Comparison of Task Loads between Usages of Computer-based Procedures in an Advanced Control Room

Yochan Kim[a*], Wondea Jung[a], and SeungHwan Kim[a]
[a]Korea Atomic Energy Research Institute, Daejeon, Republic of Korea

Abstract: With the development of a computer-based control room in an APR1400, the behaviors of operators in the control room have changed. To investigate the effects of the computerized instrument and control systems on workloads, the workloads of operators in an APR1400 who employ three different usages of a computer-based procedure were compared. The COCOA framework, a task-loading approach of workload evaluation, was employed to evaluate the workloads, and some statistical analyses were conducted to compare them. We performed a total of 22 experiments in a full scope simulator of an APR1400 under LOCA and SGTR scenarios, and obtained workload scores in cognitive, communicative, and operative dimensions. The results showed that the SS-centric usage requires many activities to the SSs, and the other usages require fewer activities to the SSs than the SS-centric usage. Based on the findings, we discussed whether the workloads between operators in an MCR can be adjusted by the CPS usages.

Keywords: Computer-based control room, Computer-based procedure, Workload, COCOA.

1. INTRODUCTION

With the development of a computer-based control room in an APR1400 (Advanced Pressurized Reactor-1400), the behaviors of operators in the control room have changed. Main human-system interfaces of a computer-based control room include an advanced alarm system, computer-based procedure (CBP) system, and graphic display system [1]. Because operators interact with the plant system using digital devices such as touch screens or mice, it is certain that the behaviors of the operators differ from the behaviors in conventional control rooms.

However, Kim et al. indicated that digitalized interfaces can also affect the cognitive tasks or activities of operators [2]. For example, shift supervisors (SSs) in a computer-based control room can directly notice or monitor plant information from workstation-based information systems or a large display panel; hence, the SSs can accurately understand the plant situation without a report from the board operators (BOs). Meanwhile, the new features of digitalized control rooms may demand new operative tasks, which have not yet been performed in conventional control rooms. For example, the control room of an APR1400, which is a computer-based control room, requires SSs to follow a CBP by clicking on every instruction. Because clicking and following the CBP is a new and additional task to SSs who manage the overall situation of a plant, it is possible for SSs to have a higher workload than other operators and SSs in conventional control rooms.

In this paper, we compared the workloads of operators in an APR1400 who work with three different usages of the CBP. The first usage is similar to the method used when operators in conventional CE-based plants usually follow an emergency operating procedure. Using the first usage, only the SS checks all instructions of the CBP line by line and directs actions to the other operators. The second usage appoints each BO as a manager of the selected steps. Instructions in each step of the procedure are then conducted and checked by the appointed BOs in the CBP. After a BO checks all instructions of the step, the SSs simply review the behaviors of the BO during the step and progress to the next step. The third usage requires an SS to simply check only the key steps in the procedure. The SS commits the progression of the procedure to the appointed BOs in the CBP and checks the BO's operations during the key steps. The workloads of the operators were compared by the COCOA (cognitive, communicative, and operative activity) framework [3]. The COCOA framework, a task-loading approach of workload evaluation, calculates the operator's workloads based on a task analysis or experiments. We conducted a total of 22 experiments in a full scope simulator of an APR1400 under LOCA (Loss of coolant accident) and SGTR (steam generator tube rupture) scenarios, and obtained the workload scores in cognitive, communicative, and operative dimensions.

The remainder of this paper is organized as follows. Section 2 introduces techniques including the COCOA framework to evaluate the operator workloads. Section 3 explains the experimental environment and CBP usages to compare the workloads in different CBP usages. Section 4 shows the results of the comparison. Section 5 discusses insights regarding the distribution or balance between the operator workloads.

2. RELATED WORK

The techniques used to evaluate a workload can be categorized by self-assessment or subjective rating scales, performance measures, psychophysiological measures, and task-loading measures [4, 5]. The subjective rating scales assess the feelings of the workload, effort, mood, or fatigue based on self-reported rankings or scales. Although various scales have been used, the following scales are primarily addressed from the literature: NASA-TLX (NASA task load index), SWAT (subjective workload assessment technique), MCH (modified cooper harper scale), ZEIS (sequential judgment scale), and so on. The performance measures evaluate how well a subject performs the given task using the performance time, error or success rate, or response latency. To analyze the margin of mental resources and elevate the diagnosticity of the measures, the subjects are sometimes demanded to perform additional tasks. Psychophysiological measures are used to calculate the physical responses of the body of a subject. Cardiac activity, brain activity, respiratory activity, speech measures, or eye activity are used to evaluate a workload. The task-loading measures are used to analytically evaluate the demands of given tasks using mathematical modeling, task analyses, simulation modeling, or expert opinions.

