Reliability Engineering and System Safety 163 (2017) 1–13

Contents lists available at ScienceDirect

Reliability Engineering and System Safety

journal homepage: www.elsevier.com/locate/ress

A classification scheme of erroneous behaviors for human error probability estimations based on simulator data

Yochan Kim*, Jinkyun Park, Wondea Jung

Integrated Safety Assessment Division, Korea Atomic Energy Research Institute, 111 Daedeok-daero 989 Beon-gil, Yuseong-gu, Daejeon, Republic of Korea

ARTICLE INFO

Keywords:
Human reliability analysis
Unsafe act
Human error probability
Simulator data

ABSTRACT

Because it has been indicated that empirical data supporting the estimates used in human reliability analysis (HRA) is insufficient, several databases have been constructed recently. To generate quantitative estimates from human reliability data, it is important to appropriately sort the erroneous behaviors found in the reliability data. Therefore, this paper proposes a scheme to classify the erroneous behaviors identified by the HuREX (Human Reliability data Extraction) framework through a review of the relevant literature. A case study of the human error probability (HEP) calculations is conducted to verify that the proposed scheme can be successfully implemented for the categorization of the erroneous behaviors and to assess whether the scheme is useful for the HEP quantification purposes. Although continuously accumulating and analyzing simulator data is desirable to secure more reliable HEPs, the resulting HEPs were insightful in several important ways with regard to human reliability in off-normal conditions. From the findings of the literature review and the case study, the potential and limitations of the proposed method are discussed.

1. Introduction

The reliability of human operators has been recognized as a determinant factor in socio-technical systems such as nuclear power plants (NPPs), chemical plants, and aviation, where securing the safety of systems is crucial [1–3]. Many types of human reliability analysis (HRA) methods, which produce a human error probability (HEP) for a given task or context, have been developed and implemented as an important aspect of probabilistic risk assessments in complex systems [4]. However, it was recently indicated that the empirical data that supports the basis to validate the HEP estimates is insufficient for the following reasons [5,6]. First, because the reference datasets used with current HRA methods were mostly generated in the 1970s, new data reflecting the state of the art of human error trends according to changes in instrument and control systems and training programs is required. Secondly, solid empirical evidence which supports statistical validations of human reliability estimates is necessary to enhance the transparency of HRA results. Lastly, HEP estimates should be based on a classification scheme that reflects the characteristics of human cognitive process models.

For this reason, several databases have been constructed, as addressed in earlier work [5,6]. For example, the U.S. Nuclear Regulatory Commission (NRC) developed the SACADA (scenario authoring, characterization, and debriefing application) system to collect the human reliability data of licensed operators of full-scope simulators [6]. Via an agreement between the NRC and the company involved, information regarding situational factors and performance results of significant tasks, referred to as training objective elements, is recorded in this system. The context information levels are determined by scenario designers, while the performance results, including the overall performance results, error modes, error causes, error recovery outcomes, scenario end effects, and remediation efforts, are evaluated by the operators using the debriefing information from each simulation. On the other hand, KAERI (the Korea Atomic Energy Research Institute) has also established a data collection framework, the HuREX (Human Reliability data Extraction), to gather information about the characteristics of (1) overall scenarios and crews, (2) crew responses during task completion efforts, and (3) performance shaping factors (PSFs) affecting unsafe acts from full-scope simulations in off-normal situations [7]. The obtained data are accumulated in the OPERA (Operator Performance and Reliability Analysis) database. To minimize the variability in the data-gathering process results, all information about the context and crew performance is inputted by dedicated analyzers using audio-visual records, parameter logs, and event-action logs. In addition, the template was designed to mainly collect data using directly measurable or observable surrogates, such as number of manipulation tasks described during a procedural step instead of the subjective difficulty rankings of task complexity levels.

* Corresponding author.
E-mail addresses: yochankim@kaeri.re.kr (Y. Kim), kshpjk@kaeri.re.kr (J. Park), wdjung@kaeri.re.kr (W. Jung).

http://dx.doi.org/10.1016/j.ress.2017.01.022
Received 25 April 2016; Received in revised form 20 January 2017; Accepted 30 January 2017
Available online 07 February 2017

The databases supporting HRA can be classified in terms of whether each database represents a computed HEP list for a given context according to their own HEP estimation methods or whether it describes human performance levels on a given task with contextual information. For HEP-based databases such as the Nuclear Computerized Library for Assessing Reactor Reliability (NUCLARR) [8], the Computerized Operator Reliability and Error (CORE) database [9], and the GRS (Gesellschaft für Anlagen und Reaktorsicherheit) HEP list [10], the number of error opportunities, the number of error occurrences and the corresponding HEP values are shown for each observed situation. However, human-performance-based databases such as the SACADA and OPERA database describe how successfully operators performed the given tasks and which factors were related to operator performance instead of representing probabilistic error rates [6,7]. These types of databases allow closer examinations of the contextual factors that can affect performance levels in detail; however, a mathematical treatment is also required to generate meaningful statistics from the databases to support the current HRAs.

