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Inclusion of task dependence in human reliability analysis

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ABSTRACT

Dependence assessment among human errors in human reliability analysis (HRA) is an important issue, which includes the evaluation of the dependence among human tasks and the effect of the dependence on the final human error probability (HEP). This paper represents a computational model to handle dependence in human reliability analysis. The aim of the study is to automatically provide conclusions on the overall degree of dependence and calculate the conditional human error probability (CHEP) once the judgments of the input factors are given. The dependence influencing factors are first identified by the experts and the priorities of these factors are also taken into consideration. Anchors and qualitative labels are provided as guidance for the HRA analyst's judgment of the input factors. The overall degree of dependence between human failure events is calculated based on the input values and the weights of the input factors. Finally, the CHEP is obtained according to a computing formula derived from the technique for human error rate prediction (THERP) method. The proposed method is able to quantify the subjective judgment from the experts and improve the transparency in the HEP evaluation process. Two examples are illustrated to show the effectiveness and the flexibility of the proposed method.

1. Introduction

Human error is an important factor to be considered in the design and risk assessment of large complex systems. Human reliability analysis (HRA) is a systematic framework to assess the human contribution to system risk, which includes the process of evaluation of human performance and associated impacts on structures, system, and components for a complex facility [1]. The process and the results are highly subjective, and they are the input for probabilistic safety assessment (PSA) [1]. Various methods have been developed for HRA [2–18].

In HRA, dependence analysis refers to assessing the influence of the failure of the operators to perform one task on the failure probabilities of subsequent tasks [2,19]. An appropriate assessment of dependence is essential to avoid underestimation of the risk, since the dependent failure probability may be an order of magnitude or more larger than the independent one [20]. The result of the assessment is a conditional human error probability (CHEP), given failure on the preceding task [19]. The ideal method for assessing dependence is to determine the conditional probabilities from real-world observations. However, sufficient data for statistical analysis is typically not available, thus the relevant conditional probabilities are qualitatively inferred from the nature of the tasks and their interrelationships [19].

Several methods have been developed for the consideration of dependency between human failure events (HFEs) in HRA based on expert judgment. The most commonly used method is the technique for human error rate prediction (THERP). The traditional THERP method provides both guidelines for assigning the level of dependence between two tasks (i.e., two HFEs) based on several factors and a set of modification formulas to calculate the impact of the level of dependence on the CHEP of the subsequent event. The assessment of the dependence level in THERP is highly subjective and requires considerable amount of expert judgment. The absence of specific guidance makes the use of the THERP dependence method difficult and the results may lack traceability and repeatability [20].

To address this problem, the assignment of the dependence level is frequently supported with decision trees (DTs), which can be found in several methods, e.g., the Standardized Plant Analysis Risk-Human Reliability Analysis (SPAR-H) [21], the Institute Jožef Stefan human reliability analysis (IJS-HRA) [22,23], the Electric Power Research Institute (EPRI-HRA) [24], and the DEPEND-HRA method [25]. By using the DTs, the analyst only has to give judgments on the input factors, but is not required to draw conclusions on the dependence level, which reduces the subjectivity. However, the DTs are not

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flexible since the analyst's judgments are typically constrained to extreme situations [20]. An increasing number of the judgment options will result in an excessive branching of the tree. Moreover, different implementations of DTs may produce significantly different results (see detailed discussion in [1]).

Due to the uncertainty in the real world [26–31], fuzzy set theory has been exploited in HRA due to its advantage in the representation of ambiguity [32–35]. In recent presented literature [19,20], a fuzzy expert system (FES) is developed to model the dependence between HFEs. The FES-based dependence assessment method is not only able to describe the ambiguity of judgments, but also can capture the rules used by experts to assess dependence levels and incorporate this knowledge into an algorithm and software tool to be used by HRA analysts, which increases the transparency and the repeatability of the results [20]. Nevertheless, the correspondence rules provided by experts in advance are subjective, and may increase exponentially along with the number of input factors. Any change in the input factors will require developing new correspondence rules, and thus increased effort, time and expense. Further, information is either added or lost within the fuzzification and defuzzification procedures in the FES-based method.

In this paper, we present a computational model for handling dependence in HRA, which could be seen as one possible refinement of the THERP. The aim of the study is to automatically provide conclusions on the overall dependence degree and calculate the CHEP among HFEs once the judgments of the input factors are given. The dependence degree is defined for the sake of calculation. Similar to the FES method, the input value could be a point or an interval, thus representing ambiguity in the judgment. Anchors are also provided as guidance for the HRA analyst's judgment of the input factors as in [20]. The priorities of different input factors are taken into consideration in the proposed model which is usually the case in realistic situations. Then, the overall dependence degree between HFEs is calculated based on the input values and the priorities of the input factors. Finally, the CHEP is obtained according to a computing formula derived from THERP.

