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The alarm system and a possible way forward

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Abstract. The aim of this paper is to make a review of studies concerning problems with alarm systems and to make a theoretical analysis of these problems. The aim is also to show some general design ideas to improve alarm presentation in process descriptions. Using research results from situation awareness and decision making a number of suggestions for further development of alarm systems are presented. Recommendations include providing operators of complex systems feedback that can support their mental models and situational awareness. Furthermore a recommendation is to design alarm systems that can learn from experience.

Keywords: Alarm systems, dynamic decision making, process control, complex systems

1. Introduction

Alarm systems are used in many different settings (e.g. health care, process industry, energy producing industry, transportation industry) to help operators control processes of different kinds. The processes that are being controlled in these settings have a number of important characteristics. They are continuous and relatively slow. Feedback from control activities are often delayed and seldom, if ever, available for direct perception. Complex processes are common and often composed of many sub processes organised in different ways. Sub processes may be organised hierarchically but also cross-coupled. If sub processes are cross-coupled changes in one process may have an impact on other processes and produce side effects of different kinds. Furthermore complex processes are partly unpredictable. To control a partly unpredictable process alarm systems are often used. Alarm systems should be able to detect deviations from ideal states, especially deviations that may cause hazards for people or be very costly for process owners or both.

1.1. Objectives

The aim of this paper is to make a review of studies concerning problems with alarm systems, to make a theoretical analysis of these problems, and then to show some principle design ideas for improvement of alarm systems adapted to operators' needs of adequate alarm information in different operational situations in process industry. These ideas are based on several empirical studies performed by researchers from Chalmers University of Technology in Gothenburg, Sweden [1]

2. Necessary conditions for process control

To control a process an operator must have access to a model (causal) of the process [2]. If this model is incorrect or incomplete the control of the process will be less than optimal. This may lead to low productivity or, in the worst case, accidents. There must also exist a goal or many goals for the process, and it must be possible to get information concerning the current status of the process. It must also exist possible ways to change or control the status of the process and to receive feedback from control activities. Finally there

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must be operators that are motivated and have the necessary skills to control the system.

2.1. Situation awareness

Situation awareness (SA) is a central concept in complex systems where people are interacting with technology. According to Endsley [3] SA can be divided into three levels. The first level is perception of task relevant elements, for instance the information sources (displays and co-workers) that are of importance for the control of a process. The second level is the interpretation of the task relevant elements, for instance the interpretation of the information from different displays and people. The third level represents a prediction of the future, for example what will happen in the near future. It can be argued that what are task relevant elements in the control of a process depends upon the strategy used for control. A proactive strategy may make different demands on information compared to a reactive strategy.

2.2. Decision making

Important research in decision making [e.g. 4] has shown that operators of complex systems have more problems to learn to control processes with causal net structure (when side effects occur) compared to processes with causal chain structure (no side effects can occur). It was also noted that people have other problems in dealing with complex processes. One problem was to consider the dynamic or time aspect of a process. People also had problems to deal with nonlinear relations between control actions and system responses. Other researchers [5, 6] have also pointed out that delay in feedback from control activities may have a negative impact on operators' ability to control a system.

2.3. Feedback

Feedback from control activities can be provided in different ways. A common strategy is to use outcome feedback and simply provide information whether the activity had the desired outcome or not. Cognitive feedback, on the other hand, aims at a deeper understanding of the process or task to be controlled. Research [7] has shown that cognitive feedback may result in faster learning of a task compared to outcome feedback. Using outcome feedback means to provide the operator with important information concerning properties of the process being controlled. For instance the relation between control activities and system responses (i.e. the relation between the time a pump is activated and the temperature of a process). By doing this it is possible to help operators to form a mental model of the process being controlled.

