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Danfoss User Centred Design Group

7 Networked products for communities of users

In modern plants many industrial components are computer controlled and linked in networks. This poses new challenges for interaction design far beyond the one product–one user paradigm: Products relate to each other and so do the multiple users that constitute a community with its own social networks and work organisation. To examplify, we'll introduce the Water Vision Project, and in particular focus on the study of plants, products and people.

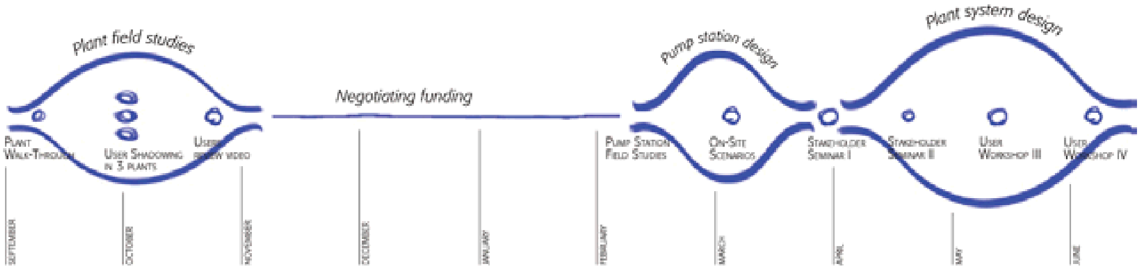
The Water Vision Project

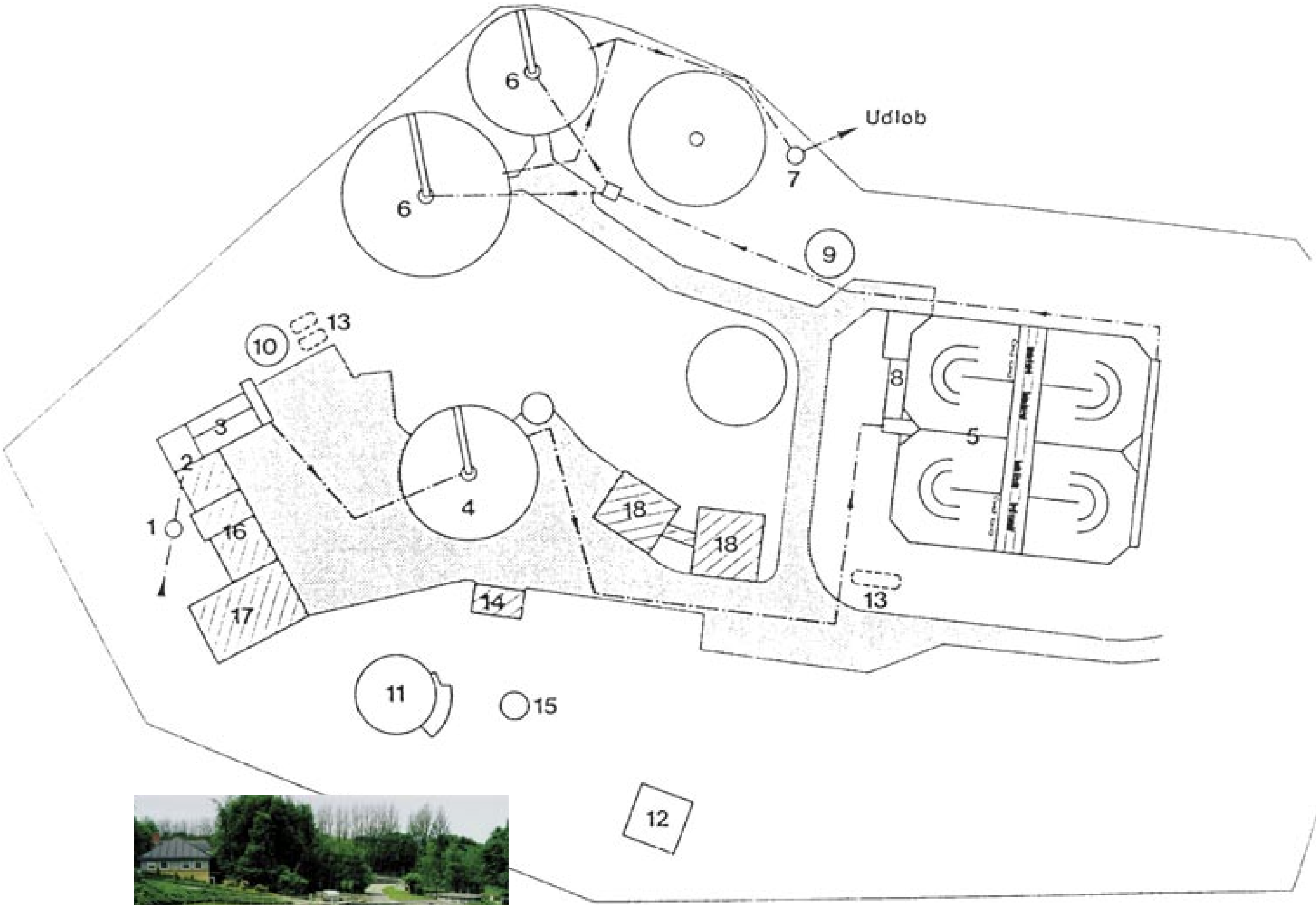
The Water Vision Project was initiated by the Corporate User Centred Design group and jointly funded by 4 business units. The goal was to study the water treatment field from a user's perspective and suggest directions that the business units may take in future product development.

