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Automation Inflicted Differences on Operator Performance in Nuclear Power Plant Control Rooms

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Abstract

Today it is possible to automate almost any function in a human-machine system. Therefore it is important to find a balance between automation level and the prerequisites for the operator to maintain safe operation. Different human factors evaluation methods can be used to find differences between automatic and manual operations that have an effect on operator performance; e.g. Predictive Human Error Analysis (PHEA), NASA Task Load Index (NASA-TLX), Halden Questionnaire, and Human Error Assessment and Reduction Technique (HEART). Results from an empirical study concerning automation levels, made at Ringhals power plant, showed that factors as time pressure and criticality of the work situation influenced the operator's performance and mental workload more than differences in level of automation. The results indicate that the operator's attention strategies differ between the manual and automatic sequences. Independently of level of automation, it is essential that the operator retains control and situational understanding. When performing a manual task, the operator is "closer" to the process and in control with sufficient situational understanding. When the level of automation increases, the demands on information presentation increase to ensure safe plant operation. The need for control can be met by introducing "control gates" where the operator has to accept that the automatic procedures are continuing as expected. Situational understanding can be established by clear information about process status and by continuous feedback. A conclusion of the study was that a collaborative control room environment is important. Rather than allocating functions to either the operator or the system, a complementary strategy should be used. Key parameters to consider when planning the work in the control room are time constraints and task criticality and how they affect the performance of the joint cognitive system.However, the examined working situations were too different with respect to levels of automation and therefore it is not possible yet to propose general automation level guidelines. Further studies are still needed.

Key words

Automation level, function allocation, cognitive workload, human reliablity, performance, control room design

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Automation Inflicted Differences on Operator Performance in Nuclear Power Plant Control Rooms

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Background

The overall purpose of this ongoing project is to develop and evaluate new technology in order to ensure safe implementation in power plant control rooms. The overall goal is to develop design criteria and inspection guidelines for control systems and alarm systems based on new technology. The project is divided into two partial projects and runs for two years, 2006 and 2007. The first project (I) deals with alarm systems and alarm presentation. The second project (II) deals with choice of new technology, proper level of automation in new systems, and function allocation. Control systems and alarm systems have to be developed together to achieve the best results. These systems are dependent of each other, and a less functioning control system will affect the alarm system negatively and vice versa. It is essential for a secure system that both the control system and the alarm system fits perfect to each other.

This report describes the results from the first year of partial project II – automation level and function allocation. In the end of the report, the planned activities for the project during 2007 are described.

Introduction

The purpose of the ongoing project is to study what level of automation and human-system interface design that is best suited for different working situations and plant statuses, with regard to catch the operator's attention and guide him in the correct way.

The goal of the project is to identify guidelines and measurable criteria for control room design. These criteria should be able to use when developing new techniques and sub-systems for control rooms.

The initial research questions to be answered during the first year of the project (2006) were:

- Which factors have an affect on the level of automation and the type of human-system design the operator needs, irrespective of plant status and working situation?

- Can theory as Fitts' MABA-MABA list (Men Are Better At – Machines Are Better At) be refined or used for different plant statuses, to help the development of new technology in the area of function allocation?

- Which factors should the selection of automation level and human-system interface design be based on, to guarantee a safe introduction of new technology?

A discussion of the accomplished results for the initial research questions is presented in Appendix A. A literature review concerning types and levels of automation and function allocation is shown in Appendix C. In Appendix D a summary of future technology in automation is presented.

The project includes studies in different generations of control rooms. The first part of the project has dealt with empirical studies of operators working in hybrid control rooms, i.e. control rooms based on analogue technology that have been modernised to some extent (Andersson et al., 2007) (Appendix B). The control rooms used in the studies are Ringhals 3 and 4. These control rooms still use mimic walls, many hard controls and analogue meters complemented with some computer based systems. The second year (2007) of the project should also include studies of new control room design, the so called generation III control room, with more computer based information and technology and soft controls.

Method

Experimental Setup

The chosen nuclear plant control rooms to study during the first part of the project were hybrid control rooms at Ringhals (unit 3 and 4). These two units are so called twin units with almost identical instrumentation and control. Therefore, the results from the two units will not be treated separately.

The chosen situations in the empirical studies were: (1) Switch of feed-water pumps and (2) Blackout with house-load operation. These two situations were chosen in discussion with the reference group of the project. The motivation for the selection of these situations was that they are related to the secondary side in the control room. This makes the results more applicable and representative for other plants as well, since the primary side is much more specific for each plant. Further, the two tasks are different in character. The first situation is characterised by planning of task, performance of actions, intervention with the controls and assessment of the effects of the actions taken. The second situation involves identification and diagnosis of a disturbance and the use of checklists to assess and ensure a safe plant status. The operations and actions included in each situation were described by a hierarchical task analysis diagram (HTA). The task analysis methodology is used to describe goals, contents, context and structure of a task, especially used for operators' handling of information in complex systems. The HTA diagrams describing the work tasks for the situations are presented in Appendix E and F.

To simplify the analysis House-load operation was divided into three sub-situations in line with the human information processing model (information acquisition – information analysis – decision making & action selection – action implementation). The situations are presented in Figure 1. Identification is connected to information acquisition, supervision to information analysis and decision making and synchronization to action implementation. Shift of feed water pumps is treated as a homogenous situation and can be related to action implementation in the information processing model.

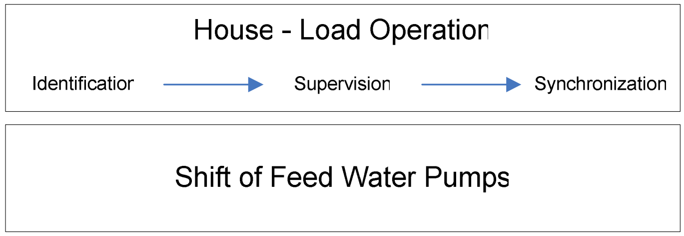

Figure 1 The two studied situations and the division of hose-load operation into sub-situations.

The test subjects included in the study were 8 turbine operators at the Ringhals nuclear power plant, of approximately sixteen available at the Ringhals reactors 3 and 4. Two of these operators were under education and working together with a more experienced operator. All interviews were made in the power plant control room during shift hours.

Used methods

Several methods within the area of human factors engineering were studied, and a combination of useful methods was chosen to be included in the empirical studies.

To study the operators' mental workload in different work situations and plant statuses subjective methods can be used. The method chosen was NASA-Task Load Index (NASA-TLX). The NASA-TLX allows users to perform subjective workload assessments on operators' work with various human-machine systems (Stanton et. al., 2005). NASA-TLX is a multi-dimensional rating procedure that derives an overall workload score based on a weighted average of ratings on six subscales. However, all of the subscales are not relevant for the chosen tasks and the control room environment. The four subscales used were: Mental and temporal demand, effort and frustration level. Physical demand and performance were left out as the pilot study showed lack of relevance in the studied situations. The NASA-TLX questionnaire is presented in Appendix H.

Furthermore, to study the collaboration between the operators and the automatic functions, a questionnaire (Skjerve & Skraaning, 2004) was used, developed by researchers at the Institute for Energy Technology, in Halden. The Halden Human-Automation Cooperation Questionnaire is presented in Appendix I.

Two human reliability analysis methods; Human Error Assessment and Reduction Technique (HEART) and Predictive Human Error Analysis (PHEA) were used to identify type of human errors that might occur and probability of human error (Sandom & Harvey, 2004).

The methods were used to evaluate risks connected to different tasks in the studied situations. Examples of the HEART and PHEA questionnaires are presented in Appendix J and K. In PHEA the risk is calculated as the estimated probability for a certain error multiplied by the estimated consequence. For actions with a risk clearly above the rest the risk and consequence has been evaluated individually and the cause has been clarified. The different error types are presented in the PHEA questionnaire in Appendix K.

Results

To present the results of the operator estimations median values were chosen instead of mean values due to a wide distribution of the estimations and relatively small population of test subjects.

Generally there was a wide distribution of the estimations between different operators. This is presumed to be connected to the subjective estimations of the individual operators and the difficulty of "resetting" the test subjects to estimate a given task in a similar way. There are no visible connection between the operators' level of experience and distribution of the answers.

Below is a summary of the most important results from each method sorted by the different situations. A full description of the questions connected to each method can be found in Appendices H to K.

NASA-TLX

The NASA-TLX results show that inexperienced operators make higher estimations of their work load in all four categories (mental demand, time pressure, effort and frustration) compared to experienced operators. The largest difference can be seen in effort and frustration.

The highest estimations of mental demand are found in supervision and synchronization during house-load operation. Identification and shift of feed water pumps both have medium estimations of mental demand.

The questionnaire indicates that time pressure increases with time during house-load operation and peaks at synchronization, but synchronization also got the widest distribution of the answers. During shift of feed water pumps time pressure show a low value.

The estimations of effort and frustration show the same pattern as time pressure but at a lower level. It increases as house-load operation proceeds and peaks at synchronization. Shift of feed water pumps show a low estimation of effort.

Halden Questionnaire

The estimations of operator-automation cooperation were all given high estimations indicating that cooperation works well. No differences could be seen between house-load operation and shift of feed water pumps nor between experienced and inexperienced operators.

HEART

The estimations of importance of factors influencing the risk of erroneous actions show a very wide distribution across the whole scale. The medians lies high indicating that the evaluated factors are important. There is no difference within house-load operation while the estimations are slightly lower for shift of feed water pumps.

PHEA

The estimations connected to identification of house-load operation shows a wide distribution of the answers but the medians are low.

The correct check on the wrong trend curve (trend curves for the wrong turbine are displayed) during supervision of house-load operation was one of the tasks given a risk estimation well above other tasks. This relates to a high estimation of the consequence of reading the wrong curve. The probability of wrong checking was given low estimations.

All three errors linked to “Estimation of time to critical point” gave indications of high risk. The three errors were “estimation omitted”, “wrong estimation – you believe you have plenty of time” and “wrong estimation – you think you have lack of time”. They were all given high estimations for consequence and low to medium estimations for probability.

During synchronization after house-load operation the task “Check alarms” was given a higher risk compared to other actions during synchronization. The probability of occurrence was given low estimations and consequence high estimations.

During shift of feed water pumps there is one task where risk lies above the other actions. The task “selection of pumps in operation” is given medium level estimations for both probability and consequence.

Overall, the largest contribution to risk comes from high estimation of consequences of erroneous actions while the probability is generally estimated as low.

Summary of Results

The NASA-TLX results show a lower value of mental workload and stress for shift of feed water pumps compared to house-load operation.

The Halden Questionnaire shows no differences between the two examined situations.

The estimated importance of different factors in HEART shows little or no distinction but has high estimated values indicating that all the proposed factors have relevance in both situations.

The PHEA results show that the situations of interest can be analyzed in detail and events where the operator might need support can be identified.

Analysis

Comparison of method results with assessed Levels of Automation

The assessed Levels of Automation (LoA) are based on Sheridans LoA (Parasuraman, 2000). The list has been further developed to also contain levels for Information Acquisition, Information Analysis and Decision Making & Action Selection. In Appendix G, the list of LoA is presented.

The shift of feed water pump task is of manual character and the LoA are very low, shifting between 1 and 2 on the Sheridan scale. Therefore the LoA variations are not presented in detail for this situation.

Correlation of results between situations

While relations were hard to find when comparing the results from the methods, an additional comparison was made to deeper look at possible connections. The sub-situation “Synchronization after house-load operation” has more similarity as situation with “Shift of feed water pumps" while both situations include manual action implementation. Therefore Synchronization and Shift of feed water pumps were compared again and more closely this time to search for relations with levels of automation.

Synchronization compared with Shift of feed water pumps

No new connections could be found when examining the results from NASA-TLX, Halden Questionnaire and HEART. The PHEA results from Synchronization and Shift of feed water pumps were grouped by types of failures and then compared to see if the risk was higher for any type of failure or if risk was estimated higher or lower depending on level of automation. No differences in risk estimations could be found for specific types of failures nor could any dependencies on level of automation be noted.

Conclusions

A straight forward interpretation of the results would imply that there are no connections between level of automation and risk of erroneous actions, cooperation or workload. This explanation is not plausible. The conclusion is that the examined situations are too different to compare with respect to levels of automation. The greatest difference in situation characteristics lays not in automation but in criticality and time pressure. This impacts the estimations and overshadows effects caused by automation levels. Therefore it is not possible to yet draw conclusion and generalize them to automation level guidelines. Further studies are still needed.

However, the results indicate that the operator's attention strategies differ between the manual and automatic sequences. Independently of level of automation, it is essential that the operator retains control and situational understanding. When performing a manual task, the operator is "closer" to the process and in control with sufficient situational understanding. When the level of automation increases, the demands on information presentation increase to ensure safe plant operation. The need for control can be met by introducing "control gates" where the operator has to accept that the automatic procedures are continuing as expected. Situational understanding can be established by clear information about process status and by continuous feedback.

Furthermore, a conclusion of the study is that a collaborative control room environment is important. Rather than allocating functions to either the operator or the system, a complementary strategy should be used. Key parameters to consider when planning the work in the control room are time constraints and task criticality and how they affect the performance of the joint cognitive system.

Further research

To cover the lack of usable relations connected to levels of automation, more suitable situations should be chosen for further evaluation. A possible alternative is the Turbomat system controlling the start up of a turbine. This system involves different subsystems that can be started automatically through the Turbomat or manually following a start up sequence.

Planned activities during 2007

The results from the empirical studies made in the project during 2006 are valid for a hybrid control room. During 2007 studies of automation level, mental workload and design criteria will be continued, mainly in hybrid control rooms but also new generations of control room will be studied to some extent.

