What We Have Learned so Far About the Importance of MTO in Control Room Design

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Abstract: The OECD Halden Reactor Project has for many years performed research on the safety of nuclear power plants (NPPs). The focus has been on empirical research in our simulator laboratory HAMMLAB (HAlden Man-Machine LABoratory) as well as on empirical studies in the field and in training simulators in NPPs. The MTO (Man-Technology-Organisation) perspective is a system-oriented perspective in which we seek to understand the dynamic relation between humans, technology and organization. The importance of MTO in control room design is evident by the fact that Human Factors Engineering (HFE) is included as a specific element in regulatory guidance in all countries that operate NPPs. This paper focuses on the need for empirical evidence to support MTO research; experience shows that empirical evidence can often contradict a-priori assumptions. Empirical investigations can help to: 1) identify key questions that control room designers and regulatory reviewers should ask; 2) define ideas for new and innovative designs; 3) evaluate and validate human performance in the control room, with respect to both integrated system validation (ISV) as well as human reliability. This paper outlines examples of results from empirical research carried out by the Halden Reactor Project to address these different needs in the nuclear industry.
Keyword: Man-Technology-Organisation (MTO), human performance, empirical studies

1 Introduction

MTO (Man-Technology Organisation) is a system-oriented conceptual framework. MTO is central to process control; it provides a framework for understanding and designing complex technology such as that found in an NPP, whilst considering the dynamic interplay between the people monitoring the plant, the organization and the technology itself. The role of MTO and human factors in the design process is well described in guidelines for Human Factors Engineering, such as NUREG-0711 [1]. Such process-oriented guidelines include verification of basic design according to prescribed standards and guidelines. This is done to verify that the control room design is usable and that the potential for human error is minimized.

This paper focuses on the need for empirical evidence to support MTO research. During simulator experiments of specific control room topics, we experience that it is difficult for subject matter experts to predict the outcomes. Expert assumptions about predicted difficulties for the control room operating crew have often been challenged. Thus, there is a real need for empirical investigations, to test hypotheses and collect evidence. In this paper three different needs and how empirical data can support them are discussed: 1) Identification of the key questions that designers and regulatory reviewers should ask; 2) Ideas for new and innovative designs; 3) Evaluation and validation of human performance in the control room.

2 The need for empirical evidence

During many years of performing experiments in HAMMLAB, we have identified a number of dimensions that are difficult to predict, including expected procedure paths in difficult scenarios, as well as expected time to perform actions. Assumptions about plausible procedure paths that the operating crew was expected to follow have shown not to be confirmed by reality, and there may be several reasons why. One reason is simply the complexity of the situation, that it is impossible to foresee the details of the situation to such an extent that one will be able to predict the procedure path, nor the time required to perform the proceduralized actions.

An example was present in the steam generator tube rupture (SGTR) scenarios of the International human reliability analysis (HRA) Empirical Study [2]. In one of the scenarios the transfer from the main diagnostic emergency operating procedure to the steam generator isolation procedure was made more difficult by masking all the radiation indications on the secondary side. In addition other disturbances were introduced, so the timing of the procedure execution showed great variability between the crews. This led to large variability in the procedure paths between the crews [ibid. pg. 2-20], since the plant situation and transfer conditions were different for the crews at the point in time when they were supposed to transfer between procedures.

We have seen many similar situations in HAMMLAB, that it is very difficult to foresee whether and how the crews may perform the required actions in time in difficult scenarios.

