The NRC's New Human Reliability Analysis Method IDHEAS-ECA – Integrated Human Event Analysis System for Event and Condition Assessment

Jing Xing, Y. James Chang, Jonathan DeJesus Segarra
U.S. Nuclear Regulatory Commission
(01)-301-802-3196, jing.xing@nrc.gov

Abstract

This paper describes a human reliability analysis (HRA) method, developed by the U.S. Nuclear Regulatory Commission (NRC), referred to as the Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA). IDHEAS-ECA was developed based on the General Methodology of an Integrated Human Event Analysis System. IDHEAS-ECA supports NRC's risk-informed decisionmaking by providing an HRA method to be used in probabilistic risk assessment (PRA) applications. The intent of IDHEAS-ECA is to be applicable to the same scope that existing HRA methods model (e.g., nuclear power plant internal events while at-power) and beyond (e.g., external events, low power and shutdown events, and events where flexible and coping strategies equipment are used). The IDHEAS-ECA method provides step-by-step guidance for analysing a human action and its context, modelling a human action, calculating the human error probability, and integrating the results into PRA models. The NRC also developed an IDHEAS-ECA software tool to facilitate the documentation of the analysis of a human action and its context and uses the results of the analysis as input to calculate the human error probability.

In IDHEAS-ECA, any human task can be modelled by five macrocognitive functions: Detection, Understanding, Decisionmaking, Action Execution, and Interteam Coordination. The failure of a task is modelled with the failure of macrocognitive functions, referred to as cognitive failure modes (CFMs). Human error probability of an event is determined by the effect of event context on the CFMs of the critical tasks in the event. Context is the condition that challenges or facilitates human performance. IDHEAS-ECA uses 20 performance-influencing factors (PIFs) to model event context in four categories:

- *PIFs modelling environment and situation context: Work location accessibility and habitability, Workplace visibility, Noise in workplace and communication pathways, Cold/heat/humidity, Resistance to physical movement*
- *PIFs modelling system context: System and I&C transparency to personnel, Human-system interfaces, Equipment and tools*
- *PIFs modelling personnel context: Staffing, Procedures/guidelines/instructions, Training, Teamwork and organizational factors, Work processes*
- *PIFs modelling task context: Information availability and reliability, Scenario familiarity, Task complexity, Multi-tasking / interruption / distraction, Mental fatigue, Time pressure and stress, Physical demands.*

The human error probability of an event is calculated by combining the error probability due to time availability of performing the tasks in the event as well as the effects of PIFs on the CFMs of the tasks. The calculation of the effects of PIFs on CFMs is based on human error data generalized from the large variety of research literature and human performance databases.

IDHEAS-ECA improves existing HRA methods by (1) providing a systematic process and guidelines to analyse and model human actions and the associated scenario context, (2) including an extensive set of PIFs to represent the context of scenarios under various operational conditions, (3) using a human error database to calculate human error probabilities, and (4) including a cognition-based approach to model dependency between human actions. IDHEAS-ECA is envisioned to be used by NRC staff in PRA applications.

1. Introduction

The Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA) [1] is a human reliability analysis (HRA) method developed by the U.S. Nuclear Regulatory Commission (NRC) to support risk-informed decisionmaking. IDHEAS-ECA analyses human events and estimates human error probabilities (HEPs) for use in probabilistic risk assessment (PRA) applications. The method is based on the General Methodology of the Integrated Human Event Analysis System (IDHEAS-G) (NUREG-2198) [2]. IDHEAS-G and IDHEAS-ECA were developed because, in recent years, the scope of HRA applications has expanded into situations beyond the scope of existing HRA methods, and the NRC Commission, in a Staff Requirements Memorandum M061020 [3], directed the Advisory Committee on Reactor Safeguards to "work with the [NRC] staff and external stakeholders to evaluate different Human Reliability models in an effort to propose either a single model for the agency to use or guidance on which model(s) should be used in specific circumstances."

The application scope of IDHEAS-ECA is broad. It has a set of cognitive failure modes to model failures of any human tasks. It also has a comprehensive set of performance-influencing factors (PIFs) that model the context of a human failure event (HFE). The method covers all the PIFs in existing HRA methods and the factors reported in the broad literature and human events. Because of the comprehensiveness of the PIF structure, IDHEAS-ECA can model the context of HFEs inside and outside the control room of a nuclear power plant (NPP)—including the use of the diverse and flexible coping strategies (FLEX) [4]—and during different plant operating states (i.e., at-power and shutdown). IDHEAS-ECA can be used in PRA applications, such as the review of risk-informed license amendment requests, evaluations of Notices of Enforcement Discretion, and analyses of operational events in NRC Incident Investigation Program and Accident Sequence Precursor Program, and inspection findings (i.e., the Significance Determination Process).

