Design methods

Putting the human in focus

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How many people would dare board a plane without a pilot on board even though technology has advanced to a point where “flying” a plane from the ground is possible. Can technology be trusted enough to also run nuclear power plants or complex industrial processes without the presence of operators? Of course people make mistakes and often accidents such as nuclear meltdowns or airplane crashes are attributed to human error. However, in many cases a lack of relevant information for handling a critical situation has been at fault.

Rather than eliminate humans from the process, the trend nowadays is to fully utilize their capacities and strengths by integrating them more into the overall design. This means designers must harmonize two very different complex models – that of a technical process control system with one representing human behavior – to produce a well-functioning automation system that cannot afford to fail in critical and unpredictable situations. This article gives an overview of how this is done.

In general human nature is uncomfortable with the idea of giving away overall responsibility for a complex process – a pilotless plane is evidence of that. Another example to illustrate this comes from the oil and gas industry where the trend is to move the operation of offshore installations to onshore centers to reduce personnel risks and operational costs. Some teams, however, need to remain offshore not only for safety reasons but also to perform inspection and maintenance tasks. Understandably, there is considerable apprehension towards moving control and responsibility hundreds of miles away from the process itself. Because the operator is such an important element in any automation loop – especially when critical and unpredictable events occur – new systems need to be designed with an extended focus on the human user. A poorly designed system can have dreadful consequences of which the Three Mile Island nuclear accident is a good example **Factbox**.

The accident was a catalyst that brought about a new way of thinking in terms of system design. While many technical issues needed to be re-examined, so too did the role of the human operator in certain industrial processes. Following the accident investigation, sweeping changes were made to emergency response management, operator training and, more importantly, human factors engineering for plant operations. Many of these changes later filtered through to other industries.

Many institutes have researched the role of the human in industrial processes. The Institute for Energy Technology (IFE) in Norway, for example, has focused[1)] its research on: human cognitive processes; design and prototyping; and task allocation. Similar research in other safety critical industries, such as oil and gas have been following the same trend. Other process industries with fewer safety requirements have been relatively slow at introducing new methods, paradigms and thinking related to safety concerns and the human user. This is, however, beginning to change as new design approaches supporting cognitive elements are gradually finding their way into the industrial marketplace.

Knowing the human mind

Models of human mental processes and behavior, and user-centered design increase the focus on the operator as an integral part of an advanced automation system. Many such models exist and each represents some aspect of the cognitive processes of the human mind. Two of these are discussed in the following paragraphs.

Models of human mental processes and behavior, and user-centered design increase the focus on the operator as an integral part of an advanced automation system.

Rasmussen [1] has developed a model to help designers combine information requirements for a system with aspects of human cognition. Also known as the SRK (Skills-Rules-Knowledge) model, it describes three levels of human behavior: skill-based, rule-based and knowledge-based **1**. Skill-based and rule-based behavior patterns represent situations and tasks that are familiar to an operator. To be more specific, the skill-based level requires almost no conscious human control or cognitive effort to perform an action based on perceived inputs. Human performance at this level is automated and consists of highly integrated patterns of behavior acquired through training. The rule-based level occurs when a situation or an event is familiar and the operator uses a selection of acquired rules and procedures to formulate a course of action. Operators base their performance on this type of behavior when they follow specific maintenance procedures, for example. The knowledge-based level of behavior is the most demanding cognitive process and it takes place when the human experiences an entirely unknown and unexpected event or situation.

Unlike many other models of human cognitive processes, Rasmussen's model is based on industrial process operators and how they manage information and perform tasks. This model is therefore highly relevant for complex industrial automation systems.
In practice, Rasmussen's model can be used to decide at which level of behavior the operator performs specific

Factbox Three Mile Island nuclear accident – an overview

Three Mile Island nuclear generating station sits on a 3.29 sq. km island in the Susquehanna River in Dauphin County, Pennsylvania. In 1979 a sequence of events led to the partial meltdown of the nuclear reactor. Initially a failure in the cooling system caused a relief valve to stick in the open position. Signals to the operator failed to indicate that the valve was open. As a result cooling water continued to pour out of the reactor causing it to overheat. There was no indication of the level of coolant in the reactor. Instead the operators judged this based on the coolant level in the pressurizer, and since this was high, they assumed the core was properly covered.

