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# Estimation of Operator's Required Time using Monte Carlo Simulation and Experiments

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## 1. Introduction

Operator's required time refers to the duration of time that is required for operators to perform a task, while time available is the time period within which the operators should perform a task. The estimation of operator's required time is required in several human factors-related activities for nuclear power plants (NPPs). For instance, NUREG-0711 [1], which provides a guideline for human factors engineering program, addresses that the task analysis should estimate the time required to perform tasks, especially, for important human actions. In addition, the analysis of required time is necessary for crediting manual operator actions in diversity and defense-in-depth (D3) analyses [2]. The required time is also used for estimating human error probabilities (HEPs) in the Human Reliability Analysis (HRA). Human Cognitive Reliability (HCR) method that is an HRA approach considers the time required for estimating the HEPs of diagnosis tasks [3].

However, the estimation of operator's required time is complicated because many factors can affect it, for example, operator's capability and difficulty of task. Thus, operator's required time has often been estimated by structured interviews with instructors, operators, and other knowledgeable experts instead of actual data [3], while the time available is usually estimated by specific approaches, e.g., thermo-hydraulic analysis.

This study presents an approach to estimating operator's required times by using Monte Carlo simulation and experiments. First, we define task units in the emergency operation. Task unit refers to a task element that operators should carry out to accomplish a task, such as information searching, step changing in the procedure, identify parameters, performing execution on the controller. Generally, an assembly of task units composes a task, e.g., controlling the steam generator level. Second, required times for task units are collected from an experiment in an APR1400 simulator. Lastly, the operator's required time is estimated through the Monte Carlo Simulation applying the required time for task units measured in the experiment. As an example, this study attempts to estimate the required time for the manual isolation of auxiliary feedwater to the damaged steam generator (SG) in the event of advertent opening of SG atmospheric dump valves (ADVs).

## 2. Definition of Task Units

A total of 16 task units are defined in this study. The task units are elementary subtasks necessary for performing tasks. These task units are identified for the APR1400 main control room (MCR). A task can be regarded as a composition of several task units. Table I shows the definition of task units.

Table I: Definition of Task Units

| No | ID | Definition |
|---|---|---|
| 1 | TI | Acknowledging the event |
| 2 | NP | Opening a procedure |
| 3 | NS | Checking an instruction |
| 4 | TO | Providing a direction to a system operator |
| 5 | NI | Navigating screens in the Information Processing System (IPS) |
| 6 | NQ | Navigating screens in the QIAS-N |
| 7 | NE | Navigating screens in the ESCM |
| 8 | VD | Identifying digital parameters |
| 9 | VT | Identifying trend information |
| 10 | CID | Performing discrete control in the IPS |
| 11 | CIC | Performing continuous control in the IPS |
| 12 | CED | Performing discrete control in the ESCM |
| 13 | CEC | Performing continuous control in the ESCM |
| 14 | CHD | Performing discrete control in the hardware controller |
| 15 | CHC | Performing continuous control in the hardware controller |
| 16 | PT | Moving physically |

## 3. Measuring Required Times for Task Units

An experiment has been designed to collect the data for the required time of task units. Ten scenarios were conducted in an APR1400 simulator, including loss of coolant accident (LOCA), SIAS malfunction, steam generator tube rupture, and safety console operation.

Three retired operators participated in the experiment as subjects. The operation by them are recorded by video and audio recorders. Then, times for task units are collected from the video and audio records. The number of samples for task units ranges from 27 to 561.

Fig. 1 shows the required time for the task unit NP measured from the experiment. The mean time and standard deviation were 12.60 sec and 3.55 sec, respectively.

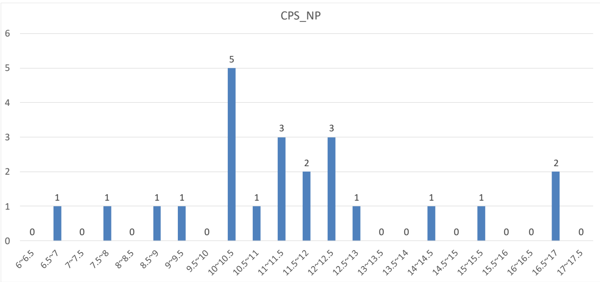


Fig. 1. Required time for the task unit NP

### 3. Monte Carlo Simulation

A Monte Carlo simulation has been performed to estimate the required time for operator's tasks. In this study, an operator action, i.e., isolation of auxiliary feedwater to the damaged SG in the advertent opening of ADV, was analyzed. Chapter 15 in the safety analysis report says that the operator performs the action in 50 min after the initiation of the event.