Danfoss is organised in several business units that have grown ever more independent, to an extent that products don't any longer share the same principles of user interaction. Water treatment plants is one context where products from several business units are integrated into one system – leaving users puzzled with the question why products with the same brand behave so differently.

The project ran over 10 months, and was staffed with 4 UCD members, 2 business unit representatives, and 4 university interns. It was organised in collaboration with Universities in Aarhus and Malmö, which allowed comparative field studies at six wastewater plants. The project fell in two phases: A 2-month study period and a 5-month design period. The time in-between was spent negotiating funding and involvement from business units.

Overview of the activities in the 10-month Water Vision project





1. Flow meter well
2. Grating
3. Grit and fat trap
4. Mid-way clarification tanks
5. Aeration tanks
6. After clarification tanks
7. Testing well
8. Return sludge station
9. Concentration tank
10. Sludge thickener
11. Digesting tank
12. Gas tank
13. Chemical tank
14. Valve building
15. Sludge tank
16. Workshop and garage
17. Sludge pressing machines
18. Work team rest area and control room

The Wastewater Treatment Plant

Water treatment is a very special industry. Wastewater plants receive something like 20.000 tonnes of material per day of unknown quality. The end product is politically sensitive, and increased public awareness steadily increases the demands on treatment quality. The product has to be delivered 24 hours a day, and there is hardly any storage capability. There may easily be 50 tonnes of waste product per day, which is sometimes characterised as hazardous. All this is typically performed by a staff of about 10 persons.

Modern wastewater treatment plants are large installations, which include mechanical, chemical and biological processes. Only few process parameters can be measured and there are limited possibilities for actually controlling the process. New plants are typically equipped with a central computer system for monitoring and control and some1000-2000 sensors, actuators and controls. The installation is geographically spread out with walking distances between 500 and 2000 meters. The sludge is pumped between open basins, and pumps and valves are typically gathered in basements between the basins.

Samples are taken daily and lab tests made to adjust the addition of chemicals and the mechanical operation of the plant. Many plants produce electricity by using gas from the fermentation tanks in gas turbines.

The wastewater treatment plants in Scandinavia are typically run by the municipalities, organised under the authorities responsible for drinking water and environmental control. There is a trend towards closer collaboration between water suppliers, users, authorities and wastewater treatment. Experts use the term water factory to illustrate an integrated water treatment system, from the source of drinking water to waste water treatment. The aim is to achieve an optimal allocation and use of water in an appropriate quality and quantity where needed. Water of different qualities will be obtainable at different prices. Fire fighting and industrial cooling systems, for instance, don't require first class drinking water.

The idea of the Water Vision Project reported on here, was to take a user's perspective to create a vision for Danfoss products and their user interfaces in the water treatment area. The work was based on field studies at six wastewater plants and a number of water works and industries in Denmark and Sweden. The field studies were organised in collaboration between the Danfoss User Centred Design group and researchers and students from Aarhus University and Malmø University College. We visited the plants on an ordinary working day and videotaped what we saw - typically with three camera teams working in parallel. After analysing the video material we brought highlight videos back to the users for them to verify our conclusions.