These findings cannot be explained by the "laboratory" factor either, e.g., that operating crews don't know the simulator well enough. In a study where the data collection was done in a real training simulator at an actual plant with the licensed operators from that plant, the plant instructors were interviewed by a set of HRA analysts. The event under analysis was a scenario with loss of component cooling water and reactor coolant pumps (RCPs) sealwater. The operators had to take manual control of the feedwater flow, trip the RCPs and start the positive displacement pump, within a few minutes after the leakage. This particular scenario had included a failed distribution panel in the beginning of the scenario. In spite of this, the instructors at the plant predicted that the operating crews would manage to execute the actions in the required procedure within time, since they were well trained in the general scenario. However, the complexity of the situation led to more difficulties for the crews, so none of the participating crews managed to do the required actions within the available time, [3, pg. 8-8 and 5-14]. This was an important discovery for the plant, which introduced more specific training on these kinds of scenarios in order to mitigate this problem.

3 Finding the right questions

How do we know that our efforts in safety research focus on the important aspects of nuclear safety? Especially in regulatory nuclear work, it is important to identify the aspects of operation of the nuclear power plants that have an impact on nuclear safety. Thus, an important research focus is to find the right questions. Knowledge building experiments and exploratory testing may be good tools for this.

One example is a recent study performed in collaboration with the U.S. Nuclear Regulatory Commission (NRC) in their training centre in Chattanooga, in which new computerized procedures systems (CPSs) were tested, see [4] and [5]. One result was that there are different human error modes depending on the way in which the CPS fails. In this study, the focus was specifically on three error types in their computerized procedure system, one of which was detection of automatic evaluation errors. [4, from abstract] states:

"Results indicate that failure of the automatic evaluation function may not be easily detected by the operator, leading the operator to accept an incorrect recommendation from the system. This effect seems to affect primarily evaluations resulting in a green check mark (procedure condition met), while operators appear more thorough and critical when the system shows a red X (conditions not met). Note that the informational value of both of these symbols is identical, and it may be that the symbols themselves induce a bias ("green checkmark = everything is OK")."

Even though this was a short study with a limited number of participants, these results help identify a whole range of questions for designers of such systems as well as for regulatory reviewers. Also, they help pinpoint the questions to answer in replicated studies and in future research.

Other examples of valuable results from empirical studies are details on plant operation and how operating crews make decisions in very difficult scenarios. Such results have been achieved in many studies, especially in a series of studies looking into human reliability of mitigation actions in post-initiating events, see e.g., [6]. Such scenarios include the use of emergency operating procedures, and these are trained extensively at NPPs throughout the world. However, it is not possible to train all plausible variants of such scenarios. Some scenarios are also outside of expected conditions, and results from such studies are instrumental for design of systems in the control room, as well as important information for human reliability analysis (HRA) practitioners.

A report entitled *"Diagnosis and decision-making with Emergency Operating Procedures in Non-Typical Conditions: A HAMMLAB Study with U.S. Operators"*, [7], highlights many aspects of this, such as *"can the operators handle situations in which the procedures do not provide detailed guidance, and what are the consequences to the plant?"* and *"how do the operators recognize a procedure-situation mismatch and resolve the conflict between the procedures' "understanding" of the situation and their own understanding?"*

This kind of information is important for HRA practitioners, in order to know what kind of information to look for when doing talk-throughs and walk-throughs with operating personnel as part of their data collection and qualitative analysis for HRA. If analysts are aware that process experts may not have a complete understanding of the complexity of the situation for the operators in various scenarios, then the analysts can ask more specific questions during data collection to identify more details of the scenario development and gain more knowledge on the detailed context, e.g., time available, for operators' actions. Such detailed knowledge will improve the analysis and may be used as input to error reduction or redesign or design of similar systems.

In the work on human-automation collaboration we studied transparency of automation in a HAMMLAB experiment. The idea was that higher levels of automation would be accepted if the automation would tell the operators what it is doing and what the automation goals are. A transparent automation interface was designed to *"(i) inform the operators about the goals and activities of the automatic system, and (ii) ease the interaction with automation. This transparent interface was compared to a typical non-transparent interface for interaction with automation in current control rooms."* [8, from the abstract].