Even as alarms rang and warning lights flashed in the control room, operators failed to realize the seriousness of the situation. In fact a decision to reduce the flow of coolant into the reactor only served to exacerbate the situation. In the investigation that followed, it was discovered that the operators did not have all the information necessary to understand the real situation. Because of the lack of information, the operators' "picture" – or mental model – of the situation was wrong and all actions taken were based on this incorrect model. Even when the predicted outcomes of specific actions did not match the mental model, operators disbelieved alarms rather than question their own understanding of the situation.
For more detailed information, please refer to www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html (Referenced in November 2006).

tasks and what information should be available at this level. It can also allocate tasks between the human and the control system.

Situational awareness – prerequisites for human decision making

Endsley's [2] situation awareness model describes how people who deal with complex and dynamic systems – such as an industrial process – actively look for and interpret specific information, and how decisions are made based on this information. Endsley's model comprises three levels 2:

- Perception of elements in the environment within a volume of time and space.
- Comprehension of the meaning of these elements.
- Projection of the elements' status into the near future.

The first level describes how the human perceives bits of information in an environment that either deviates from the original situation or represents a state that contributes to the "picture" of the current situation. At the second level, the person acquires a deeper understanding of the current situation while still actively searching for additional and complementary information. Finally, the human operator uses his mental model of the industrial process to simulate potential actions based on perceived information as well as the present interpretation and understanding of specific information. When a solution has been found which solves the problem the decision regarding what actions are required naturally takes place.

> The challenge of good system design is to fully utilize the strengths of both man and his "machine" (the control system) to achieve what neither can alone.

Endsley's model helps designers understand how automation and decision support systems collaborate to direct the operator's attention to specific information essential to comprehend any given situation. In practice, it can be easily applied and is especially effective where there are long periods of normal or low activity that are suddenly interrupted by the occurrence of a critical event requiring the operator's full attention. It does not, however, say anything about the individual's mental "picture" or any decision the human operator will take.

Designing for improved human-machine collaboration

The challenge of good system design is to fully utilize the strengths of both man and his "machine" (the control system) to achieve what neither can alone. Where technology-centered design focuses entirely on the technology, user-centered design aims at developing technology to support the specific user and his tasks in context.

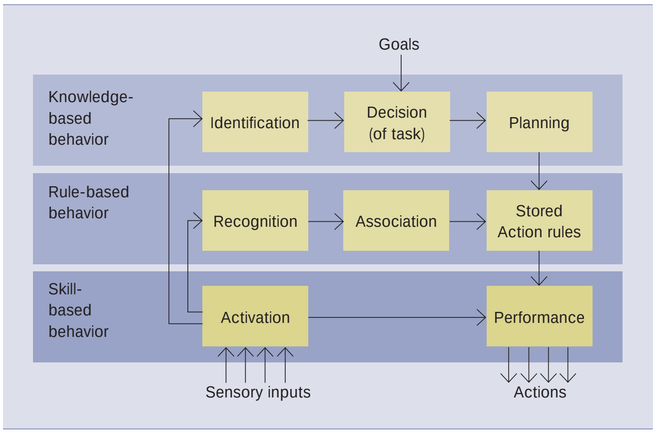
The job of integrating the human operator into a well-functioning automation system belongs to the system designers. Even though the system design process – which includes a number of phases, analysis and methods – varies between different industries, the common denominator for all designers is that they must collect relevant information on the *human in the loop* to design an effective human machine interaction. Such a system acts as a communication channel between the operator and the control system.

Requirement specification

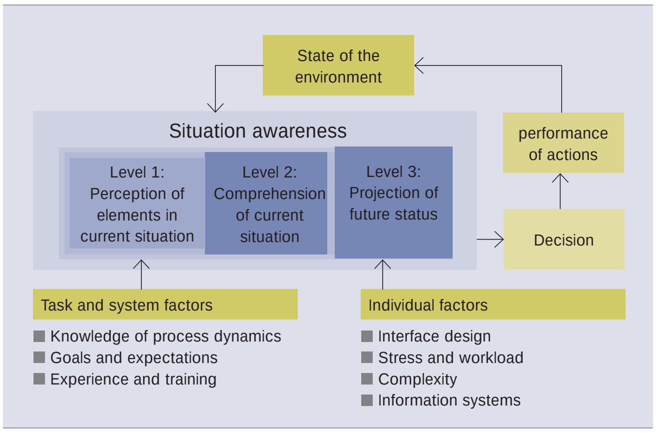
Almost all designers perform a requirement analysis to translate overall system goals and objectives into specific system specifications. Few however focus on the human user as part of the overall system. A complete set of design specifications should consider the industrial process itself, the users, the tasks, the environment and the operational requirements. Knowledge about the operator and how he performs his tasks ought to drive the design of the automation system.

