includes price information, information for manufacturing and a dimensional sketch with the basic geometric measurements.

Redesign and Case Based Redesign. COMIX has to perform the redesign task, i.e. the adaptation of an agitator to changed prerequisites. Often a customer is satisfied by a existing machine and would like to have it rebuilt. Or similarly, during contracting it turns out that the mixing task is slightly different from the original prerequisites for the design. In this case, the agitator's current configuration can be loaded and modified. The system will then compute all of the necessary changes, taking into account the actual parts available and their properties.

Another possibility during routine design is that the problem is very similar to an previously solved problem. For example, the mixing task could be similar to a previously solved mixing task. Or, the design of the impeller system is closely related to a previously designed agitator. The search for similar mixing tasks or similar agitators is performed by searching data bases, which contain information about previously configured agitators. The criteria for search are left open to the user, so that the user can define his own similarity criteria .



Propeller

Disperser Disk

Figure 2: Two Different Designs of Impeller

Non-Routine Design Assistance. COMIX can also assist in non-routine design by looking for partial configurations w.r.t. the available information. When designing a special purpose agitator, such as a specialized impeller which is not in the system knowledge base, it is possible for the system to look for a shaft and drive that will handle the forces placed on the impeller. To perform this operation, the user has to know some special characteristics about the impeller and enter them into the system.

The System

Knowledge Representation

In this application domain, four types of domain specific knowledge can be identified. Each of them is represented differently in COMIX. Figure 3 provides an overview of these kowledge types.

- **Available parts and their technical data** are kept in various data bases. Some components, such as motors and gears, are not manufactured on-site, but are bought from other manufacturers instead. Data about such components, such as pricing, frequently changes. It is important to make updating simple. By keeping the data in data bases, the data is easy to maintain without changing anything inside COMIX.
- **Knowledge about structure and classification of components** is represented in different part-of and is-a hierarchies in an object-oriented manner. This enables maintenance with little work in case of changes in the types of manufactured parts. During the development of COMIX, this was often necessary and could be easily done.
- **Component-specific configuration knowledge** is the knowledge about how to determine a special component or single parameter of a component or how to satisfy a related constraint. This information is often given in algorithmic or computational form and is coded in a functional way. It is attached to components by methods. This enables message passing to objects without having to worry about the component's type. For example, the system can send the message "compute-your-weight" to the impeller of the agitator without checking if it is a marine propeller or a disperser disk. These impellers are quite different and use completely different methods to compute their weight. They are shown in figure 2.

- **Knowledge about causal dependencies** is represented using directed constraints. These are dependencies in the sense of design knowledge, not physics, i.e. which component depends on the design of another component. In combination with a so-called "standard agenda", this reflects the order in which an experienced engineer would configure the machine. This knowledge is used to direct the process of configuration.

The constraints are controlling the design process. In each construction cycle the constraints which can be applied are determined. To satisfy the constraint, the corresponding constraint function has to be applied. In each constraint function the configuration knowledge about how to design a component is represented. Each design decision is done by sending messages to the related components. The configuration knowledge is attached to the components by methods which are activated by messages. The configuration knowledge also includes information about how to determine lower and / or upper boundaries for parameters, which are used as criteria for data base searches.

Process of Routine Design

The design process is accomplished in two stages. First, a specification of a machine with the intended functionality has to be derived from information about the mixing task. This step is quite different depending on the basic process engineering task, i.e. blending or suspending. Thus, different data is needed. For instance, in the case of blending just density and viscosity of the product have to be known to determine the impeller system, whereas particle size and solids volume concentration have to be also known for suspending. This process knowledge includes complex algorithms, scale up computations and iterations. It is handcoded for each basic mixing task for the sake of performance.

