HRA Data for Performance Shaping Factors Reflecting Digital MCR

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Abstract: In this paper, the design characteristics in a digital MCR (Main Control Room) including related HF (Human Factor) issues and operator behavior characteristics of digital environment from a simulator data analysis are described. In addition, HRA (Human Reliability Analysis) data items for UA (Unsafe Act) IGT (Information Gathering Template) to reflect the characteristics of a digital MCR are suggested. Thirteen HRA data items based on the characteristics of a digital MCR such as a computer-based information display system, CPS (Computer-based Procedure System), and SCs (Soft Controllers) are derived and the HRA data items are connected to the category in the existing UA IGT for a conventional MCR. The added HRA data are based on the operators' behavior found from the simulation data. Research to calculate the HEP (Human Error Probability) reflecting a digital environment is being performed by KAERI (Korea Atomic Energy Research Institute) and HRA data items derived from this paper are expected to be applied in the identification of the relation between the UA and PSF (Performance Shaping Factor).

Keywords: HRA data, PSF, Digital MCR

1. INTRODUCTION

A human error is one of the most critical factors affecting the safety of complicated systems such as NPPs (Nuclear Power Plants). Consequently, a huge amount of effort has been made to reduce the possibility of human error, and one of the most tried approaches is to perform an HRA (Human Reliability Analysis) because it allows assessing the risk of a system attributable to human error. Thus, many researches to develop a HRA methodology have been performed. In addition, HRA data are an important prerequisite for improving the HRA quality. The necessity for an HRA database based on real event data or simulator data has increased since it is difficult to perform an HRA owing to insufficient data. Therefore, a number of efforts to collect HRA data using a simulator of an NPP have progressed [1].

In this situation, KAERI (Korea Atomic Energy Research Institute) developed a systematic framework called HuREX (Human Reliability data Extraction) for HRA data collection and analysis to produce a human error probability (HEP) from diverse sources such as simulator recordings and LERs (Licensee Event Reports). In parallel, standardized guidelines used to specify how to gather HRA data from simulator training records were developed, and IGTs (Information Gathering Templates) used for data collection and data analysis were designed [2,3].

IGTs consist of three kinds of data sheets such as Overview, Response, and Unsafe Act (UA) IGTs. An Overview IGT is to collect general information about a plant, crew, and scenario. A Response IGT is for a timeline analysis about operator responses. It is to collect data for what kind of tasks by a crew were performed in chronological order to mitigate a given scenario. A UA, which is defined as an inappropriate human behavior that has a potential for leading the safety of NPPs toward a negative direction, is selected during a Response IGT creation. After UAs are selected, a UA IGT is created for each UA to collect HRA data affecting PSFs (Performance Shaping Factors). This means that data items for a UA IGT are categorized into some representative PSFs such as the time pressure, task familiarity, task complexity, procedure quality, HMI (Human Machine Interface) and information quality, and communication quality [4].

