A Framework for Data-Based HEP Predictions[1]

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Abstract: Lack of suitable human performance information for human reliability analysis (HRA) has been identified as a key factor affecting the quality of HRA applications. In support of its risk-informed regulation, the U.S. Nuclear Regulatory Commission has sponsored the development of the Human Event Repository and Analysis (HERA) system, which is a human performance database system, to provide empirical evidence to inform HRA. The original objectives of HERA development had focused on providing event insights to inform qualitative HRA. Recently the use of HERA in informing quantitative HRA (i.e., estimating human error probabilities) has been emphasized. This paper discusses a proposed data framework that expands and enhances the current HERA methodology for quantitative use of HERA data.

Keywords: HRA, HEP, human performance, database

1 INTRODUCTION

Lack of suitable human performance information for human reliability analysis (HRA) has been identified as a key factor affecting the quality of HRA applications. In support of its risk-informed regulation, the U.S. Nuclear Regulatory Commission (NRC) has sponsored the development of the Human Event Repository and Analysis (HERA) system [1, 2], which is a human performance database system, to provide empirical evidence to inform HRA. This paper provides an introduction to the HERA system and its current status and outlook on informing HRA application in the context of probabilistic risk assessment (PRA).

The HERA development was started in 2003. The original objective was to systematically collect and analyze human performance information of the nuclear power plants events in PRA-relevant settings. The main efforts have included developing taxonomies for data collection, developing a database software for information storage, and conducting pilot studies to test the HERA system. The HERA framework and data taxonomies were documented in [1, 2]. A simplified version of HERA was used in the international HRA empirical study [3] to communicate the HRA results. A web-based HERA database application became operational (https://hera.inl.gov/[2]) in mid 2009.

To date, the data sources to the HERA have focused on the NRC special inspection reports, the plant licensees' event reports, or on recordings from simulator exercise scenarios. The process of preparing data for entry into HERA is one of collecting the source reports and then extracting a description of the event evolution from a human performance perspective. This analysis yields a timeline of subevents

[1] The opinions expressed in this paper are those of the authors and not those of the USNRC or of the authors' organizations
[2] Access to the HERA database can be granted by NRC. Contact the authors for more information.

(human successes and failures and system/equipment states and responses) and as complete a description as possible of the factors that shaped important human subevents.

Preparing data for entry into HERA requires team work to obtain the information and analyze the events to categorize and characterize the subevents per the HERA data taxonomies. A team typically consisted of a combination of experts in the fields of human factors/performance, plant system, and plant operation. The collected information ranged from overview of an event to details on the factors contributing to a human failure; and from objective information (e.g., event timeline) to more subjective judgments (e.g., presence and level of various performance shaping factors). Both the objective and more subjective types of information have great value in helping capture the variables underlying the human performance of the analyzed events. Unfortunately, the analysts typically found that the existing event reports did not provide sufficient human performance information to uniformly enable the detailed analysis and description that the HERA taxonomies and database supported and is required for many HRAs. This necessitated the analysts to do extensive inferring from the data that was available or to simply omit parts of the analysis.

A drawback to the HERA data framework is that it was not specifically developed to generate quantitative outputs to support the estimates of human error probabilities (HEPs), an essential HRA objective. To inform HEP estimates, the NRC's data for HRA activities has expanded the data sources to other available sources including data/information available in industries other than nuclear power operation. Because each of these other data sources was developed for that industry's unique purpose, there is no consistency among the data in terms of format or level of detail. To enable the NRC to consolidate and use data from such heterogeneous sources, the authors are currently developing an integrated data framework that they can use to collect and integrate the available data with different formats to support HEP quantification.

Section 2 provides an overview of this emerging integrated data framework; section 3 provides a more detailed discussion of the framework; section 4 identifies the perceived technical challenges in implementing the framework, and; section 5 provides a final summary.

2 OVERVIEW OF THE PROPOSED DATA FRAMEWORK

The objective of the proposed framework is to support the calculation of the HEPs of the human failure events (HFEs) identified in PRA models. A key bounding assumption of the data framework presented in this paper is that the HFEs of interest are already identified in existing PRA models; hence this paper does not prescribe methods for identifying new HFEs. Figure 1 is a graphical representation of the framework and its proposed use. At the left and middle of the top row of figure 1 are the PRA and HRA models (and most specifically the HFEs which are the subject of interest). The bottom row consists of the three key elements of the framework: the data sources, data repository, and use of data. The framework is explained below.

Block 1 of figure 1 shows a simplified PRA event tree that contains the HFEs of interest. The PRA event sequences (or scenarios) typically provide information only at the level of plant functions. The HFEs identified in these scenarios often represent or include a wide range of human performance (contextual) situations. This contextual variation affects the uncertainty of their HEPs accounted for in recent HRA approaches. For example, ATHEANA [4, 5]), stresses the importance of identifying these different contextual situations that could occur for a given PRA's HFE.   Block 2 of figure 1 represents the HFE in different contexts.