Towards intelligent components
Danfoss supplies a large number of components to water and wastewater plants. The products are used to control and optimise water treatment processes. To design such products, it is important to know not only their functions in the plant, but also how people work and what the trends are in this particular field.

Evita sensors: The Evita sensor series consists of sensors for measuring dissolved oxygen in water and nutrient sensors for measuring ammonia, nitrate and phosphate. These parameters are of paramount importance for the control of wastewater plants. The dissolved oxygen sensor is used to control the aeration of the biological processes. This is state of the art in most plants and helps saving energy and improving process control. The nutrient sensors on the other hand are new products that have not yet gained general market acceptance. The sensors are developed for measuring directly in the process tanks in contrast to other systems that rely on ultra-filtration. The value of the sensors depends on the plant operator’s ability to use the new knowledge acquired for controlling the process.

Magnetic flow meters: Flow meters are used extensively in water and wastewater plants. They monitor how much water arrives at the inlet, how water is routed in the plant, how much is re-circulated, how much is taken out for sludge treatment and so on. Measuring flow in plants has always been important. An older method is to lead the water through a V-formed weir and then measure the water level over the weir to derive the flow by semi-empirical formulae. Mechanical flow meters had a rotating propeller inside the tube to count the flow, but particles in wastewater could cause the meter to clog up. Today measurement of flow is much easier and far more precise with the use of magnetic flow sensors. The sensors are mounted as part of the pipe and work for years with very little maintenance.

Manual and controlled valves: Water valves are installed at numerous points in water facilities for flow control, change of flow direction, and service shut off. Manual valves are used wherever it may become necessary to shut off pipes, for example when a leak occurs. Automatic valves are used for control purposes. In some plant set-ups, for instance, the flow direction is alternated frequently. Also, valves are used to in chemical dosage systems and sludge treatment.

VLT Frequency converters: Frequency converters are drives which convert the 50 cycle mains current into a variable frequency to run electro-motors at variable speed. In wastewater plants the most important motors to control are those that are used for water pumps and compressors. The advantages of using a VLT drive are lower energy consumption and smoother operation. The Danfoss VLTs have extensive computational power that allows advanced control algorithms like feedback control. For instance a water level sensor in a well may be used to maintain the water level at a set point.

The intelligent pump station

At wastewater treatment plants heavy rainfall pose a serious problem to the process, because of overflow in the basins and poor de-segmentation of the sludge. This is true for those countries, which employ mixed rainwater/sewage nets. In the water vision project we used the rainwater de-routing problem as a starting point for exploring the design of future intelligent water components. The subsystem involves flow meters, Evita sensors, VLTs and controlled valves. With Evita sensors it is possible to check the water quality on-line in the pump stations and thus detect rainwater before it reaches the wastewater treatment plant. Pending municipal authorisation, it should be possible to de-route the water in pump stations as soon as it exceeds the quality that the plant can produce.

Can components negotiate?