The following activities are planned to be performed during 2007:

(1) Continue the empirical studies on level of automation and mental work load during highly automated work situations and situations with low degree of automation respectively, at Ringhals Power Plant.

(2) Study visit and interviews with e.g. design engineers and presumptive operators at Olkiluoto 3, to get a better understanding of how the new generation of control room is built. What are the theories behind the chosen design solutions and how are these related to the cognitive psychology theories about mental processing?

(3) Compare the results from the empirical studies from Ringhals, and other studies presented in literature, to how the new generation of modern control rooms is designed.

(4) To validate the results from (3) above, or if presumptive operators can not participate, theoretical studies will be performed using frameworks and models of:
    a. Levels of automation (framework developed by Chalmers, influenced by the theories presented by Sheridan, 2000 and Parasuraman et al., 2000)
    b. Levels of behaviour and information processing (skill, rules and knowledge based) (Rasmussen, 1983)
    c. Human error (Reason, 1990)

(5) Identification of critical work situations and evaluation how the chosen design assists the operator in these situations.

(6) Compare and combine the results from the studies made in hybrid control rooms and in new control rooms as a base for presenting general guidelines for function allocation and design of control systems in nuclear power plants.

(7) Discuss abut how the control system and alarm system should fit together in future control room designs.

SUMMARY: The deliverables from the second part of the project are planned to be measurable criteria for new control rooms, and conclusions about of which guidelines and criteria that are the same for both types of control rooms. This will end up in general guidelines and measurable criteria for new control room design and how these guidelines fit together with new ideas for alarm system design.

References

Parasuraman, R., Sheridan, T.B. & Wickens, C.D., (2000) *A Model for Types and Levels of Human Interaction with Automation* IEEE Transactions on Systems, Man and Cybernetics – Part A: Systems and Humans, vol. 30, no. 3, p. 286-297

Sandom, C. & Harvey, R. S. (2004) *Human Factors for Engineers,* The Institution of Electrical Engineers, London ISBN: 0-86341-329-3

Skjerve, A.B.M., & Skraaning, G. Jr. (2004) *The quality of human-automation cooperation in human-system interface for nuclear power plants.* International Journal of Human Computer Studies, no.61, p. 649-677

Appendix

Appendix A: Answers to the Initial Research Questions, first year of project (2006)

Appendix B: Paper - "*Automation Inflicted Differences on Operator Performance in Nuclear Power Plant Control Rooms*". Submitted to the MTO sessions at the Enlarged Halden Programme Group (EHPG) Meeting 2007, Gol, Norway, 11-16th March 2007.

Appendix C: Literature Study – *Types and levels of automation and function allocation*
Author: Johanna Oxstrand, Divison of Design, Chalmers University of Technology, GÖTEBORG, Sweden (In Swedish)

Appendix D: Summary – *Future Technology in Automation*
Author: Jonas Andersson, Divison of Design, Chalmers University of Technology, GÖTEBORG, Sweden

Appendix E: HTA for work situation: – Switch of feedwater pumps

Appendix F: HTA for work situation: – Blackout with houseload operation

Appendix G: List of Levels of Automation divided into Information Acquisition, Information Analysis and Decision Making & Action Selection

Appendix H-K *gives examples of the questionnaires used in the study. All four methods are used in each of the two studied work situations.*

Appendix H: NASA-TLX questionnaire

Appendix I: Halden Human-Automation Cooperation questionnaire

Appendix J: HEART – Human Error Assessment and Reduction Technique questionnaire

Appendix K: PHEA – Predictive Human Error Analysis questionnaire

Appendix A

Research Question 1

What factors affects the level of automation and which human-system interface design is the most suitable to help the operator irrespective of the plant status and work situation?

Since the results from the study did not show any clear relations between level of automation and the examined factors, it is difficult to give definite guidelines on what factors affect the proper choice of level of automation. The reason of the lack of explicit relations can be lead to the great influence of time pressure and criticality. These two factors overshadowed influences from other factors in the estimations for house-load operation. Time pressure and criticality are two factors well known in human factors engineering to be of importance to operator performance. To reduce time pressure in a situation is difficult while it lies in the properties of the situation and is tightly coupled to the machines used in the system (i.e. available time during house-load operation depends on thermal shrinking affecting the distance between turbine blades and housing). In the present graphical user interface in the control room, trend curves are used to present the thermal shrinkage over time. The interface can be improved by also implementing proactive estimation tools to support the operator in making estimations of time to critical point.

Research Question 2

Can theory as Fitt's MABA-MABA (Men Are Better At-Machines Are Better At) list be refined or made suitable for different plant statuses to help the development of new technology in the area of function allocation?

The conclusion that automatic systems and the human operator should be viewed as cooperating parts in a system puts the Fitt's MABA-MABA list theory in a new perspective (Sheridan, 2000). The use of this approach implies that the interaction between the human and the automatic system is decomposed into smaller elements where the list is applicable. In this process functions are treated separately and thus the nature of the complex system is lost to some extent (Hollnagel & Woods, 2005). The complexity itself lies within the dependencies between the individual factors and their dynamic properties. In specific function allocation problems Fitt's list can still be of help, but to handle the complexity of dynamic systems a broader perspective is needed. To improve the ability of handling system deviations Hollnagel & Woods (2005) suggest overlapping function allocation. This increases the number of possible ways to respond to a deviation or error and gives better system stability.

Research Question 3

On which factors should the selection of automation level and human-system interface design be based to guarantee a safe introduction of new technology?

Since it was difficult to find connections between the results of the used methods and levels of automation in the studied situations, no specific factors can be presented from the results of the study. Anyhow, some general guidelines can be mentioned. From a human factors perspective it is important to start with an overall system view of the problem at hand. This is important while the dependencies between the systems are to be introduced and the legacy sub-systems have to be clear if a functioning cooperation should be reached between the human operator and the automatic system. Further, tasks in a new system should be designed with consideration to the operators work situation. This is of course more difficult in a hybrid system where old technology often sets the boundaries of task design. Tasks are often designed so that the user has to work near maximum capacity to handle basic tasks (Hollnagel & Woods, 2005) (Figure 1). Instead it should be possible to meet maximum task demands with as little effort as possible. This creates better conditions to deal with unexpected events.

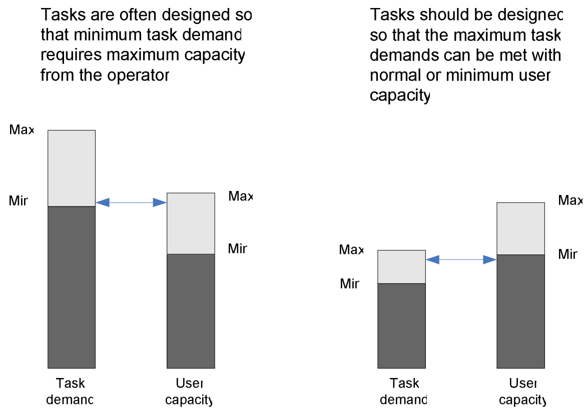

Figure 1. *The demand-capacity match (Hollnagel & Woods, 2005).*

References

Hollnagel, E. & Woods, D. D. (2005) Joint Cognitive Systems – Foundations of Cognitive Systems Engineering, CRC Press, Boca Raton

Sheridan, T.B (2000), *Function allocation: algorithm, alchemy or apostasy?* International Journal of Human-Computer Studies, vol. 52, no. 2, February 2000, 203-216(14)

Appendix B

Paper submitted to the Man - Technology - Organization sessions at the Enlarged Halden Programme Group Meeting 2007, Gol, Norway, 11-16th March 2007

Automation Inflicted Differences on Operator Performance in Nuclear Power Plant Control Rooms

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Abstract

Today it is possible to automate almost any function in a human-machine system. Therefore it is important to find a balance between automation level and the prerequisites for the operator to maintain safe operation. The purpose of this study was to test how different human factors evaluation methods can be used to find differences between automatic and manual operations that have an effect on operator performance. Four methods have been used; Predictive Human Error Analysis (PHEA), NASA Task Load Index (NASA-TLX), Halden Questionnaire, and Human Error Assessment and Reduction Technique (HEART). Eight turbine operators from Ringhals power plant, Sweden, were used as test subjects. Two situations with different levels of automation were studied; House-load operation and Shift of feed water pumps. The results showed that factors such as time pressure and criticality of the work situation influenced the operator's estimations of performance and mental workload more than differences in level of automation. The studied situations also need to be more similar to allow a better comparison of effects induced by level of automation.

1. INTRODUCTION

Since technical development in human-machine systems makes it possible to automate almost any function, the system designer faces the question of what functions to automate and to what extent. How ever, the question of how to best optimise what functions the human and the machine should perform respectively, is far from solved. Therefore, it becomes important to find a balance between automation level and the prerequisites for the operator to maintain safe operation of the plant. It is important to understand that the best allocation of functions constantly changes due to development of technology and operators' individual behaviour.

Parasuraman et al. [3] presented a guiding framework for choosing types and levels of automation in human-machine systems. This framework emphasize that both output and input functions of the human-machine system can be automated. The framework proposes that automation can be applied to four classes of functions:

- Information acquisition
- Information analysis
- Decision and action selection
- Action execution

Further, Parasuraman et al. [3] proposed a flow chart describing how the framework could be applied in automation design. The workflow includes two stages of evaluation for selection of an appropriate automation level. However, the task of how to identify proper levels of automation which can be evaluated would draw benefit if guidance could be provided. There are many different aspects to consider, for example: Is a high level of automation always preferable in time critical situations? Is there an upper bound on the level of automation? What will the the consequences be if automation is introduced? Is there a higher need for feedback when automation level is high? These factors need to be considered, weighed and made trade-offs between. If it is possible to identify if there exist relationships between the characteristics of the task, the situation, the system and the operator, this guidance could be used to choose proper level of automation.

This paper attempts to evaluate if there are any relationships between a certain level of automation, the task characteristics, the operator's mental workload and possible human errors, as well as understanding which factors guide the proper level of automation.

There is a large span between full automation and no automation at all. It can vary across a continuum of levels [3] and since automation can exist to different extents in a system, the operator and the automated system need to work together to manage both normal and critical situations. Therefore, automation can be considered as a participating agent in the teamwork in a nuclear power plant control room. This issue has been described as extended teamwork. Evaluation of the collaboration between the automated agent and the human agent clearly affects the human performance and therefore need special attention. At Halden reactor programme in Norway, researchers have developed a questionnaire which could be included in the evaluative part of the automation design process [5].

Additionally, standards and design guidelines recommend designers to allocate functions properly. The question is how this is achieved? Parasuraman et al. [3] imply that the chosen levels of automation should be evaluated by application of primary and secondary evaluative criteria, but how should the evaluation be performed? Do reliable methods exist that are applicable for these types of evaluations?

This paper addresses the need to identify guidelines to make the choice of proper level of automation easier in system design. The study is part of a large ongoing research project at Chalmers University of Technology, Göteborg, Sweden, in the area of control room design from the operator's perspective. The aim of the large research project is to develop design criteria and principles for evaluation of control- and alarm systems when new technology will be implemented in legacy systems.

2. PURPOSE AND AIM

The purpose of the present study was to find tools for selection of appropriate levels of automation considering the human operators needs and limitations in different work situations.

The first aim of the study was to test how different evaluation methods can be used and combined in the automation design process. The second aim was to find differences between automatic and manual operations that have an effect on operator performance. The results should contribute to the methodology, proposed by Parasuraman et al. [3] for choosing level of automation in control rooms.

3. METHODS

The nuclear power plant control rooms included in the study were hybrid control rooms at Ringhals Power Plant in Sweden, unit 3 and 4. These two units are so called twin units with almost identical instrumentation and controls. Therefore, the results from the two units will not be treated separately. The test subjects in the study were eight turbine operators. Two of these operators were under training and worked together with a more experienced operator. The methods were put together in a questionnaire with a rating scale from 1-10 and presented to the test subjects in the control room during shift hours.

The chosen work situations in the control room were: (1) Switch of feed water pumps and (2) House-load operation. To simplify the analysis, House-load operation was divided into three sub-situations, according to the human information processing model (information acquisition – information analysis – decision making & action selection – action implementation) [3]. The work situations are presented in Figure 1. Identification is connected to information acquisition, Supervision to information analysis and decision making and Synchronization to action implementation. Shift of feed water pumps is treated as a homogenous situation and can be related to action implementation in the information processing model.

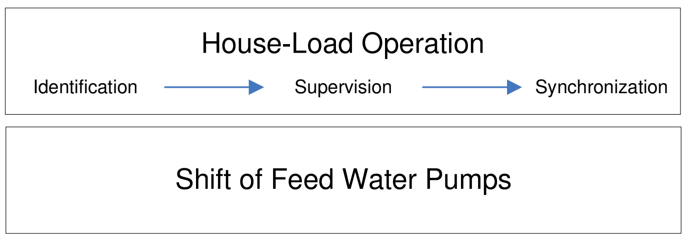


Figure 1. The two studied situations and the division of house-load operation into sub-situations.

The two work situations were chosen in discussion with experts from the reference group of the large research project. The motivation for the selection of these situations was that they are related to the secondary side of the control room (turbine operation). This makes the results more applicable and representative for other plants, since the primary side (reactor operation) is more specific for each plant. Further, the two tasks are different in character, the first situation is characterised by planning of task, performance of actions, intervention with the controls and assessment of the effects of the actions taken. The second situation involves identification and diagnosis of a disturbance and the use of checklists to assess and ensure a safe plant status. The operations and actions included in each situation were described by a hierarchical task analysis diagram (HTA). The task analysis methodology is used to describe goals, contents, context and structure of a task, especially used for operators' handling of information in complex systems [4].