The COCOA framework was developed to sensitively evaluate the workloads of operators in digitalized systems and explicitly compare the workloads between operators who collaborate as a team [3]. This framework provides the taxonomy of activities conducted by operators in computer-based control rooms. Three dimensions of activities are defined in Table 1 below. The cognitive activities are defined using task definitions of the CORA method [6]. The communicative activities were obtained by selecting frequent activities from the speech-act code scheme [7]. In addition, the operative activities were established based on a task analysis of the operations in the control room of an APR1400.

Table 1: Operator activities of COCOA framework

Dimension	Activity	Description
Cognitive activity	COMPARE	Comparing two or more entities of system states.
	DIAGNOSE	Recognizing or determining the cause of the system states by signals or parameters.
	EVALUATE	Checking a system state with consideration of other system parameters or states
	EXECUTE	Performing a single prescribed action (ex. open, close, turn on, etc.)
	MAINTAIN	Sustaining a specific system state by executing or regulating systems.
	MONITOR	Continuously observing the system states or parameter.
	RECORD	Writing down or logging the system states or events.
	REGULATE	Changing the quantity, speed, or direction of the system parameters or states.
	VERIFY	Checking an entity of system states
	SCAN	Briefly reviewing specific system states by displays or other information
	PLAN	Formulating a path to achieve specific goals.
	IDENTIFY	Recognizing the overall state of a specific system.
Communicative activity	COMMAND	Ordering an operator to execute or regulate a system or component.
	COMMAND-ACK	Informing whether a listener understood a command.
	INQUIRY	Asking about system states or parameters.

	REPLY	Answering a question.
Operative activity	SWITCH_SCR	Altering a display screen to read or operate specific parameters or states.
	OPEN_CTRLPNL	Opening a control panel to operate a specific system.
	CLOSE_CTRLPNL	Closing a control panel that has been opened.
	CLICK_EXECUTE	Pushing a button to operate a single entity (ex. opening a valve)
	CLICK_REGU_UPDN	Pushing a direction button to regulate a system parameter or state (ex. opening a valve)
	CLICK_REGU_FASTUPDN	Pushing a double-direction button to regulate a system parameter or state (ex. opening a valve)
	CLICK_ENABLED	Pushing a button to enable a control panel to be usable.
	CLICK_MANNUAL	Pushing a button to manually operate a single entity.
	CONF_STEP	Clicking a button confirming that all instructions of a step have been completed.
	CONF_SUBSTEP	Clicking a button confirming that an instruction of a step has been completed.
	ACK_ALARM	Checking and silencing a notifying alarm
	CONF_CHANN	Pushing a button to verify the channel of an entity to be operated.

In this study, the numbers of activities that operators conducted during the experiments were counted. First, which activities can be used was identified from the required procedures. Who conducted the activities were then analysed by audio-video records. To calculate the numbers of operative activities, all operative behaviours of crews were also tracked using the video records.

3. METHOD

3.1. Control Room of APR1400

The APR1400 is a CE-type nuclear power plant, which was developed based on the OPR1000 (Optimized Power Reactor-1000) design. Hence, there are similarities between the two plants. First, the crew in a main control room consists of five members: SS, RO (reactor operator), TO (turbine operator), EO (electric operator), and STA (shift technical assistant). Most responsibilities of each member between the two plants are also similar. When an emergency situation occurs, an SS generally follows the procedures and instructs the BOs including RO, TO, and EO to obtain information or take an action for coping with the situation. The BOs then inform the plant situations or execute the actions as the SS instructed. In this study, who follows the procedure, an issue related to CBP usages, can be changed in the experiment design, as described in section 3.2. An STA usually manages the critical safety functions of the plant. In addition, the contents of the emergency operating procedures of the APR1400 and OPR1000 are quite similar.

Because the APR1000 employs a computer-based control room, all operators use a workstation-based information system. Each operator obtains information from four personal displays, a large display panel, or advanced alarm system. One of the four displays is dedicated to an operating CBP system. All operators control the system status, parameters, or CBP system by clicking mice or touch screens.