Because IDHEAS-ECA is cognition-centred, it is technology neutral. It is applicable to all NRC's HRA applications; for example, PRA, integrated safety analysis, spent fuel handling, nuclear material users, and nuclear medicine. For PRA applications, the scope includes:

- Level-1 and level-2 PRA
- Internal and external hazards
- At-power and shutdown operations
- Conventional (analog) and digital control rooms
- Control room and onsite (field) actions
- Actions with installed component and portable equipment
- Significance determination process and accident sequence precursor analysis
- Pre-initiator, initiator, and post initiator HFEs

The following reports are related to IDHEAS-ECA and can provide additional information for using IDHEAS-ECA:

- The NRC report, "Integrated Human Event Analysis System Dependency Analysis Guidance (IDHEAS-DEP)," [5] presents guidance for using the IDHEAS dependency model along with IDHEAS-ECA to perform HRA dependency analysis. The guidance is also incorporated in the IDHEAS-ECA Software Tool.

- The NRC report, "The General Methodology of an Integrated Human Event Analysis System (IDHEAS-G)," [1] documents the IDHEAS general methodology and detailed guidance for performing each analysis step. It is highly recommended that users should use this report along with the guidance in IDHEAS-ECA. IDHEAS-ECA is developed from IDHEAS-G. Both have the same eight-step process, and the qualitative analysis is the same. The specific guidance on various steps in IDHEAS-G appendices are applicable to IDHEAS-ECA.

- The NRC report, "Human Error Data Generalized in the Integrated Human Event Analysis System (IDHEAS-DATA)," [6] presents a database of human error data. The base HEPs and PIF attribute weights used in IDHEAS-ECA are integrated from the human error data in IDHEAS-DATA. The report helps to understand the data basis for calculating HEPs with IDHEAS-ECA. The refences to the original data sources also help to understand the cognitive failure modes in various tasks and PIF attributes in various operational context.

2. Development of IDHEAS-ECA

IDHEAS-ECA is developed from IDHEAS-G. IDHEAS-ECA uses the cognitive basis and the qualitative analysis guidance described in IDHEAS-G. For HEP quantification, IDHEAS-ECA uses the HEP quantification model, in which the base HEPs weights of PIF attributes are integrated from the data documented in IDHEAS-DATA.

2.1 From IDHEAS-G to IDHEAS-ECA

IDHEAS-G is a general HRA methodology from which application-specific HRA methods can be developed. IDHEAS-G consists of a Cognitive Basis Structure, an HRA process implementing the Cognitive Basis Structure, supplementary guidance for performing the HRA process, and an interface for generalizing human error data. IDHEAS-G is intended to be general so it can be adapted to all nuclear HRA applications. It has the following features [1]:

- IDHEAS-G has a basic set of cognitive failure modes (CFMs) at three levels of detail and 20 PIFs each with a comprehensive list of attributes. Those allow the modelling of a variety of human actions and contexts in HRA applications. Yet, using all the detailed CFMs and PIF attributes can be very time consuming for HRA analysts.
- IDHEAS-G provides multiple approaches for estimating HEPs. It is intended that different approaches may be adapted for specific HRA applications, depending on the available resources and data.
- IDHEAS-G establishes an interface for generalizing human error data from various sources to the CFMs and PIFs.

Developing an application-specific HRA method from IDHEAS-G is to have a method specific for the application. The application-specific method should be concise, easy to use, and ideally having a model that allows HRA analysts to calculate HEPs. IDHEAS-G recommends the following approach for developing an application-specific HRA method:

- Define the scope of the application, requirements, and available sources for the intended use
- Keep the qualitative analysis the same as that in IDHEAS-G
- Develop application-specific sets of CFMs, PIFs, and an HEP calculation model.

The NRC defines the development of IDHEAS-ECA method as the following:

- Scope: the method should allow for the performance of event and condition assessments for nuclear-related HRA applications. Specifically, it should be able to model operator actions outside control rooms under severe operating conditions, such as implementations of FLEX.
- Requirements: The method should be easy to use and should not over-burden HRA analysts. It should allow HRA analysts to quickly explore "What-If" questions in an HRA.
- Data sources: IDHEAS-DATA and the data in NRC's SACADA database [7].