Several methods within the area of human factors engineering were studied and evaluated, and a combination of useful methods was chosen to be included in the empirical studies. The chosen methods were Predictive Human Error Analysis (PHEA), NASA-Task Load Index, The Halden Questionnaire and Human Error Assessment and Reduction Technique (HEART). Figure 2 shows a simplified model of interaction between the operator and the system [2] together with the chosen methods. The purpose for the choice of methods was that they intend to give information on different aspects of the interaction.

NASA-Task Load Index is a multi-dimensional rating procedure that derives an overall workload score based on a weighted average of ratings on six subscales [1]. It allows users to perform subjective workload assessments on operators' work with various human-machine systems. In this study the different ratings were treated separately and no overall workload score was calculated. The operators made subjective ratings of four different dimensions of workload; mental demand, temporal demand, frustration and effort. Two dimensions (physical demand and performance) were left out from the original method while the pilot study showed lack of relevance in the studied situations. The four workload dimensions used in the study were of interest when comparing automated and manual procedure, since they gave a picture of cognitive aspects regarding the operator.

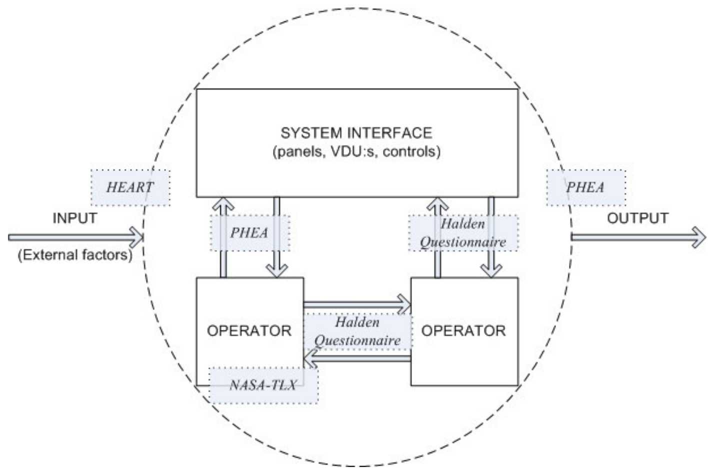


Figure 2. The methods used and their intended focus in the operator-system interaction.

To study the collaboration between the operators and the automatic functions of the system, a questionnaire was used, developed by researchers at the Institute for Energy Technology in Halden, Norway [5]. The questionnaire uses six questions related to relation, quantity, manner and quality of information exchange.

The two human reliability analysis methods, HEART and PHEA, were used to identify types of human errors that might occur and the probability of these errors [4]. The methods were used to evaluate risks connected to different tasks in the studied work situations. In PHEA the risk is calculated as the estimated probability for a certain error multiplied by the estimated consequence of the error. A number of different error types are used to categorize possible errors, for example "action omitted" or "right check on wrong object". The operator makes subjective estimations of the probability of action occurrence and its eventual consequence. For errors with risk estimation clearly above other errors in the same task, the risk and consequence has been evaluated individually and the cause has been clarified. In HEART a number of 'perfomance influencing factors' relevant to the situations are chosen. In this study the operators made estimations of the importance of these factors to see if differences between low and high level of automation could be observed.

4. RESULTS

4.1 PHEA

The PHEA results show that the situations of interest can be analyzed in detail and events where the operator might need support can be identified. Table 1 presents all error types used in the study and the types that were given high estimations in at least one task.

Identification and Supervision of House-load operation

The estimations connected to identification of House-load operation show a wide distribution of the answers, but the medians are low. The 'correct check on wrong trend curve' (trend curves for the wrong turbine are displayed) during Supervision of House-load operation was one of the tasks given a much higher risk estimation than other tasks. This relates to a high estimation of the consequence of reading the wrong trend curve. The probability of wrong checking was given low estimations.

All three errors linked to 'estimation of time to critical point' gave indications of high risk. The three errors were 'estimation omitted', 'wrong estimation – you believe you have plenty of time' and 'wrong estimation – you think you have lack of time´. They were all given high estimations for consequence and low to medium estimations for probability.

Table 1. PHEA Error Types with high operator estimations.

Error Types	High operator estimations	Error Types	High operator estimations
Actions		**Retrieval**	
Action mistimed		Information not obtained	X
Right action on wrong object		Wrong information obtained	X
Action omitted		Information retrieval incomplete	X
Action incomplete		Estimation omitted	X
Wrong action on wrong object		Wrong estimation – plenty of time	X
Checking		Wrong estimation – lack of time	X
Checking omitted	X	**Selection**	
Checking incomplete	X	Wrong selection	X
Right check on wrong object	X	Selection omitted	X
Wrong check on right object	X	**Communication**	
Wrong check on wrong object	X	Message not received	X
		Message transmission incomplete	X

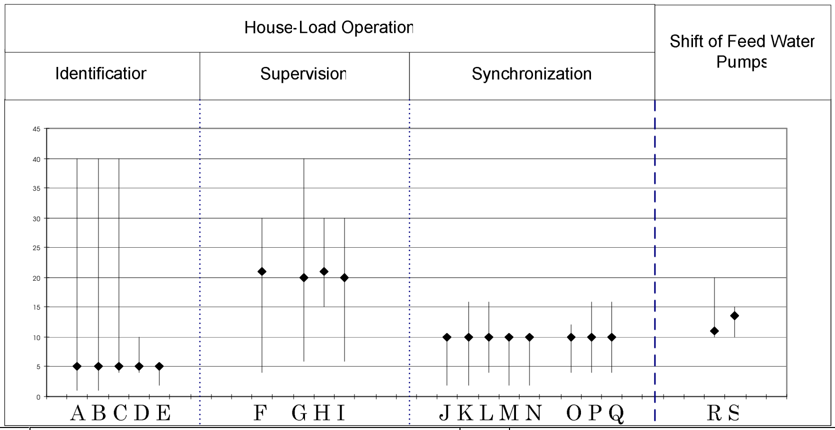
Synchronization after House-load operation

During Synchronization after House-load operation the task 'Check alarms' was given a higher risk compared to other actions during Synchronization. The probability of occurrence was given low estimations and the consequence of the error high estimations.

Shift of feed water pumps

During Shift of feed water pumps there was one task where the risk lies above the other actions; in the task 'selection of pumps in operation' the errors 'selection omitted' and 'wrong selection' was given medium level estimations for both probability and consequence.

For PHEA in general, the largest contribution to risk comes from high estimation of consequences of erroneous actions, while the probability for erroneous actions is estimated as low. Figure 3 presents a graphical view of the tasks with the highest estimations in each sub-situation and the errors connected to them.



A,O	Information not obtained	I	Wrong estimation – lack of time
B,P	Wrong information obtained	J	Checking omitted
C,Q	Information retrieval incomplete	K	Checking incomplete
D	Message not received	L	Right check on wrong object
E	Message transmission incomplete	M	Wrong check on right object
F	Right check on wrong object	N	Wrong check on wrong object
G	Estimation omitted	R	Wrong selection
H	Wrong estimation – plenty of time	S	Selection omitted

Figure 3. The diagram shows the highest estimations of risk, calculated as probability x consequence, in the different sub-situations. The table presents the error types connected to the estimations from PHEA.

4.2 NASA-Task Load Index

The NASA-TLX results show that inexperienced operators make higher estimations of their work load in all four categories (mental demand, time pressure, effort, and frustration) compared to experienced operators. The largest difference can be seen in effort and frustration. The highest estimations of mental demand are found in 'Supervision' and 'Synchronization' during House-load operation. Both 'Identification' and 'Shift of feed water pumps' show medium estimations of mental demand on the grading scale from 1-10. During 'Shift of feed water pumps' time pressure and effort show a low value.

4.3 Halden Questionnaire

The Halden Questionnaire showed no differences between the two examined situations. The estimations of operator-automation cooperation were all given high estimations indicating that the cooperation works well. No differences could be seen between House-load operation and Shift of feed water pumps nor between experienced and inexperienced operators.

4.4 HEART

The estimated importance of different factors in HEART shows little or no distinction. The estimations of importance of factors influencing the risk of erroneous actions show a wide distribution across the whole scale. The medians are high, which indicate that the evaluated factors are important. There is no difference of the estimations between the three sub-situations within House-load operation, while the estimations are slightly lower for Shift of feed water pumps.

5. DISCUSSION

The first aim of the study was to test how different evaluation methods can be used and combined in the automation design process. The results show that the methods PHEA and NASA-TLX gave results that were separable and therefore most useful in the study. They are therefore recommended to use - at least in the evaluation stages. Halden questionnaire and HEART did not give results that could be distinguishable between the situations and thus it is difficult to tell whether they are useful or not.

The second aim was to find differences between automatic and manual operations that have an effect on operator performance. The results showed that factors such as time pressure and criticality of the work situation influenced the operator's estimations of performance and mental workload more than differences in level of automation.

To find a connection between automation level and different types of errors (e. g. if a certain type of human error is more common with a particular level of automation), the error types from PHEA were grouped together and a comparison between Synchronization and Shift of feed water pumps was made. Synchronization and Shift of feed water pumps were chosen because of the difficulty of making a comparison with Identification and Supervision of House-load operation included. The separation was needed because the sub-situations do not lie in the same class of function as Synchronization and Shift of feed water pumps, which falls within action execution. Synchronization and Shift of feed water pumps are both executed manually but differ while Synchronization is induced by an automatic course of events. The comparison did not show any differences in the estimations that could be connected to automation. The lack of differences indicates either that estimations of human error and risk is not a relevant factor in this context, or that the examined situations can not be compared to clarify automation inflicted differences.

The results showed a lower level of mental workload and time pressure for shift of feed water pumps, although this situation includes more manual actions. A direct interpretation of the NASA-TLX results would imply that automation creates high mental workload and temporal demand to the operator but this is not a plausible conclusion. Instead it is evident that the criticality and time pressure, that also characterizes and differs between the situations, influences the results to a considerable extent. The NASA-TLX method gave results that are possible to evaluate, but again the differences between the studied situations makes it difficult to draw conclusions about what influence the level of automation might have.

The estimations of operator-automation cooperation in the Halden questionnaire were all given high estimations indicating well functioning cooperation in both situations, despite the different character of the situations. This indicates either that the level of automation does not influence cooperation or that other factors that affects the operator in a more direct way (such as interface design and usability) overshadows the effect of different levels of automation.

The HEART results are similar to the Halden questionnaire results with high estimations of factor importance in the studied situations. No conclusions could be made regarding if any factor is more important in a situation with high or low level of automation.

The results obtained in this study showed large spread which probably can be explained with the influence of factors connected to persona of the operator. To reduce the effect of individual characteristics, more test subjects would be beneficial.

Another challenge is the difficulty of getting the test persons to make the estimations from the same starting point. This was confirmed by the questions from the test persons regarding how to interpret the questionnaire. Naturally a given situation will be perceived in different ways depending on surrounding circumstances such as parallel system deviations. This is probably one of the causes of the large spread in the estimations visible in the results. A more extensive introduction to the situations and presentation of a given scenario will most likely reduce this problem. Evidently a simulator based test is preferable to avoid as much personal bias as possible from the operator.

In summary the subjective evaluation methods gave answers about the operator-task relation but it proved difficult to draw conclusions about the influence of the automatic system on operator performance. The reason to this is probably found in the comparability of the studied situations. The situations need to be more similar to achieve a better comparison. A possible alternative is to study the Turbomat system at Ringhals, unit 3 and 4. This system involves a variety of different subsystems that can be started automatically through the Turbomat, or manually by following a start up sequence. This would create a more favourable starting point for good comparability. Another explanation to the difficulties is that the used methods do not bridge the gap between task and automation; they only cover the operator-task relationship and in this aspect they are useful. More research is needed to see if the relation operator-automation, with the task as an intermediate, can be analyzed with human factors methods or if another angle of approach is needed.

6. CONCLUSIONS

The following conclusions could be drawn from the results of the study:

- The examined work situations need to be more similar to reach a better comparison between automatic sequences and manual execution.
- To draw conclusions and generalize these conclusions into automation level guidelines was difficult since the factors time pressure and criticality did impact the estimations and overshadowed eventual effects caused by automation levels.
- PHEA and NASA-TLX proved useful in a methodological perspective – but they did not provide the expected outputs for choice of levels of automation.

7. FURTHER RESEARCH

More suitable situations should be chosen for evaluation to cover the lack of usable relations connected to levels of automation. A possible alternative is the Turbomat system. More research is also needed to see if the relation operator-automation would benefit from another angle of approach than taken in this study.

8. REFERENCES

[1] S.G. Hart and L.E. Staveland, "Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research", In P.A. Hancock & N. Meshkati (Eds.), *Human Mental Workload*, Amsterdam: North Holland Press, 1988.

[2] A. Jönsson and A-L. Osvalder, "Development of a Theoretical Cognitive Model of the Nuclear Power Plant Operator´s Information Process", Proceedings of the Man-Technology-Organisation Sessions, HPR-365, Vol. 2, Enlarged Halden Programme Meeting, Lillehammer, Norway. Oct. 16-21, 2005.

[3] R. Parasuraman, T.B. Sheridan and C.D. Wickens, "A Model for Types and Levels of Human Interaction with Automation" IEEE Transactions on Systems, Man and Cybernetics – Part A: Systems and Humans, vol. 30, no. 3, p. 286-297, 2000.