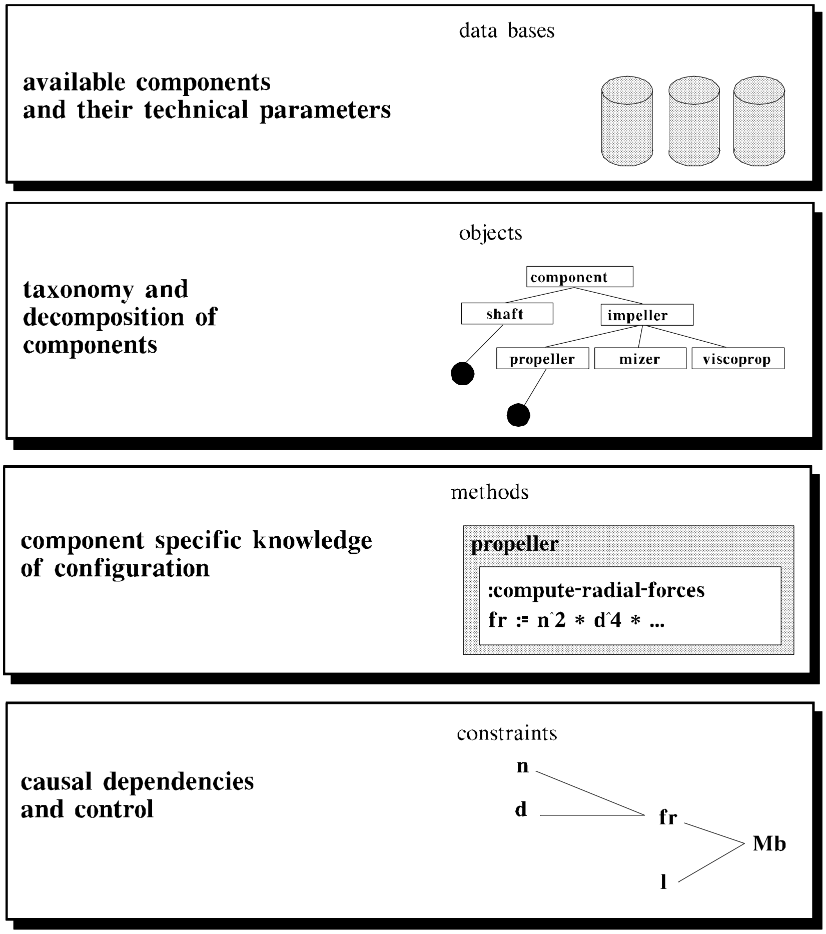


Figure 3: Knowledge Types and their Representation

Second, the detailed mechanical design of the machine has to be determined. This is based on a constraint propagation.

The constraints used in COMIX can be characterized as

- **directed**: the values of all but one of the parameters have to be known to determine the missing one,
- **simple**: the set of possible values of a constraint parameter contains at most one element,
- **functional**: the definition of the constraint relation is given by a function, in contrast to a characteristic predicate,
- **constructive**: given all but one of the values of the constraint parameters, the missing value to satisfy the constraint can be determined constructively.

For each constraint, the following are explicitly stated:

- which parameters have to be known,
- which parameter can be determined,
- which additional preconditions have to be satisfied,
- where to find the definition of the constraint relation, i.e. which function to evaluate to satisfy the constraint.

The chosen algorithm for the propagation is based on the use of local consistency. A solution is found when an overall local consistent value assignment is found. This leads also to global consistency while only using simple constraints.

During the design process some decisions have to be made under uncertainty. Backtracking can not be avoided. There are several strategies implemented to guide the propagation to reduce backtracking as well as manufacturing costs.

Variable Ordering for Backtracking Reduction. A good order of design decisions can often lead to a reduction or even avoidance of backtracking. The ordering knowledge may come from experience as well as from dependencies between decisions. Using constraint propagation results in an order of design decisions based on dependencies. Conflicts can arise when there is more than one constraint ready to fire at the same time. To resolve this kind of conflict, a "standard agenda" is introduced. All relevant parameters of the design process are listed in this agenda in a fixed order. This agenda reflects the order an experienced engineer would proceed during the design. In case more than one constraint is ready to fire at the same time, this agenda is taken into account when determining which one of the constraints should fire first. The use of this agenda lead to considerably reduced backtracking in many cases.

Dependency Directed Backtracking. The process of finding a suitable configuration can be regarded as a search process in the space of all possible combinations of available components. In this domain the parameters are highly interdependent and there are many dependency cycles. So, the use of guessing and backtracking in the search process can not be avoided. The search process is guided by the domain independent strategy of dependency directed backtracking that is similar to EL (Stallman, Sussmann 77). For management of the dependencies, a mechanism like JTMS (Doyle 79) is implemented with special features to handle dependency cycles and to act with parameters which are represented in an object-oriented manner. For more details on the treatment of dependency cycles, please refer to (Brinkop, Laudwein 92).

