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Envisioning Human-Automation Interactions for Responding Emergency Situations of NPPs : a Viewpoint from Human-Computer Interaction

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1. Introduction

With the development of automation technologies including recent algorithms of artificial intelligence, there have been many efforts for introducing such technology into nuclear systems [1]. Those new automation technologies are expected to improve some parts of the limitations in the nuclear safety, which has been considered vulnerable from human cognitive characteristics. However, interactions between human agents and new automated systems are crucial to the plant system performance and reliability [2]. This is related to the fact of that fully-automated systems without collaboration with a human does not always ensure perfect responses to all emergency situations in nuclear power plants (NPPs). Most recent algorithms depend on the accumulated data; hence, the quality of algorithms is also associated with the quality of data [3]. For emergency or severe situations, disclosed data are so rare and lots of uncertainties are involved in the information. The plant parameters can be thus predicted by simulation models which are expected to embrace model uncertainties or parameter uncertainties [4].

Therefore, it is important to identify potential issues that come from collaborations of human operators and automated systems and to derive considerations of those interactions for optimizing the performance of the human-automation joint system [2]. In this paper, we introduce the issues of system automation and propose significant considerations for designing human-automation interactions using previous research of human-computer interactions or human-robot interactions.

2. Human Performance Issues

Regarding the human performance issues in automated systems, Park and Jung surveyed issues of digitalized control rooms including automation problems [5]. O'Hara and Fleger [2] and Dekker [6] also introduced significant issues of automation. The addressed issues can be summarized as follows.

Reduced situation awareness due to out-of-the-loop in automated system: When the automated system predicts a situation and respond an ongoing situation by excluding a human operator, the operator may not understand why and how the system works. It might be also difficult to notice whether the change of plant systems is attributed to the automated system or not when the automation is not transparent. New systems should aid operators to readily verify their activities [7].

Added complexity for operators to understand: It is also asserted that transparency of automated system is not sufficient to support human operators [8]. This is mainly caused by the task complexity or workloads of operators. New automated systems require operators to understand the mechanism of automated systems and grasp mental models of new systems. This can increase the complexity of the related operators.

Change of tasks with respect to automation: Introducing automation is expected to generate new tasks such as a monitoring task or transform the types of previous tasks.

New sources of workload: Taking monitoring can cause data overload when an automated system produces lots of information or lots of parameter information is being changed.

Skill degradation and loss: The level of skills of human operator can be decreased since automated tasks are seldom performed

Excessive passive monitoring raising vigilance and complacency issues: Some automated functions can transform active executive tasks to passive monitoring tasks. If the automated functions normally work continuously, the operators might feel tedious or lose vigilance of current situations.

New type of human error: As an example, when there is an option to select automation and manual operation, an operator might commit a mode error, which is a failure of understanding the current mode, the way of works in the different modes, the impact of the different modes, or the role of operators.

Human errors during the loss of automation: with respect to the abovementioned issues, the reliability of human operators might be lowered when the automated systems fail. [8,9] showed an interesting example related with this automation issue. In this experiment, when the automated evaluation function of computer-based procedure inappropriately checks plant situations (i.e., the system displayed that the condition in procedure coincided with the plant parameter, but, in fact, they did not coincide), the operators could not identify the false positive error of the automated function.

Trust: In some cases, human operators do not trust new automated systems or be too complacent with the systems. When the human operators do not have willing to use the new systems, they will try to control all initiatives of the human-automation systems [10]. In the opposite case, the operator may have a low alertness.

3. Design Considerations of Human-Automation Interactions

3.1 Task Allocation

Design of interactions between human and automation is based on the assignment of tasks in the joint human-automation systems. Four basic considerations for these assignments were addressed in [11].

- The individual tasks or functions of the joint systems to be achieved for the safety of performance of the nuclear system should be analyzed.
- The limitations and capabilities of human operators who are involved in the operation or maintenance of the system should be considered.
- The limitations and capabilities of the available automation techniques should be understood for implementing the system into NPPs.
- Criteria determining how the tasks or functions are allocated between humans and automated systems should be derived.

3.2 Five Attributes of Human-Automation Interactions

Goodrich and Schultz defined five attributes that are influential to the interactions between human and robot systems [12]. Based on the attributes for the interactions, we suggest considerations of the human-automation interactions.

3.2.1 Autonomy and Interaction

Designing interactions between human and automation is closely related with the level of autonomy. Tom Sheridan distinguished the different levels by the subsequent continuum [13]:

(1) Automation offers no aid; humans do it by themselves.
(2) Automation inquires a complete set of action alternatives.
(3) Automation provides a few choices by narrowing the selections down.
(4) Automation suggests a single plan or action.
(5) Automation executes that action after getting human approves.
(6) Automation allows limited time that the human can veto before it executes automatically.
(7) Automation necessarily informs the human after automatic execution.
(8) Automation executes actions in advance and informs the human only when the human asks.
(9) Automation executes actions in advance and informs only when it decides necessity of a communication.
(10) Automation makes decision makings for all problems and behaves autonomously, ignoring the human.

The interaction strategies can be determined based on the autonomy levels. For example, in the case of the fifth level of autonomy, the system can generate a yes-no question, while it may ask wh-questions during automation in the third level of autonomy [14].

It is notable that the level of autonomy can be differently applied according to the situations or task characteristics [14-16]. Bruemmer et al. [15] presented an example of how unmanned vehicles can have a different initiative of control based on task types (refer to Fig 1). Kim et al. [14], also showed that the level of autonomy and related interactions can be changed by the ambiguity of the problems and interrupt-ability of its user.