Block 3 indicates two types of information: analysis of individual events (e.g., event investigation reports) and HEPs of performing certain tasks that derived from empirical data (e.g., CORE-DATA [6]). Because the format of Block 3 information varies, Block 4 performs analysis on both types of information provided from Block 3, based on a common data framework or set of taxonomies and stores the analyzed information in the data repository. The Block 4 analysis involves identifying and characterizing the human performance context of the tasks as described in the event reports or other data. This characterization is done from a human-centered perspective. This human-centered characterization unlinks the task performance from the specific task and event sequence to allow the task (subevent) to be treated independently. With the subevents now unlinked from the task but still rich in contextual information, they can now be aggregated in calculating HFEs for similar subevents under similar contexts. Similarity matching is the concept to identify the relevant information in the data repository to inform the human performance of the HFEs (Block 5). Section 3 provides a more detailed discussion of the framework approach.

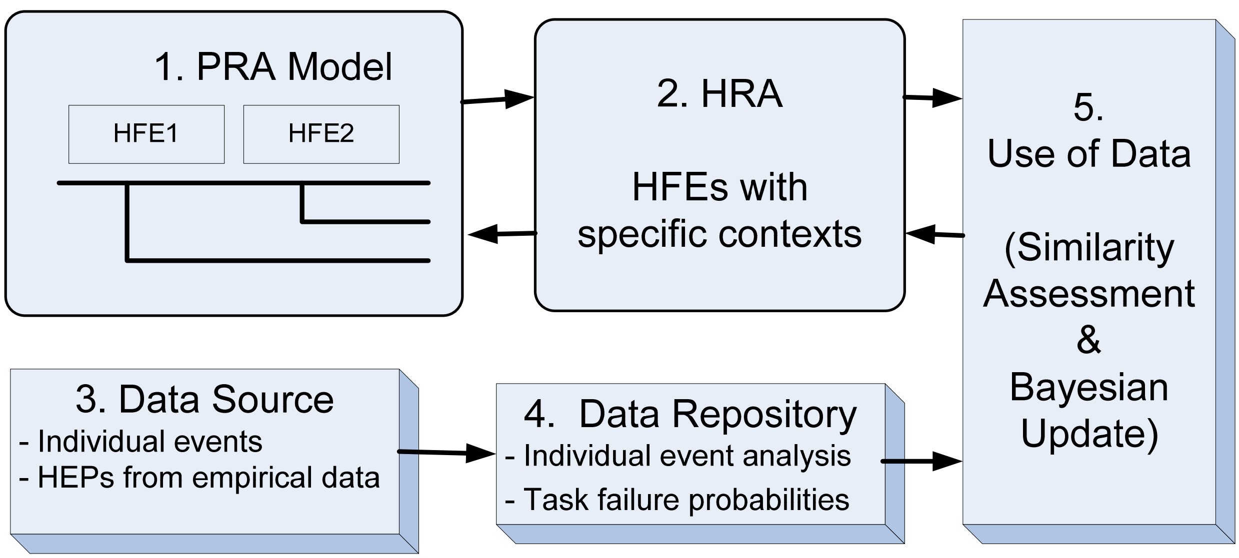

Figure 1 A proposed framework for data-based human error probabilities predictions

3 APPROACH

3.1 Basic Concept

An HFE's HEP is defined as the probability of the human failing in response to a demand situation and can be represented by Eq. 1:

$$HEP = \frac{\#\,Failures}{\#\,\mathrm{Re}\,sponseOpportunities} = \frac{\#\,Failures}{\#\,Failures + \#\,Successes} \qquad (Eq.\,1)$$

Ideally the performance of the same tasks as defined in PRA HFEs would be used for the parameters in Eq. 1. However due to the rarity of the HFEs occuring in real events, high costs associated with simulator exercises, and other considerations, it is generally impractical to estimate the HEPs based on the same tasks to the HFEs.

An alternative is to characterize each observed task performance in the data repository using a human-centered approach and then aggregate task performances that occurred under similar contexts. Thus, performance of different tasks can be used to inform the performance of the HFEs of interest. In this paper, we refer to this human-centered characterization approach as a human performance profile (HPP). The HPP consists of a set of human performance factors neutral to the physical system. The tasks with similar HPPs as the HFEs of interest can be used to inform the performance of HFEs despite the fact that these tasks may, on the surface, appear to be quite different. Eq. 2 represents this approach.

$$HEP(HFE \mid HPP) = \frac{\#\,Failures(HPP)}{\#\,Failures(HPP) + \#\,Successes(HPP)} \qquad (Eq.\,2)$$

3.2 Human Performance Profile

The recent HRA methods have moved from primarily using obvious task-centered variables toward using human-centered (contextual) terms in the calculation of HEPs. Three elements used by the newer HRA methods to calculate HEPs are expected to be used to develop the proposed HPPs: activity types; error/failure modes or error/failure mechanisms; and performance shaping factors. Each human performance observation as it is stored in the data repository will be required to be characterized by these HPP factors and given one or more specific HPP designation(s).