A user analysis identifies the different users of the automation system. It further groups and characterizes these users based on bibliographic information, competence, experiences and preferences. This type of analysis helps the designer to get to know the users and to understand how they perform their tasks. Additionally, environmental requirements relate to ex-

1 Rasmussen model of human behavior – also known as the SRK model – helps designers combine information requirements for a system and aspects of human cognition



2 Endsleys situation awareness model describes how people in complex and dynamic systems look for and interpret information, and how decisions are made from this information



ternal factors such as the layout of work places, lighting conditions and the surrounding environment (ie, explosion risks, dust, humidity, noise, etc.).

Functional analysis and task allocation

Functional analysis identifies the functions of the entire automation system including both the human and the control system. The main objective of a functional analysis is to allocate labor – also referred to as task allocation – between the human and the control system. Use cases and scenarios are examples of techniques needed to gather functional requirements.

> It is recognized now more than ever that the human operator is an irreplaceable part of the automation loop, especially when critical and unpredictable events occur.

In many situations, task allocation can be pretty straightforward: nothing matches a computer, for example, when it comes to handling large amounts of data, performing repetitive tasks and following procedures. In addition visualizing and ergonomically presenting complex information in terms of overviews and drill down objects is easier. The human, on the other hand, is good at reasoning, judging, solving problems and making decisions. However, the real world is not black and white and many tasks demand close collaboration between the computer system and the human operator in order to solve a task optimally. As well as task allocation, the degree of automation is a highly relevant topic. The complexity and degree of automation varies within different industries and sometimes even within a specific process. Also, the way human operators react to problems and situations is dependent on their experiences and skills. However, a conscious decision regarding the level of automation and when the human operator should interact with or override it is essential. This important guideline makes the operator's workload "visible" to the designer.

Task analysis

The main aim of a task analysis is to understand the tasks, goals and expectations the user will demand of a new system. It is therefore critical to clarify which tasks an operator should perform to get the job done. The order in which the tasks are carried out to fulfill the goal and the tasks themselves may differ between operators so long as safety is not compromised. A basic task analysis, for example, identifies a number of goals and the related tasks needed to achieve each goal.

A number of variations of task analysis methods exist. Two such variations are known as *Hierarchical Task Analysis and Cognitive Task Analysis*. A Hierarchical Task Analysis simply divides a job into tasks based on a hierarchy whereas a Cognitive Task Analysis focuses on the cognitive processes needed to perform a task. For example, a field inspection is a rather simple task to define. On the other hand, an unexpected situation novel to the operator demands a higher level of definition. According to Rasmussen's model of human behavior, this task takes place at the knowledge-based level of behavior, which means it may involve tasks such as problem solving and decision making. With this knowledge designers can then determine (a) what information the operator should see and how it is presented, and (b) the decision support and task allocation between the control system and the human operator.

Conclusions

The trend within almost all industries is towards safer systems (despite increasing complexity) and a higher level of automation. The design process in the past was more technology-centered, but now there is a growing focus and understanding of the importance of the *human in the loop*. It is recognized now more than ever that the human operator is an irreplaceable part of the automation loop, especially when critical and unpredictable events occur. People are however different and unpredictable and respond in slightly different ways to critical situations.

> A complete set of design specifications should consider the industrial process itself, the users, the tasks, the environment and the operational requirements.

A number of methods support an extended understanding of the *human in the loop* and help to define and characterize the typical operator or groups of operators. To ensure a well-designed and safe automation system, the system designer will, now and in the future, need to combine the outcome of these various models and methods.

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Footnote

[1] Initially for nuclear power plants.

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[1] **J. Rasmussen**, Skill, Rules, and Knowledge; Signals, Signs, and Symbols, and Other Distinctions in Human Performance Models. IEEE Transactions on Systems, Man, and Cybernetics 13 (1983) 3, 257–266.

[2] **M. R. Endsley**, Towards a Theory of Situation Awareness in Dynamic Systems. Human Factors 37 (1995) 1, 32–64.

Further reading

T. B. Sheridan, Telerobotics, Automation, and Human Supervisory Control. The MIT Press, Massachusetts, 1992.