3. Problems with alarm systems

The aim of an ideal alarm system is to alert and inform the operator of a deviation, guide the operator's response and, in a timely manner, confirm if the response corrected the deviation [8]. However, a large number of studies have pointed out some common problems with alarm systems. A specification of important problems with alarm systems was identified by Lees [9] False or nuisance alarms, ambiguous or underspecified alarm messages, too many alarms during a short time, alarms that not really are alarms but rather an indication of system status are some examples. Mumaw et al. [10] also point out a number of problems with alarm systems. Many of the weaknesses are a result of alarm set points that are not context sensitive. This will generate several false or nuisance alarms. Nuisance alarms may also be a result of the fact that multiple alarms may be generated by the same initial problem. Rigid alarm limits may also contribute to an avalanche of alarms. Research results concerning alarm and alarm systems within sectors such as nuclear power, oil refinery, emergency care, energy production, paper and process industry have been performed by the Division of Design and Human Factors at Chalmers University of technology in Gothenburg [1] These studies all show the same pattern of problems: too many alarms, irrelevant alarms, lack of priority concerning risk level associated with the different alarms etc.

To design an ideal alarm system a number of problems must be solved. First of all it must be possible to know which the deviations are, or might develop to be, dangerous, costly or both. Second, since many processes will show some variation it must be possible to establish when a variation is large enough to be dangerous, costly or both. It must be possible to communicate effectively with the operators, for instance when to initiate the communication and how to communicate.

To know what is and what is not an undesirable deviation from an ideal state a model of the process to be controlled must exist [2] either in a computer or in the head of the operators or both. There must also exist reliable ways to observe these deviations, directly or mediated by some kind of displays. To know when a deviation is large enough to be or develop into an undesirable state a criterion must be established, with a balance between false alarms and real problems. To communicate effectively with operators involves designing the information adapted to their needs, abilities and limitations. Feedback must be designed to support the operators' mental models of the process to be controlled.

4. Principle design ideas for improvement of alarm system

To make it possible for operators to learn a more correct mental model of a process and to get a high level of situational awareness Thunberg and Osvalder [1] developed visual presentations to be integrated in the process description. Here alarm infor

mation is included in the process description and thereby makes it possible for the operators to focus their attention on relevant parts of the process. A visual representation of disturbances in the process representation can also be used to show side effects of different kinds. If, for instance, the triggering event is a stop in a pump in a cooling system it is possible to show side effects (e.g. increased temperature) in other parts of the system.

Figure 1 shows an overview of a limited subsystem of a nuclear power plant, where new ideas for alarm information is integrated in the process description. The figure presents examples of how relevant alarm information can be presented in the user interface, to facilitate for the operators to detect anomalies, to detect and handle individual alarms, and to identify and take corrective measures in disturbances.

A key factor for successful performance is that operators get continuous information and useful feedback of the status of the system. The operators need feedback regarding the results of their measures, automatic sequences and information regarding critical process data. For example, safety-critical alarms should be spatially dedicated and continuously visible, which provide pattern recognition. Given this, the operator can quickly detect variations in the system..