Mode of Autonomy	Defines Task Goals	Supervises Vehicle Direction	Motivates Motion	Prevents Collisions
Teleop	*Human*	*Human*	*Human*	*Human*
Safe	*Human*	*Human*	*Human*	*Robot*
Shared	*Human*	*Human*	*Robot*	*Robot*
HLTasking	*Human*	*Robot*	*Robot*	*Robot*
Autonomous	*Robot*	*Robot*	*Robot*	*Robot*

Fig. 1. Initiative chart for the autonomous vehicle (HLTasking: High-level tasking mode) [2]

Adaptive automation, which can dynamically and real-time transfer the level of autonomy in response to situational factors is also proposed for nuclear safety system [2]. For example, a computer-based system can transit its role from aiding human operators to autonomously controlling plant components. Such kind of feature can provide a high degree of freedom to manage the human performance. However, the issues of adaptive automation including workload due to change of autonomy levels, unexpected change, and interruption of autonomous systems should be also resolved.

3.2.2 Information exchanges

For coping with emergency situations, the joint system of human and automation should be aware of the critical information of the ongoing situation and tasks to be conducted. The information to be delivered between two kinds of agents can include the followings at least:

- Causality: In addition to actions to be executed, why the actions should be executed (triggering conditions), what consequences are predicted including time estimated, and how much the suggested actions are convinced could be presented.

- Rules, procedures, and requirements: Because the operators mandatorily follow procedures or requirements, the documentary rules related to the planned actions should be shared.
- Means-ends relation: The goals and means of the suggested or executed actions should be exchanged for correctly understanding behaviors of both agents. The abstraction hierarchy is a good tool for identifying those relations [17]. Fig 2 shows an example of abstraction hierarchies [18].
- Additional vulnerability: The system or component to be protected or monitored for successfully performing the suggested actions should be shown.

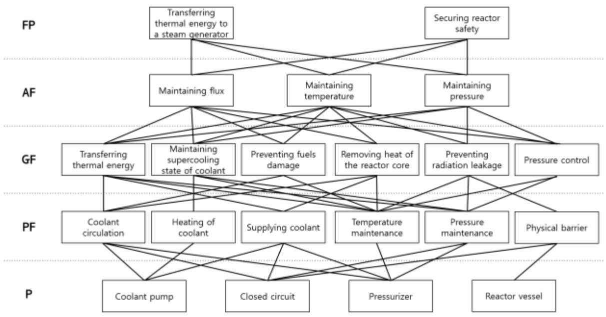

Fig. 2. An example of an abstraction hierarchy (a reactor coolant system) [18]

Several kinds of communication medium can be possible for the human-automation interaction: (1) visual displays such as graphical user interfaces, texts, or virtual reality interfaces, (2) gestures, (3) speech and natural language, (4) non-speech audio including an alert sound, and (5) haptic or physical interfaces. The choice of medium will be conducted with consideration of tasks, control environments, and existing interfaces that used for other purposes. For example, in most emergency situations, it is very urgent, it can be interrupted by annunciated alarms, and many operators send and receive conversations. In this case, the auditory interface may be easy to be ignored or misunderstood by human operators.

3.2.3 Team structure

In main control room environments of NPPs, a single operator or multiple operators can interact with automated systems. In addition, it is also feasible to develop multiple automated systems that cannot only interact with each other but also with operators. These systems can be embedded in the nuclear control systems or be employed as an independent supporting system. For local operations, tele-operative robotic systems can be also developed. In this case, the team structure of control room operator, local operator and teleoperation should be determined.

With respect to the organization of a team in human and automation, the four questions can be considered: (1) who has the authority to make a specific decision?, (2) which level can be used for instructing or commanding automated system: operational, tactical, or strategic?, (3) how a conflict will be resolved when operators and automated systems have different plans?, and (4) how the role of automation can be defined: a peer, an assistant, a slave, or an independent agent? These question should be addressed along with task characteristics, interaction medium, and capabilities of both agents in communication and task performance.

3.2.4 Adaptation, learning, and training

In NPPs, it is important to pursue minimizing training of operators by forming natural interactions. Archetype patterns of behavior or well-known metaphor are useful to generate such interactions. Appropriately training operators is also required. Managing an automated system could be included in training programs. Training automation can be also a useful strategy for enhancing performance. The automated system can adapt the crew dynamics of operation teams or improve the prediction or planning capabilities of itself through collaboration with human operators during simulation or implementation phases.

3.2.5 Shape of the task

Introducing an automation implies that the way to achieve a task will be changed or a new task can be generated. It is important to consider how the changed or generated task might be modified for improving interactions and resolving the abovementioned issues. Several kinds of task analyses, cognitive work analyses, and ethnographic studies can be conducted.

4. Conclusions

The developers of autonomous systems are required to consider the need to collaborate or coordinate with human operators [19]. However, compared with a huge amount of research of interactive system in other industries, those interactions in NPPs have not been deliberated [2]. O’Hara and Higgins developed a general guideline for human-automation interactions [20]. In [9, 20], general principles for enhancing human-automation interactions or general recommendations of designing interfaces are described. However, lots of theoretical and/or empirical research about how to realize automatic systems for supporting human operators are needed. Interdisciplinary researches will be carried out for these applications [11] (Fig. 3)

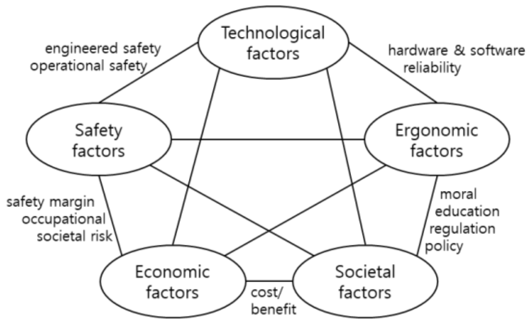

Fig. 3. Factors influencing human-automation interactions [11]

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