With the above definition, the following approach was made to develop IDHEAS-ECA method:

- Use the same guidance for the scenario, HFE, and task analysis as well as the guidance for time uncertainty analysis as those in IDHEAS-G.
- Adapt the basic set of CFMs in IDHEAS-G by using the five high-level CFMs to model the failure of a critical task.
- Use the 20 PIFs, but with a consolidated subset of the attributes.
- Use the HEP quantification model in IDHEAS-G to directly calculate HEPs.
- Integrate the available human error data to obtain the base HEPs and PIF weights needed in the HEP quantification model.

Regardless of HRA application, the first four steps of the IDHEAS methodology involve the qualitative analyses of the scenario context and timing, HFE definition and the critical tasks of the HFE, and identification of the CFMs that apply for each critical task. The analysts use the results of the scenario context analyses to determine the PIFs and their attributes applicable to each CFM of the critical tasks. Thus, the qualitative analysis steps, documented in IDHEAS-G, are the fundamental elements of the IDHEAS methodology and apply to all IDHEAS-related HRA methods.

2.2 Integration of human error data for calculation of human error probabilities

IDHEAS-DATA is a database documenting the human error data generalized from various sources, including nuclear-related operational data and experimental data in the cognitive science literature. IDHEAS-DATA generalizes the original data into the same structure as in the IDHEAS-G cognitive basis—macrocognition model (i.e., CFMs) and PIF Structure (i.e., PIF attributes).[1] IDHEAS-DATA contains 27 tables for each PIF and other elements of the IDHEAS methodology, such as PIF interaction, dependency, and recovery effects. The tables document human error data that are generalized into the IDHEAS-G taxonomy (the cognitive failure modes and PIF attributes). The generalized data are used to inform HEPs in various approaches for HEP estimation.

In developing IDHEAS-ECA, the NRC staff integrated the available data as of July 2019 in the Human Error Tables to develop the base HEPs and PIF weights for every CFM and PIF attribute in IDHEAS-ECA. Because of the limitations and uncertainties in the available data, the integration involves interpolation, reasoning, and engineering judgment. The human error data are first evaluated for their uncertainties and practicality in the source documents. The NRC staff considered that the NPP operational data that were systematically collected for HRA had the highest practicality. The NRC staff used high practicality data to anchor a base HEP or PIF weight and used other data points to adjust the uncertainties in the high-practicality data points. After the initial base HEPs and PIF weights were developed, they were checked for internal consistency against the literature that ranks the likelihood of certain types of human errors and the contribution of various PIFs. The NRC staff also used reported human failure events to check and adjust some base HEPs and PIF weights within their uncertainty ranges.

3. The cognitive basis of IDHEAS-ECA

IDHEAS-ECA uses the cognitive basis in IDHEAS-G, which consists of a macrocognition model and a PIF structure. HRA models HFEs under a given context, which is the conditions that challenge or

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[1] In NUREG-2198 [2], the terms “cognition model” and “cognitive basis structure” have the same meaning as “cognitive basis” and “macrocognition model” in this paper, respectively.

facilitate human performance. The macrocognition model describes how a human action can be achieved or failed, and the PIF structure models how the event context impacts human reliability.

Figure 1 shows the IDHEAS-ECA hierarchy for modelling human actions in a scenario. The method begins with scenario analysis, which identifies HFEs in the scenario and subsequently identifies critical tasks in an HFE. The human action defined in an HFE may be decomposed into a set of discrete tasks for modelling. A "critical task" is essential to the success of the HFE; failure of any critical task in an HFE will result in the occurrence of the HFE. The failure of a critical task is modelled with the CFMs, i.e., failure of the five macrocognitive functions in the macrocognition model.