[4] C. Sandom and R.S. Harvey, *Human Factors for Engineers*, T he Institution of Electrical Engineers, Hart, 2004.

[5] A.B.M. Skjerve and G. Jr. Skraaning, "The quality of human-automation cooperation in human-system interface for nuclear power plants", International Journal of Human Computer Studies, no.61, p. 649-677, 2004.

Appendix C

Literature Study – Types and levels of automation and function allocation (in Swedish)

Litteraturstudie: Automationsgrad & funktionsallokering

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Introduktion

Som en del i NKS projektet har en litteraturstudie utförts. Syftet med denna studie var att undersöka vilka åsikter och tankar om automation som redan finns publicerat av forskare. Studien utgick från några begrepp; automation och automationsnivåer, automationstyper. Dessa begrepp valdes eftersom de hade framkommit tidigt under projektet och ansågs därför vara grundläggande och centrala. Automationsnivåer kan ses som en skala på hur mycket av kontrollen över uppgiften som finns hos operatören respektive hos maskinen/systemet. Automationstyper kan ses som olika sätt att dela in automation i, t.ex uppdelning efter vilken typ av uppgift som ska utföras eller uppdelning efter hur viktig uppgiften är.

Som beräknat så vidgades området allt efter som mer litteratur studerades. Detta ledde till att området funktionsallokering (eng. function allocation) valdes att studeras. Tyvärr hittades få artiklar om just detta. Det som framkom av studien om funktionsallokering bakades ihop med resten av litteraturstudien, vilket passar bra då funktionsallokering är starkt kopplat till automation.

I denna litteraturstudie har många artiklar lästs men till denna sammanställning används bara fyra referenser. Detta beror bland annat på att vissa artiklar visade sig vara ointressanta för denna studie. En av de främsta anledningarna är dock att av de intressanta artiklarna var de flesta skrivna av R. Parasuraman. I denna sammanställning används två artiklar som han har varit med och skrivit.

Sammanställning av litteraturstudie

Parasuraman och Riley (1997) definierade automation på följande sätt ”Exekvering av en funktion som utförs av en maskin (oftast en dator) och som tidigare utfördes av en mänsklig operatör”. Tre år senare kom Parasuraman et al. (2000) men en förlängd version av definitionen, nämligen ”en apparat eller system som fullbordar (delvis eller fullt) en funktion som tidigare utfördes, eller kunde ha utförts (delvis eller fullt) av en mänsklig operatör”. Definitionen innebär att automation inte bara behöver existera eller inte existera, utan att alla möjliga nivåer av automation som finns mellan min och max är tänkbara (Parasuraman et al., 2000).

Det finns många tankar kring vad som ska automatiseras. Parasuraman et al. (2000) gör följande uppdelning:

- Operatörens roll och ansvarsområden bestäms av automationen. Det som designern inte kan automatisera får operatören ha hand om.
- Det maskinerna gör bäst får de göra medan operatören utför de uppgifter som operatören gör bäst. (Fitts MABA-MABA Lista, se bilaga)

Idag anses Fitts Lista vara den bästa regeln när det gäller funktionsallokering och automationsfördelning, åtminstone är den vanligtvis accepterad som en del av mytologin (Sheridan, 2000). Sheridan (2000) säger även att det finns två punkter där människan är bättre än maskinen, och de är:

- Bestämma objektiva funktioner (mål, vad som är bra och dåligt, osv.)
- Använda kreativitet vid rätt tid och tillfälle

Parasuraman och Riley (1997) beskriver fyra olika sätt som automation kan användas på:
Use – frivillig aktivering eller frikoppling av automationen utfört av mänskliga operatörer
Misuse – övertillit på automation
Disuse – försummelse eller underanvändning av automation
Abuse – designers och chefer automatiserar funktioner utan att ta hänsyn till de konsekvenser det får för den mänskliga prestationen.

”Abuse of automation” kan leda till så kostsamma problem att de kan reducera eller nollställa de fördelar (t.ex. ekonomiska) som automationen kan leda till (Parasuraman & Riley, 1997).

Parasuraman et al. (2000) har delat upp automationen i olika typer. Dessa typer är Acqusition Automation, Analysis Automation, Decision Automation och Action Automation. Dessa beskrivs mer utförligt senare. Parasuraman et al. (2000) har även gjort en sammanställning av automationsnivåer. Denna sammanställning finns som bilaga. När det hänvisas till automationsnivåer i denna text är det dessa som avses.

För att kunna avgöra vad som bör automatiseras i ett system kan designern använda en modell som dels urskiljer de olika automationstyperna och nivåerna, dels tillämpas utvärderingskriterier (Parasuraman et al., 2000). Denna modell ska inte blandas ihop med mentala modeller.

Genom att strukturera det intelligenta systemets kunskapsbas runt en modell över operatörens aktiviteter blir det enklare för den operatör som är ansvarig för övervakning och guidning av systemet. Detta beror på att operatören har en bättre förståelse för vilka aktiviteter systemet utför och varför, då de är baserat på hur operatören själv skulle ha genomfört dem (Brann et al., 1996).

Designern och operatören utgår oftast inte från samma mentala modell, vilket kan leda till att lösningen (automationen) inte är lämplig för en specifik driftsituation (Parasuraman et al., 2000). Förståelse om hur automation används av operatörer kan hjälpa designers att producera bättre automatiserade system som operatören kommer att tycka är användbart. Dessutom visar studier av hur operatörerna använder automation på stora individuella skillnader (Parasuraman & Riley, 1997). Sheridan (2000) skriver att för att klara av nya situationen, dvs. införande av automation måste gamla mentala modeller ändras. Både designerns och operatörens mentala modeller måste ändras.

Det är ofta skillnad i hur en designer och en Människa-Maskin ingenjör ser på hur säker automationen kan göras. Enligt Brann et al. (1996) antar designern att mjukvaran i automationen inte kommer att fela om den debuggas, valideras och verifieras på rätt sätt. Människa-Maskin ingenjörer hävdar å andra sidan att det är omöjligt att garantera att mjukvaran inte kommer att fela då man har att göra med dynamiska och invecklade komplexa system. Människa-Maskin ingenjören skulle hävda att det är både praktiskt och teoretiskt omöjligt att garantera ett helt felsäkert system.

Enligt Parasuraman et al. (2000) är valet av automationstyper och nivåer viktigt eftersom det inte endast ersätter den mänskliga aktiviteten utan även ändrar den och på så sätt skapar nya krav på den mänskliga operatören. Brann et al. (1996) håller med om detta och säger att automationen inte alltid leder till att minska antalet uppgifter utan bara till nya uppgifter för operatören. Introduktionen av automationsteknologi och automationskontroll kan minska antal operatörer som behövs, men den kunskapsnivå som måste finnas hos de operatörer som är kvar måste öka om systemet ska vara fortsatt produktivt (Brann et al., 1996). Parasuraman och Riley (1997) skriver att automatisering inte ersätter den mänskliga aktiviteten utan ändrar den bara. Dessa ändringar är oftast något som designern inte är medveten om eller kunde ha förutsett.

Varje enskild automationsnivå bör utvärderas genom att studera de associerade konsekvenserna på den mänskliga prestationen. Det är dessa konsekvenser som blir de primära utvärderingskriterierna för att se hur välanpassad automationen är. Det är viktigt att designa automation på ett sådant sätt att den mänskliga prestationen inte påverkas negativt av ”reduced Sitauation Awareness, complacency & skill degradation”. Dessa tre faktorer kan vara ett hot mot säkerheten i fall ett systemfel skulle inträffa (Parasuraman et al., 2000). Enligt Parasuraman och Riley (1997) är tekniska och ekonomiska faktorer giltiga anledningar till att automatisera system. Men det gäller bara om den mänskliga prestationen inte påverkas negativt i det slutliga systemet.

Automation kan öka den mentala arbetsbelastningen. Ofta beroende på att automationen är svår att inleda och underhålla, vilket leder till ökad kognitiv arbetsbelastning. Om en stor mängd indata behövs ökar även den fysiska arbetsbelastningen (Parasuraman et al., 2000). Parasuraman och Riley (1997) upptäckte i sin studie att många piloter upplevde att automationen ökade deras arbetsbelastning precis när de hade som högst arbetsbelastning, vilket var under upp- och nedstigning. Detta berodde på att piloterna inte ansåg att automationen utförde uppgiften på rätt sätt.

Sheridan (2000) menar att det är lätt att tro att datorn måste lösa hela uppgiften istället för bara delar av den. Han menar även att det är fel att tro att en automationsnivå skulle passa för hela uppgiften och att den bästa lämpade automationen för en viss uppgift/funktion förändras med tiden.

Enligt Parasuraman och Riley (1997) är det hittills inte bevisat att det finns något samband mellan uppgiftens svårighet och operatörens användning av automation, med andra ord så är det inte alltid så att operatören använder automation för att lösa en svår uppgift trots att det antagligen skulle minska operatörens mentala arbetsbelastning. Operatören kan utföra uppgiften då arbetsbelastningen är medelhög. Om arbetsbelastningen blir hög kan operatören låta automationen utföra uppgiften för att sedan återta kontrollen över uppgiften när arbetsbelastningen har minskat (Parasuraman & Riley, 1997).

Vissa automatiska system är designade på ett sådant vis att operatören inte får utrymme att praktisera de kunskaper som är involverade i att manuellt utföra den automatiserade uppgiften. Detta riskerar att leda till att operatören tappar kunskap om hur utförandet går till. Denna kunskapsminskning kan leda till ännu mer tilltro till automationen, vilket då bildar en ond cirkel (Parasuraman & Riley, 1997). Parasuraman et al. (2000) skriver att om beslutfattandet konstant ligger hos automationen kommer operatören tillslut inte längre vara skicklig på att utföra handlingen.

Det går inte att ta bort mänskliga fel från systemet genom att ta bort operatören. Att ta bort operatören kan däremot leda till att systemet blir ännu mer sårbart för fel gjorda av designern då fler subsystem är automatiserade. Ju fler subsystem som är automatiserade desto mer ökar risken för misslyckande i övervakningen. Man kan automatisera själva övervakningsuppgiften för att försöka minska antalet övervakningsfel, detta leder dock till att nya automatiska system måste övervakas av operatören (dvs. de system som utför ursprungsövervakningen) (Parasuraman & Riley, 1997).

Oftast designas automationen baserat på antagandet att mänskligt ingripande är sällsynt (om det någonsin egentligen behövs) och därför tas lite hänsyn till gränssnittet mellan operatör och automation. Interaktionen mellan operatör och automationen har en kritisk påverkan på huruvida ett sofistikerat autonomt kontrollsystem blir lyckat (Brann et al., 1996).

Enligt Parasuraman et al. (2000) har det visat sig att datatransformation (ex grafisk representation) har minskat den mentala arbetsbelastningen hos operatörer. Men de skriver även att ”Automated cueing (attention guidance)” kan leda till att operatören inte är tillräckligt uppmärksam på de delar som inte innefattas av ledtrådarna. Genom att göra de indikatorer som visar automationens tillstånd mer tydliga kan övervakningen av systemen bli bättre. Tydlighet och återkoppling är särskilt viktigt för automation som är designad för att ha relativt höga autonominivåer (Parasuraman & Riley, 1997).

Parasuraman och Riley (1997) menar att ”Adaptive task allocation” kan bidra till andra sätt att förtydliggöra automationens beteenden genom att fräscha upp operatörens minne när det gäller den automatiserade uppgiften. Man bör se uppdelningen av uppgifter mellan operatörer och maskiner som flexibel och anpassa detta utefter hur operatören utför sitt arbete.

Visualiseringstekniker som tillåter en ”direkt” perception av systemets tillstånd kan också förbättra tydligheten om vilket tillstånd automationen är i. Detta skulle ge bättre återkoppling till operatören om vad automationen gör, vilket i sin tur kan minska överförtroendet till automationen (Parasuraman & Riley, 1997).

”Over-trust” eller ”Complacency” är som störst när operatören är engagerad i flera olika uppgifter och mindre tydlig när övervakningen av automatiserade systemet är operatörens enda uppgift. Complacency uppstår när operatören litar på ett system som inte är helt pålitligt (Parasuraman et al., 2000). Operatörer kan vara dåliga på att övervaka automation om de ska utföra andra manuella uppgifter samtidigt (Parasuraman & Riley, 1997).