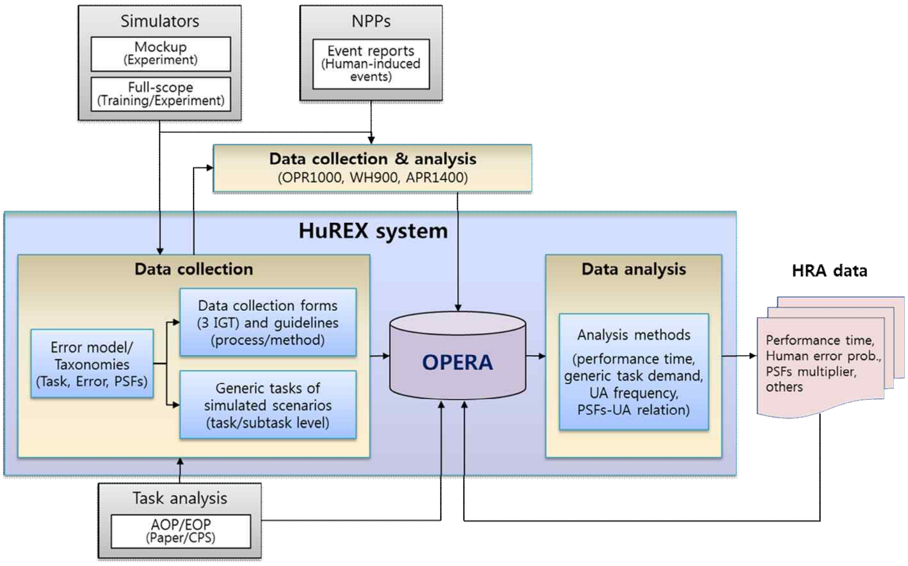

Figure 1: HuREX Framework

Based on the HuREX framework, KAERI successfully extracted a set of HEPs for 21 generic task types from audio-visual records that were collected from full-scope training simulators equipped with conventional MCRs (Main Control Rooms). However, recently, another issue has been raised in the extraction of HRA data because the use of up-to-date digital technologies is typical in the development of MCRs in NPPs. In Korea, there are NPPs that use a digital MCR. Therefore, a research project to develop HEPs and extract HRA data using a simulator at the APR 1400 (Advanced Power Reactor 1400MWe), which has a digitalized MCR, was launched in 2016. To this end, we investigated the HuREX framework and newly derived HRA data items that can reflect the digitalized environment because the project has been performed based on the HuREX framework.

The purpose of this paper is to describe the characteristics in a digital MCR and operator behavior characteristics of a digital environment from simulator data and suggest data items for UA IGT to reflect the characteristics of a digital MCR.

2. CHARACTERISTICS OF DIGITAL MCR

2.1. Environment of Digital MCR

A digital MCR has characteristics those are totally different from conventional MCRs, as shown in Figure 1.

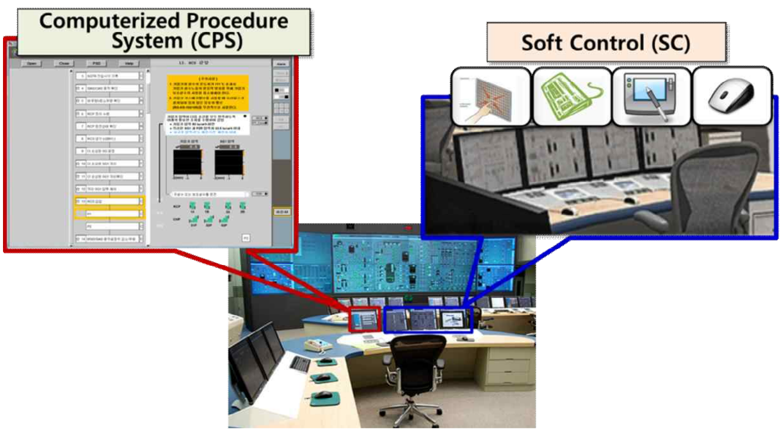

Figure 1: Design Features in Digital MCR

A digital MCR in an APR1400 consists of new significant HMIs such as a workstation-based IPS (Information Processing System), LDPs (Large Display panels), SCs (Soft Controls), an advanced alarm system, and a CPS (Computer-based Procedure System). An LDP is designed to provide plant-level overview information and essential safety information in the fixed area to determine the overall plant status. A CPS provides all instructions of operating procedures directly on each operators' monitors and supports links to the related information systems. An inter-operator procedure operation progress can be shared among the crew through the CPS. An SC is responsible for controlling equipment and is divided into safety class soft controllers and non-safety class soft controllers. As such, researches have been carried out on HF (Human Factor) issues concerning the design of digital MCRs, which have changed a lot from plant information to device control [5]. They are as follows:

Table 1: Human Factor Issues in Digital MCR

Design Element	HF Issue	Description
Computer based information display system	Information Overload	• Overlapping windows • Too much information • Faster information than visual process of human
	Interface management tasks	• Navigation task before the primary task • Losing the information because of secondary task under workload condition
Computerized procedure	Team performance	• Breakdown in communication between operators
	Situation awareness	• Reliance on computerized procedures
	Level of automation	• Automation level
	Keyhole effect	• The limitation of parallel processing
	CPS failure in complex situation	• The conversion to paper procedures
Soft controller	Unintentional activation	• Unintended activity
	Description errors	• Error by ambiguous information
	Mode errors	• Mode error
	Disordering the components of an action sequence	• Skip, repetition, and reverse
	Capture error	• Confusion with the task performed infrequently
	Loss of activation errors	• Errors induced by the limited memory of operator

2.2. Characteristics of Operator' Behaviors in Digital MCR

For a preliminary study to quantify HEPs reflecting a digital MCR, we analyzed APR1400 simulation recordings to select the UAs. From this study, we realized that there exist operator' behavior characteristics reflecting a digital environment. We categorized the characteristics into tasks related to digital device types.