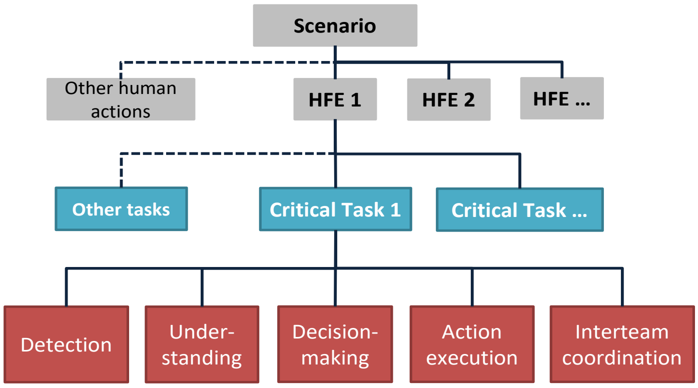


Figure 1 IDHEAS-ECA Hierarchy for Modelling an Event (taken from [1])

3.1 Macrocognition model

A human action or a critical task involves performing cognitive activities, which demand brain resources. IDHEAS-ECA models the cognitive demands of a critical task using five macrocognitive functions, which are the high-level brain functions that must be successfully accomplished to achieve the cognitive activities. IDHEAS-ECA uses the following macrocognitive functions:

- Detection (D) is noticing cues or gathering information in the work environment.
- Understanding (U) is the integration of pieces of information with a person's mental model to make sense of the scenario or situation.
- Decisionmaking (DM) includes selecting strategies, planning, adapting plans, evaluating options, and making judgments on qualitative information or quantitative parameters.
- Action Execution (E) is the implementation of the decision or plan to change some physical component or system.
- Interteam Coordination (T) focuses on how various teams interact and collaborate on a critical task.

The first four macrocognitive functions (D, U, DM, and E) may be performed by an individual or a team, and Interteam Coordination is performed by multiple groups or teams.

With the macrocognition model, IDHEAS-ECA provides a set of five CFMs to model failure of a critical task. Each CFM represents the failure of a macrocognitive function demanded to accomplish the critical task, which are defined as follows:

- CFM1 – Failure of Detection
- CFM2 – Failure of Understanding
- CFM3 – Failure of Decisionmaking
- CFM4 – Failure of Action execution
- CFM5 – Failure of Interteam coordination

3.2 PIF structure

IDHEAS-ECA process begins with analysing a scenario and searching for the context that challenges or facilitate human performance. The method uses 20 PIFs and the associated attributes to model the scenario context. The IDHEAS PIF structure is composed of the following: 1) PIF category, (2) PIFs, and (3) PIF attributes.

PIFs are categorized into the four categories of event context: environment and situation, system, personnel, and task. They are described as follows:

1) Environment and situation context — This consists of conditions in personnel's work environment and the situation in which actions are performed. It includes the weather, radiation or chemicals in the workplace, and any extreme operating conditions.

2) System context — Systems are the objects of the HFEs. The actions' objectives are achieved through systems, which include operational systems, supporting systems, instrumentation and control (I&C), physical structures, human-system interface (HSI), and equipment and tools.

3) Personnel context — Personnel are the people who perform the action. Personnel includes individuals, teams, and organizations. The personnel context describes who the personnel are; their qualifications, skills, knowledge, abilities, and fitness to perform the action; how they work together; and the organizational measures that help personnel work effectively.

4) Task context — The task context describes the cognitive and physical task demands for personnel and special conditions in the scenario that make tasks difficult to perform. An action may consist of one or more discrete tasks.

IDHEAS-ECA uses PIFs to characterize the contexts. IDHEAS-ECA has 20 PIFs in the four context categories as shown in Table 1. This list of PIFs covers all PIFs in the reviewed HRA methods and factors reported in the literature and nuclear-specific human event databases.

Table 1 PIFs in IDHEAS-ECA

Environment and situation	System	Personnel	Task
• Work location accessibility and habitability • Workplace visibility • Noise in workplace and communication pathways • Cold/heat/humidity • Resistance to physical movement	• System and I&C transparency to personnel • Human-system interfaces • Equipment and tools	• Staffing • Procedures, guidelines, and instructions • Training • Teamwork and organizational factors • Work processes	• Information availability and reliability • Scenario familiarity • Multi-tasking, interruption and distraction • Task complexity • Mental fatigue • Time pressure and stress • Physical demands

A PIF is characterized with a set of attributes. A PIF attribute is an assessable characteristic of a PIF and describes a way the PIF increases the likelihood of error in the macrocognitive functions. For example, Table 2 shows the attributes for PIF Scenario Familiarity and PIF Human-System Interface.