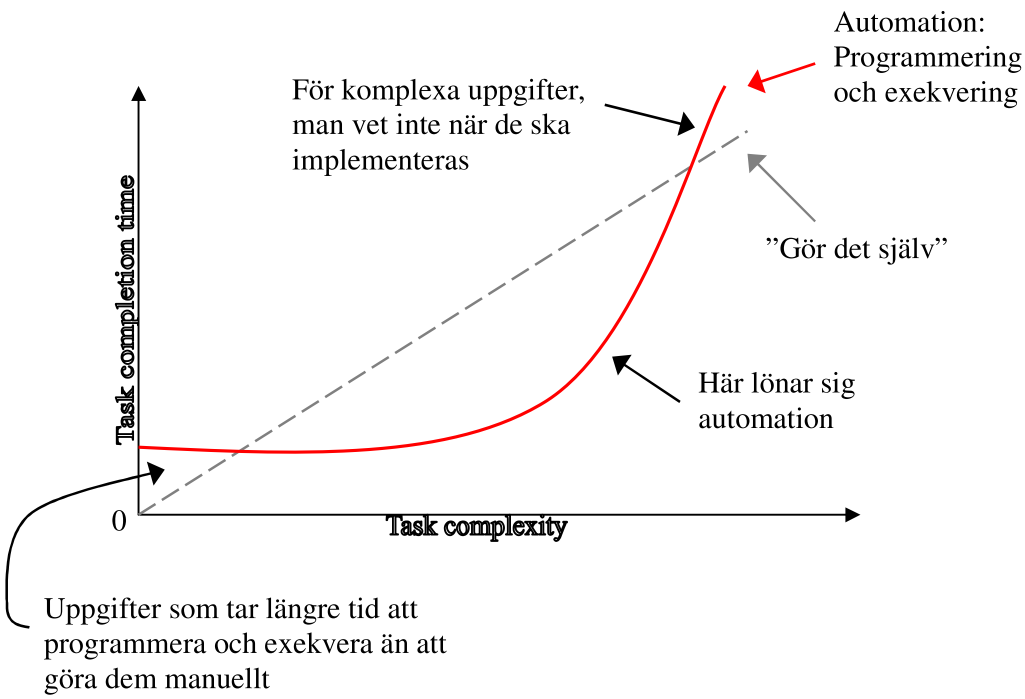
De fördelar som automationen har på operatörens mentala arbetsbelastning och situation awareness räcker inte till om automationen är opålitlig. Är inte automationen pålitlig finns det risk för att operatören har övertro på systemet. Därför är försäkran på hög pålitlighet ett kritiskt utvärderingskriterium för att se huruvida automationen är bra anpassad för organisationen (Parasuraman & Riley, 1997).

Opålitlighet sänker operatörens tilltro på systemet och kan därför leda till de eventuella fördelarna på systemets prestanda undermineras. Dessutom är det förtroendet för systemet som oftast avgör hur automationen används (Parasuraman & Riley, 1997). Operatörer väljer manuell kontroll om deras självförtroende på deras egen förmåga när det gäller att kontrollera processen överskrider deras tro på automationen. Annars väljer de automation (Parasuraman & Riley, 1997).

Det är viktigt att hitta den rätta balansen mellan för mycket och för lite när det gäller operatörens tilltro till systemet (Sheridan, 2000). Övertro på systemet kan leda till olyckor som uppstår på grund av brist i övervakandet. Övertro på automatiserade lösningar kan också leda till minskad Situation Awareness. Operatören kan ibland tycka illa om eller inte lita på ett nytt automatiserat system. Automation som är pålitligt kommer att få operatörernas tilltro när de har fått erfarenhet av att använda det (Parasuraman & Riley, 1997).

Sheridan (2000) illustrerar med en graf när det lönar sig att använda automation. Bilden nedan visar denna graf tillsammans med några kommentarer. Den streckade linjen mitt i grafen representerar hur tiden av utförandet av en uppgift varierar beroende på uppgiftens komplexitet om operatören skulle utföra uppgiften själv. Den andra linjen representerar hur utförandet varierar när automationen ska utföra uppgiften (dvs. den tid det tar för programmering och exekvering).

För uppgifter som är enkla och som går snabbt att utföra lönar det sig att göra dem manuellt. Det tar längre tid att programmera exekvera uppgiften i det automatiserade systemet än om operatören skulle utföra uppgiften manuellt. Uppgifter som är väldigt komplexa kan vara svåra att programmera och det kan vara svårt att förutse när de ska implementeras och exekveras. Därför går det oftast snabbare att utföra även dessa uppgifter manuellt. De uppgifter som inte tillhör någon av de två tidigare beskriva grupperna kan med fördel automatiseras enligt Sheridan (2000).



Figur 1. "Advantages of automation for tasks of intermediate complexity"

Enligt Parasuraman et al. (2000) finns det fyra funktionsklasser där automation kan appliceras:

- Information acqusistion
- Information analysis
- Decision and action selection
- Action implemantation

Inom varje klass kan hela spannet från låg till hög automationsnivå finnas, dvs. från helt manuellt till helt automatiskt. Vad som innefattas i de olika klasserna förklaras nedan.

Acqusition Automation:
– Uppfatta och registrera indata

Låg nivå: Bland annat strategier för att mekaniskt flytta sensorer för att skanna och observera. (t.ex. radar som skannar i ett bestämt mönster)
Medel nivå: T.ex. organisering av inkommande information utefter vissa kriterier och "highlighta" delar av informationen. (t.ex. prioriteringslistor)
Hög nivå: Filtrering av information där vissa delar väljs ut och visas för operatörer.

Analysis Automation:
– Involverar kognitiva funktioner så som arbetsminne och slutna processer

Låg nivå: algoritmer som förutspår framtiden baserat på det indata den får. (t.ex. trender som visas i kontrollrummet)
Medel nivå: flera inputvariabler kombineras till ett värde

Hög nivå: ”Information managers” som summerar/sammanfattar data som sedan presenteras för operatören. Data sammanfattas ”context-dependent”, dvs. beroende av den kontext som den tillhör eller presenteras i.

Decision Automation:
– Val bland olika beslutsalternativ. Automationen i detta skede innebär varierande nivåer av utvidgning eller ersättande av ”human selection of decision” genom att låta maskinen ta besluten.

De olika nivåerna motsvarar tabellen Levels of automation of decision and action selection, se bilaga.

Action Automation:
– Exekvering av den valda händelsen (action)

Automation i denna fas involverar olika nivåer av maskinexekvering beroende på den valda händelsen. Vanligtvis ersätts människans hand och röst. De olika nivåerna motsvarar den relativa mängd manuella vs. automatiska aktiviteter under genomförandet.

Information acquisition och Analysis automation kan fungera bra på en hög automationsnivå så länge operatören har tillgång till rådata (dvs. highlightning men inte filtrering) och operatören är uppmärksam på osäkerhetsnivån. Är operatören uppmärksam på detta kommer han att se till att ha viss uppmärksamhet riktad på originalinformationen. Med andra ord så är det möjligt att nå relativt höga automationsnivåer så länge operatören har tillgång till rådata och är medveten om systemets opålitlighet (Parasuraman et al., 2000).

Beslut som har relativt liten risk gör sannolikt ingen större skada. Det är därför oftast bättre att låta dessa beslut tas automatiskt. Skulle operatören vara tvungen att ta alla dessa relativt enkla beslut finns det risk för att operatören blir så överbelastad att det hindrar honom från att utföra viktigare handlingar (Parasuraman et al., 2000).

Enligt Sheridan (2000) ska dynamiska uppgifter automatiseras med dynamisk automation. Om expertsystem eller liknande väljer och exekverar beslut i en dynamisk miljö finns det risk för att operatören inte kan upprätthålla en bra överblick över systemet och informationskällorna. Detta eftersom operatören inte är aktiv utvärderingen av informationen som leder till beslut. (Parasuraman et al., 2000)

En hög automationsnivå kan vara berättigad för väl av beslut och för genomförande i system som är tidskritiska eftersom operatörens reaktionstid kan vara för långsam (Parasuraman et al., 2000). Men det är viktigt att tänka på att hög automationsnivå kräver lika hög återkopplingsnivå till operatören för att kompensera operatörens bristande involvering i utförandet (Parasuraman & Riley, 1997). Ett uttryck som beskriver att all kontroll över systemet ges till automationen (som då ersätter den mänskliga operatören) är ”Lights-out automation” (Brann et al., 1996).

Operatörer tenderar att vara mindre medvetna om ändringar i miljön eller i systemet om ändringarna utförs av någon annan (antingen annan operatör eller automation) än om operatören själv skulle ha utfört ändringen (Parasuraman et al., 2000). Om ett automatiserat system är svårt att modifiera eller utöka kommer operatörerna inte tycka att det är lätt att använda. När ansträngningen som krävs för att använda eller underhålla systemet är större än vad som krävs för att utföra uppgiften manuellt kommer systemet inte att användas (Brann et al., 1997).

Samtidigt som man är emot fel och varians i ett automatiskt system är det detta som gör att vi utvecklas och lär oss nya saker. Ett bra system bör därför tolerera en viss nivå av fel och varians (Sheridan, 2000).

Sheridan (2000) skriver även att det är dags att sluta jämföra människa och maskin och istället inse att de kompletterar varandra. Detta är den slutsats som gjorde störst intryck under litteraturstudien.

Referenser

Brann, D., C. Mitchell & D. Thurman (1996), *Human Interaction with Lights-out Automation: A Field Study*, Human Interaction with Complex Systems, HICS '96. Proceedings, Third Annual Symposium, 25-28 Aug. 1996, 276-283

Parasuraman, R., T. Sheridan & D. Wickens (2000), *A Model for Types and Levels of Human Interaction with Automation*, Transactions on systems, man, and cybernetics, vol. 30, no. 3, May 2000, 286-297

Parasuraman, R. & V. Riley (1997), *Humans and Automation: Use, Misuse, Disuse, Abuse*, Human Factors, 39(2), 230-253

Sheridan T.B., (2000), *Function allocation: algorithm, alchemy or apostasy?*, International Journal of Human-Computer Studies, vol. 52, no. 2, February 2000, 203-216(14)

Fitts List & Parasuramans Table

The Fitts MABA- MABA list:

Men Are Better At:

- Detecting small amounts of visual, auditory or chemical energy
- Receiving pattern of light or sound
- Improvising and using flexible procedures
- Storing information for long period of time, and recalling appropriate parts
- Reasoning inductively
- Exercising judgment

Machines Are Better At:

- Responding quickly to control signals
- Applying great force smoothly and precisely
- Storing information briefly, erasing it completely
- Reasoning deductively

Levels of automation of decision and action selection (Parasuraman et al., 2000)

High	10. The computer decides everything, acts autonomously, ignoring the human
	9. Informs the human only if it, the computer, decides to
	8. Informs the human only if asked, or
	7. executes automatically, then necessarily informs the human, and
	6. allows the human a restricted time to veto before automatic execution, or
	5. executes that suggestion if the human approves, or
	4. suggest one alternative
	3. narrows the selection down to a few, or
	2. the computer offers a complete set if decision/action alternatives, or
Low	1. the computer offers no assistance: human must take all decisions and actions.

Summary of Future Technology in Automation

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1 Introduction

Within a time perspective of 5-10 years the main activity will be upgrading present analogue control rooms (Generation II plants) with computer based presentations into hybrid control rooms (O'Hara, 2004). The power plants being built today (Generation III) will have computer based workstations instead of large control boards. There will also be visual display units (VDU) for monitoring safety systems and VDU for both control and monitoring of non-safety systems. Automation of predefined operating sequences will be available for the operator as well as alarm prioritization and filtering (O'Hara, 2004). In a longer perspective of thirty years or more the concept of advanced reactors (Generation IV) will most likely be a reality (O'Hara, 2004). It is difficult to say anything about what the Generation IV control rooms will look like but they will certainly be highly computerized and use further developed components from the Generation III power plants.

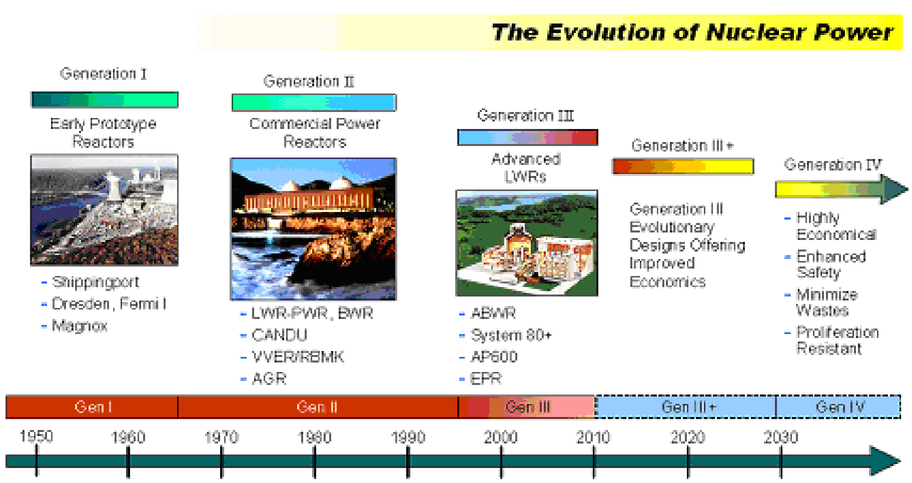


Fig 1. The Evolution of Nuclear Power (DoE, 2006)

2 Function Allocation

The question how to best optimize what functions the human and the machine should perform respectively is far from solved. It is important to understand that proper allocation of functions is constantly changing while human operators and technology are doing the same. The best allocation last year is not necessarily the best today (Sheridan, 2000). Parasuraman et al. (2000) presents a model for guidance when choosing types and levels of automation of human-machine systems. Another interesting issue is dynamic (automated) function allocation. This technique allows a system to change the distribution of tasks between the human operator and the automated system as the operational situation changes (O'Hara, 2004). This makes it possible for the operator to focus attention on the functions that are of most importance in situations that otherwise would cause high mental workload.

There is a clear trend in putting the human operator as supervisor of an automated system. The Halden research facility has made experiments where a single operator supervises more than one nuclear reactor in co-operation with automated agents and on-site technical personnel. The agents help the operator with operations and control of the turbines. These agents can be seen as virtual robots and are considered as team members in the organization. The expression "extended team work" is used to address the fact that components of the control system are actually seen as team members (IFE, 2006). The evaluation of the experiments is still ongoing but according to Ann-Britt Miberg Skjerve, scientist at the Halden facility, the results indicate reduced mental workload when using automated agents (Skjerve, 2006). The operators trust in the automated system is also increased and the overall human-automation co-operation is improved. Some drawbacks could also be noted. When the operator controls the reactors alone without any other human team member he or she feels vulnerable and experiences an increased level of stress compared to normal operating conditions. It also gets more difficult for the operator to maintain a good over all view of the situation when the number of operators is decreased. Another conclusion from the experiment was that to reach satisfactory human-automation co-operation with automated agents a lot of operator training will be necessary (Skjerve, 2006). In the future, automated agents will be able to provide support for online monitoring, fault detection, situation assessment, diagnosis, and response planning as sensor and computer technology becomes more advanced (O'Hara, 2004).

