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Phoenix – A model-based Human Reliability Analysis methodology: Qualitative Analysis Procedure

Nsimah J. Ekanem [a,1], Ali Mosleh [a,2], Song-Hua Shen [b]

[a] Center for Risk and Reliability, University of Maryland, College Park, USA
[b] US Nuclear Regulatory Commission, Washington, DC, USA

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ABSTRACT

Phoenix method is an attempt to address various issues in the field of Human Reliability Analysis (HRA). Built on a cognitive human response model, Phoenix incorporates strong elements of current HRA good practices, leverages lessons learned from empirical studies, and takes advantage of the best features of existing and emerging HRA methods. Its original framework was introduced in previous publications. This paper reports on the completed methodology, summarizing the steps and techniques of its qualitative analysis phase. The methodology introduces the “Crew Response Tree” which provides a structure for capturing the context associated with Human Failure Events (HFEs), including errors of omission and commission. It also uses a team-centered version of the Information, Decision and Action cognitive model and “macro-cognitive” abstractions of crew behavior, as well as relevant findings from cognitive psychology literature and operating experience, to identify potential causes of failures and influencing factors during procedure-driven and knowledge-supported crew-plant interactions. The result is the set of identified HFEs and likely scenarios leading to each. The methodology itself is generic in the sense that it is compatible with various quantification methods, and can be adapted for use across different environments including nuclear, oil and gas, aerospace, aviation, and healthcare.

1. Introduction

Phoenix, as the name implies is developed from the ashes of its predecessors in an attempt to address the current issues in the field of Human Reliability Analysis (HRA). Presently, dozens of HRA methods exist and new methods are still being developed. In the nuclear industry, the need for improved HRA methodologies for application to Probabilistic Risk Assessment (PRAs) has motivated a number of major activities in research and development worldwide since early 1990s. These efforts have resulted in some improvements in the application of the so-called first generation HRA methods (e.g. Technique for Human Error Rate Prediction – THERP [1], Human Error Assessment and Reduction Technique – HEART [2], Success Likelihood Index Method Multiattribute Utility Decomposition – SLIM-MAUD [3]) and a number of new techniques and frameworks often referred to as second generation, or advanced methods (e.g. Cognitive Reliability and Error Analysis Method – CREAM [4], Standardized Plant Analysis Risk Human Reliability Analysis – SPAR-H [5], Information, Decision and Action in Crew context – IDAC [6]) that have been developed.

Major limitations of the first generation methods in error identification and error probability quantification have been widely discussed and can be summarized as follows:

- The methods lacked procedures for identifying perhaps the most risk-significant category of human error, errors of commission (EOC), as compared with errors of omission (EOO).
- For the errors covered, the methods do not provide a convincing basis for error probabilities, and no theoretical foundations were offered for the quantification procedures. The limited experimental data used by some methodologies were insufficient to instill confidence in numbers on statistical grounds.
- Methods do not provide a causal picture of operator error – a need if one wishes to take steps towards reducing error probabilities. The basic assumption of the quantification methods in virtually all first generation methods is that error probabilities can be estimated using some explicit or implicit function relating a set of “Performance Shaping Factors” (PSFs) to error probabilities.
- Methods were insufficiently structured to prevent significant analyst-to-analyst variability of the results generated.

The development of the second generation HRA methods has taken place mostly along two parallel tracks. One track attempts to enhance the quality of HRA analysis within the “classical”

E-mail address: njekanem@gmail.com (N.J. Ekanem).
[1] Current affiliation: Chevron Technology Company, Houston, TX, USA.
[2] Current affiliation: University of California, Los Angeles, CA, USA.

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framework of PRA [7,8]. The other track reflects the belief that substantive improvement in HRA for PRA applications requires structural changes to the PRA methodology, moving from the static, hardware-driven view of the world to a more flexible dynamic model of accident scenarios. One way of achieving this is by integrating models of operator behavior, plant thermal-hydraulic response, and systems performance in a probabilistic-deterministic simulation approach [6]. These two tracks also share many common objectives and face many similar challenges. Both intend to address error identification and probability estimation which are the two key components of a comprehensive HRA methodology. These methods have an increased emphasis on context and operator cognition than first-generation methods. However, they still have some limitations which include:

- The lack of sufficient theoretical and experimental basis for the key ingredients and fundamental assumptions of many of these methods.
- The lack of a causal model of the underlying causal mechanisms to link operator response to measurable Performance Influencing Factors (PIFs)/PSFs or other characterization of the context.
- Majority of the proposed approaches still rely on very simple and in some cases implicit functions to relate PIFs to probabilities without the theoretical or empirical basis for such relations.
- In many instances, numbers are the result of expert elicitation, use of highly subjective scales, and unsubstantiated “reference probabilities”.