The example of CBP screens can be seen in figure 1. When an operator who controls the CBP enters a step, the CBP shows instructions of the steps in the right part of it. After the CBP controller performs an instruction and clicks the instruction, the CBP then highlights the box with a black circle. If all instructions are checked and black circles are shown the instructions, the controller can click the ‘complete’ button, which is in the lower part of CBP. After the controller reviews what they did and clicks the complete button, the CBP shows the next step.

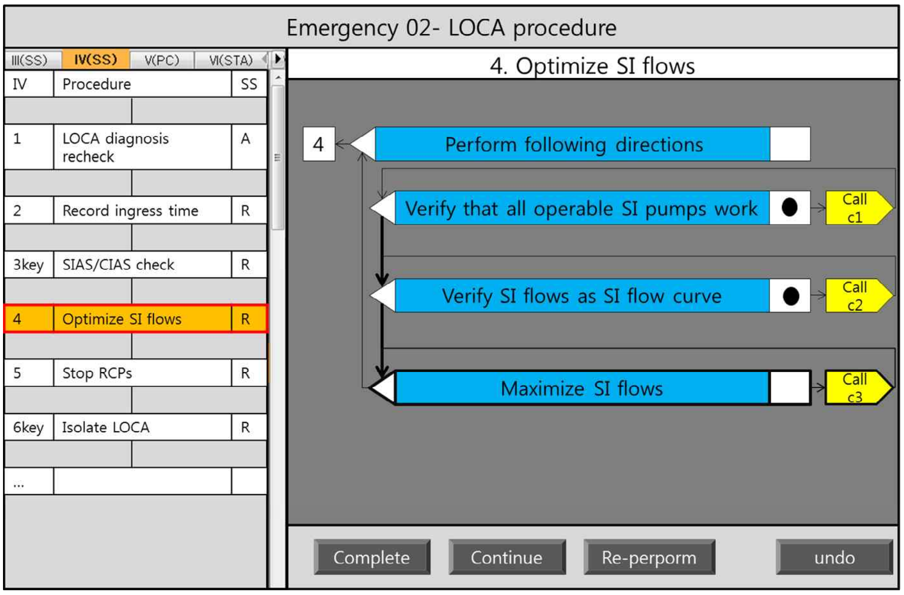

Figure 1: Snapshot of CBP system (conceptual image)

3.2. CBP Usages

Twenty-two experiments were conducted to compare the workloads of operators according to the CBP usages. Currently, the reserved operators of the APR1400, who are participants of these experiments, use the SS-centric usage, which has been used in many conventional control rooms. That is, only an SS manages the CBP including the clicking activities, while the BOs simply follow the SS's directions. The BO-SS-collaborative usage, which is newly proposed for this study, requires an SS to ingress a new step and entrust a BO with conducting the instructions of the step. The BO-centric usage lets the BOs manage most steps of the CBP, and an SS simply reconfirms the BOs work during key steps. Table 2 summarizes the difference between the CBP usages. It is noticeable that an SS can interrupt the behaviors of other operators and manage the CBP at any time, if necessary, even when a BO manages the step under BO-SS collaborative or BO centric usage. In addition, the BOs should announce what they did when they click an instruction of the CBP.

Table 2: Three CBP usages

Usages	Role of SS about CBP control	Role of BO about CBP control
SS-centric (current usage)	An SS checks and progresses all sentences of CBP.	BOs monitor CBP screens and follow the SS's directions.
BO-SS-collaborative (newly proposed)	An SS initially instructs to a BO to check a step. After the BO checks all instructions of the step, the SS review the CBP.	After the SS's initial announcement, the BO checks and performs the instructions written in the given step.
BO-centric (newly proposed)	When progressing to a key step, An SS reviews results come by the previously performed steps and instructs things to do until the next key step to BOs.	Until the next key step, the appointed BO verifies all checkpoints of CBP and performs the instructions of procedures.

3.3. Experimental Design

Experiments in a full-scope simulator were conducted under the following conditions.

- Independent variable: CBP usage
- Dependent variable: workload analyzed by COCOA method
- Participants: reserved operators of APR1400
  - Three teams in experiments for SS-centric usage
  - Five teams in experiments for BO-SS-collaborative
  - Three teams in experiments for BO-centric usage
- Scenario:

- LOCA (performing all steps of standard post trip action and diagnostic procedure and steps number 1 through 18 of LOCA procedure)
- SGTR (performing all steps of standard post trip action and diagnostic procedure and steps number 1 through 16 of SGTR procedure)

The quantity of operator activities for each CBP usage was compared with activities of other usage. In addition, a statistical analysis with a one-way ANOVA followed by Duncan's post hoc test ($P < 0.05$). The ANOVA and Duncan tests appraise which groups have different averages with others.