3 Transparency of an automation system's activity

A critical problem associated with use of automation is the difficulty for the operator to know what the automated system is doing. This makes it hard knowing if the system performs as planned (Skjerve et al., 2004). Skjerve et al. performed experiments at the Halden research facility to test if the quality of the human-automation co-operation increased when using an experimental interface adapted to increase the observability of the automated system. Verbal feedback was also used as a mean to deliver information about the automatic system's activity. The experiment was performed in a nuclear power plant simulator using experienced operators as test subjects. The experiments showed a higher quality in the human-automation co-operation when using the experimental user interface although it presented more information in a way that seemed very complex before the experiment. The operators found the information useful and did not get disturbed by the dense information presentation. The operators concentrated at one area of interest at a time and these areas individually were not perceived as complex. A higher rate of operator ability to detect critical plant occurrences was also observed, compared to the conventional interface. Indications that verbal feedback could be an efficient tool to provide information about automatic system activity were also found.

With new technology the complexity of power plants increases (O'Hara, 2004). This makes it more difficult for the operator to understand what the computerized system is doing. Operators can have a number of different roles to play as automation becomes more flexible. Historically, processes have been either manual or automated but as intermediate levels of automation are being implemented, better crew support for increased awareness can be achieved. This gives the operators a more informed starting point when handling process disturbances through a more transparent human-automation interface.

4 Automation of human pattern recognition

Within the Halden Aladdin project, tools to diagnose and analyse plant status has been developed. By using fuzzy logic and artificial neural networks it is possible to teach a computerized system to recognize plant status through a pattern of signals (Farbrot, 2006). Every unique situation that deviates from the normal operation has its own pattern of signals that is obtained by the diagnostic software. This technology is a way of automating the human pattern recognition in a control room and can be used to make the operator aware of certain situations that are difficult to detect. It also makes it possible to use situation adapted interfaces to present information that is important in a specific plant mode. A drawback is that it is not possible to use the technology for unknown deviances while the system needs to learn the pattern from a real or simulated situation.

Computerized tools for diagnosis and prognostics will give the system designers increased possibilities of using situation adapted presentations in future systems (O'Hara, 2004). With neural networks it is possible to learn a control system to recognize certain plant conditions with help from acquired power plant data. It is then possible to automate the graphical user interface and choose the information or a predefined GUI for a specific situation. It is also possible to simulate, test and predict how a system will react before an action is performed in the real plant. This affects the operators as they are forced to deal with the uncertainties in operation that follows with simulated predictions. Through this technology it will be possible to collect knowledge and experience from the industry as a whole to further improve the systems capabilities.

5 Computerized procedures

The use of computerized procedures in nuclear power plants, e.g., administrative, operating, emergency, monitoring, test and maintenance procedures will most likely increase as sensor input and control capabilities become more advanced. As the functionality expands, these procedures will more and more resemble complex automated systems, which stress the question of function allocation. The operator must also here be able to decide if the intended procedure is appropriate from a plant status point of view. A question that arises is whether the computerized procedures should only automate lower level functions such as data gathering or if they should also automatically evaluate procedure step decisions. A central function for computerized procedures is the ability to compare parameter values with set point values, but it is at the same time very important to reach sufficient reliability in the evaluation of the collected data.

Teamwork is considered to be an important topic when discussing future control room designs. The use of computer supported co-operative work can help minimizing accidents and events that can lead to accidents connected to teamwork flaws (O'Hara, 2004). Computer supported cooperative work refers to advanced information systems to provide information to help the team perform their work in the best way possible, and to the use of technology to support crew communication and coordination for advanced reactors. The technology is used to distribute knowledge and information among work groups, support how to conduct and coordinate work within a power plant, and principles for use of computer support tools to enable broad group communication (O'Hara, 2004).

6 Needs in future systems

To create well functioning human-automation co-operation it is of importance to first understand the concept of co-operation. Co-operation seems to require the existence of a common goal between the partners involved and that each partner contributes to assist in reaching the other partner's goal. It is also necessary to have some kind of communication to achieve planning and coordination to reach the common goals (Skjerve, 2004). These factors are all necessary to reach success in future automated systems. An important step to increase understanding of the human-automation problems is to stop seeing technology and people as independent components and that failure in either one of them is the cause for breakdown (Christoffersen & Woods, 2002).

Economic and safety goals will likely result in increased use of automation (O'Hara, 2004). How to determine an appropriate level of automation considering for example system and operator reliability, the cost of system failures, training et cetera is and will continue to be an important issue. Highly automated systems may take care of all actions unless the operator takes exception. To be effective the operator must have sufficient information to be able to make correct decisions about the appropriateness of the actions proposed by the automated system.

It is assumed that the development of the Generation IV (30+ years from now) plants will go even further with digital I&C and computerized control rooms (O'Hara, 2004). Load following technology is mentioned as one of the innovative near term functions that will be incorporated in future power plants. Load following will automatically change the power production in response to demand. This means more automation and that the function needs to be monitored by the operators to ensure safe operation.

The trend of digital communication in advanced reactors is that it will be more extensive and complicated than present reactors. As communication technology improves, greater fault tolerance will also be possible (O'Hara, 2004). Features such as automatic re-configuration and ability for the system to "heal itself" or taking equipment out of service will be possible. This means that the human operator somehow must be informed about the system's actions and questions about operator involvement and situation awareness arises when a manual corrective action must be performed.

7 Conclusions

As automation becomes more advanced, the need to understand human-automation interaction and co-operation increases. Though operators benefit from the technical development, it often means that the solving of tasks is being moved from the operator to the system designer. This is a problem or a possibility depending on a number of factors. In the future, automation will become more flexible and take new forms as human and system becomes more intertwined. Therefore human operators and automation systems must be seen as co-operating parts when developing new and well functioning solutions.

References

Bye, A., Hollnagel, E. & Brendeford, T.S., (1999) *Human-machine function allocation: a functional modelling approach* Reliability Engineering and System Safety 64, p. 291-300

Christoffersen, K. & Woods, D., (2002) *How to make automated systems team players* Advances in Human Performance and Cognitive Engineering Research, vol. 2, p.1-12

DoE (2006) U. S. Department of Energy, Office of Nuclear Energy. Picture downloaded from http://gen-iv.ne.doe.gov 2006-08-23

Farbrot, J. E. (2006) Interview at the Halden IFE facility in June 2006.

IFE, (2006) Kjernekraftindustrien-aktuelt.pdf. Downloaded from the OECD Halden Reactor Project website www.ife.no 2006-05-24

Hoc, J-M., (2000) *From human-machine interaction to human-machine cooperation* Ergonomics, vol. 43, p.833-843

O'Hara, J., Higgins J., Brown, W. & Fink R. (2004) Draft: *Human Performance Issues in Advanced Reactors* BNL Technical Report No: Y6646-T411/03, Rev. 3 Prepared for U.S. Nuclear Regulatory Commission

Parasuraman, R. & Riley, V., (1997) *Humans and Automation: Use, Misuse, Disuse, Abuse* Human Factors no.39 (2), p.230-253

Parasuraman, R., Sheridan, T.B. & Wickens, C.D., (2000) *A Model for Types and Levels of Human Interaction with Automation* IEEE Transactions on Systems, Man and Cybernetics – Part A: Systems and Humans, vol. 30, no. 3, p. 286-297

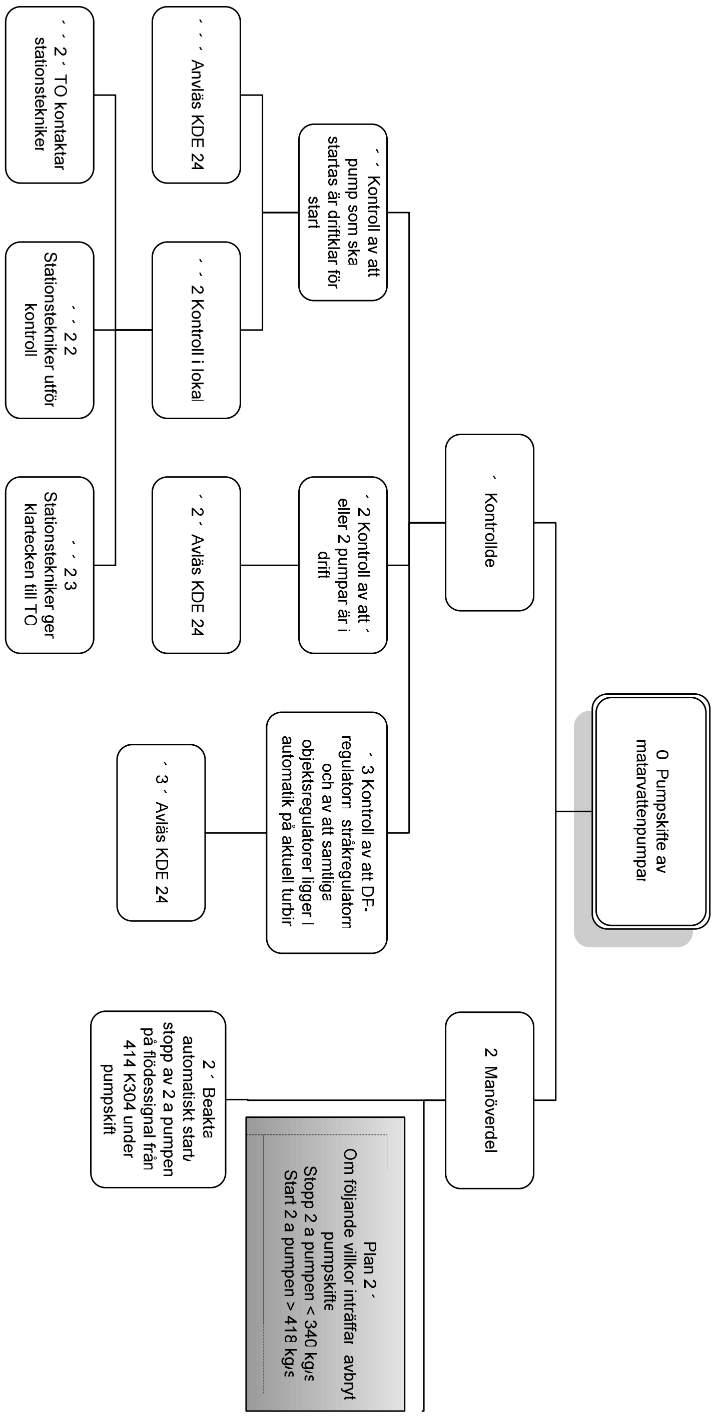
Sheridan, T.B. (2000) *Function Allocation: algorithm, alchemy or apostasy?* International Journal of Human Computer Studies, no.52, p.203-216

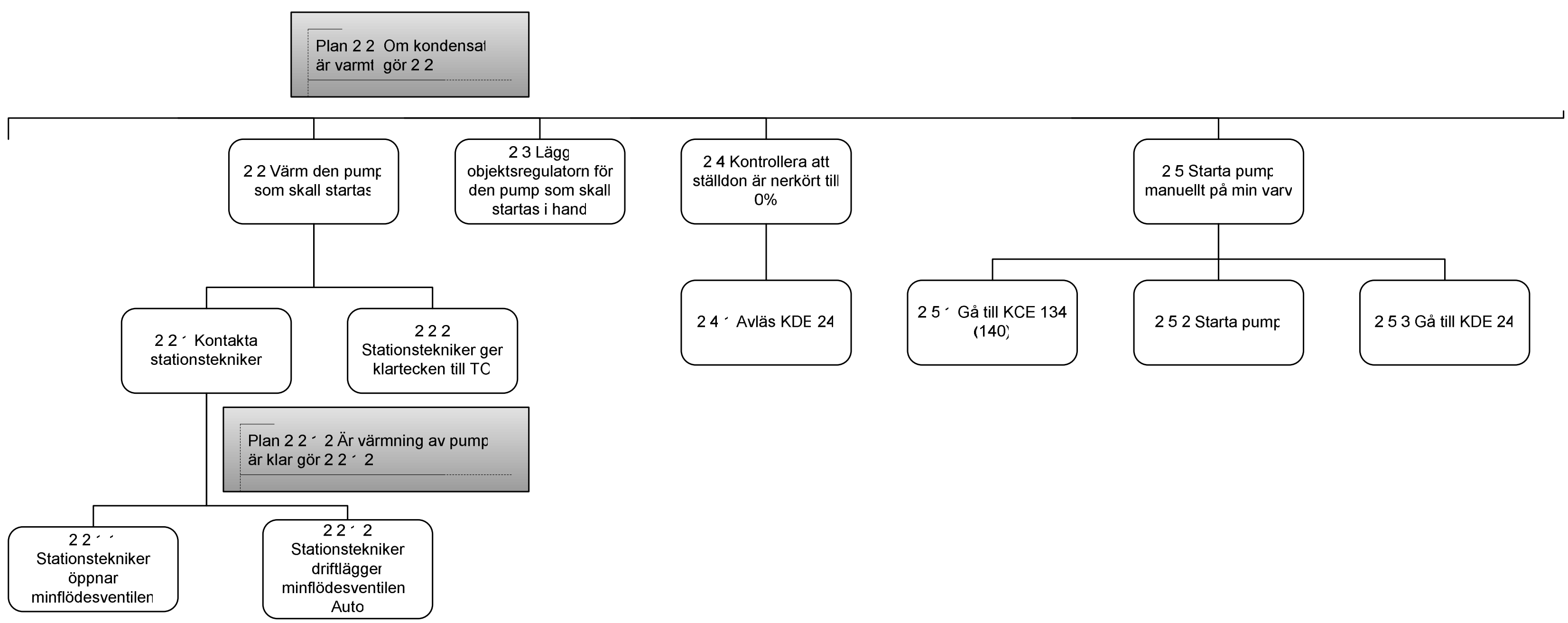
Skjerve, A.B.M. & Skraaning, G. Jr. (2004) *The quality of human-automation cooperation in human-system interface for nuclear power plants.* International Journal of Human Computer Studies, no.61, p. 649-677