In general, these issues in both first and second generation HRA methods have led to inconsistencies, insufficient traceability and reproducibility in both the qualitative and quantitative phases. Also, it has resulted in significant variability in the results seen in the application of different HRA methods, and also in cases where different HRA analysts apply the same method.

The framework for this model-based hybrid HRA methodology was originally proposed in [9,10] in an attempt to address the aforementioned issues. It incorporates strong elements of current HRA good practices, leverages lessons learned from empirical studies and takes advantage of the best features of existing and emerging HRA methods. The methodology itself is generic in the sense that it is compatible with a number of popular HRA quantification methods, and can be adapted for use across various environments including nuclear, oil and gas, aerospace, aviation, and healthcare. The specific version presented in this paper is developed for use in nuclear power plant PRA to support HRA in full-power internal events PRAs, low-power and shutdown operations, event assessment, and significance determination. Extensions to fire and seismic PRAs can be easily developed on the same foundations. Essentially what changes from one application domain to another are specific details of the analysis modules, techniques of the approach, and emphasis placed on aspects that are more relevant to the particular application.

The development of this methodology has been completed and this paper provides a summary of the steps and techniques of the qualitative analysis phase. It discusses the major steps and important sub-steps required by an HRA analyst to successfully implement this methodology. Also presented are the products of each step and the information required by the analyst in order to conduct the analysis. The detailed quantitative analysis aspect of Phoenix HRA is covered in [11], with an overview provided in [12].

2. The qualitative analysis framework

The broad objective of HRA qualitative analysis is to identify Human Failure Events (HFEs) and characterize crew-system scenarios that lead to those HFEs. As such, there is a tight coupling between understanding and analyzing the plant/system response and conditions (systems behavior), and understanding and analyzing the crew activities (operator behavior). Therefore, the process of HFE identification and the definition of the scenarios leading to the HFEs are, in general, inseparable from the process of modeling the plant response in a Probabilistic Risk Assessment (PRA).

The qualitative analysis framework uses two modeling vehicles namely [10]: (1) a process and representational method for analyzing crew-plant interactions with a focus on the identification and quantification of HFEs and possible recoveries, and (2) a human response model which relates the observable Crew Failures Modes (CFM) to “context factors” for example, Performance Influencing Factors (PIFs). These are explained in more details in the following sections.

2.1. Layers of the framework

The framework has three main layers namely: the Crew Response Tree (CRT) (top layer), the human performance model

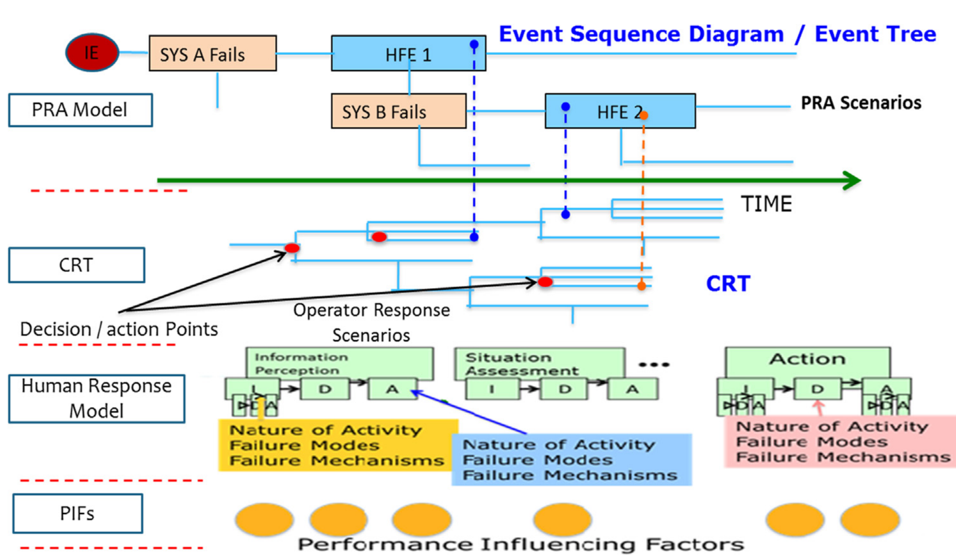

Fig. 2-1. The Phoenix qualitative analysis framework layers and a typical PRA event sequence model.