Table 2 PIF Attributes for Scenario Familiarity and Human-System Interface

Scenario Familiarity	Human-System Interface
SF0 – No impact • Frequently performed tasks in well-trained scenarios • Routine tasks SF1 – Unpredictable dynamics in known scenarios • Shifting task objectives • Dynamic decisionmaking is required SF2 – Unfamiliar elements in the scenario • Non-routine, infrequently performed tasks • Unlearn a technique and apply one that requires the application of an opposing philosophy SF3 – Scenario is unfamiliar, rarely performed • Notice adverse indications that are not part of the task at hand • Notice incorrect status that is not a part of the routine tasks • Lack of plans, policies, and procedures to address the situation • Rare events (e.g., Fukushima accident) SF4 – Bias or preference for wrong strategies exists, mismatched mental models	HSI0 – No impact – well designed HSI supporting the task HSI1 – Indicator is similar to other sources of information nearby HSI2 – No sign or indication of technical difference from adjacent sources (meters, indicators) HSI3 – Related information for a task is spatially distributed, not organized, or cannot be accessed at the same time HSI4 – Un-intuitive or un-conventional indications HSI5 – Poor salience of the target (indicators, alarms, alerts) out of the crowded background HSI6 – Inconsistent formats, units, symbols, or tables HSI7 – Inconsistent interpretation of displays HSI8 – Similarity in elements - Wrong element selected in operating a control element on a panel within reach and similar in design in control room HSI9 – Poor functional localization – 2 to 5 displays / panels needed to execute a task

HEP estimation of a CFM is based on the assessment of PIF attributes applicable to the CFM. Appendix B of IDHEAS-ECA report [1] lists all the attributes for IDHEAS PIFs.

3.3 HEP quantification model

IDHEAS-G provides guidance on several ways to estimate HEPs, one of which is its HEP quantification model. The estimation has two parts: estimating the error probabilities attributed to the CFMs (P_c) and estimating the error probability attributed to the uncertainties and variability in the time available and time required to perform the action (P_t). The estimation of the HEP is the probabilistic sum of P_c and P_t:

$$P = 1 - (1 - P_c)(1 - P_t) \quad (1)$$

In Equation (1), P is the probability of the HFE being analyzed (i.e., the HEP), and P_c and P_t have already been defined. Note the following:

1. P_t can also be viewed as the probability that the time required to perform an action exceeds the time available for that action, as determined by the success criteria. P_t does not account for the increased likelihood of a human error due to time pressure. Time pressure is treated as a PIF and contributes to P_c.

- P_c assumes that the time to perform the HFE is sufficient. Sufficient time means that the HFE can be successfully performed within the time window that the system allows P_c captures the probability that the human action does not meet the success criteria due to human errors made in the problem-solving process.

<u>Estimation of P_c</u>

P_c is the probabilistic sum of the HEPs of all the CFMs of the critical tasks in a human action. The probability of a CFM applicable to the critical task is a function of the PIF attributes associated with the critical task. The calculation of the probability of a CFM for any given set of PIF attributes, provided that all the PIF impact weights and base HEPs are obtained, is estimated as:

$$P_{CFM} = P_{CFM_{Base}} \cdot \left(1 + \sum_{i=1}^{n}(w_i - 1)\right) \cdot C \cdot \frac{1}{Re} = \frac{P_{CFM_{Base}} \cdot \big(1 + (w_1 - 1) + (w_2 - 1) + \cdots + (w_n - 1)\big) \cdot C}{Re} \quad (2)$$

The terms in Equation (2) are defined as follows:

- $P_{CFM_{Base}}$ is the base HEP of a CFM for the given attributes of the following three PIFs: *information availability and reliability*, *scenario familiarity*, and *task complexity*. $P_{CFM_{Base}}$ is also calculated as the probabilistic sum of the base HEPs for the three PIFs:

  $$P_{CFM_{Base}} = 1 - [(1 - P_{INF})(1 - P_{SF})(1 - P_{TC})] \quad (3)$$

  where P_{INF}, P_{SF}, and P_{TC} are the base HEPs for *information availability and reliability*, *scenario familiarity*, and *task complexity*, respectively. In the situations when no adverse conditions are identified in the three base PIFs, a lowest base HEP of the CFM is assigned to $P_{CFM_{Base}}$.