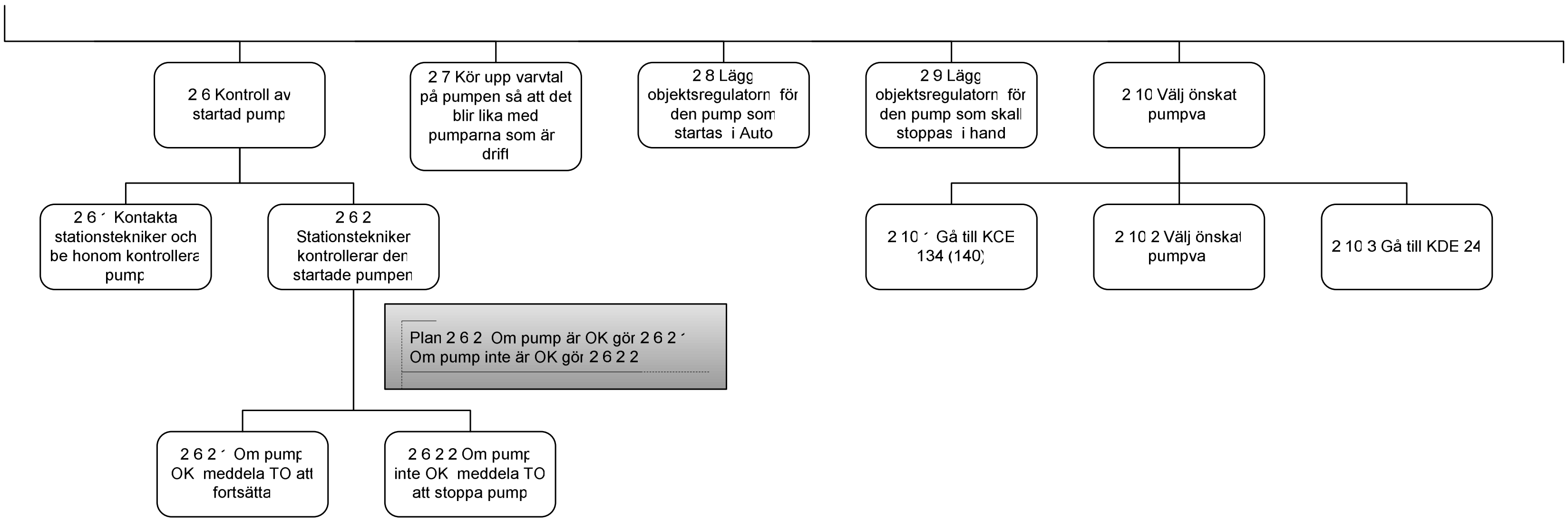
Skjerve, A.B.M. (2006) Interview at the Halden IFE facility in June 2006.

Appendix E HTA – Switch of feedwater pumps

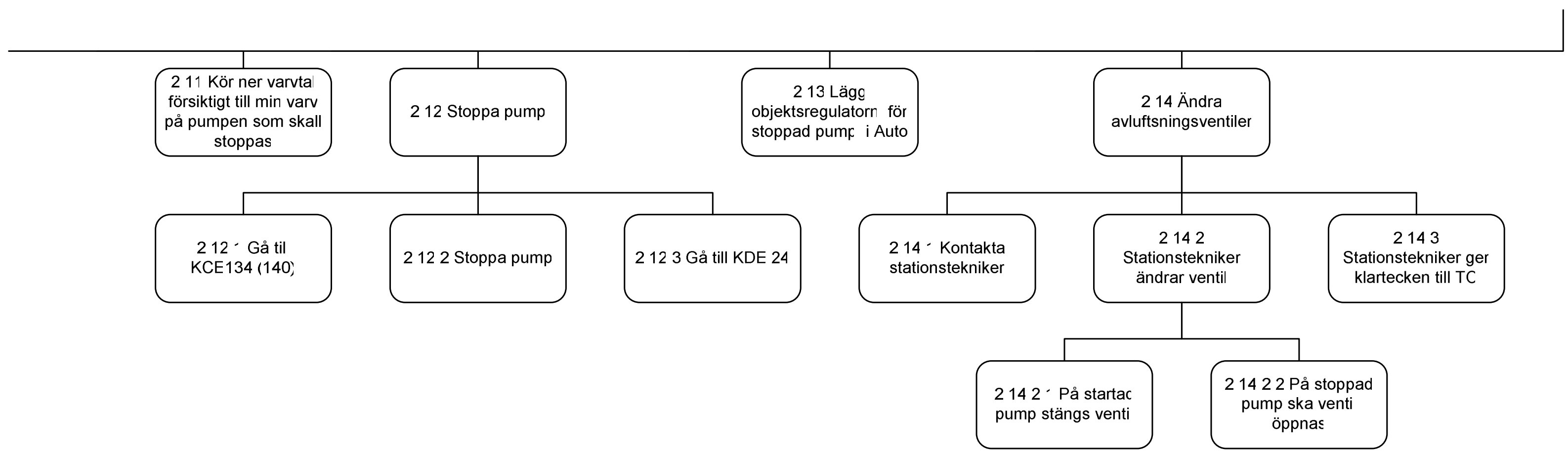
Resultat av HTA för MAVA-pumpskifte




Plan 2 2 Om kondensat är varmt gör 2 2
2 2 Värm den pump som skall startas
2 3 Lägg objektsregulatorn för den pump som skall startas i hand
2 4 Kontrollera att ställdon är nerkört till 0%
2 5 Starta pump manuellt på min varv
2 2 ´ Kontakta stationstekniker
2 2 2 Stationstekniker ger klartecken till TC
Plan 2 2 ´ 2 Är värmning av pump är klar gör 2 2 ´ 2
2 2 ´ ´ Stationstekniker öppnar minflödesventilen
2 2 ´ 2 Stationstekniker driftlägger minflödesventilen Auto
2 4 ´ Avläs KDE 24
2 5 ´ Gå till KCE 134 (140)
2 5 2 Starta pump
2 5 3 Gå till KDE 24



2 6 Kontroll av startad pump
2 7 Kör upp varvtal på pumpen så att det blir lika med pumparna som är drift
2 8 Lägg objektsregulatorn för den pump som startas i Auto
2 9 Lägg objektsregulatorn för den pump som skall stoppas i hand
2 10 Välj önskat pumpva
2 6 ´ Kontakta stationstekniker och be honom kontrollera pump
2 6 2 Stationstekniker kontrollerar den startade pumpen
Plan 2 6 2 Om pump är OK gör 2 6 2 ´ Om pump inte är OK gör 2 6 2 2
2 6 2 ´ Om pump OK meddela TO att fortsätta
2 6 2 2 Om pump inte OK meddela TO att stoppa pump
2 10 ´ Gå till KCE 134 (140)
2 10 2 Välj önskat pumpva
2 10 3 Gå till KDE 24



2 11 Kör ner varvtal försiktigt till min varv på pumpen som skall stoppas
2 12 Stoppa pump
2 13 Lägg objektsregulatorn för stoppad pump i Auto
2 14 Ändra avluftsningsventiler
2 12 Gå til KCE134 (140)
2 12 2 Stoppa pump
2 12 3 Gå till KDE 24
2 14 Kontakta stationstekniker
2 14 2 Stationstekniker ändrar ventil
2 14 3 Stationstekniker ger klartecken till TC
2 14 2 På startad pump stängs venti
2 14 2 2 På stoppad pump ska venti öppnas

Appendix F HTA – Blackout with houseload operation

1. Identifiering av HT-drift.
2. Övervakning av HT-drift.
3. Åtgärder inför fasning. Kontrollera att villkor för fasning är uppfyllda.
   - Kontrollera utlösta skydd. (622 viktigast → fasning ej möjlig.)
   - Lägg från lastfördelnings-automatiken.
     - Lokalisera lastfördelning KDE24.[1]
     - Lägg i hand.
     - (Ändra förvalt lastbörvärde till 100 MW.)[2]
   - Blockera HTFV lokalt i bypassläge med handrattarna.
     - Åtgärd lokalt i rum D4.01
   - Kontrollera att spänningen på FL67 mellan 375-455 kV
     - Avläs KCE136.
   - Kvittera och återställ samtliga flaggreläer KFE405-KFE409
   - Kontrollera att inget 622 larm finns i turbinpulpet.
     - Om larm finns, kontakta KR1.[3]
   - Kontrollera att turbotrol är i auto.
     - Kontroll KDE23.
   - Lägg fasningsmätsatsen i läge A.
     - Gå till KCE136.
     - Ändra till läge A resp. B.[4]
     - Gå tillbaka till pulpet.
   - Tryck in ”Fasning T4x-400-S”
     - Kontrollera att synkronoskop gör utslag.
   - Verifiera att fasningsutrustning kopplas ned.
     - Kvittera T4x-400-S KDE23.
     - Ändra vred T4x-400-S KCE136.

Appendix G List of Levels of Automation divided into Information Acquisition, Information Analysis and Decision Making & Action Selection

LoA	**Information Acquisition**	**Information Analysis**	**Decision Making & Action Selection**	**Action Implementation**
High **10**	The system collects data without informing the operator.	The system analyses information, ignoring the operator.	The system decides everything, acts autonomously, ignoring the operator.	The system implements actions, ignoring operator.
9		The system analyses and informs human if system finds it necessary.	Informs the operator only if the system decides to.	The system implements and informs the operator if it decides to.
8	The system alerts the operator, prioritizes information, and highlights critical alarms.	The system analyses and informs the operator if asked to.	Informs the operator only if asked to.	The system implements and informs operator if asked to.
7	The system alerts the operator and prioritizes the information.	The system analyses, and then informs the operator.	The system selects automatically then informs operator.	
6	The system alerts the operator and indicates what's wrong <u>with</u> integration to meaningful information (alarm + panel).	The system integrates data into meaningful information.	The system selects and allows a restricted time for veto.	The system executes action but leaves a restricted time for operator veto.
5			Suggests one alternative.	The system executes action if approved by operator.
4	The system alerts the operator and indicates what's wrong <u>without</u> integration to meaningful information (alarm + panel).	The system offers a complete set of data in an organized form.	Narrows selection down to a few.	
3	The system alerts the operator (alarm).	The system offers a complete set of data.	The system offers a complete set of decision/action alternatives.	
2	Instructions are available for guidance.	Instructions are available for guidance.	Instructions are available for guidance.	
1 Low	The system offers no assistance. Operator has to read deviances manually.	The system offers no assistance.	The system offers no assistance; operator must take all decisions and select actions.	Manual action implementation.

Appendix H NASA-TLX questionnaire

Skattning av arbetsbelastning

Mental belastning – Hur stor mental aktivitet krävs för uppgiften? (T ex slutledning, beslutsfattande, beräkningar, komma ihåg saker.)		1	2	3	4	5	6	7	8	9	10
	Mycket liten mental belastning										Mycket stor mental belastning
Tidspress – Hur stor tidspress känner du under utförandet av uppgifter?		1	2	3	4	5	6	7	8	9	10
	Mycket liten tidspress										Mycket stor tidspress
Ansträngning för att uppfylla må – Hur mycket måste du anstränga dig för att uppnå målen i uppgiften?		1	2	3	4	5	6	7	8	9	10
	Behöver inte anstränga mig alls										Behöver anstränga mig mycket
Frustration – Hur frustrerad, osäker, irriterad eller besvärad känner du dig under utförandet av uppgiften?		1	2	3	4	5	6	7	8	9	10
	Inte alls										Mycket

Appendix I Halden Human-Automation Cooperation questionnaire

Samarbete operatör-automation

A	I vilken utsträckning tillhandahåller det automatiserade systemet information om dess aktiviteter?	´	2	3	4	5	6	7	8	9	10
		Det ger mig ingen relevant information							Det ger mig all relevant information		
B	I vilken utsträckning erhåller du relevant information från det automatiserade systemet i tid för att för att hinna dra nytta av det?	´	2	3	4	5	6	7	8	9	10
		Aldrig									Alltid
C	I vilken utsträckning förstår du omedelbart den information som det automatiserade systemet presenterar?	´	2	3	4	5	6	7	8	9	10
		Aldrig									Alltid
E	I vilken utsträckning utför det automatiserade systemet de uppgifter som du förväntar av det?	´	2	3	4	5	6	7	8	9	10
		Aldrig									Alltid
F	Hur bedömer du samarbetet mellan dig och det automatiserade systemet som helhet?	´	2	3	4	5	6	7	8	9	10
		Obefintligt									Mycket bra
G	Hur viktigt bedömer du att samarbetet med dina kollegor i skiftlaget är i denna situation?	´	2	3	4	5	6	7	8	9	10
		Klarar mig helt utan samarbete									Det är omöjligt utan

