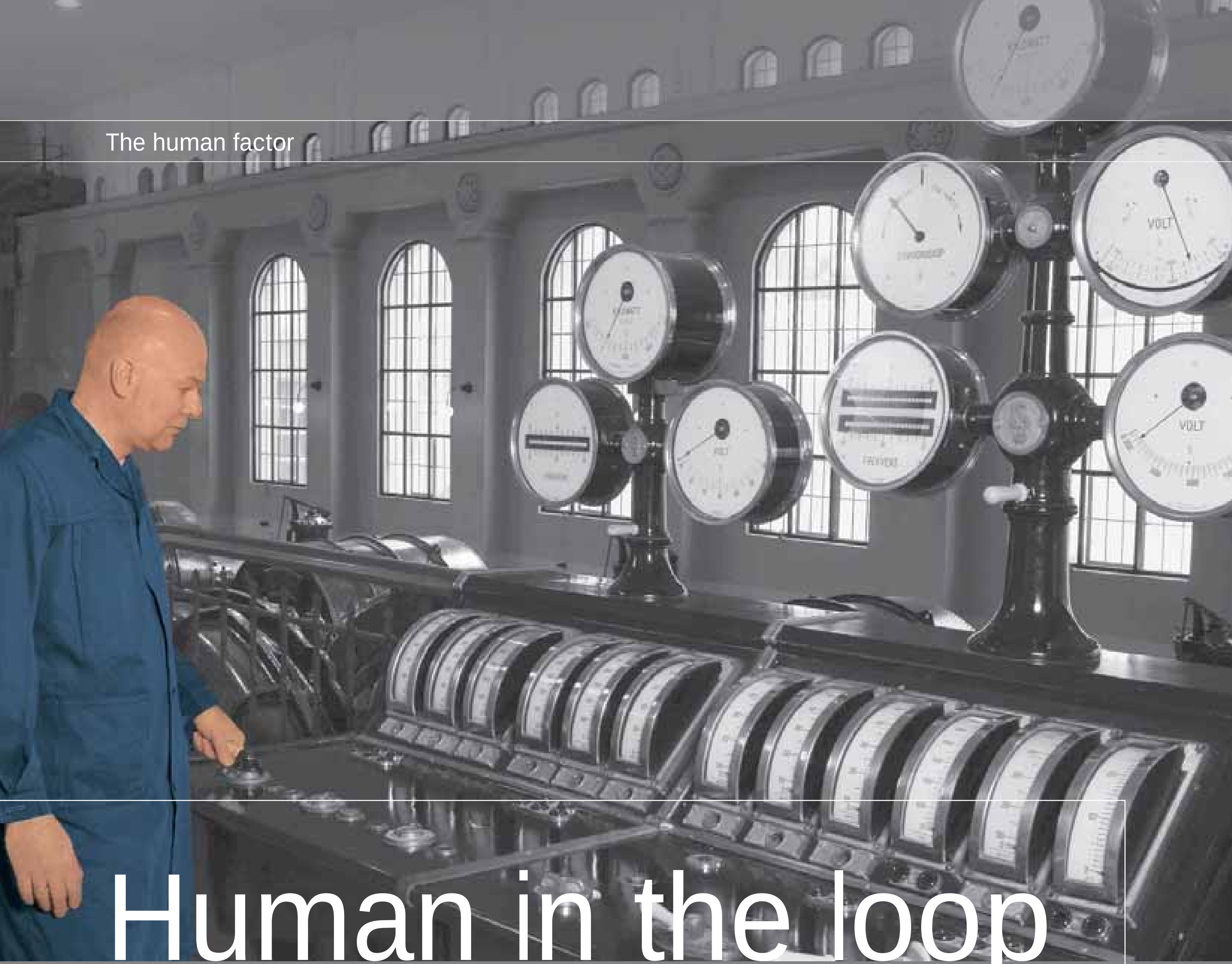


Human in the loop

The human operator is a central figure in the design and operation of industrial automation systems

John Pretlove, Charlotte Skourup

Since the advent of computer control based industrial automation processes in the mid sixties, engineers have been continuously striving to minimize the discrepancies between a human's cognitive model of what he wants to accomplish and the control system's understanding of the task. Continued success comes in the form of improved system performance and safety, and greater reliability. Such improvements have resulted in the gradual elimination of the mundane tasks previously accomplished by operators, thus allowing the *human in the loop* to handle the more challenging tasks of supervision, exception control, optimization tasks and maintenance duties. Hence over the last 50 years a clear division of responsibilities between the human and the machine has evolved based on the optimal ability of each.