Knowledge Guided Backtracking. Generally, in COMIX the satisfaction of a constraint implies the intended functionality. But, there is one critical situation where the proper function is no longer guaranteed: when the number of revolutions of the machine is too close to the natural oscillation of the machine. While the number of revolutions has to be fixed in an early state, the natural oscillation of the machine can only be determined when all parts of the machine are known in detail. Nearly all parameters depend, either recursively or directly, on the number of revolutions. In this case, even dependency directed backtracking is to inefficient.

To solve this crucial problem, the backtracking is guided by domain specific knowledge combined with lookahead. When the number of revolutions is too close to the natural oscillation, the system has two possibilities, either to change the former or the latter. Past experience demonstrated how to change some properties that were already selected to achieve an increase or decrease of the natural oscillation without major influence on the overall behaviour. Some of these techniques are tried by the system and tested to see if they would succeed. Having done so, the succeeding activities are suggested to the user, who can decide to act on the suggestions or to choose another strategy to solve the problem.

Main Decisions by User. The process of finding a configuration can also be regarded as a model based search problem. It starts with a coarse model of the machine, the one implied by the specification. During the configuration process, the model is refined stepwise until all the parameters have been determined. In this process, all main design decisions are left to the user. COMIX determines the consequences of design decisions, evaluates constraints and makes suggestions for possible choices. "This division of labor seems to build on the strengths of each party; making the computer responsible for completeness and consistency and the human responsible for strategy." (Steinberg 87)

Preferences. Another control strategy used in COMIX is the use of different levels of preference for key components so that manufacturing costs can be reduced. Premanufactured parts, which can be held in stock, are preferred as long as possible. Since these parts can be manufactured in large numbers, the manufacturing costs for the mixing machine are lowered. The use of premanufactured parts also helps to reduce the manufacturing time for a complete agitator.

For instance, impeller-hub combinations are classified in three levels of preference:

I. A small set of fixed impeller-hub combinations already manufactured.
II. A larger set of impeller-hub combinations with existing blueprints for manufacturing. They are manufactured as needed.
III. Depending on type and diameter of impeller, diameter of shaft and occurring forces the needed hub is computed. The combination has to be drawn in the design department and has to be manufactured as needed.

COMIX tries as long as possible to use the level I combinations. Only when it is no longer possible to use a combination of this level, the system will ask the user if it should switch to a level of lower preference or revise a previous design decision.

Related Work. COMIX is designed to solve problems in the special domain of agitators. It was not designed to be a tool for configuration or design. Many ideas from other systems were taken and used when they were appropriate. The combination of these ideas lead to a system which is now successfully used in the field.

The architecture of COMIX is very similar to PLAKON (Cunis et al. 87) (Cunis et al. 91), a tool for planning and configuration tasks. In COMIX only propagation of directed constraints in combination with JTMS techniques is used, whereas PLAKON can handle non-directed constraints and offers different levels of control from backtrack-free up to ATMS (de Kleer 86) techniques.

One of the best known systems using the domain independent strategy of dependency directed backtracking is EL (Stallman, Sussmann 77). But, COMIX is not able to handle EL's symbolic expressions.

Knowledge guided backtracking and different levels of preference can also be found in VT and SALT respectively (Marcus et al. 88) (Marcus, McDermott 89). The difference between VT and COMIX is related to the kind of constraints and the way they are used. Predicative constraints in combination with procedures are used in VT, while constructive constraints are used in COMIX. In VT the strategy of knowledge guided backtracking is used exclusively, whereas in COMIX this strategy only takes place in special situations. Also, preferences are defined in VT for each parameter, whereas in COMIX they are only defined for some special key components.

VEXED (Steinberg 87), a design aid for NMOS digital circuits, is also based on top-down refinement plus constraint propagation. But, in VEXED, all control decisions are left to user, including the order of design decisions and the choice of the way to proceed. In COMIX only the main design decisions are left to the user.

Refinement techniques in combination with constraint handling can also be found in ALL-RISE (Sriram 87), an extension of HI-RISE, which is a system for the design of high rise buildings. In ALL-RISE all possible solutions are explored, whereas COMIX stops at the first solution found.

Integration

COMIX is integrated in the information system of EKATO. It can produce different printed documents and exchange data with the CIM system.

