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A statistical approach to estimating effects of performance shaping factors on human error probabilities of soft controls

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ABSTRACT

Despite recent efforts toward data collection for supporting human reliability analysis, there remains a lack of empirical basis in determining the effects of performance shaping factors (PSFs) on human error probabilities (HEPs). To enhance the empirical basis regarding the effects of the PSFs, a statistical methodology using a logistic regression and stepwise variable selection was proposed, and the effects of the PSF on HEPs related with the soft controls were estimated through the methodology. For this estimation, more than 600 human error opportunities related to soft controls in a computerized control room were obtained through laboratory experiments. From the eight PSF surrogates and combinations of these variables, the procedure quality, practice level, and the operation type were identified as significant factors for screen switch and mode conversion errors. The contributions of these significant factors to HEPs were also estimated in terms of a multiplicative form. The usefulness and limitation of the experimental data and the techniques employed are discussed herein, and we believe that the logistic regression and stepwise variable selection methods will provide a way to estimate the effects of PSFs on HEPs in an objective manner.

1. Introduction

A human reliability analysis (HRA), which predicts the error probabilities of the operators, has been conducted for several decades in order to visualize the contributions of human errors to the reliability of systems [1]. In the HRA community, however, it has been commonly stressed for many years that data for supporting the HRA method development and application should be collected and analyzed, because many kinds of HRA methods offer human error probabilities (HEPs) or the quantitative effects of the performance shaping factors (PSFs) on such probabilities without sufficient empirical evidence [2–6]. In addition, in accordance with the development of computer-based main control rooms, an empirical basis of human reliability related to new digitalized interfaces is also required [7–11].

To overcome the lack of human performance data, efforts to collect data from several types of data sources such as plant experience, training, or experimental records in full-scope simulators, and laboratory experiments have been recently made [12]. Plant experience-based databases include HERA (Human Event Repository Analysis) [13], HFIS (Human Factors Information System) [14], CORE-DATA (Computerised operator Reliability and Error Database) [15], CAHR (Connectionism Assessment of Human Reliability) [16], and the HEP list of GRS (Gesellschaft für Anlagen und Reaktorsicherheit) [17]. The performance or reliability data of qualified operators were also obtained from replicas of actual main control rooms. For collecting this kind of data, H2ERA (Halden HERA) and OPERA (Operator PErformance and Reliability Analysis) were developed [18,19], and US NRC (Nuclear Regulatory Commission) is developing the SACADA (Scenario Authoring, Characterization, and Debriefing Application) database by collecting human performance information in the operator training programs [5]. KAERI (Korean Atomic Energy Research Institute) has also recently established a data framework to continuously collect information on both unsafe acts of operators and the relevant PSFs [20]. Finally, experimental data can be produced from laboratories; for example, Jang et al. [7] and Benish et al. [21] performed controlled experiments employing graduate or undergraduate students in mock-up scale simulators.

Although the data collected provides significant information regarding both the frequency of human errors and the contributions of related PSFs, there is still a lack of empirical basis in determining the effects of PSFs on HEPs (this issue will be discussed in Section 2). For instance, many recent researches

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modeling the relations between PSFs and HEPs have mainly employed Bayesian networks; however, the parameters quantifying such relations generally depend on the analyst's subjective judgments [22] because most data accumulated do not include a sufficient amount of samples, and the levels of PSFs in the data were subjectively or conceptually rated [22]. Another reason is that scientific methodologies used to empirically identify the relations between PSFs and HEPs have not been scrutinized yet.

To develop a concretely grounded model for human reliability, it is necessary to investigate which PSF significantly affects human errors, and if so, how much the PSF influences the HEPs [12]. In this study, we attempt to analyze the effects of PSFs using a logistic regression method, which is a statistical method to probabilistically classify categorical dependent responses. The required data were obtained through laboratory experiments of the soft controls in a compact nuclear simulator (CNS) [7]. A soft control is a type of interfaces for operating digitalized power plants, e.g., mouse controls and touch screens. Despite the differing knowledge, ability, or psychological states of the participants, as well as the differences in the simulation environment compared with the real systems in a nuclear power plant, this controlled experiment has remarkable advantages. It is easy to obtain sufficient samples for building a statistical or data-based model. In addition, the experimental simulation allows efficiently controlling one or more variables to investigate the impacts of the designed factors [12,23].

