CHEMICAL ENGINEERING TRANSACTIONS

VOL. 99, 2023

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Sauro Pierucci, Flavio Manenti

ISBN 978-88-95608-98-3; **ISSN** 2283-9216

DOI: 10.3303/CET2399046

Decision Making for Process Control Management in Control Rooms: a Survey Methodology and Initial Findings

Chidera Winifred Amazu[a]*, Ammar Abbas[b,c], Micaela Demichela[a], Davide Fissore[a]

[a] SAfeR - Department of Applied Sciences and Technology, Politecnico di Torino, Italy
[b] Department of Computer Science, Technology University Dublin, Ireland
[c] Data Science, Software Competence Center Hagenberg, Austria
chidera.amazu@polito.it

Control rooms and their operators are active elements in complex socio-technical systems such as process plants. Control room operators monitor process operations, respond to alarms, and manage process deviations until emergencies. The increase in automation of plants and equipment makes the operators less involved in manual process control or other physical roles while more exposed to cognitive load generated, for example, by increasing the number of alarms or potential system failures in abnormal situations. A shift in process control design and management techniques to holistically capture risks due to evolving process or monitoring capabilities and the related influencing factors is necessary. This study aims to collate and understand existing approaches for decision-making on process control design and management of safety-critical operations through a proposed survey methodology. Based on the preliminary results and recommendations, it appears that a human-centered approach to assessing and enhancing process control elements for human-in-the-loop configurations in process control rooms could be a promising path forward for decision-making for process control management.
Keywords: process control rooms, human centred decision making, performance shaping factors

1. Introduction

The nature of control rooms of process plants is changing, and so are the roles of operators from more active physical engagement to more involvement in active monitoring or supervision (Li X. et al., 2011; Stanton et al., 2009; Cacciabue P. C., 1998). These changes are driven by increasing automation, more excellent centralisation, and changing process control interaction elements (displays, support aids, and more...standards) that increase operators' mental workload and reduce situational awareness (Li X. et al., 2011; Nachreiner F. et al., 2006).
Therefore, considering the criticality of the operators' role in ensuring safety during emergency conditions and the role the interaction elements play in aiding operators, decision-makers must assess how these changes impact performance and safety in their reviews in comparison to initial assessment during design and implementation. Earlier work by Cacciabue P. C., (1998), has similarly hinted at these concerns and provided some models to approach this. Process control room interaction elements (organisational and technological factors) are to be updated to meet the operators' needs in their current process control configuration using such human-in-the-loops models and evaluated continuously on their ability to maintain the same performance expectation.
Current standards for reviewing and evaluating control room elements, such as ISO 11064-10 (2020) series, specifically 11064-1 and 11064-7, and ISO 9241 (Ergonomics of human-system interaction), provide some methods and measures that can guide assessment. Methods introduced range from paper and pencil techniques to observational, experimental techniques and expert judgment (ISO 11064-7, 2006). However, these methods do not highlight extensively how evaluations can be done for current HITL process control configurations considering the challenges earlier highlighted. Also, few recent research efforts have been made towards developing practical evaluation methods that address the human factors gaps, as the consideration of

Paper Received: 19 December 2022; Revised: 14 March 2023; Accepted: 9 May 2023
Please cite this article as: Amazu C., Abbas A., Demichela M., Fissore D., 2023, Decision Making for Process Control Management in Control Rooms: a Survey Methodology and Initial Findings, Chemical Engineering Transactions, 99, 271-276 DOI:10.3303/CET2399046

cognitive and behavioural changes, for a more human-centred evaluation and optimisation of the elements of interaction in process control rooms. Though no unified standard exists for designing and evaluating control rooms and their elements in process plants, the aforementioned standards are being adapted by process industries. However, it is unclear what the current status quo is in process industries. Also, considering that the standards are optional for adaptation in process plants, it would be interesting to understand current practices in these plants and the efforts towards adapting them for the changing human-in-the-loop configurations.