- Information gathering from a computer based information display system
  - One of the most noticeable characteristics is that SSs (shift supervisors) are able to check the plant status by themselves using process variables and alarms on LDP or IPS, while they asked BOs (board operators) to check the plant status in conventional MCRs. In a digital MCR, some SSs instruct BOs to check the process variables as used in a conventional MCR, and other SSs check the process variables directly first, and then confirm the status with the BOs. The rest check on their own without asking questions before performing the following operations.
  - With the effects of the visibility of values from digital indicators, operators are able to measure the process variables clearly and confirm their trend effectively using graphs on the operator console, although they should estimate a process parameter trend from a log sheet of

analog indicators and the time span for measuring the trend was short owing to the operators' ability to identify the trend from the log sheet.
  - When a process variable indicator is not located on the LDP, the operators are sometimes confused to find its location of the indicator on their console to check the related plant status. In addition, operators are confused to find an alarm to check because alarms are installed in various locations such as the LDP and operator console.
  - Operators can detect a situation in which a component is manipulated by another operator. Thus, the number of reports by the BOs regarding a component manipulation are increased compared to the case of a conventional MCR.

- Component manipulation with soft controllers
  - Operators should find an appropriate screen where the component that needs to be operated is located using an interface management task such as navigation.
  - Because the type of devices to manipulate a component are significantly different from the conventional MCR, several operators are confused to use soft controls, in particular during continuous controlling.

- Procedure operation with CPS
  - In a digital MCR, a CPS significantly affects an operation following procedure. One of them is that several operators can view the same procedure at the same time. Thus it is allowed to perform a cross checking between operators for a procedural operation.
  - Operators benefit from the automation functions provided by the CPS. For instance, the CPS will not require operators to perform logic calculation directly.
  - As a characteristic of the CPS design in Korea, it is necessary to perform a procedural operation more carefully. For example, there exists a hold step in an emergency operating procedure (EOP), which is capable of advancing to the next step after the operation condition required in a step of the EOP is fully performed.
  - When a CPS is not available to operators owing to its failure, a CPS operation should be switched to a paper procedural operation rapidly, which is kept in MCR for backup. As such, operators were required to operate more carefully owing to the loss of automation provided by a CPS, such as logic processing and highlighting.

3. HRA DATA REFLECTING DIGITAL ENVIRONMENT FOR UA IGT

A UA IGT is to collect HRA data affecting PSFs. This means that data items for UA IGT are categorized into some representative PSFs such as the time pressure, task familiarity, task complexity, procedure quality, HMI and information quality, and communication quality. We developed 45 HRA data items for a UA analysis from simulations in conventional MCRs, and collected related data to identify the relation between UA and PSFs as shown in Table 1.

Through the preliminary study to quantify HEPs for a digital MCR, we realized that UAs have occurred reflecting the characteristics of the digital environment, from which we need to consider HRA data for PSFs. In this paper, we suggested HRA data for UA IGT to reflect the characteristics of digitalized devices and operator behaviors in a digital MCR, as mentioned in Section 2.2. Table 3 shows the added HRA data for the UA IGT grouped by design element in a digital MCR.