The remainder of this paper is organized as follows. In Section 2, the main dependence assessment methods are briefly reviewed. In Section 3, the proposed methodology to handle dependence in HRA is presented. In Section 4, two examples are used to illustrate the effectiveness of the proposed method. Section 5 discusses the impact of the linear assumption on the dependence levels, the validation issue and the comparison between weight elicitation process and corresponding rules elicitation process. Section 6 concludes the paper.

2. Review of dependence assessment methods in HRA

2.1. THERP

The dependence assessment method in THERP is the foundation of various dependence models such as SPAR-H [21] and IJS-HRA [22,23]. The THERP approach provides guidelines for assigning dependence level between one task and a subsequent task according to several factors. The five dependence levels are zero dependence (ZD), low dependence (LD), moderate dependence (MD), high dependence (HD), and complete dependence (CD) [2]. And the suggested factors include closeness in time and space, functional relatedness (e.g., tasks related to the same subsystem), stress, and similarity of the performers [2,20]. However, the guidelines in THERP approach are general terms, thus lacking transparency and repeatability. For example, for the factor "closeness in time and space", the guideline reads [2,20] as

> "*Evaluate the spatial and time relationship among all events. Dependence between any two events increases as the events occur closer in space and time. For example, displays or controls that are physically close to each other or that must be manipulated at about the same time have a higher level of dependence than items that are widely separated either spatially or as to the time of their manipulation*"

The THERP approach also provides a set of modification formulas to calculate the impact of the dependence level on the CHEP of the subsequent event. Assume that task T_B is subsequent to task T_A, and B and A are the corresponding failure events. P_A and P_B are the basic probabilities of failure of task T_A and task T_B, respectively, then the conditional human error probability (CHEP) of B given A is determined as follows [2]:

$$P_{XD}(B|A) = (1 + K \cdot P_B)/(K+1) \quad (1)$$

where $K=0, 1, 6, 19$, and ∞, for dependence levels CD, HD, MD, LD, and ZD, where XD=CD, HD, MD, LD, and ZD, respectively.

Thus, the joint probability of dependent HFEs A and B can be obtained as

$$P_{XD}(B,A) = P_A \times (1 + K \cdot P_B)/(K+1) \quad (2)$$

2.2. Use of decision trees (DTs) in THERP

The repeatability of the traditional THERP model can be improved with the help of decision trees. The guidelines become more concrete through the use of DTs. For example, Fig. 1 shows the IJS-HRA dependence assessment method for the action "calibration" performed by the same person, in a parallel system in pre-initiator HFEs [1]. The internal node represents a factor, each branch represents an optional status of the factor, and each leaf node represents a dependence level. A path from root to leaf represents rules for assigning the dependence level. As can be seen in Fig. 1, HEFs that are closer in time, are more similar in procedure and action, are more dependent. By using the DTs, the analyst only has to give judgments on the input factors, but is not required to draw conclusions on the dependence level, which comes from the model [20]. Then, the impact of the assessed dependence level is still modeled with the THERP dependence assessment method as is shown in Eq. (1).

However, there are still some limitations of the DT-based method: (1) the binary options for a node in DTs are not flexible enough to represent all the possible states; (2) different implementations of DTs may produce significantly different results of the HRA and in the evaluation of the risk contributors [1]; and (3) the construction of the DTs is often not based on a transparent

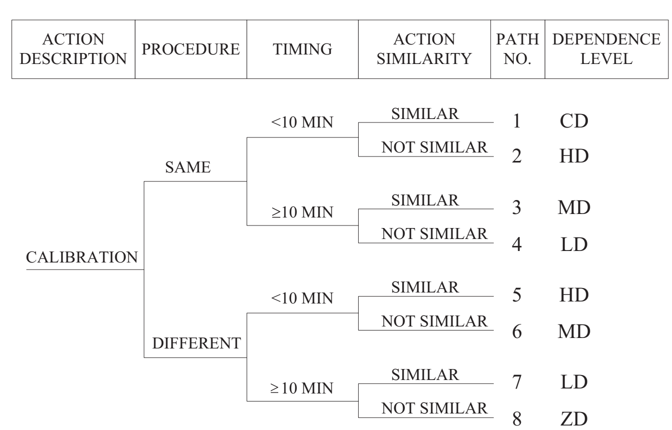

Fig. 1. The IJS-HRA dependence decision tree [1].