4. RESULTS

The activity frequencies of operators during both LOCA and SGTR are depicted in figures 2 and 3. The blue, red, and green bars indicate the average frequencies of SS-centric, BO-SS-collaborative, and BO-centric usages, respectively. The annotated terms, such as SD (significantly different) and NSD (not significantly different), indicate that the quantities of two bars that the terms indicate are statistically equal or not. The NSDs over tailed range marks imply all frequencies under the marks are not statistically different.

From the resulted values of the workloads, we obtained the following findings:

- With the SS-centric usage, the SSs conducted many cognitive, communicative, and operative activities than other operators.
- The BO-SS collaborative and BO-centric usages significantly reduced the SS's cognitive and operative activities than the SS-centric usage.
- The RO's activities during the BO-SS collaborative and BO-centric usages are larger than activities during the SS-centric usage.
- Significant differences between workloads caused by the BO-SS collaborative and BO-centric usages were not found.
- The TOs conducted more cognitive and communicative activities during the SGTR than the LOCA situation.
- The EOs generally conducted fewer activities than other operators and were not affected by the CBP usages.

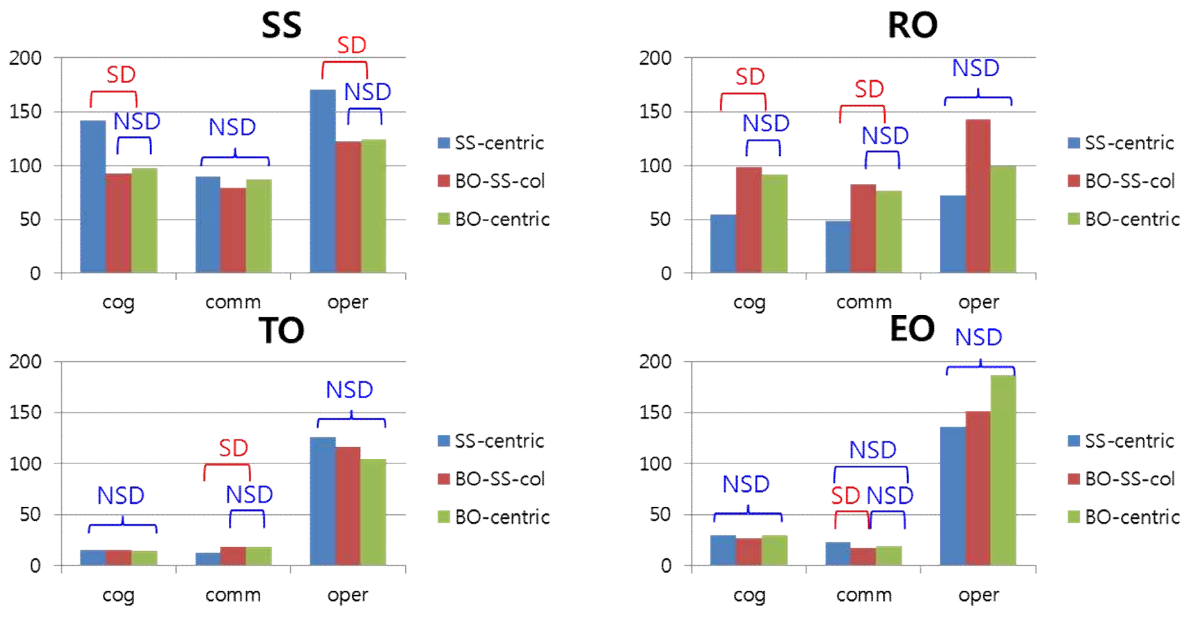

Figure 2: Difference between activity frequencies of CBP usages during LOCA scenario