Maximising to the utmost this human-machine collaboration, however, depends on continued technology development in three major areas – decision support tools; ergonomics and visualization technologies; and ease-of-use of complex systems. The optimal synthesis of these three fields creates the state-of-the-art operator environment of modern automation systems.

Over the last fifty years or so, greater performance and improved reliability of industrial automation systems has relieved operators of tasks that are tedious, repetitive or hazardous. Instead, human operators in highly complex industrial automation systems such as electrical power networks, pulp and paper mills, power plants, and refineries now play a central role in tasks such as supervision, detection of abnormalities, maintenance, and process optimization. Despite the apparent paradox, it is clear that the human operator is an integral part of any automated control loop in almost all industrial applications of any size. Therefore understanding and maximising the collaboration between the control system and the human operator is essential. Adopting a systematic design approach is crucial for reasons of safety and optimum system performance.

Humans as part of the automation system

In the early days of industrial automation, system designers attempted to automate everything and remove the human operator – whom they considered the weakest link in the process control loop – entirely. When this approach failed the human was assigned tasks the designer was unable to automate.

The skill sets associated with people as compared to machines were already well understood in the 1960s. The underlying principles were first described by Paul Fitts in 1951 [1]. Although his model was helpful in determining the allocation of functions between humans and machines, it did not consider the integration of both sets of skills nor how to improve the effectiveness of the human operator through computer system support and cooperation. Rather than eliminate people in industrial process automation, the trend nowadays is for substantial human involvement[1]. The reasons for this are:

- The degree of control in a process is a function of the predictability of process behavior and the degree of complexity. For all but the simplest of elements, it is not possible to model a plant fully or with sufficient explicitness. Nor is it possible to consider how external influences can affect the control system.
- Some processes could, from a technical point of view, be fully automated but the cost would be prohibitive. In any case, it is highly unlikely that the public would accept high-risk systems without humans taking overall responsibility. For example, the automation systems of a modern day passenger jet can handle both take-off and landing without pilot interaction. However, not many people would fly without a responsible pilot on board.

Important process characteristics that should be considered when designing a system with *humans in the loop* include:

- Process size and complexity
- The rate of change of the process
- The variability of the product schedule
- The process impact on the environment
- The economic cost of shutdowns
- The safety issue concerning people, equipment and the environment

Understanding and maximising the collaboration between the control system and the human operator, and adopting a systematic design approach is crucial for optimum system performance.

Humans are (largely) adept at dealing with the consequences of many of these factors. For example, they have the ability to recognise patterns and abnormal events based on large datasets, devise procedures to suit a new situation, store large amounts of knowledge for long periods of time, and reason and exercise judgement. To perform these tasks effectively, human operators have to be aware of the current situation at all times. They need the "right" information at the "right" time to be able to understand the current situation and to make the "right" decision. For this to happen, suitable visual support is needed. The most effective way of presenting large amounts of information so that the

1 A380 cockpit – courtesy Airbus

Footnote

1) Dividing the labor between large, complex and dynamic industrial automation systems and knowledgeable human operators is one thing. The other more important thing is striking the right balance.

The human factor

salient points can be quickly absorbed in critical situations has been researched within the field of cognitive science. In addition the disciplines of ergonomics and design must be properly applied to secure ease-of-use. The guinea pigs in these areas have been the cockpit of aircraft and the instrument panels of cars 1.

Decision support

"Decision support systems are a class of computer-based information systems or knowledge-based systems that, in a very different manner, support decision making activities" [2].

An efficient decision support system for modern and complex industries needs to consider both the degree of automation and the human behavior. A significant part of most industrial processes are relatively straight forward to model and therefore to automate. On the other hand human behavior is much more complex, unpredictable and almost impossible to model. Instead of modeling the human (with a view to replacing him) the purpose of decision support in large automation systems is to add value to the human by assisting in the decision making process concerning a specific situation or an acute issue. It is however critical that the human operator remains in charge 2. The decision support system should not attempt to define what to do. Rather it should equip the user with enough information to enable him to fully comprehend an actual situation and predict the consequences of potential decisions. At the end of the day, it is the *human in the loop* who must decide on the best possible course of action.