The remainder of this paper is organized as follows. In Section 2, we review the literature scrutinizing the quantitative relation between PSFs and human errors. For an easier understanding of this research, logistic regression and the variable selection method employed are also briefly introduced. In Section 3, how the experimental data were obtained is explained. In Section 4, we present the statistical process and data results. The results produced are also interpreted. In Section 5, based on the experimental experience, the strong and weak points of the logistic regression for estimating the impacts of the PSFs are discussed. Finally, we present some concluding remarks and areas of future work in Section 6.

2. Related work

2.1. Effect of PSF on HEP

Many kinds of quantitative HRA methods provide mathematical relations between PSFs and HEPs to calculate the HEP of a given task. Some methods such as THERP [24] and HCR [25] include an empirical database for calculating an HEP. However, the information used in the existing HRA methods was generated relatively many years ago and the methods do not provide solid empirical evidence for the information, such as the statistical significance [15,22,23]. Another limitation of data in the HRA methods is that these data were obtained without sufficient consideration of the cognitive processes in human behaviors [23]. Some HRA methods, in particular, do not comprehensively consider the factors that are suspected to contribute to human reliability [12]. Consequently, the HEPs in the existing methods are partly or fully based on expert judgment. Although there were several recent studies assessing how multiple PSFs influence HEPs through Bayesian networks, the relationships were also mainly represented by expert judgment or the parameters of the existing methods [22].

As addressed in Section 1, various types of data have been collected to improve the quality of HRA [5,13–20]. However, a systematic investigation on identifying the relationship between the levels of PSFs and HEPs has yet to be started [3,26]. To identify the effects of PSFs on HEPs, it is obvious that a sufficient amount of data should be accumulated. However, a systematic data collection framework is also required to obtain statistically significant information related to the PSF effects [20]. For example, CORE-DATA [15] and the GRS HEP list [17] provide an HEP table that includes the error probability for each error type or error mode, as well as the related PSFs of the error types. However, the presented results do not describe how much a certain level of PSF affects the basic HEP. The HERA database [13] and the simulation database of KAERI [20] comprise important information related with the PSF levels. However, because the analysts of these databases collect detailed information regarding the PSFs only when an unsafe act is found during a task, for an understanding of the practical impacts of the PSFs, it is necessary to additionally analyze the differences in PSF effects under situations in which an unsafe act exists or not. In addition, as noted in [27], many kinds of supporting databases may include unreliable information about the PSF ratings, because many data items are subjectively evaluated by analysts.

There have been attempts to statistically analyze the relation of a set of PSFs or PSF-related variables with human performance. For example, Kim et al. developed a measure concerning the procedure progressions and conducted a correlation analysis of the measure and its performance time [28]. Park also developed a measure of task complexity and compared the scores against the performance time and level of subjective workload [29]. This measure was also compared with the bounds of empirical HEPs obtained through Bayesian updates [30]. Hallbert and Kolaczkowski analyzed the relations of seven PSFs and the performance time using multiple linear regression techniques and estimated how much each PSF positively or negatively contributes to the performance time [31]. Several empirical studies on the OECD Halden Reactor Project have been conducted to examine the relations between time pressure, information load, and masking and operator performance [32,33]. From the observations in the simulation studies, the influences of the crew's work processes, skills, and knowledge on the performance outcomes were also discussed [33].

Using the HERA database, some quantitative estimations of the causality among multiple PSFs have been attempted. Groth and Mosleh identified the four error contexts using a factor analysis in which a certain combination of the PSFs can produce human errors [34]. Sundaramurthi and Smidts generated a causal graph using the parameter learning system, which illustrates the strengths of the interrelations between PSFs from the HERA data [35].

Liu and Li investigated the effects of PSFs on human errors [36]. From experimental data obtained using a microworld simulator, the interrelationship between task complexity, time availability, and training, along with their effects on the HEP, was analyzed using statistical techniques. However, although it was revealed that the relationship between PSFs and human performance may differ according to the contexts [31], the effects of the PSFs were not estimated for each error type. In [36], a comparison of the HEP between error types under unskilled and skilled situations was conducted; however, which PSF has dominant effects on a certain type of error probability was not provided with any statistical significance.

In this study, to present empirical evidence of the execution errors relevant with soft controls, how eight different factors contribute to the occurrence of nine types of errors was estimated using a logistic regression method. Combinational effects of the considered factors were also included in the estimation process, and significant factors were deduced through a stepwise regression technique.

2.2. Logistic regression and variable selection

Logistic regression is used to model the relationship between a categorical dependent variable (typically binary variable) and one