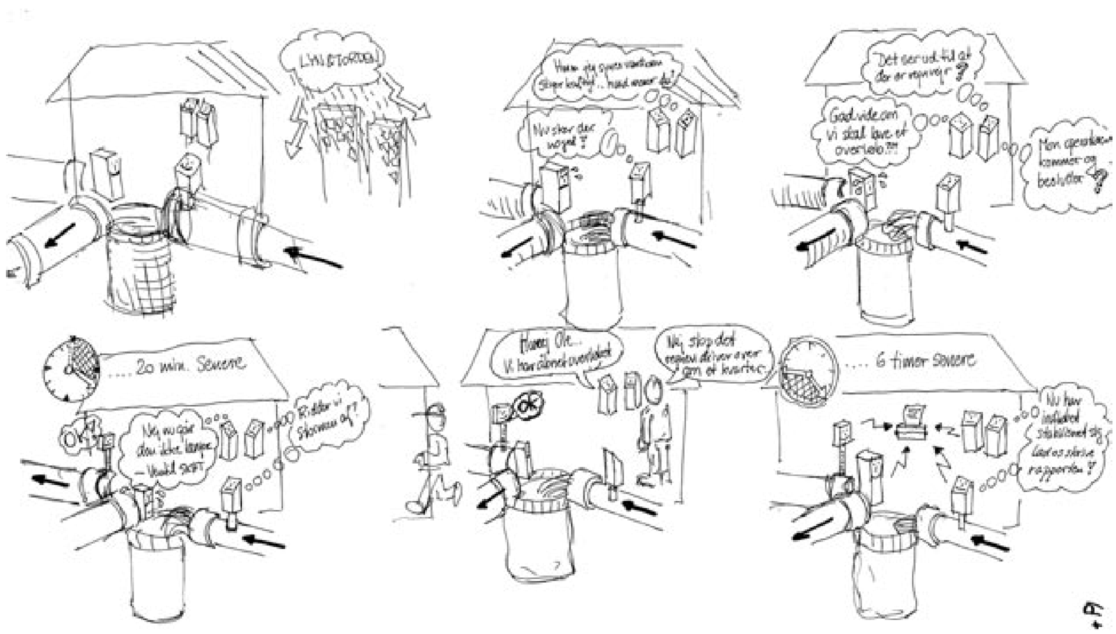
Could industrial components like those of Danfoss manage the task of rainwater de-routing all by themselves, if they were communicating on the same net? The traditional approach to pump station design is to program a programmable logic controller (PLC) to work as a central controller. This means that the PLC all the application knowledge of this particular pump station design. The system must be designed and completed at a specific time. But the reality of most plants is that their instrumentation and control keeps changing with new technological opportunities, tougher regulations a.s.o. Would it be possible to realise a control system that is continually updated, when a new component is added to the system? A system in which the components each incorporate application knowledge sufficient to negotiate the task in a net of distributed intelligence? And what would the operator's role then become?

Speaking the application language

It seems important to build application specific knowledge into sensors. With sensors new knowledge could be added to the plant. New sensors could measure a wider spectrum of nutrients and their concentration to improve the process. How do application-specific components interact with the users? In application language naturally! Here is a major shortcoming in most industrial components today: They aim to cover the entire market in the same product version and thus need to generalise and abstract information. They speak the engineering language of their designers. VLTs for instance show Hz in the display though water plant operators need to know pump speed.

The intelligent pump station scenario

At a pump station the flow and nutrient sensors detect a heavy rainfall as a first flush situation. To protect the plant from settler overload, the flush needs to be routed to the overflow. The components do this autonomously, as soon as the pollution readings are below the value set by the authorities. When the operator arrives some time later he checks the components. Their data tell him of the first flush situation and that de-routing was initiated. The operator assumes that the rainfall will soon be over, so he resets all components to normal operation.



People keep the process running
The core concern of the people working at a wastewater plant is to keep the process going. But who are they, and what do they do? Today's intensive instrumentation helps to illustrate most processes in the plant on computer screens. But plant employees are reluctant to work in the control room: They need to feel, see, hear, and smell the process on-site. From experience they are suspicious of computer-controlled systems. In unexpected situations they need to work around the system. Seeing the process as a whole is crucial to them.

As a component manufacturer for the water industry, we need to design information-rich products based on those concepts and models that derive from users' ways of reasoning. Therefore future information devices should cover the whole range of what is knowledgeable, and of what is reasonable in a given situation to support the user's holistic perspective of the plant. Typically people work in one of four roles at a wastewater plant:

The Process operator: Operators make sure that the required level of water purification is achieved, that the outlet water is clean and that the sludge has a suitable quality. Operators might have an area of their own responsibility, e.g. pre-treatment, biological treatment or sludge treatment. Process operators walk their daily rounds to check that all processes are running satisfactorily. They identify problems, and diagnose where and what is wrong in the plant.

The Plant Manager: Plant managers and process operators share a common educational background. Mostly they are trained as fitters, mechanics, or assistant engineers. The plant manager is generally the most knowledgeable person on the plant when it comes to waste water treatment. He takes on most of the office work. He decides whether to buy new equipment, and he makes strategic decisions about larger plant modifications.

The Technician: Technicians perform the majority of routine tasks at the wastewater plant: Sludge dewatering, sample collection, maintenance of equipment, pump station rounds etc. Rather than specialise, the technicians often rotate between the different duties to increase job quality and readiness in case of staff shortage. Larger plants have laboratory facilities with personnel specially trained to perform chemical analysis. At smaller plants this is work is performed by technicians. Though it is rare to encounter people specifically trained in computing, there is nearly always one person on a plant that bears this responsibility. This person, sometimes a technician, sometimes an electrician, is more or less self-taught on computers, but might get assistance from an external consultant.