Appendix J HEART – Human Error Assessment and Reduction Technique questionnaire

HT-drift		
Skattning av faktorers inverkan på risk för felhandlingar		
Hur stor inverkan anser du att de olika faktorerna har på risken för felhandlingar i denna situation?		
Identifiering av situationen husturbindrift		Kommentarer
Ovana inför en situation som är viktig men som inträffar sällan.		
Begränsad tid tillgänglig		
Överbelastning - samtida händelser och informationspresentation		
Dålig, tvetydig eller dåligt anpassad återkoppling från processen/systemet		
Brist på erfarenhet eller vana i situationen hos operatören		
Övervakning av husturbindrift		
Ovana inför en situation som är viktig men som inträffar sällan.		
Begränsad tid tillgänglig för felsökning och åtgärder		
Överbelastning - samtida händelser och informationspresentation		
Dålig, tvetydig eller dåligt anpassad återkoppling från processen/systemet		
Ingen direkt, tydlig och i rätt tid given bekräftelse på en utförd handling		
Brist på erfarenhet eller vana i situationen hos operatören		
Fasning		
Ovana inför en situation som är viktig men som inträffar sällan.		
Begränsad tid tillgänglig för fasning		
Överbelastning - samtida händelser och informationspresentation		
Dålig, tvetydig eller dåligt anpassad återkoppling från processen/systemet		
Ingen direkt, tydlig och i rätt tid given bekräftelse på en utförd handling		
Brist på erfarenhet eller vana i situationen hos operatören		
Skifte av MAVA-pumpar		
Behov av att minnas specifik information mellan olika handlingar		
Dålig, tvetydig eller dåligt anpassad återkoppling från processen/systemet		
Ingen direkt, tydlig och i rätt tid given bekräftelse på en utförd handling		
Brist på erfarenhet eller vana i situationen hos operatören		

Appendix K PHEA – Predictive Human Error Analysis questionnaire

PHEA HT-drift					
		Skatta sannolikheten för att de olika möjligheterna till fel inträffar. Bedöm sedan hur allvarlig konsekvensen av felet blir. Skriv gärna en kort beskrivning av händelsen.	1=mycket liten sannolikhet 10=mycket stor sannolikhet	1=obetydlig 10=mycket allvarlig	
			Sannolikhet	Konsekvens	Beskrivning/ kommentar
Identifiering av HT-drift		Tolkar ej informationen			
(t.ex. effekt, säk.olja utlöst, varvtal, larm)		Tolkar informationen fel			
		Tolkar inte informationen fullständigt			
		Meddelande om HT-drift ej mottaget			
		Meddelande om HT-drift ofullständigt			
Övervakning av HT-drift	Trender för diffutvidgning	Kontroll utebliven			
		Kontroll ofullständig			
		Rätt kontroll på fel trendkurva			
		Fel kontroll på rätt trendkurva			
		Fel kontroll på fel trendkurva			
		Tolkar inte informationen			
		Tolkar informationen fel			
		Tolkar inte informationen fullständigt			
	Trender för vibrationer	Kontroll av vibrationer utebliven			
		Kontroll av vibrationer ofullständig			
		Rätt kontroll på fel trendkurva			
		Fel kontroll på rätt trendkurva			
		Fel kontroll på fel trendkurva			
		Tolkar inte informationen			
		Tolkar informationen fel			
		Tolkar inte informationen fullständigt			
	MAVA- & ångflöde	Kontroll av MAVA- eller ångflöde utebliven			
		Kontroll av MAVA- eller ångflöde ofullständig			
		Rätt kontroll på fel objekt			
		Fel kontroll på rätt objekt			
		Fel kontroll på fel objekt			
	Uppskattning av tid till kritiskt läge	Uppskattning utebliven			
		Fel uppskattning - tror att du har gott om tid			
		Fel uppskattning - tror att du har ont om tid			

PHEA HT-drift	Skatta sannolikheten för att de olika möjligheterna till fel inträffar. Bedöm sedan hur allvarlig konsekvensen av felet blir. Skriv gärna en kort beskrivning av händelsen.	1=mycket liten sannolikhet 10=mycket stor sannolikhet	1=obetydlig 10=mycket allvarlig		
		Sannolikhet	Konsekvens	Möjlighet till återtagande Ja/Nej (Endast handlingar)	Beskrivning/ kommentar
Kontrollera att villkor för fasning är uppfyllda	Kontroll utebliven				
	Kontroll ofullständig				
	Rätt kontroll på fel objekt				
	Fel kontroll på rätt objekt				
	Fel kontroll på fel objekt				
	Tolkar inte informationen				
	Tolkar informationen fel				
	Tolkar inte informationen fullständigt				
Kontrollera utlösta skydd	Kontroll utebliven				
	Kontroll ofullständig				
	Rätt kontroll på fel objekt				
	Fel kontroll på rätt objekt				
	Fel kontroll på fel objekt				
	Tolkar inte informationen				
	Tolkar informationen fel				
	Tolkar inte informationen fullständigt				
Lägg från lastfördelnings-automatiken	Handling utförd vid fel tidpunkt				
	Rätt handling på fel objekt				
	Handling utebliven				
	Handling ofullständig				
	Fel handling på fel objekt				
Blockera HTFV lokalt i bypassläge med handrattarna	Handling utförd vid fel tidpunkt				
	Rätt handling på fel objekt				
	Handling utebliven				
	Handling ofullständig				
	Fel handling på fel objekt				
	Meddelande till STT ej mottaget				
	Överföring av meddelande till STT ofullständig				
Kontrollera att spänningen på FL67 är mellan 375-455 kV	Kontroll utebliven				
	Kontroll ofullständig				
	Rätt kontroll på fel objekt				
	Fel kontroll på rätt objekt				
	Fel kontroll på fel objekt				
	Tolkar inte informationen				
	Tolkar informationen fel				
	Tolkar inte informationen fullständigt				

PHEA HT-drift	Skatta sannolikheten för att de olika möjligheterna till fel inträffar. Bedöm sedan hur allvarlig konsekvensen av felet blir. Skriv gärna en kort beskrivning av händelsen.	1=mycket liten sannolikhet 10=mycket stor sannolikhet	1=obetydlig 10=mycket allvarlig		
		Sannolikhet	Konsekvens	Möjlighet till återtagande Ja/Nej (Endast handlingar)	Beskrivning/ kommentar
Kvittera och återställ samtliga flaggreläer KFE405-KFE409	Handling utförd vid fel tidpunkt				
	Rätt handling på fel objekt				
	Handling utebliven				
	Handling ofullständig				
	Fel handling på fel objekt				
Kontrollera att inget 622 larm finns i turbinpulpet	Kontroll utebliven				
	Kontroll ofullständig				
	Rätt kontroll på fel objekt				
	Fel kontroll på rätt objekt				
	Fel kontroll på fel objekt				
	Tolkar inte informationen				
	Tolkar informationen fel				
	Tolkar inte informationen fullständigt				
Kontrollera att turbotrol är i auto	Kontroll utebliven				
	Kontroll ofullständig				
	Rätt kontroll på fel objekt				
	Fel kontroll på rätt objekt				
	Fel kontroll på fel objekt				
	Tolkar inte informationen				
	Tolkar informationen fel				
	Tolkar inte informationen fullständigt				
Lägg fasningsmätsatsen i läge A	Handling utförd vid fel tidpunkt				
	Rätt handling på fel objekt				
	Handling utebliven				
	Handling ofullständig				
	Fel handling på fel objekt				
Tryck in ”Fasning T4x-400-S”	Handling utförd vid fel tidpunkt				
	Rätt handling på fel objekt				
	Handling utebliven				
	Handling ofullständig				
	Fel handling på fel objekt				
Verifiera att fasningsutrustning kopplas ned	Kontroll utebliven				
	Kontroll ofullständig				
	Rätt kontroll på fel objekt				
	Fel kontroll på rätt objekt				
	Fel kontroll på fel objekt				

PHEA - Skifte av MAVA-pumpar						
		Skatta sannolikheten för att de olika möjligheterna till fel inträffar. Bedöm sedan hur allvarlig konsekvensen av felet blir. Skriv gärna en kort beskrivning av händelsen.	1=mycket liten sannolikhet 10=mycket stor sannolikhet	1=obetydlig 10=mycket allvarlig		
			Sannolikhet	Konsekvens	Möjlighet till återtagande Ja/Nej (Endast handlingar)	Beskrivning/ kommentar
Beakta auto start/stopp.		Kontroll utebliven				
		Kontroll ofullständig				
		Rätt kontroll på fel objekt				
		Fel kontroll på rätt objekt				
		Fel kontroll på fel objekt				
		Tolkar ej informationen				
		Tolkar informationen fel				
		Tolkar inte informationen fullständigt				
		Meddelande ej mottaget				
		Meddelande ofullständigt				
Kontroll att förberedande uppgifter är utförda.		Kontroll utebliven				
		Kontroll ofullständig				
Värm pump som ska startas.		Meddelande ej mottaget				
		Meddelande ofullständigt				
Lägg obj.reg. i hand för pump som ska startas.		Handling utförd vid fel tidpunkt				
		Rätt handling på fel objekt				
		Handling utebliven				
		Handling ofullständig				
		Fel handling på fel objekt				
Kontrollera att ställdon är nerkört till 0%.		Kontroll utebliven				
		Kontroll ofullständig				
		Rätt kontroll på fel objekt				
		Fel kontroll på rätt objekt				
		Fel kontroll på fel objekt				
		Tolkar ej informationen				
		Tolkar informationen fel				
		Tolkar inte informationen fullständigt				
		Meddelande ej mottaget				
		Meddelande ofullständigt				
Starta pump manuellt på min. varv.		Handling utförd vid fel tidpunkt				
		Rätt handling på fel objekt				
		Handling utebliven				
		Handling ofullständig				
		Fel handling på fel objekt				

PHEA - Skifte av MAVA-pumpar						
		Skatta sannolikheten för att de olika möjligheterna till fel inträffar. Bedöm sedan hur allvarlig konsekvensen av felet blir. Skriv gärna en kort beskrivning av händelsen.	1=mycket liten sannolikhet 10=mycket stor sannolikhet	1=obetydlig 10=mycket allvarlig		
			Sannolikhet	Konsekvens	Möjlighet till återtagande Ja/Nej (Endast handlingar)	Beskrivning/ kommentar
Kontroll av startad pump.		Meddelande ej mottaget				
		Meddelande ofullständigt				
Kör upp varvtal på startad pump så att det blir lika med pumparna i drift.		Handling utförd för lite				
		Handling utförd för mycket				
		Handling utförd vid fel tidpunkt				
		Rätt handling på fel objekt				
		Handling utebliven				
		Handling ofullständig				
		Fel handling på fel objekt				
Lägg obj.reg i auto för pump som startats.		Handling utförd vid fel tidpunkt				
		Rätt handling på fel objekt				
		Handling utebliven				
		Handling ofullständig				
		Fel handling på fel objekt				
Lägg obj.reg. i hand för pump som ska stoppas.		Handling utförd vid fel tidpunkt				
		Rätt handling på fel objekt				
		Handling utebliven				
		Handling ofullständig				
		Fel handling på fel objekt				
Välj önskat pumpval.		Val uteblivet				
		Fel val				
Kör ner varvtal på pump som ska stoppas.		Handling utförd för lite				
		Handling utförd för mycket				
		Handling utförd vid fel tidpunkt				
		Rätt handling på fel objekt				
		Handling utebliven				
		Handling ofullständig				
		Fel handling på fel objekt				
Stoppa pump.		Handling utförd vid fel tidpunkt				
		Rätt handling på fel objekt				
		Handling utebliven				
		Handling ofullständig				
		Fel handling på fel objekt				
Lägg obj.reg. i auto för pump som stoppats.		Handling utförd vid fel tidpunkt				
		Rätt handling på fel objekt				
		Handling utebliven				
		Handling ofullständig				
		Fel handling på fel objekt				

Title	Automation Inflicted Differences on Operator Performance in Nuclear Power Plant Control Rooms
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Abstract

Today it is possible to automate almost any function in a human-machine system. Therefore it is important to find a balance between automation level and the prerequisites for the operator to maintain safe operation. Different human factors evaluation methods can be used to find differences between automatic and manual operations that have an effect on operator performance; e.g. Predictive Human Error Analysis (PHEA), NASA Task Load Index (NASA-TLX), Halden Questionnaire, and Human Error Assessment and Reduction Technique (HEART). Results from an empirical study concerning automation levels, made at Ringhals power plant, showed that factors as time pressure and criticality of the work situation influenced the operator's performance and mental workload more than differences in level of automation. The results indicate that the operator's attention strategies differ between the manual and automatic sequences. Independently of level of automation, it is essential that the operator retains control and situational understanding. When performing a manual task, the operator is "closer" to the process and in control with sufficient situational understanding. When the level of automation increases, the demands on information presentation increase to ensure safe plant operation. The need for control can be met by introducing "control gates" where the operator has to accept that the automatic procedures are continuing as expected. Situational understanding can be established by clear information about process status and by continuous feedback. A conclusion of the study was that a collaborative control room environment is important. Rather than allocating functions to either the operator or the system, a complementary strategy should be used. Key parameters to consider when planning the work in the control room are time constraints and task criticality and how they affect the performance of the joint cognitive system.However, the examined working situations were too different with respect to levels of automation and therefore it is not possible yet to propose general automation level guidelines. Further studies are still needed.

Key words: Automation level, function allocation, cognitive workload, human reliablity, performance, control room design

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