Operators' performance was measured with subjective performance measures such as operators' trust in automation and situation awareness, and with more objective task performance measures such as expert observer ratings of correct detections and actions. The results were [ibid. pg 45]:

"The participants seemed to accept the automated work environment, and the transparent interface improved the collaboration and trust between operators and the automatic system. However, the transparent displays negatively affected the operators' ability to detect disturbances, produced no effect on overall task performance, and yielded inconclusive results with regards to workload and situation awareness."

Over-reliance on automation is a known problem, and here we see a case in which operators trust an automated system with which they perform worse than with a more manual system. It is of crucial value to the industry to identify such conditions and characterize these settings and control room systems in such a way that one can give important input to the design of automation systems.

Self-assessment of performance is not easy, and we have seen other cases where operators believe they are doing better, or worse, than they really are. The operators are not aware that their performance is better in one condition compared to another one. Thus, in empirical studies, there is a need for a variety of measures of performance, including objective measures. Using only subjective measures of performance or statements from users are not sufficient, since the subjective measures will not capture the real performance in these cases.

Some of these insights are not possible to find only by verification of the design or by designers thinking according to certain models of performance. By performing empirical studies one will discover results that should be considered and can be used as inputs to the design.

4 Ideas for new designs

Monitoring complex industrial processes such as an NPP can be challenging, and has been studied for many years. Both design of Human System Interfaces and Human-Machine Interaction have grown into specific fields. The original questions around traditional process control have lately also been expanded to Human-Automation Interaction, following the trend to include more automation in industrial processes. This development also increases rapidly in other domains, such as for self-driving cars.

The Halden Reactor Project has done considerable work in studying new human-system interfaces (HSIs), including large overview displays, detailed process displays and handheld displays, and automation designs in our laboratories during the last 30 years. The purpose has been to identify whether, and the way in which, these new designs support operators in their work of monitoring the plant and mitigating accidents.

An integrated way of presenting and interacting with the process is made in the "near-term" HSI project. This includes intuitive ways of presenting the state of the process on large overview screen; task-based displays, which shows procedure execution support in the process displays and includes process information in computerized procedure displays, thereby linking the procedure execution to process surveillance; and a state-based alarm system, [9], [10], [11]. Design of such systems requires an understanding of how the operating crew works as well as an understanding of the nuclear process itself. One also needs to take into account the organizational impact, the conduct of operations of the crew. The way in which the crew is supposed to collaborate, as well as their distributed functions and tasks, has a profound impact on the optimal solution of the control room and interface design. Hence the whole MTO system needs to be considered in order to make a best possible design.

5 Validating human performance

Above there are numerous examples where the complexity of the plant in various scenarios proves to be different, when studied empirically, from what analysts and process experts thought in the first place. This may of course also be the case when validating the final design and comparing it to the intentions of the designers. This is one of the reasons why the last step in Human Factors Engineering (HFE) guidelines such as NUREG-0711 [1], is to validate the final design by evaluating the human performance when real users are using the system in a training simulator. This is done by running realistic scenarios with operating crews and measuring human performance in the simulated control room. Similar methodology can be used for single subsystems as well as for the whole control room.

The Halden Reactor Project has for many years studied Integrated System Validation (ISV), especially focusing on the necessary human performance measures. What are the important human performance aspects to focus on, and how can they be measured in an effective way? See e.g., [12]. Knowledge from this work has also been used in real ISV applications of new control rooms in NPPs that have upgraded their control rooms, [13]. We have also been involved in international task forces on ISV organized by OECD NEA, working group on human and organizational factors. The main purpose was to capture the current state of the art as well as to identify the future needs in this methodology.

6 Conclusions

Knowledge of the way in which control room and interface designs impacts human reliability is crucial for the design and evaluation of new control room solutions. This paper underlines the need for empirical information about the way in which humans collaborate and interact with the technical system as well as with other people. By performing empirical studies one will reveal results that are important input to design of control rooms. This paper discussed three particular issues: 1) identifying the important questions for safety; 2) facilitating improved solutions through exemplifying designs; 3) validating the final result through measuring human performance in interplay with the technical system in its organizational context.