The in-house electrician: A wastewater plant has lots of electrical and electronic equipment to be looked after, maintained, and repaired. Practices vary from plant to plant: Some employ their own in-house electricians, some work with external contractors. A typical pattern is that major plant extensions are completed by consultant engineering companies, while the local electricians do installations for smaller modifications.

Feeling, watching, controlling

We found three keywords that nicely summarise the work of the operators at wastewater plants. They are the human activities one needs to support with industrial components in the future.

Feeling the process: Wastewater treatment is a complex and subtle process. The operator needs to maintain a tactile/physical feeling of how the process is currently running. He can detect a warm pump by smelling or touching it before it becomes overheated. But he also knows from experience whether a troublesome pump still might do it until the new one arrives. Helping the process operator to learn more than there is too see is a real challenge.

Watching the components: Electronic components are potentially unstable. And malfunction can be serious. The operator needs ways of reassuring himself that each component is working properly. And when problems occur, components should display information to help operators in locating the malfunction. The first question asked when faced with a problem is always: Where should I look? Is it the sensor, the drive, the pump or another external component?

Controlling the control system: Control systems are designed for status quo, but wastewater plants develop continuously. Operators need to check and circumvent the system on a regular basis. When situations arise the control systems developers did not foresee, the system is likely to react inappropriately. Unexpected situations require improvisation and sometimes immediate action. So all components nee to offer ways for the human to take over control without the system overreacting unforeseeably in connected sections.

People and technology in the future
One could assume that unmanned plants are the key to rationalising wastewater treatment in the future. For a number of reasons we have learned that this is not the case.

The world is imperfect: No matter how nice it would be it is not possible to foresee all kinds of incidents that may happen. The world is complex and new unforeseen things keep happening all the time. At wastewater plants things break down, the water composition changes, the weather poses problems, electricity falls out, … There are simply too many factors that can influence the operation of a plant to design an automatic system to anticipate them all and at the same time ensure an effective, consistent and compliant operation.

Plants get increasingly complex: Plant designs aren't stable. Plants are being extended and expanded in a running process in order to improve effectiveness both in terms of lowering the concentration of known pollutants and in terms of removing new substances.

More information needs more interpretation: Additional focus on process optimisation through more and more sensory information in the systems will need people for their interpretation. Every time new information is added to the system more knowledge about the plant can be extracted. Some of the information can be used directly in control algorithms and therefore is of no concern as long as it works. But during special occasions a human interpretation of all the signals is necessary. In addition, in order to steadily improve the performance of the plant, human skills are necessary to understand where improvements can be made.