Table 2: HRA Data of UA IGT for Conventional MCR

Category	HRA Data
UA information	UA code
	UA overall description
	UA type
	UA effect
	Effected component type
	Effected system type
	Recovered UA
	Recovery timing
	Related UA Code
UA Initiator	UA performer
	Related operator (causality)
Plant/ system state	Failed system/ component
	Failed alarm/ indicator/display
	Failed switch/controller
Time pressure	Time pressure
Task familiarity	Task familiarity
Task complexity (diagnosis)	UA occurred during the performance of a contingency action part
	The type of state identification
	Note or caution
	Change of procedure strategy
	Procedure conformity
Task complexity (execution)	Number of detailed instructions
	Number of manipulations
	Component manipulation mode
	Continuous action step
Procedure quality (clarity)	Confusing statement
	The number of conditional statements
	Multiple constraints
	Clarity of decision-making criteria
Procedure quality (description level)	Description of object
	Specification of means
HMI & Information quality	Information clarity
	Feedback information
Communication quality	Procedure compliance
	Precise instruction
	Controversial expression
	Standard terminology
	Communication level
	Reporting omission with respect to unauthorized manipulation
Recovery information	Recovery code
	Recovery description
	Recovery worker
	Time to recovery
	Recovery cue
	Recovery Initiator

Table 3: Added HRA Data of UA IGT to Reflect Digital MCR

Design Element	HRA data	HRA Data Attributes	Category of UA IGT
Computer based information display system	The type of SS's information gathering	- Independent confirmation w/o direction to BO - Direction to BO - Notification to BO after independent confirmation	Task complexity (decision-making)
	Information on LDP	- Y or N	HMI & Information quality
	The type of alarm display	- Alarm on dedicated alarm (alarm tile) - Alarm on process mimic display - Alarm on alarm list only	HMI & Information quality
Computerized procedure	Logic of the state identification or instructions	- NOT / - AND / - OR - NOT & AND - NOT & OR - AND & OR - NOT & AND & OR - Simple Statement (No Logic)	Task complexity (decision-making)
	The procedure type	- Paper based procedure - Computer based procedure - Back up procedure	Task complexity (execution)
	Key step	- Y or N	Task complexity (execution)
	Hold step	- Y or N	Task complexity (execution)
	The number of procedures performed at the same time	- 0, 1, 2, 3…	Task complexity (execution)
	Design consistency of back up procedure	- Y or N	Procedure quality (Clarity)
	CPS-IPS direct link	- Y or N	HMI & Information quality
	CPS automation level	- 1 (Manual Operation) - 2 (Shared Operation) - 3 (Operation by Consent) - 4 (Operation by Exception) - 5 (Autonomous Operation)	HMI & Information quality
Soft controller	The type of control device for component manipulation	- Conventional device - Mouse (non-safety) - Mouse+ESCM*(safety) - Device on safety console	Task complexity (execution)
	The number of screen changes to the proper control device	- 0, 1, 2, 3…	Task complexity (execution)

*ESCM: ESF-CCS (Component Control System) Soft Control Module

4. CONCLUSION

KAERI developed a systematic framework called HuREX (Human Reliability data Extraction) for HRA data collection and analysis to produce a HEP from diverse sources such as simulator recordings and LERs. In addition, IGTs for data collection and a data analysis were designed. Based on the HuREX framework, KAERI successfully extracted a set of HEPs for 21 generic task types from audio-visual records that were collected from full-scope training simulators equipped with conventional MCRs. However, recently, another issue has been raised in the extraction of HRA data because the use of up-to-date digital technologies is typical in the development of MCRs in NPPs. Therefore, a research project to develop HEPs and extract HRA data using a simulator in the APR 1400 of Korea which use a digitalized MCR was launched.

In this paper, we described the design characteristics in digital MCR including related HF issues and operator behavior characteristics of a digital environment from a simulator data analysis, and suggested HRA data items for UA IGT to reflect the characteristics of a digital MCR. We derived 13 HRA data items based on the characteristics of a digital MCR, such as a computer based information display system, CPS, and SCs, and connected the 13 HRA data items under the category of the existing UA IGT for a conventional MCR. The added HRA data are based on the operator' behaviors found from the simulation data.

In a further analysis, we investigated more various HF issues through a literature survey and discussed additional HRA data items. For example, several researches insisted on the issue of operator' fatigue owing to the digitalized device in a digital MCR however, we did not consider the issue. Therefore, we plan to continue to modify or add HRA data items through a further simulation data analysis.

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