COMIX is implemented in GoldWorks III (GoldenCommonLisp, Windows 3.1, DOS) and is running in a network of PCs using NOVELL netware 386 for the LAN. The LAN is connected via gateway with the CIM system running on a mainframe. An overview of the network is given in figure 4.

Several printed documents are needed for the information system. One of them, which contains details of the configuration, including price information, is needed for documentation in an internal file. Another document, containing part identification numbers of the CIM system and hints for their assembly, is used to guide the machine during the entire manufacturing process.

Additionally, a document presenting the final offer, including a drawing of the proposed machine, is produced. The offer is created by combining predefined text parts which depend on the actual configuration of the machine. With an integrated editor, the user can change the vocabulary of the offer, add special information or change standardized formulations to get a document ready to be send to the customer. The drawing of the machine is stored in a PostScript document, with symbolic representations of the components of the machine in scale. It shows the tank as well as the agitator. Therefore, it is possible to get an impression of the size of the machine and its components.

Benefits

Integrating knowledge from process technology lead to a higher flexibility in the design of agitators and enabled the development of series of standardized parts. By building a large numbers of mixing machines with a small number of standardized parts, manufacturing costs are considerably reduced.

Placing the design of agitators on a standard platform allowed the comparison of different designs and reduced cases of malfunction or even non-function. This resulted in a considerable reduction in design time and in reclamation costs.

After more than one year of being in the field, some benefits are quantifiable. The total time needed for an offer lies between 4 and 12 hours. This includes the time needed from first contact with the customer to the complete offer being ready to send to the customer. The average time to prepare a offer was reduced by 2 hours. This resulted in a savings of DM 660 000 per year out of a volume of DM 2 300 000 per year of total costs for producing offers. Comparing it with the costs of DM 1 300 000 for EKATO for the development of COMIX, the system will be amortised after 2.5 years of being in the field.

This reduction in design time was not achieved just by the high performance of COMIX. With COMIX it is possible to design a machine in less than 10 minutes, whereas the elder system took 45 minutes. But, the main reason for the reduction in average design time is the flexibility of COMIX. It can even assist in difficult design situations with suggestions about how to solve a problem, such as when the number of revolutions approaches the critical speed. Right now, about 80 % of all inquiries can be handled using COMIX.

The redesign ability of COMIX allows the user to try alternative designs to solve the mixing task and to meet the customers needs. Therefore, an increase in quality can be achieved. This is demonstrated by the ratio of offers given versus successful offers. Under COMIX, the ratio of offers which lead to contracting was increased from 27 % to 32 % of all offers. This means EKATO saw a 20 % increase in the number of offers which lead to contracting.

During the development of COMIX (3 years), many maintenance activities were necessary. These activities were analyzed and incorporated into COMIX's design. This resulted in a high degree of maintainability.