This study aims to collate and understand existing approaches in process plants and, as described in the literature, for decision-making on process control design and management with evolving processes or monitoring capabilities and to suggest a way forward. Through this survey, the techniques and tools for the evaluation and optimisation decisions for these elements, the make-up of the decision-making team, variables considered during evaluation for optimisation, and associated performance indicators are identified and discussed. This study focuses on decisions made for the design and optimisation of five control room elements; works design structure, human system interfaces, AI-based support systems, procedure, and training.

In section 2, a brief introduction of these elements is presented, with section 3 describing the approach to achieving the goal of this research, including the data collection format. The paper ends with a summary and conclusion of the study and plans for future work.

2. Process control room elements and human factors

Control rooms are where operators perform monitoring, alarm handling, and control actions using different components as control systems through human-machine interfaces (Naito T., 2011). Though many components of interaction can be identified during human-machine interaction, some elements have been identified as key for managing process operations, especially considering their impact on ensuring safety (Joshi, 2018; Li X. et al., 2011; ISO 11064-10, 2020; HPOG, 2021). Such elements include; human-system interfaces (including alarms), procedures, AI-based decision support systems (anomaly detection or process control and setpoint suggestions), and training. The authors discuss in this section, in brief, the first three mentioned elements, their relevance for control room process operations, current issues in the industry concerning them and the gaps in consideration for the changing human-in-the-loop configuration in process control rooms. The authors also briefly highlight in this section, for each element, the potential benefits of operator monitoring, which we propose for future work.

2.1 Human system interfaces (HSI)

The human system interfaces constituting alarms and interface display design are critical control room elements and performance-shaping factors for human-computer interaction. The operators in control rooms observe the plant conditions from the interface and articulate their feedback via the interface by responding to alarms or performing control actions. However, there are issues concerning current human interfaces and their ability to support operators.

Displays: The interface displays provide control room operators with information on trends of process variables and real-time plant conditions. However, with increased automation and plant complexity, operators have to process a lot more information from the interface displays, which impacts their cognitive load. Considering these complexities and information overload in process control rooms, operators would need even more situational awareness support from the interface displays. The displays should provide cues that direct operators' attention to relevant details, especially in abnormal conditions. Therefore, the optimisation of the displays should be done in consideration of how it impacts the operators to provide targeted support. That means, in addition to the existing guidelines for display design and presentation, evaluation and decision-making methods or models that integrate the cognitive impact of the interface design on operators should be explored.

Alarms: Part of the human system interface are the alarms. The alarms are triggered to call the operators' attention to a disturbance requiring their intervention (EEMUA 191). However, alarm failures, either from poor software design or engineering, are part of the human system interface issues operators have to deal with daily. Issues from poor alarm management, such as alarm floods and nuisance alarms, are becoming major concerns as they increase operators' cognitive load and stress in current HITL configurations (Li X. et al., 2011). Similarly, to decision-making recommendations for the design and management of interface displays, decision-makers have to put into consideration the human dynamics to adequately address alarm issues and provide targeted support for control room operators.

2.2 Procedures

Procedures (operating procedures or intervention strategies, etc.) are key performance-shaping factors and key to safety management. They are classified in human reliability studies either as technological, task-related or organisational factors critical to human-machine interaction especially intervention in safety-critical status

(Morais C, 2022; Groth M. K, 2012). The operators are guided and provided with information through the procedures to ensure safe operations and these procedures can be computerised or paper-based. Ideally, the procedures should support the operators within the available time from projected early warning and should be easily accessible and easy to use in order not to lose available time, especially in current process control configurations where operators are placed out-of-the-loop.

Investigations into major incidents, as highlighted in HPOG (2021), have shown that procedures are one of the key incidents contributing factors. Reasons range from the irrelevance of the procedures to addressing actual situations, procedure overload, poor presentation, and contradictory procedures. Such inadequacy in procedural support can impact operators' performance and, consequently, process safety.

Therefore, it is important to update these procedures frequently to address the issues. Decisions for optimisation can be done together with an up-to-date or real-time understanding of operator-system interaction or work-as-done in process operations, as also recommended in (HPOG, 2021). This is to understand the gaps in the usage of procedures and the impact of the procedural design alongside other performance-shaping factors on operators. Similarly, adopting expert experience on task and comparing this with task risk analysis outcomes can make for a better approach to updating existing procedures.