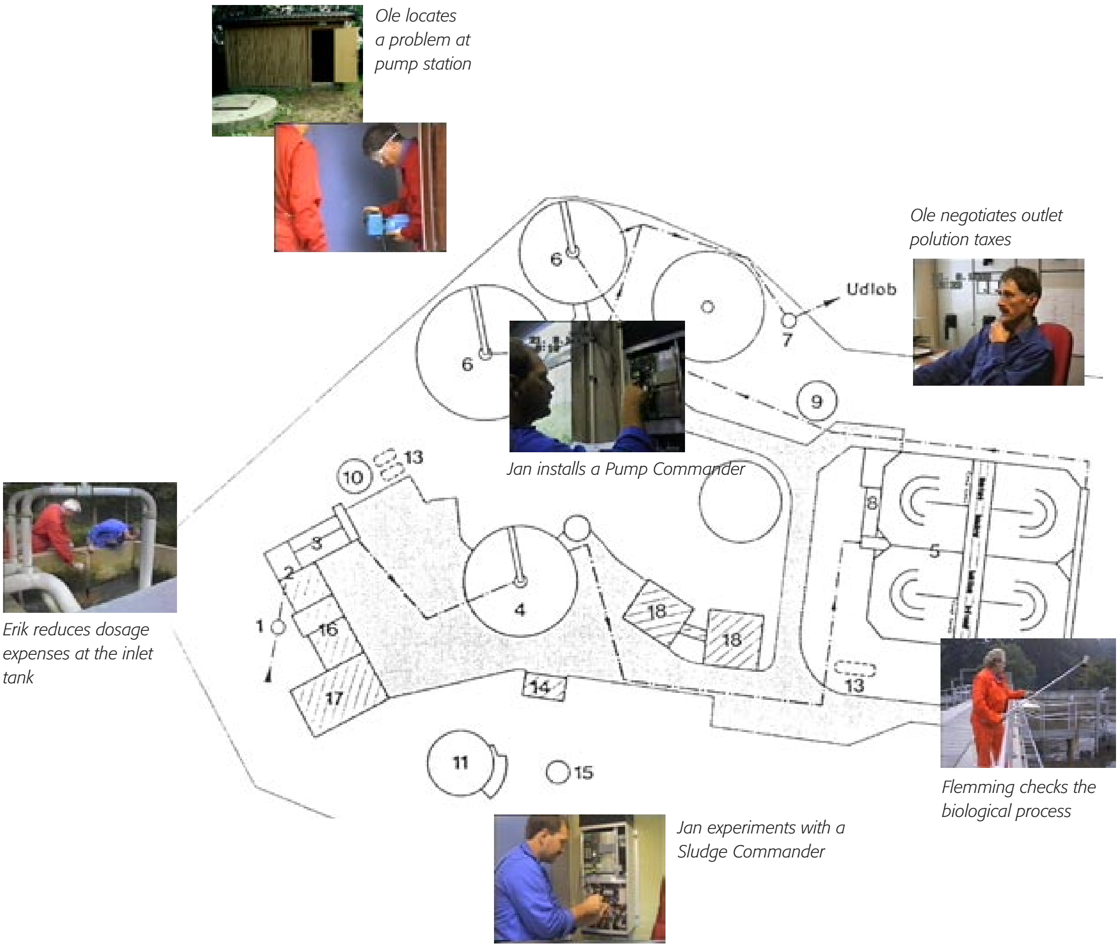
Human sensing is crucial: Not everything can be monitored via computer networks. Human operators can to a certain degree »feel« the processes. An important part of the job of an operator is to walk the plant and listen, see, smell and feel different parts of the process and the machinery. Human sensing is very difficult to replace with automatic sensors. Humans can react to things, which have not been foreseen.

Monitoring is a boring job: Sitting in the central control room and monitoring the computer systems is boring. Monitoring doesn't make the most of human resources (e.g. experience) and it will become difficult to find qualified personnel for control room work. At wastewater plants with computer system operators spend very little time in front of the monitor, often less than an hour a day. One must bear in mind that the processes of wastewater treatment is very slow and therefore dull to follow constantly.

Augmenting the plant environment

Augmented Reality is a promising concept that aims at using computer power to add new capabilities to the physical surroundings and tools we work with. The motor, for instance, could tell what temperature it actually has, and for how long it has been hot. The sludge could show what the concentration of nutrients is at this very moment.

In contrast to Virtual Reality techniques, which seek to create an entirely artificial environment in the computer, augmented reality acknowledges the needs of humans to be part of a real environment and work with real tools. For our purpose, augmented reality offers a new perspective on the components we develop. It helps to shift our focus from what the product should do to how we could support the human operator in doing his work competently in the actual environment.



Ole locates a problem at pump station

Ole negotiates outlet polution taxes

Jan installs a Pump Commander

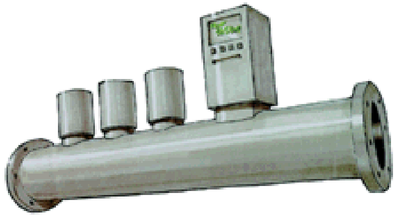
Erik reduces dosage expenses at the inlet tank

Flemming checks the biological process

Jan experiments with a Sludge Commander

Product concepts that provoke

To conclude the vision project, the team decided to present a set of product concepts that provoked the business units to rethink current convictions:



The Water Quality Meter combines several sensors to provide one reading that the operators would treasure: Pollution cost. But this would require two business units to collaborate.

The Flow Window supports the operators' preference for visual inspection. And nudges the engineering preference for numbers.

The Commander Family demonstrates the power of built-in application knowledge and urges that business unit to accept more system responsibility.

The Bioscope is a control-room screen moved out in the open, where work is actually performed. It provokes the engineers to give up the utopia of complete virtual control from a central control-room.