For the Monte Carlo simulation, a simulation software called ARENA has been used. ARENA is a discrete event and automation software developed by Rockwell Automation.

This study modeled the operating procedure that the operator needs to follow to perform the action. In the scenario, the operator identifies the abnormal situation based on the plant information and trip the reactor manually. Then, the operator carries out the standard post trip action procedure and decision action procedure and then enters the emergency operation procedure for excessive steam dump event (ESDE). In the ESDE procedure, the operator isolates the damage SG. The isolation of auxiliary feedwater is one of actions required for isolating the damaged SG. Fig. 2 shows the ARENA model for the operator action based on the number of task units necessary to perform the action. It is assumed that the distribution of task unit's required time follows the normal distribution.

Table II presents the result of 20,000 times simulation for the estimation of operator's required time for the action. The average was 1540 sec, i.e., about 25 min. Ninety percent of simulation results was located within 1585 sec. Fig. 3 also shows the distribution of simulation result. From the simulation result, it can be concluded that the isolation of auxiliary feedwater to the damaged SG can be performed within 50 min after the initiation of event.

Table II. Simulation Result

| Average | Min | Max | 90% |
|---|---|---|---|
| 1540 sec | 1398 sec | 1683 sec | 1585 sec |

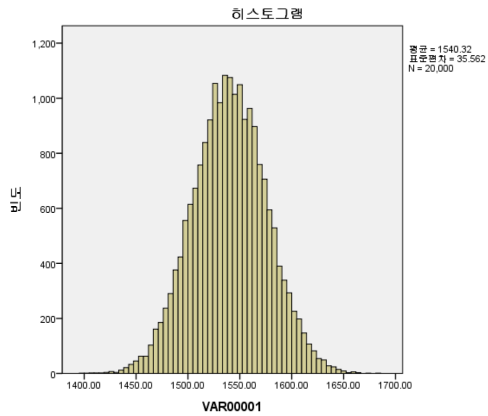


Fig. 3. The distribution of simulation result

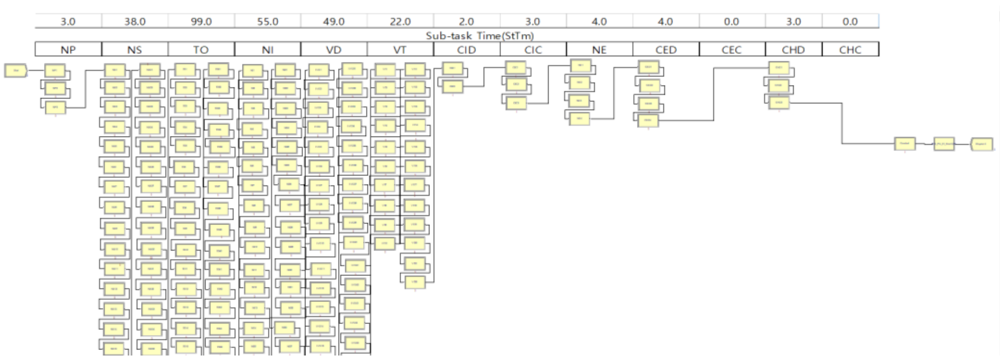


Fig. 2. ARENA modeling for the isolation of auxiliary feedwater to the damaged SG

## 4. Discussion

This study suggested an approach to the estimation of operator's required time based on the Monte Carlo simulation and experiments. In order to apply this approach to the analysis of human factors engineering in NPPs, the following limitations should be noted.

- The result of this study is not representative for the APR1400 operators. The result can be relevant only for the operators who have similar experience and knowledge to participants of experiment.
- The approach is not applicable for the all the tasks in the APR1400. The result may be applicable to the scenarios that have been tried in the experiment.
- The simulation is the simple sum of task unit times. Thus, it does not consider the following performance shaping factors in the scenario: operator's stress, complexity of scenarios, integrity of procedure, adequacy of human-system interface, experience and training. In addition, the timing effect of scenarios, i.e., the require time for the same procedural step may be different according to the initiating event, is not considered.

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