2.3 AI-Based Support

Artificial Intelligence (AI) can significantly enhance the functionality of control rooms, making them more intelligent and responsive. One of the significant advantages of utilizing AI in control rooms of process industries is the capability to process a large amount of data with precision and speed. Chemical plants and process facilities generate big data from sensors and devices, including temperature, pressure, and flow rates. AI algorithms can analyze this data in real-time, spotting patterns and anomalies that may indicate a problem, thus allowing operators to quickly identify and rectify issues, resulting in less downtime and higher productivity.

AI algorithms can control the process and pinpoint areas that require improvement in efficiency. For instance, an AI-powered system can optimize the chemical process by managing the set points of variables according to the changing environment or optimizing the process control by considering the environment's stochasticity and configuring the optimal control strategies based on the observed state of the system. Furthermore, AI can enhance the facility's safety by monitoring for potential hazards and alerting operators to potential problems. In emergency scenarios, AI can improve the decision-making process of operators. For instance, AI-powered systems can provide operators with real-time information, such as the location of the emergency, the cause, and the best course of action. Therefore, the information provided enables operators to make more informed decisions and respond quickly to emergencies.

However, only a few AI-based support systems are used in real-world scenarios due to their uncertain black-box nature and lack of explainability. Therefore, Interpretable-AI systems have a higher potential to be used in such safety-critical systems (Lefevre K. et al., 2022). Such interpretable AI-based decision support systems are designed in a hybrid architecture, including a white-box system (such as Bayesian Networks) and a black-box system (such as Neural Networks), providing the best of both worlds. In addition, most AI-based use cases are now limited to virtual reality or simulated environments for such safety-critical systems because experimentation related to AI-based systems can be expensive (Mentler T. et al., 2022).

The authors recommend a human-centred AI-based decision support system that keeps humans in the human-in-the-loop for safety-critical systems. Having humans and AI working together and helping each other in such scenarios; to teach and learn from each other in which they are most capable. Humans are good at making complex decisions from intuition and experience based on logic. In contrast, AI can process lots of historical and online data, find hidden connections between them, and find similar patterns based on which it can provide suggestions or decisions. In this way, both humans and AI can support such critical decision-making as in the maintenance of aircraft engines or minimizing alarms in the process industry, helping operators to have a better overview of the system and troubleshooting it when some dangerous event is about to happen to be able to avoid it with the help of AI that can analyze tons of data and find the actual cause behind the problem. As there is no known literature that provides the details of such a decision support system, therefore, to the best of our knowledge, it should capture the state of the system that includes: human factors, process variables, process and control variable thresholds, and set points of the system.

In order to gain insights into the present-day methods of decision-making employed in process plants for assessing and enhancing process control elements, as well as overall process control management, a survey was conducted within the industry and is examined in section 3 and 4. The outcomes of this industrial investigation can provide insights into the current state of affairs in the industry with regard to decision-making approaches utilized in process plants for process control design and management.

3. Methodology

Process plants were the focus of this industrial study. Information was collected using a questionnaire designed with the Qualtrics software, and the MoSCo technique was explicitly used to get their recommendations. The MoSCo technique is a prioritisation technique used to classify a collection of requirements into priorities of 'MUST have', 'SHOULD have' and 'COULD have'. Through this survey, the authors collected responses on the techniques and tools used by the decision makers to make decisions for the evaluation and optimisation of process control room elements, variables and their measures considered during evaluation, and the associated performance indicators for the elements.

3.1 Participants

The target respondents were control room operators and those involved in designing and optimising process control rooms. Participation was made voluntary, and there was no risk posed to the participants by using the survey. The participants were informed that personal information would only be identifiable with their permission as the survey was also collected anonymously.