A large plant with 10,000 loops or more would, under normal steady state conditions, perform for hours without any human interaction. The concern today is how to get the operator's attention when something abnormal and crucial suddenly happens. Again parallels can be drawn between the human reaction in this example and that of pilots in the airline industry. Intercontinental travel provides pilots with hours of no engagement. However if anything unusual happens, pilots are immediately jolted into action to quickly resolve any problems. This is one of the most critical issues of *human in the loop* systems. On the one hand the operator monitors the system but with few "hands-on" actions required. On the other hand when something deviates from the normal, the operator is expected to not only be fully aware of the (current and recent) state of the process, but he must also know what manual actions are required to handle the situation.

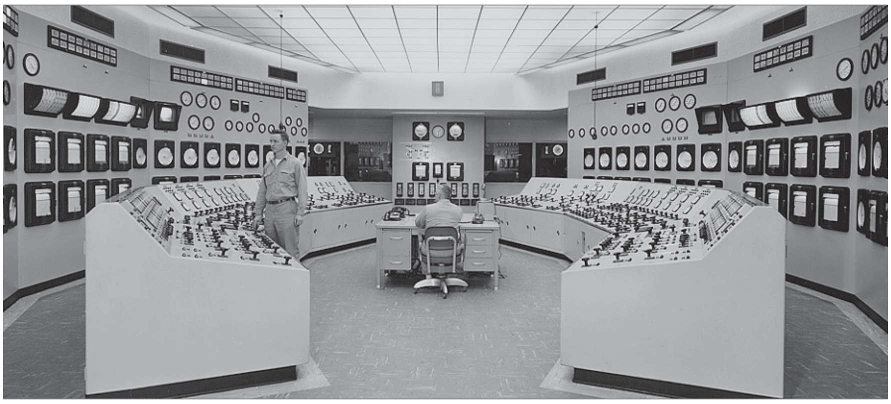
It is critical that the human operator remains in charge. The decision support system should not attempt to define what to do.

Research has shown that one very important area of support for the operator is how information is distilled and presented to provide an immediate and full overview of the situation.
In a process plant environment for example, critical information such as:

- Initial alarms (but not the sequence of consequential alarms) should be easily and quickly identifiable.
- Performance data should be reduced into key statistical measures for quick assessment rather than displaying massive tables of data points.
- The current situation should be compared with previous and similar situations including previous actions taken to resolve the issue.
- The outcome or consequence of the operator's decision should first of all be predicted to enhance his chance of making the "right" decision.

Decision support can vary from direct recommendations, which the system provides automatically, to manually sought possibilities expressed in terms of trends, statistical information and alarm prioritization. For example, to support the operator in complex alarm handling situations, the alarms in the decision support software are filtered and color-coded to direct the operator's focus to the most important ones as the majority of them often represent follow-up alarms. Another example relates to root cause identification of a situation where alarms are assessed automatically and only the real cause of the problem is presented. It is becoming more common to provide case histories of similar occurrences including their resolutions, and the operator uses these cases to extend his internal repository of experiences.

2 A control room from the 1950s



Ergonomics and information visualization

The word ergonomics comes from the Greek word "ergon" meaning work. When related to process automation it refers to the operating environment in which humans work. Variables in such an environment include the room size, the color settings, the furniture and of course the visualization of the information produced by the systems. Many studies have helped to define the minimum requirements for good operator performance, which include adjustable tables and chairs, screens with dedicated and overview information, defined color usage in displays and backgrounds, recommended methods when searching for information and parameter changes. These requirements must be clearly defined and consistently used throughout a system. Complications arise if several different systems are used in the same room, each with different ergonomic definitions. International Standards such as ISO 9241[2)] and 11064[3)], combined with industry best practice help to harmonize these systems, leading to improved overall efficiency.

The control system is one of the main sources from which operators receive inputs reflecting the status of the industrial process.

Information visualization concerns how information is presented to the human operator. A more concise definition describes it as "a branch of computer graphics and user interface which are concerned with the presentation of interactive or animated digital images to users to understand data" [3].