To generate quantitative estimates regarding the human reliability from human-performance-based data, it is important to define an appropriate classification scheme for the erroneous behaviors revealed in the data. Specifically, different types of tasks are expected to require different information processing activities of humans. These differences consequently influence the discrepancies between the HEPs related to the different tasks as the many HRA methods or databases presented [4,6–10]. It was also found that the relationships between the PSFs and the HEPs strongly depend on the error type or task type [4,5,11]. Therefore, the erroneous behaviors identified during the data collection process should be categorized based on the classification scheme and the number of erroneous behaviors, and the opportunities pertaining to these errors should be determined with the scheme to generate HEPs for each error type.

A classification scheme of erroneous behaviors should be defined considering the following requirements. First, the types of human errors completely entail all possible erroneous behaviors during the control tasks in given systems. To this end, all types of human cognitive activities which can arise when interacting with complex systems should be considered in the categorization of each error type [12]. In addition, if an operator performs a task by following one or more procedures, all tasks required during the procedures should be associated with the developed error types. Second, the meanings of human error types should be comparable to the error types provided in popular HRA methodologies and conventional database; hence, when a HEP is predicted by the collected data, the result can be used to update or validate existing HEP values. Finally, the classification scheme should enable a transparent evaluation of the success or failure of human behaviors and should allow a determination of the relevant error type from the collected data. To do this, the error types should be mutually exclusive and clearly understandable to potential users of the scheme.

The SACADA database includes comprehensive taxonomies of error causes or errors modes [6]. However, because large numbers of error types are addressed in this database and error types are selected from among them only when an instance of performance deficiency is found, sufficient discussion regarding which error types can be quantified and how the probability of each type of erroneous behavior can be predicted should be included. To this end, this paper proposes a classification scheme for erroneous behaviors identified using the HuREX framework after reviewing the literature related to the abovementioned requirements [7]. In addition, a case study is conducted to verify that the proposed scheme can be successfully implemented for the categorization of erroneous behaviors and to assess whether the scheme is useful for HEP quantification. For this end, a process to count quantities related with the HEP estimations is also developed. Because the OPERA database includes reliability information relevant to the operators of main control rooms (MCRs) and off-normal situations during which one or more procedures are considered, a classification scheme was also developed for the proceduralized tasks of MCR operators. Full descriptions of the erroneous behavior identification and quantification processes are available as a technical report [13].

2. Related work

To fulfill the four requirements of the classification scheme mentioned in the introductory section, previously investigated human cognitive process models are reviewed in this section. The categories of nominal HEPs provided in the current HRA methods and the structures of the current human reliability databases are discussed as well. The operating procedures for emergency situations are also analyzed to extract the proceduralized tasks. Finally, the characteristics of the HuREX framework relevant to determination of the human error types are explained.

2.1. Cognitive process models

Although there are various types of cognitive process models, the decision ladder template presented by Rasmussen is recognized as the best known complex system control model [14,15]. Eight cognitive activities are included in this template. These are the activation, observe, identify, interpret, evaluate, define task, formulate procedure, and execute activities. The decision ladder template has been applied for the grouping of erroneous behaviors in various fields [15–18]. For example, Reason developed the generic error modeling system (GEMS) using an adjusted version of the decision ladder template as the technical basis [16]. Fucke et al. also derived cognitive activities in aviation from the decision ladder template [17], and Silva and Nicholson classified unreliable airspeed events based on the activity list developed in Fucke et al. [18].

Several methods for assessing human reliability or task demand levels utilize simplified cognitive process models [12,15,19–22]. For example, ATHEANA (A Technique for Human Event ANAlysis), a second-generation HRA method, describes basic cognitive activities in off-normal situations involving four steps: monitoring/detection, situation assessment, response planning, and response implementation [19]. O'Hara et al. addressed identical cognitive activities with the ATHEANA model in a study for the generic primary tasks of NPP operators [20]. Hollnagel established a simplified version of the cognitive process model known as SMoC (Simple Model of Cognition) for the CREAM (Cognitive Reliability and Error Analysis Method) HRA method [15]. The SMoC model has four activities which are similar to those of the ATHEANA model. These are the observation/identification, interpretation, planning/choice, and action/execution activities. Patterson and Hoffman's macrocognitive framework, the IDAC (Information, Decision, and Action in Crew context) model, and the IDHEAS (Integrated Decision-tree Human Error Analysis System) also presented four or five cognitive activities in dynamic systems; these are not novel activities from the ATHEANA or SMoC model, though emphasis is placed on communication and coordination issues [12,21,22].

Some HRA models, including the CREAM, ATHEANA, and IDHEAS methods, describe detailed cognitive tasks or failure modes for each cognitive activity. For instance, in the CREAM method, the three error types for the 'observation/identification' activity in the SMoC are presented. These are termed 'wrong object observed', 'wrong identification', and 'observation not made'. The IDHEAS method also categorizes detailed failure modes that are associated with cognitive activities and predicted HEPs for several failure modes [23].

2.2. Error types in the HRA methods and database

The error types on the nominal HEP lists in the THERP (Technique