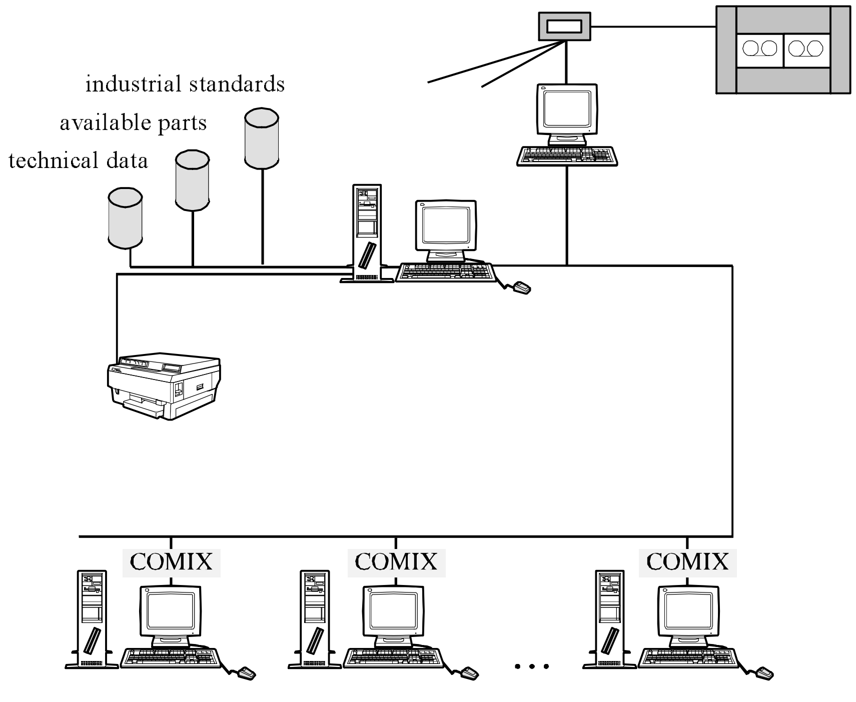


Figure 4: Overview of the Network

The Phases of Development

Basic Concepts

Most of the knowledge given by the experts, such as how to configure an agitator and when to choose a specific component, is specified using just a few parameters. The consequences of decisions made during the configuration of an agitator are not easy to estimate. So we have to cope with the problem of aggregating local information to find a global solution. This was the main reason the configuration of agitators was based on constraint propagation.

Another important reason is that constraint propagation is flexible. Depending on which kind and what subset of parts are used, the configuration process has to proceed differently. When using a sealing, the drop of power caused by friction at the sealing has to be taken into account when computing the minimal power of the drive. This can be expressed easily when using a constraint mechanism: Two alternative constraints have to be established, determining how to process with or without sealing.

The flexibility and extendibility also helped to increase the ease of maintenance and to expand the system. It is easy to add new components or to change dependencies between parameters. This occurred often during COMIX's development.

It was planned to base the propagation on non-directed constraints. This failed due to the way the configuration knowledge was provided by the experts. It included

- formulas for computing parameters,
- complex algorithms for determining parameters,
- data base searches depending on lower and / or upper boundaries of parameters.

To derive a non-directed constraint from an equation, the equation had to be solved for each occurring parameter. This failed in some cases. Also, deriving non-directed constraints from complex algorithms or data base searches failed completely. So the decision was made to use only directed constraints. Luckily, the restriction on directed constraints led to a simpler and therefore more effective mechanism for the evaluation of the constraints.

Development

The project started in the middle of 1989 with a preliminary project to investigate whether the problem could be solved by a knowledge based system and to evaluate the hardware and software requirements. Since the employees at EKATO had had experience with PCs using DOS, this was chosen as the hardware platform.

The selection of an appropriate tool was based on the following criteria:

- PC-based (DOS)
- possibility of object-oriented representation
- interface to a high level programming language available to implement complex algorithms
- interface to data base available
- support for an efficient development of a graphical user interface

GoldWorks II was chosen, which was based on GoldenCommonLisp under Windows286 on DOS. During the development the platform was changed to GoldWorks III under Windows3.1.

The main project started 1990. During the entire project, two persons at IITB and one person at EKATO have been continually involved.

The knowledge acquisition process started at IITB with an analysis of existing programs and printed documents. The basics about mixing technology were learned to facillitate speaking with the experts of EKATO.

A close contact between developer and experts was a characteristic of the main project. The knowledge acquisition process ran in a permanent loop

- acquisition
- implementation
- validation
- revision

with a 2 - 3 week frequency.

For validation, single agitators were configured with the newest version of the system and hand-checked by the experts.

The strategy of development was to construct a system as early as possible that could be given to EKATO for testing. Different stages of development and installation can be identified:

- First, a system was developed which was running stand alone and was tested in the research & development department.
- This system was extended to run on a LAN. This version was installed for testing in research & development as well as in the data processing department.

- The next stage was the installation of COMIX on several workstations in the sales department in the middle of 1991.

During the time of development, it became obvious that the choice of DBase as format for the data bases was very fortunate. The data bases had to be filled, for example, with data about thousands of motors and hundreds of gears. The data had to be checked and permanently investigated for errors. There are a lot of tools which can handle files in DBase format. So, every one could choose the tool he was the most comfortable with for editing the data bases. Therefore, the design and data entry tasks could be done independently.

Deployment

The deployment started when COMIX was installed in the sales department in the middle of 1991. It demonstrated that only a small amount of user training was needed. Thanks to the graphical user interface, only half an hour of individual introduction was needed to train members of the sales department to work with the system.

When the first version was installed in the sales department, it had nearly full functionality, but only a reduced set components was available. The reduced set of available components provoked the majority of the criticism and lead to a low acceptance of the system. Only a few members of the sales department started to work with the system.