Activity types, as a concept, have been widely adopted by HRA methods. Table 1 catalogs how various HRA methods incorporate various activity types. Note that several base the activity types solely on human cognitive activities (e.g., THERP[7], SPAR-H[8], CBDT[9], and CREAM[10]) while several others (e.g., NARA[11], HEART[12], and HCR/ORE[9]) combine both human cognitive activities and system-independent situations.

Table 1 The system-independent activity type classifications.

Activity Type	Representative HRA Methods
Diagnosis and Action	THERP*, SPAR-H, and CBDT**
Strategic, Tactical, Opportunistic, and Scramble	CREAM (Basic)
Observation, Interpretation, and Planning etc.	CREAM (Extended)
- Carry out simple single manual action with feedback. Skill-based and, therefore, not necessarily with procedure - Restore or shift a system to original or new state following procedures, with some checking - Etc.	NARA and HEART

- Response following a change in the plant damage state that is indicated by an alarm or value of a monitored parameter. - Response following an event that gives rise to a primary cue that has to be achieved when a parameter is exceeded or can be seen not to be maintainable below a certain value - Etc.	HCR/ORE

*THERP specifies multiple types of action

**CBDT only calculates failure probabilities of cognitive failures

The second factor to be included in HPP is error/failure modes or mechanisms. Among the HRA methods, only the CBDT utilizes failure modes and failure mechanisms for calculating HEPs. CBDT identifies two failure modes, each with four failure mechanisms. The failure modes and failure mechanism identified in CBDT are:

- Failures of the plant information-operator interface.
    a) The required data are physically not available to the control room operators.
    b) The data are available, but are not attended to.
    c) The data are available, but are misread or miscommunicated.
    d) The available information is misleading.
- Failure of the procedure-crew interface.
    e) The relevant step in the procedure is skipped.
    f) An error is made in interpreting the instructions.
    g) An error is made in interpreting the diagnostic logic.
    h) The crew decides to deliberately violate the procedure.

Performance shaping factors or some analogous concept, is utilized in essentially all HRA methods, from the very earliest methods down to most recently evolved methods. The number and level of detail and values/ranges for PSFs for descriptive and for calculational purposes varies widely from method to method.

3.3 Inform HEP Estimates

To assess an HFE's HEP, first the HPP for that HFE must be characterized (identified). Then, the human performance observations in the data repository with the same or similar HPPs to the HFE of interest will be identified (matched) and used for informing the HEP values. As mentioned earlier, the proposed new data framework would have data from two types of data source: detailed analysis of an individual event and HEP from empirical data. For the first type of data, because the human performance observations could be a human success or failure responding to a response opportunity and the HEPs of performing a certain task, the two types of information need to be reconciled to the same format. Equation 2 will be used to calculate a reference HEP value based on the observations of individual human success and failure responding to a response opportunity. The HEP generated from Eq. 2 is a reference HEP to the HFE of interest. The HEPs from the second type of data can be directly used as reference HEPs to the HFE of interest. The HEP of the HFE of interest then is function of the reference HEPs as shown in Eq. 3.

$$HEP = f(HEP_{REF\ i}) \qquad Eq.\ 3$$

The reference HEPs in Eq. 3 are preferred only from empirical data. This would provide more objective HEP estimates. However, in the situations in which there are no sufficient human performance observations within the data repository that have the same or similar HPP as the HFE of interest, expert judgment would be used to provide reference HEPs in Eq. 3 to supplement the data insufficiency.

4 TECHNICAL CHALLENGES

Three key technical challenges are identified in implementing the proposed HPP data framework:

- Challenge 1: Define the unit of measurement for Eq. 2
- Challenge 2: Specify the HPP
- Challenge 3: Inform HEP quantifications with incomplete data

Challenge 1 is overcoming the ambiguity inherent in specifying the analysis units to be used in Eq. 2 for the counts of the number of human successes and failures. The NRC has an on-going project looking at the HERA system where extensive exploration is underway to tackle this challenge. Several HRA experts have been involved in creating guidance and testing that guidance in parsing past events into subevents that are representative of the analysis unit. Also, the methods listed in Table 1 should be scanned for their recommended units as wells as for tackling Challenge 2—formulating a taxonomy of HPPs by combining activity types, error modes/error mechanisms, and PSFs. Challenge 3, incomplete data, has long been an issue to almost all data efforts. Bayesian methods are of value. However, methods of collecting data from the present onward that can be used per the data-based framework proposed above, should significantly help in filling out the data repository.

5 CONCLUSION

Currently the NRC has several ongoing projects addressing different aspects of the three technical challenges identified in section 4. This effort is in parallel with enhancing the HERA system based on past operational experience. The overall goal is to develop an easy to use tool for collecting and analyzing human performance data and then enhancing that tool to better inform (derive) HEP estimates from whatever data has been collected. As the tool and scope of the data evolve, the reliance on expert judgment as the primarily source of data should gradually diminish. This, in turn, should enhance the usefulness and trustworthiness (reliability and transparency) of the HEP predictions used in HRA and PRA analyses.

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