- w_i is the PIF impact weight for the given attributes of the remaining 17 PIFs and is calculated as:

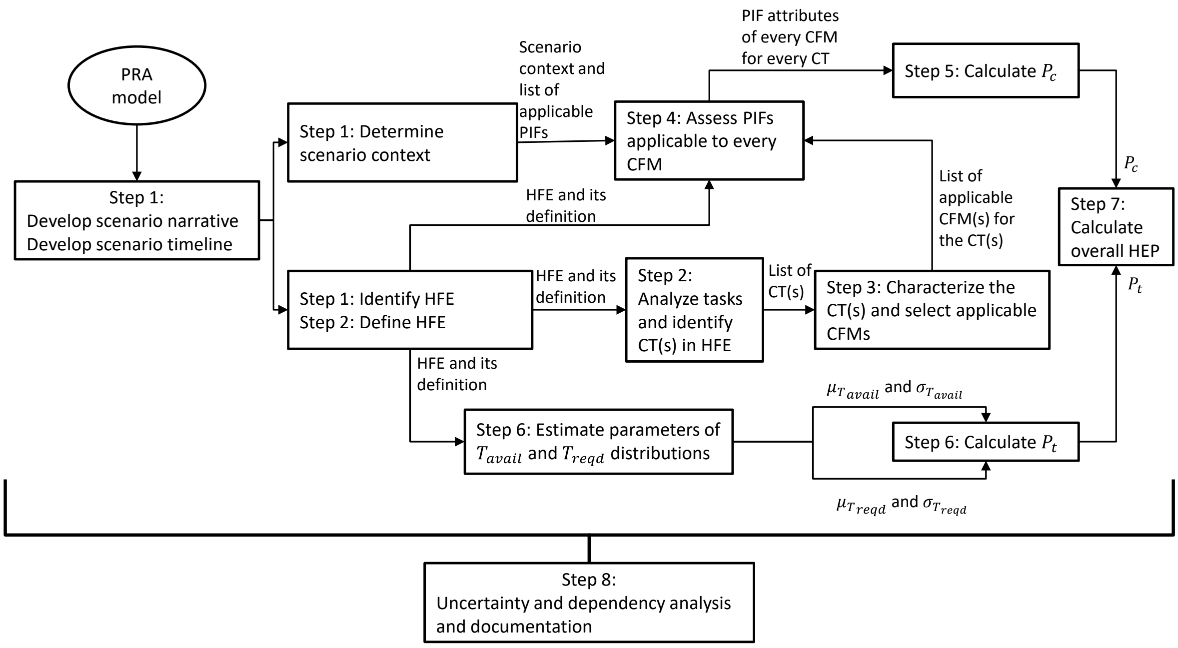
  $$w_i = \frac{ER_{PIF}}{ER_{PIF_{Base}}} \quad (4)$$

  where ER_{PIF} is the human error rate at the given PIF attribute and $ER_{PIF_{Base}}$ is the human error rate when the PIF attribute has no impact. The human error rates used in Equation (4) are obtained from empirical studies in the literature or operational databases that measured the human error rates while varying the PIF attributes of one or more PIFs.

- Re is a factor that accounts for the potential recovery from failure of a critical task, and it is set to 1 by default. C is a factor that accounts for the interaction between PIFs, and it is set to 1 for the linear combination of PIF impacts unless there are data suggesting otherwise.

4. IDHEAS-ECA process

The HRA process with IDHEAS-ECA consists of eight steps, which are briefly described below. Figure 2 presents an overview of the IDHEAS-ECA HRA process and the flow of information. Each box represents a to-do item of a step in the process. The arrows represent the input(s) and output(s) from each of the items. To perform a step, all the inputs (information) for the step need to be available.



CFM = cognitive failure mode
CT = critical task
HEP = human error probability
HFE = human failure event
PIF = performance-influencing factor
PRA = probabilistic risk assessment

P_c = error probability due to CFMs
P_t = error probability due to uncertainty in T_{avail} and T_{reqd}
T_{avail} = time available
T_{reqd} = time required
$\mu_{T_{avail}}$ and $\sigma_{T_{avail}}$ = mean and standard deviation of T_{avail}
$\mu_{T_{reqd}}$ and $\sigma_{T_{reqd}}$ = mean and standard deviation of T_{reqd}

Figure 2 Overview of the IDHEAS-ECA HRA Process

Step 1: Analyze the event scenario.