But the work of these few was worth a lot, because they tried to use COMIX for their daily work with great enthusiasm and patience. By carefully investigating each configuration done by COMIX, many of the remaining bugs were detected and could be fixed. There was also a lot of advice on how to increase the user support and therefore the usefulness of the system for daily work.

Performance measurements showed that the system spent most of its time investigating constraints and controlling dependencies. To increase the performance, a new kernel was developed with efficient control of constraints and their dependencies. The new kernel lead to a three-fold performance increase.

Meanwhile, work was also concentrated on extending the set of available components. For instance, in the first version only direct motors and helical geared motors were available. This was extended to allow the use of flat-spur gears or v-belt drives or combinations of them. Figure 5 shows the possible combinations of gears and motors now available in the system.

Fast bug fixing, extended sets of components, increased performance and user support lead to an increase in acceptance. Since the middle of 1992, the system has been in wide use in the sales department as the primary tool for agitator configuration and offer preparation.

In the beginning of 1994, the system was installed on 5 workstations in the sales department and is

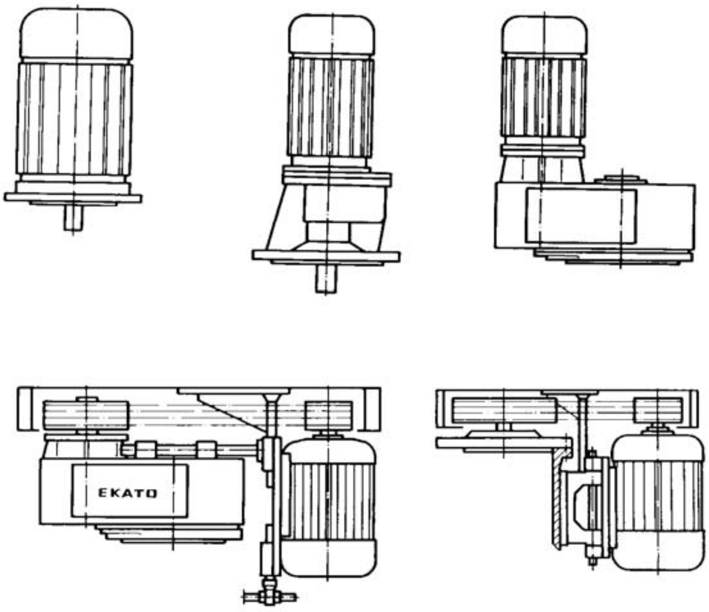


Figure 5: Different Types of Drives

permanently used by 15 engineers. For maintenance and testing the system is also installed on 2 workstations in the data processing department and on 1 workstation in the research & development department of EKATO. One system is also installed in the American subsidiary of EKATO. Currently about 300 machines are designed monthly with COMIX at EKATO's establishment in Schopfheim, Germany.

Maintenance

It was planned to hand over the maintenance of the system to EKATO after the initial system was developed at IITB. To facilitate this, courses started early in the project that covered Lisp, object-oriented programming and the implementation of COMIX. The courses were held by the original developers of IITB for two members of the data processing department of EKATO. This training was extended, modules of the system were jointly designed and, since the middle of 1992, modules have been independently implemented at EKATO, too. The main project between IITB and EKATO ended at the beginning of 1993. Since then, the system has been maintained and extended by EKATO.

During the development, it was determined that maintenance activities could be divided into four different levels:

- **changes of prices and technical parameters of components**: happens frequently, maintenance can be done by updating fields of data bases.
- **changes in the manufacture of components:** maintenance can be done with little work by making changes in the hierarchies of components or in the data bases. During development this was often necessary.
- **changes in the configuration knowledge:** happens seldom, maintenance can only be done by editing Lisp code.
- **new types of components:** objects have to be added to the hierarchies, configuration knowledge has to be coded and related constraints have to be added to the constraint network. This requires experience with the architecture of COMIX and the use of good programming skills. Experience has shown that this is also feasible.

During the last year, the system was extended by EKATO to include a new series of mixing machines and the ability to use a larger number of different types of impellers. It is planned to develop an interface to the CAD system AUTOCAD, which is used in the construction department.

The future will show whether the chosen architecture will lead to a long life for COMIX.

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