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References

[1] O'Hara, J., Higgins, J. C., Persensky, J. J., Lewis, P., Bongarra, J. P. (2004). Human Factors Engineering Program Review Model (NUREG-0711, Rev. 2). U.S. Nuclear Regulatory Commission, Washington, D.C.

[2] Lois, E., Dang, V.N., Forester, J., Broberg, H., Massaiu, S., Hildebrandt, M., Braarud, P.Ø., Parry, G., Julius, J., Boring, R., Männistö, I., & Bye, A. (2009). International HRA Empirical Study - Phase 1 Report: Description of Overall Approach and Pilot Phase Results from Comparing HRA Methods to Simulator Performance Data. NUREG/IA-0216, Vol. 1, U.S. NRC.

[3] Forester, J., Liao, H., Dang, V.N., Bye, A., Lois, E., Presley, M., Marble, J., Nowell, R., Broberg, H., Hildebrandt, M., Hallbert, B., Morgan, T. (2016). The U.S. HRA Empirical Study – Assessment of HRA Method Predictions against Operating Crew Performance on a U.S. Nuclear Power Plant Simulator. NUREG-2156, U.S. NRC.

[4] Taylor, C., Hildebrandt, M., McDonald, R. and Hughes, N., Operator Response to Failures of a Computerised Procedure System: Results from a Training Simulator Study. HWR-1198, OECD Halden Reactor Project, 2017.

[5] Taylor, C., Hildebrandt, M., Hughes, N. and McDonald, R., "Operator Response to Failure of a Computerized Procedure System," Proceedings of iHSI, Dubai, UAE, Jan 7-9, 2018. *In print*.

[6] Forester, J., Dang, V.N., Bye, A., Lois, E., Massaiu, S., Broberg, H., Braarud, P.Ø., Boring, R., Männistö, I., Liao, H., Julius, J., Parry, G., & Nelson, P. (2014). The International HRA Empirical Study – Lessons Learned from Comparing HRA Methods Predictions to HAMMLAB Simulator Data. NUREG-2127, U.S. NRC.

[7] Massaiu, S., and Holmgren, L., Diagnosis and decision-making with Emergency Operating Procedures in Non-Typical Conditions: A HAMMLAB Study with U.S. Operators. HWR-1121, OECD Halden Reactor Project, 2014.

[8] G. Skraaning Jr., M.H.R. Eitrheim, N. Lau, C. Nihlwing, L. Hurlen, T. Karlsson. Coping with Automation in Future Plants: Results from the 2009 HAMMLAB Experiment. HWR-937, OECD Halden Reactor Project, 2010.

[9] H. Svengren, L. Hurlen, C. Nihlwing, "Human Machine Interface (HMI) Developments in HAMMLAB". Proceedings of ISOFIC/ISSNP 2014, Jeju, Korea, August 24~28, 2014.

[10] H. Svengren, M.H. Rø Eitrheim, A. Fernandes, M. Kaarstad, Human-System Interfaces for Near-Term Applications: Documentation of the Design Concept. HWR-1181, OECD Halden Reactor Project, 2016.

[11] M.H. Rø Eitrheim, H. Svengren, A. Fernandes, Evaluation of the Human System Interface Concept for Near-Term Applications. HWR-1211, OECD Halden Reactor Project, 2017.

[12] Braarud, P. Ø. & Berntsson, O. (2016). Assessment of Situation Understanding, Mission, Control and Teamwork in the control room: The Development and Initial Testing of the SCORE Measure. HWR-1125, OECD Halden Reactor Project.

[13] T. Gunnarsson, P.Ø. Braarud, A. Fernandes, "Performance Based Control Room Evaluation (Integrated System Validation) for Oskarshamn 1 Periodic Safety Review," Proceedings of EHPG-2014, Røros, Norway, Sep. 7-12, 2014.