Analyzing an event includes developing the scenario narrative and timeline, determining the scenario context, and identifying the HFEs to be modelled (if not given in the PRA model). The scenario narrative is a storytelling-style representation that specifies the initial conditions, initiating event, boundary conditions of the event, and the scenario progression and end state. The scenario timeline documents the system responses (to the initiating event) and HFEs in chronological order. Together, the scenario narrative and timeline are the operational narrative. Determining the scenario context refers to the search for the conditions that challenge or facilitate human performance in the scenario and results in a list of applicable PIFs. The HFEs are usually identified in the PRA model and are the analysis units of an HRA. The results of the analysis include scenario definition, operational narrative, scenario context, and a list of HFEs in the event. The results from Step 1 serve as the inputs to all other steps.

Step 2: Analyze the HFE.

This includes defining the HFE, analyzing the tasks in the HFE with a task diagram and/or timeline, and identifying critical tasks for HEP quantification. The definition of the HFE describes the failure of the human action and its link to the affected systems in the PRA model. Analyzing the tasks within an HFE provides a representation of how the HFE can occur and aids in the identification of critical tasks, which are those that are essential to the success of the HFE. Failure of any critical task will result in the occurrence of the HFE. The results of the analysis include the HFE definition, the task diagram and/or HFE timeline that graphically illustrates the success and failure paths of an HFE, and the critical tasks that must be accomplished for the success of the HFE.

Step 3: Model the failure of the critical tasks in an HFE.

This includes characterizing the critical task, identifying cognitive activities required to achieve the critical task and subsequently identifying CFMs applicable to the critical task. Characterization of a critical task is to specify the conditions relevant to the critical task that can challenge or facilitate human performance of it. Any critical task can be achieved through one to all five macrocognitive functions. The cognitive failure of a critical task is the result of failure of any macrocognitive function it demands. Thus, the CFMs are the classifications of the various ways that a critical task may fail. The results include the characterization of every critical task and the identification of the applicable CFMs determined by the macrocognitive functions required to perform the cognitive activities in the task. Task characterization specifies the information in Step 1 and Step 2 (i.e., the operational narrative and context of the scenario, the HFE definition, and the task diagram/timeline) for individual critical tasks. The following are the guidelines for breaking down an HFE into critical tasks:

1) Use as few critical tasks as possible to represent the HFE, i.e., begin with the entire HFE as one critical task.
2) Further break down the HFE into critical tasks only when the PIF attributes vary for different critical task portions of the HFE.
3) An HFE should only be broken into critical tasks at a level that retains the context of the HFE and can be represented with macrocognitive functions.
4) Stop breaking down the tasks at the level where there are performance indications or empirical data available to inform HEPs. For example, expert judgment has been a prevalent way to estimate HEPs. If expert judgment is used, the HFE should be broken down to critical tasks at the level with which experts are familiar enough to make judgment.

Step 4: Assess the PIFs applicable to every CFM.

This step uses the results of the scenario context (Step 1), HFE definition (Step 2), and task characterization (Step 3) to select the applicable PIF attributes for every CFM. The PIFs represent the context of the HFE and facilitate quantification of the HEP. A PIF attribute is an assessable characteristic of a PIF and describes a way the PIF challenges the macrocognitive functions of a critical task and, therefore, increases the likelihood of error in the macrocognitive functions. The results are the applicable PIF attributes for every CFM. The determination of applicable PIF attributes is based on the scenario context, HFE definition, and task characterization.

Step 5: Calculate P_c of an HFE.

P_c is the probability of failure due to the CFMs and is calculated as the probabilistic sum of the HEPs of all the CFMs of the critical tasks, which are based on the PIF attributes assessed in Step 4. P_c can be computed using the IDHEAS-ECA software or manually using the data in Appendix B of the IDHEAS-ECA report [1]. This step takes the CFMs identified in Step 3 and PIF attributes identified in Step 4 as the input to the calculation.

Step 6: Analyze HFE timeline and calculate P_t of an HFE.

P_t is the probability of failure due to the uncertainty in time available and time required to perform the HFE. Using the HFE definition, the timeline for the HFE is analyzed to obtain an estimate of the parameters of the probability distributions of time available and time required. Then, the IDHEAS-ECA software is used to calculate P_t. Step 6 focuses on analyzing time uncertainty of each HFE and calculating P_t by estimating the distributions of time available and time required for the HFE. While the estimation can be made with the results of Step 1 and Step 2, the detailed analysis of the critical tasks and relevant PIFs in Step 3 and Step 4 help to refine the estimation of the time required.

Step 7: Calculate the overall HEP.

The overall HEP is the probabilistic sum of P_c and P_t. That is, $Overall\ HEP = 1 - (1 - P_c)(1 - P_t)$. This calculation is performed by the IDHEAS-ECA software. Alternatively, it can be performed manually.