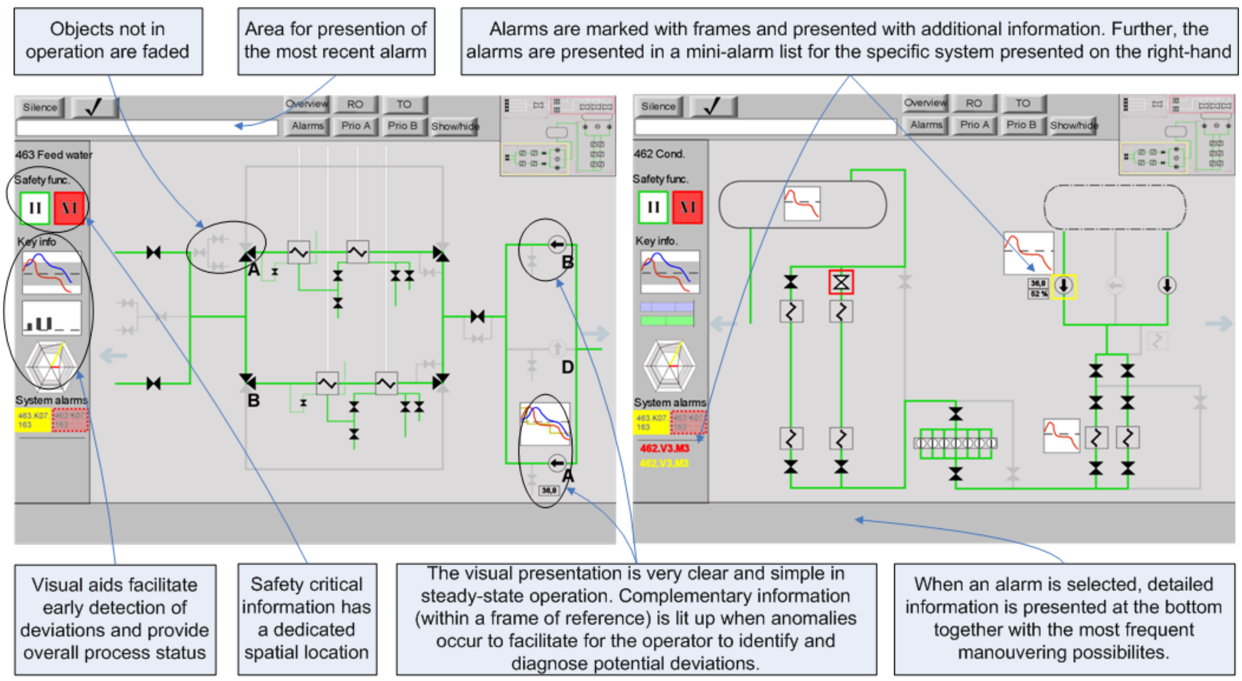

Figure 1. Examples of how relevant alarm information can be integrated in the process description

Further, visual aids to enhance detection of process changes should be implemented ¨

Operators often try to manage the process by being aware and pro-active. They actively monitor key parameters to be able to early detect deviations. To facilitate for evaluation of parameter values, the value should be presented together with the set-points and/or alarm limits.

To facilitate interpretation of alarms, the alarm should be presented within a clear frame of reference, e.g. the alarm limits. Some type of indication of the parameter's trend is also helpful and enhances correct interpretation of the alarm and helps the operators with prioritising their work. Further, a user interface that guides the operator's initial response contributes to successful alarm handling.

4.1. Operator comments of alarm design proposals

The new design proposals for alarm presentation in process descriptions (figure 1) have been discussed in focus groups with control operators working in nuclear power and process industries [1, 11, 12]..The following items were highlighted:

- Prioritisation of alarms is one of the most efficient functions to enhance alarm handling.
- The alarm system's ability to guide the operator's initial response (e.g. by action lists) to the deviation is important.
- Fast detection and interpretation of anomalies and alarms are significant to improve process availability and safety.
- Pattern recognition is efficient and visual aids (e.g. mass balances and object information in a frame of reference) enhance detection of process changes.
- Ensuring that every alarm requires a response is an efficient strategy to keep the number of alarms low.
- The operator's decision-making is much influenced by the perceived information and not so much dependent on the operator's level of expertise. The alarm handling can be made more efficient if the operator is supported by:

  - Emergency operating procedures
  - Alarm prioritisation
  - Reduction of distracting stimuli
  - Suppression of irrelevant alarms

5. Towards a learning system

To design an alarm system capable of learning from control actions might be a possibility and a step in the evolution of alarm systems. To learn from experience it must be possible to add a feedback loop into the system and learn from the effects of different measures to control a process. A simple example could be an alarm system that informs the operator about the type of error or fault that has occurred and also gives some suggestions concerning corrective actions. These corrective actions can be regarded as hypotheses about corrective actions. If the operator actions are notified, together with the system response it will be possible to test different hypotheses. A hypothesis that works most of the time can be given a prominent position in a hierarchy of suitable operator actions to solve the problem at hand.

An alarm system could also be designed to learn the characteristics of different operators. To do this it is necessary to identify different operators and also to monitor their performance in different tasks. If, for instance, the system can monitor the performance of an operator and detect that the operator has omitted a certain response a number of times, then the system could assist the operator next time and suggest an appropriate action. For instance: "Don't forget to…".

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