3.2 Survey preparation and structure

The first part of the survey comprised an introduction to the goal of the survey and a confirmation of consent page. A second section followed this to collect general information on the age, gender, role, working experience, type of industry and location of industry of each of the intending participants.
The last section focused on the study's objectives with some instructions for the respondents. This section was further split into five (5) themes, each representing a process control room element; (1) the human system interfaces (alarms and interface layout), (2) procedural support, (3) AI-based support systems, (4) training and (5) work structure. Before responding to questions within each theme, the respondents were asked to rank the themes in order of priority (with one being the most prioritised and five being the least) for their contribution to operator support and ensuring safety.

Table 1: Overview of survey content

Questions	Themes
Are decision-making techniques or tools applied in designing and optimising the human system interfaces?	Themes 1 - 5
How often are evaluations for optimisation on the human system interfaces	Themes 1 - 5
Is there real-time monitoring of operators' behaviour for the decision-making on the human system interfaces?	Themes 1 - 5
Is there real-time monitoring of systems behaviour (process abnormalities) for the decision-making on the human system interfaces?	Themes 1 - 5
Are Performance indicators in use to monitor the human system interfaces?	Themes 1 - 5
What Must, Should or Could be done better for the design and optimisation of human system interfaces (more than one response can be written)?	Themes 1 - 5
What type of procedural support is used? Please indicate.	Theme 2
Are AI-based support system (s) in use? Please provide here details on the AI tool (s) in use? How often do operators rely on the decision (s) from the AI support system?	Theme 3

3.3 Questions

Ten (10) similar questions were repeated under each theme, with exceptions for the procedures and AI-based support. Reason being that, for the procedural support, it was essential to inquire about the type of support in use by the industry (paper-based and more). Also, for the AI-based support, which the authors project to be less used, it was a priority to inquire first on the use of such support, the type of AI-based support in use, how this is presented to the operators and how it supports the operator. A summary of the questions raised in the survey is shown in Table 1.

4. Result and Discussion

Only four responses were collected at the time of writing. The responses so far were considered representative of typical process plants. For example, two participants worked in the control room operator and lead, one was a shift engineer and another a principal consultant. The industries for the first three is the Oil and Gas, and the later, Consultancy. They were all males, average age ≈ 35, and only participated based on their decision-making roles for process control room design and management.

The elements (see section 3.3 on themes) were prioritised on their contribution for operator support and ensuring safety in the facilities of the respondents. The Procedures (paper-based: 2 of 4, and computer-based: 2 of 4) and HSI were prioritised equally on an average, followed by Training, Work Structure, and AI-based support.

The frequency of optimisation of these elements mainly varied between weekly to never. In a specific case of the consultant's response, the procedures, training and work-structure was indicated as ‘never’ optimised, while HSI was optimised annually. This is contrary to the other responses. Also, the consultant mentioned that operators’ real-time behaviour was not considered for decision making which differed from the responses of others. In line with the response from the consultant, it was observed from the general responses that organisational factors were mostly considered during decision-making compared to individual and situational factors. In some cases, the respondents mentioned their awareness of these factors and cases where qualitative and quantitative measures were used for assessment, but no specific evaluation measures were mentioned. Furthermore, risk assessment techniques (HAZOP, LOPA), logs, alarm reviews and interviews were the most common decision-making techniques used, with human reliability mentioned only in the case of optimising the HSI and work structures. The detailed responses from the participants can be found here: shorturl.at/arCH6. Finally, the recommendations given for the key elements in consideration are summarised in Table 2.

Table 2: Recommendations from respondents (MoSCo technique)

Procedures	HSI	AI-based support
Must: i. Clarity ii. Auto detection upon deviation. Should: i. Quality testing. ii. Easy and interactive for everyone. iii. Reminder system to follow procedure. Could: i. Flexibility and adaptability to operations. ii. Better designing. iii. Next step guidance display.	Must: i. HSI must be simple to operate for everyone. ii. Suggestion of decision. iii. Ease of navigation. Should: i. Consideration of fatigue. ii. Zero ambiguity in display. iii. We should be taking more account of HF good practice in design HMI's. Could: i. Easy to understand and operate. ii. More interactive HSI. iii. Keep operator interactive. iv. Simple colour display	Must: Simple and interactive for everyone. Should: Better design Could: Easy to understand