The control system is one of the main sources from which operators receive inputs reflecting the status of the industrial process. Therefore, it is essential that information is presented in a way that allows the operator to thoroughly understand and comprehend the current situation. Since it is impossible to accurately model and predict human behavior, it is even more important to be aware of the power of correct presentation.

Information visualization incorporates a large range of different techniques, from conventional graphical user interface design to 3D/4D and virtual reality interfaces. Within the automation domain, information visualization covers everything from presenting (abstract) raw data on the operator screens and the interface design of human-machine interactions, to the special rooms equipped for remote collaboration. Traditionally, operator stations within the control room utilize piping and instrumentation diagrams (P&IDs)[4)] as an overview of the automated industrial process. Alarms are often presented in a separate system. However, redesigning the overview display to focus on and visualize changes in the process and combining it with alarms allows the operators to get an immediate picture of the relationship between changes and alarms. Such visualization may even prevent alarms from occurring since the operator will notice when the process is approaching the alarm limit. Spatial data visualization – such as a 3D model of the industrial process – is another way of presenting the operators with an overview of the system. Such visualization represents the geographical locations of equipment and the special interrelationships between such equipment. Furthermore, this 3D process model can integrate information from other systems to provide a complete single interface to several industrial processes or process segments.

The design process: ease-of-use

"Ease-of-use refers to the property of a product or thing that a user can operate without having to overcome a steep learning curve. Things with high ease-of-use will be intuitive to the average user in the target market for the product. The term is often used as a goal during the design of a product, as well as being used for marketing purposes." [4].

The human operator is the key to success in the application of automation technology to process control. The collaboration between the *human in the loop* and the advanced industrial automation system depends on how easy it is to use the multi-faceted functionality of modern control systems. Sometimes, well over half of the control loops are manually operated because it is simply too complex

A modern and complex oil and gas process plant

Footnotes

2) Ergonomic requirements for office work with visual display terminals. ISO 9241 provides requirements and recommendations relating to the attributes of the hardware, software and environment that contribute to usability, and the ergonomic principles underlying them.

3) Ergonomic design of control centers. This eight part standard contains ergonomic principles, recommendations and guidelines.

4) A schematic type diagram showing the functional relationship between piping, equipment and instrumentation within process units in chemical plants, power plants, water treatment and similar plants. See http://en.wikipedia.org/wiki/Piping_and_instrumentation_diagram, retrieved 20 th October 2006.

3 Today's control systems have large-screen projections and individual operator workspaces

to tune the regulators for optimal performance. It is therefore essential to focus each aspect of the control system's capabilities onto the user and to design and develop the entire system with the human operator firmly at the center 3. The basic design principles [5] include:
- Organizing technology around the user's goals, tasks and abilities.
- Organizing technology around the way users process information and make decisions.
- Keeping the user in control and aware at all times of the state of the process through the technology.

Simplifying the steps needed to perform an action is crucial if the control system's capabilities are to be used effectively. Ease-of-use of a complex automation system starts with an in-depth understanding of the *human in the loop*. The designers must constantly and consistently understand the activities of the users whether they are supervisors, operators or maintenance engineers. Knowledge about human behavior helps to outline the basic architecture of the automation system based on the users' goals, tasks and expectations.

It is essential that the design of the entire automation system is such that any misinterpretation of data is completely avoided.

When an unexpected and unknown event occurs in the plant, the operator actively searches for information in order to get a picture of the process state. He is entirely dependent on and must trust the information which is accessible from the control system. Therefore it is essential that the design of the entire automation system is such that any misinterpretation of data, that could result in wrong actions and potential serious consequences for the industrial process and people onsite, is completely avoided.

Summary

It is a common fallacy to think of automation as either fully manual or fully automatic. The situation is rarely so simplistic or so clear-cut. Instead the reality is that for most industrial automation systems a continuum of control ranging from fully manual to fully automated is adopted. There can also be different modes of operation which may be automated to different extents. Humans play a central role in modern industrial automation systems and their role in the future will be more important than ever before. The human operator also represents the most vulnerable element in the system and the one most easily overlooked. Understanding and optimizing the overall performance of industrial process control systems relies on a systematic and holistic approach, taking care both of the rapid development of technology and the special role that the human fulfills.

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Further reading

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