Step 8: Analyze uncertainties in the HRA results and perform sensitivity analysis.

The assessment of uncertainty on HEPs is a required part of the PRA. Step 8 of IDHEAS-ECA is to analyze uncertainties associated with the obtained mean HEPs and perform the sensitivity analysis. PRA is a probabilistic model that characterizes the aleatory uncertainty associated with accidents at NPPs in that the results are given in terms of the likelihoods of accident sequences. The purpose of the uncertainty analysis that is performed as part of the PRA process is to characterize uncertainties associated with the results of the PRA model. NUREG-1855 [8] provides guidance for treatment of three types of uncertainty in PRA: parameter uncertainty, model uncertainty, and completeness uncertainty. This step adapts the guidance in HRA good practices (NUREG-1792 [9]) as follows:

1) Systematically analyze and document uncertainties in Steps 1 – 5. The uncertainties should include (1) those epistemic uncertainties existing because of lack of knowledge of the true expected performance of the human for a given context and associated set of PIFs, and (2) consideration of the combined effect of the relevant aleatory (i.e., random) factors to the extent they are not specifically modeled in the PRA and to the extent that they could alter the context and PIFs for the HFE.
2) Develop uncertainty distributions for the significant HEPs to capture the center, body, and range of an HEP associated with the uncertainty factors.
3) Perform sensitivity analyses that demonstrate the effects on the risk results for extreme estimates in the HEPs based on at least the expected uncertainty range.

Step 1 analyses the entire event scenario, while Step 2 through Step 8 focuses on individual human failure events in a PRA model. When a PRA model has multiple human failure events in a cutset, analysts need to evaluate the dependency between events. For this purpose, the NRC staff developed IDHEAS Dependency Analysis (IDHEAS-DEP) [5] that can be used along with IDHEAS-ECA.

Steps 1, 2, 3, and part of Step 6 all require information collection. These steps are equivalent to the qualitative analysis portion in many HRA methods. They transform the qualitative information that analysts collect for the HRA into structured elements that assist HRA quantification in later steps. Steps 4 and 5, the calculation of P_t of Step 6, and Step 7 constitute HRA quantification. The quantification is based on the specific formats of IDHEAS-ECA qualitative analysis steps. The IDHEAS-ECA software assists HRA analysts in performing Steps 4, 5, 6, and 7 after analysts complete the first three steps and document the results in the IDHEAS-ECA Worksheets.

The outcomes of Steps 1 through 4 provide the understanding of what happens in the scenario, what human actions are needed, what can go wrong, and what challenges human performance. These steps are the fundamentals of an HRA. All the guidance on these four steps in IDHEAS-G are applicable for the same steps in IDHEAS-ECA. Steps 5, 6, and 7 are for HEP quantification. These steps can be performed with the IDHEAS-ECA Software Tool to reduce analysts' calculational burden. Yet, it is essential that HRA analysts perform the qualitative analysis and document the analysis. Only after the systematic qualitative analysis following the guidance from Step 1 to Step 4, analysts may choose to enter the results into the software to calculate the HEP. Without a systematic analysis, the selections of applicable CFMs and PIF attributes may under-represent the context challenging to human performance, therefore under-estimating the risk, misrepresenting the context with wrong CFMs and PIF attributes, and/or double-counting the impact of certain contexts. Any of these can introduce analyst-to-analyst variability in the HRA results.

5. Concluding remarks

Overall, IDHEAS-ECA was developed as a complete, off-the-shelf HRA method. IDHEAS-ECA is used to analyze human events and estimate HEPs in PRA applications. IDHEAS-ECA builds upon existing HRA methods by providing a systematic process and guidelines to analyze and model human actions and the associated scenario context. Further, it uses a human error database to calculate HEPs and includes an extensive set of PIFs to represent the context of scenarios under various operational conditions, such as using FLEX equipment.

IDHEAS-ECA is envisioned to be used by the staff involved in the NRC's risk-informed activities. The intent is for the method to be applicable to the same situations that existing HRA methods model (e.g., nuclear power plant internal events while at-power) and beyond (e.g., external events, low-power and shutdown events, spent fuel storage and transportation events, and events where portable equipment are used). Given the wide range of contextual factors included in its model, it is feasible that IDHEAS-ECA could also be used for applications beyond the nuclear domain.

6. References

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