5. Conclusion

Through this industrial survey, the authors aimed to understand the gaps within the process industry on decision-making for process control room design and optimisation, specifically on the elements discussed in this paper. Although there were limitations on the number of respondents when completing this paper, some insights could be obtained from the responses. First, the human/individual and situational factors are in low consideration while optimising these critical elements. As observed from the responses, there are also no specific measures to assess these person-related and situational factors. Furthermore, from the responses collected using the MoSCo technique, the recommendations stressed some of the earlier discussed issues that taking a more human-centred approach to optimisation can address.

Currently, work is ongoing within the collaborative intelligence for safety-critical systems (CISC) project to investigate experimentally the impact of the discussed critical elements in this paper, taking operators' cognitive states into account. Future work includes process safety analysis using selected process safety events and data collected from the experimental studies.

Acknowledgments

This work has been done within the collaborative intelligence for safety Critical systems project (CISC). The CISC project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under the Marie Skłodowska-Curie grant agreement no. 955901.

References

Cacciabue, P.C., 1998, Modelling and simulation of human behaviour for safety analysis and control of complex systems, Safety Science, 28 (2), 97-110.

Das L., Srinivasan B., Srinivasan R., 2017, Cognitive Behavior Based Framework for Operator Learning: Knowledge and Capability Assessment through Eye Tracking, Computer Aided Chemical Engineering, Volume 40, 2977-2982.

EEMUA, 2013. EEMUA-191: Alarm Systems – A Guide to Design, Management and Procurement, Engineering Equipment and Materials Users Association, London, UK.

Groth M. K., Mosleh A., 2012, A data-informed PIF hierarchy for model-based Human Reliability Analysis, Reliability Engineering & System Safety, Volume 108, 154-174.

HPOG Human Performance Oil & Gas, 2021, Best Practice in Procedure Formatting. Retrieved January 30, 2023, from hpog.org/resource-centre/best-practice-in-procedure-formatting/

ISO 11064-7:2006(en) Ergonomic design of control centres — Part 7: Principles for the evaluation of control centres.

ISO/TR 11064-10:2020(en) Ergonomic design of control centres — Part 10: Introduction to the control room design series of standards.

ISO 9241-110:2020(en) Ergonomics of human-system interaction — Part 110: Interaction principles.

Iqbal M. U., Shahab A. M., Choudhary M., Srinivasan B., Srinivasan R., 2021, Electroencephalography (EEG) based cognitive measures for evaluating the effectiveness of operator training, Process Safety and Environmental Protection, Volume 150, 51-67.

Joshi, R., and Daum, B., 2018, Human Factors in Design of Control Rooms for Process Industries.

Krauss L. H., Bostian W. C., and Raab H. F., 1980, Solid State Radio Engineering, New York: J. Wiley & Sons.

Lefevre K, Arora C, Lee K, Zaslavsky A, Bouadjenek MR, Hassani A, Razzak I., 2022, ModelOps for enhanced decision-making and governance in emergency control rooms, Environment Systems and Decisions.

Li X., McKee D.J., Horberry T., Powell M.S., 2011, The control room operator: The forgotten element in mineral process control, Minerals Engineering, Volume 24, Issue 8.

Morais C., Yung K., Johnson K., Moura R., Beer M., Patelli E., 2022, Identification of human errors and influencing factors: A machine learning approach, Safety Science, Volume 146, 105528.

Nachreiner F., Nickel P, Meyer I., 2006, Human factors in process control systems: The design of human-machine interfaces, Safety Science, Volume 44, Issue 1, 5-26.

Naito T., Takano N., Inamura E., Hadji A., 2011, Control Room Design for Efficient Plant Operation, Yokogawa Technical Report (English Edition). Vol. 54, 46-49

Stanton, N.A., Salmon, P., Jenkins, D., & Walker, G., 2009, Human Factors in the Design and Evaluation of Central Control Room Operations (1st ed.), CRC Press, doi.org/10.1201/9781439809921.