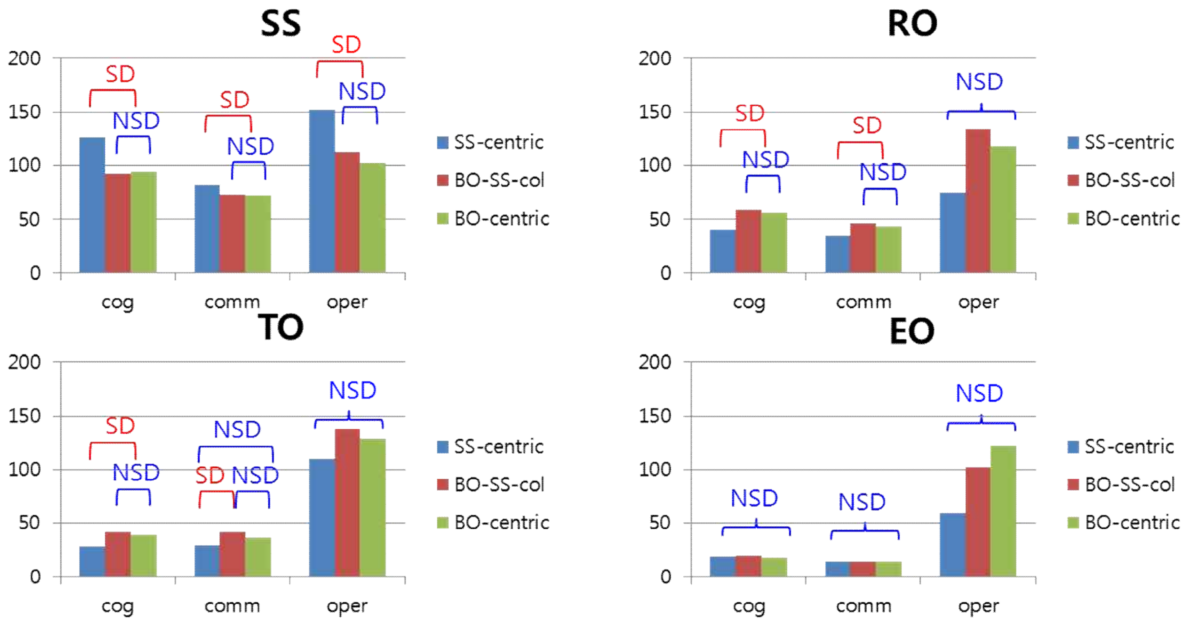

Figure 3: Difference between activity frequencies of CBP usages during SGTR scenario

5. DISCUSSION

It was found that the SS-centric usage requires many tasks of SSs. This is because controlling the CBP carries many operative activities as well as cognitive activities. It is not clear to insist which usage is a better or worse strategy than another, because this issue depends on the capability of the operators. It is noticeable that the COCOA framework evaluates workloads coming from given tasks rather than a lack of subjective knowledge, experience, or ability. However, it is also obvious that the SSs of SS-centric usage, which should incessantly identify the overall situations of the plant, have too many activities related to the CBP.

Thus, it is important that the other usages decreased the SS's activities. During the LOCA scenarios, the levels of SS activities were similar to the RO activities in the BO-SS collaborative and BO-centric usages. During SGTR scenarios, the RO and TO activities were similarly increased in both usages. These results imply that completely or partly entrusting BOs with CBP control transfers the task loads of SSs to BOs. The BO-SS collaborative and BO-centric usages enabled the SSs to manage the overall situations of the systems.

Although it seems reasonable that the BO-centric usage transfers more SS's activities to BOs than the BO-SS collaborative usage, the transferring effects were not much different. The ANOVA and Duncan tests also revealed that all types of activities of all operators between the BO-SS collaborative and BO-centric usages are not significantly dissimilar. This is because the SSs of BO-centric usage also needed to continuously monitor procedure progressions and the task loads of monitoring works were similar to the task loads during the BO-SS collaborative usage.

The differences between activity frequencies of TOs in LOCA and SGTR scenarios are probably affected by the differences of task characteristics of both scenarios. The SGTR requires more turbine- or secondary-loop-related activities than the LOCA situations. This reason provides a similar insight about why the activity frequencies of EOs were lower than for other operators. The LOCA and SGTR scenarios did not demand many activities of EOs. Station blackout or loss of offside power scenarios may show different results.

6. CONCLUSIONS

We evaluated the workloads of operators in a computer-based control room by the COCOA method, which was recently developed. Three types of CBP usages were defined and the effects of these usages on the workloads were investigated. The obtained results showed that the workloads between operators in a control room can be reassigned according to the CBP usages. Newly proposed ergonomic features can enhance the operator's efficiency or accuracy. However, in certain cases, these features can incur additional efforts or workloads of the operators. To prevent excessive workloads on specific operators, it is necessary to consider a reallocation of operative tasks, a customization of the interfaces, or system education. We believe that the results of these evaluations may provide an empirical basis of this consideration.

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