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CRUCIAL ROLE OF DETAILED FUNCTION, TASK, TIMELINE, LINK AND HUMAN VULNERABILITY ANALYSES IN HRA

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Abstract

This paper addresses one major cause for large uncertainties in human reliability analysis (HRA) results, that is, an absence of detailed function, task, timeline, link and human vulnerability analyses. All too often this crucial step in the HRA process is done in a cursory fashion using word of mouth or written procedures which themselves may incompletely or inaccurately represent the human action sequences and human error vulnerabilities being analyzed. The paper examines the potential contributions these detailed analyses can make in achieving quantitative and qualitative HRA results which are: (1) credible, that is, minimize uncertainty, (2) auditable, that is, systematically linking quantitative results and qualitative information from which the results are derived, (3) capable of supporting root cause analyses on human reliability factors determined to be major contributors to risk, and (4) capable of repeated measures and being combined with similar results from other analyses to examine HRA issues transcending individual systems and facilities. Based on experience analyzing test and commercial nuclear reactors, and medical applications of nuclear technology, an iterative process is suggested for doing detailed function, task, timeline, link and human vulnerability analyses using documentation reviews, open-ended and structured interviews, direct observations, and group techniques. Finally, the paper concludes that detailed analyses done in this manner by knowledgeable human factors practitioners, can contribute significantly to the credibility, auditability, causal factor analysis, and combining goals of the HRA.

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Introduction

Increasingly, managers and operators of complex high reliability facilities (e.g., aerospace, military, nuclear) are being required to demonstrate that their safety margin, or safety envelope, is sufficient to justify risks that might accrue to the general public and personnel operating these facilities. The most commonly used method for assessing the safety margin is the probabilistic risk assessment (PRA). Results of primary interest from the PRA are likelihood that the safety margin might be exceeded therefore causing accidents, and consequences of these accidents to life and property.

Aerospace, military and nuclear facilities are primary socio-technical in nature, that is, are made up of three components: equipment, personnel, and operating characteristics

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(e.g., policies, practices, and operating procedures). Equipment and personnel act individually and in combination in accordance with the latter operating characteristics. As such, all three system components, individually and in combination, are of concern to the PRA. In the past, however, PRA focused primarily on the equipment and operating characteristics components of the facility. Systems analysis and Failure Modes and Effects Analysis (FMEA) provide the basis for understanding the facility equipment and its vulnerabilities. The results of these analyses are used to develop logic or facility process models with which to analyze pertinent event sequences for their risk likelihood.

More recently, PRAs have attempted to look more closely at the personnel component, this brought about primarily by a recognition of the crucial role human error has played in major accidents involving these facilities (e.g., Three Mile Island, Bhopal, Challenger, Chernobyl). [1] This portion of the PRA is commonly referred to as the Human Reliability Analysis (HRA). Detailed systems analysis and FMEA are crucial for understanding and analyzing equipment operability and vulnerability. Complementary function, task, timeline, link, and human vulnerability analyses provide the basis for integrated logic or facility process models for analyzing more completely, the individual and combined effects of equipment, personnel, and facility operating characteristics on safety.

The purpose of this paper is to explore the credibility, auditability, causal factor identification, and repeated measurement and combining requirements of the HRA whose achievement are very much dependent on detailed function, task, timeline, link, and human vulnerability analyses. An iterative process is suggested for doing these analyses, which are best accomplished by human factors/human reliability practitioners describing and interpreting human actions and action sequences from a behavioral as well as an engineering perspective. Requirements for HRA and the iterative process have emerged from experience doing HRA in test and commercial nuclear reactor environments, and in medical environments where nuclear technologies are being applied. [2, 3, 4, 5]

Requirements of HRA

HRA results, whether quantitative or qualitative, will be useful for assessing the overall impact of human performance on risk, only if they are credible, auditable, support analysis of contributing factors, and are meaningfully comparable to other HRA results.

Credibility - Defensible HRA results require an experienced HRA analyst carefully using accepted human reliability analysis and quantification techniques. HRA techniques that have demonstrated reliability and validity are essential. Reliability requires reasonable consistency of results across time and analysts. Validity requires results consistent with actual human performance. The large number and complex context specific interactions of variables influencing human reliability, and the scarcity of human error data, can result in significant uncertainty if not dealt with systematically and completely by the HRA technique used. Theoretical or proposed HRA techniques must undergo extensive examination of

underlying principles-assumptions and careful applications testing before they can be accepted as credible. Useful techniques must provide supportable estimates of uncertainty for results (especially for quantitative results). Defensible estimates of uncertainty require careful, standardized, conscientious, applications of the accepted techniques by experienced HRA practitioners well trained in behavioral science, and armed with the appropriate contextual information.

A proper, and defensible application of any HRA technique is not possible without accurate and complete information on the human task actions and action sequences being assessed, obtainable from detailed function, task, timeline, link, and human vulnerability analyses.

Auditability - An HRA must be well documented and traceable for the results to be of practical use and defensible. All steps, assumptions, information, and methods relevant to the analysis must be presented in detail, to allow a reviewer to understand the origin, understand the specific context, and assess the meaning of the results. Function, task, timeline, link, and human vulnerability analyses are used to identify and assess the relevant variables; and influences upon which the HRA results are based. Appropriate and well documented analyses define much of the basic information used to perform the HRA. The information from these analyses become part of the HRA, and are linked to HRA results through complete documentation of the process, assumptions, and methods used to generate quantitative estimates, or qualitative assessments. HRA is not traceable when these analyses are not done, or are not well documented. Auditability of the HRA, including these analyses, is essential to support further assessments of contributing factors to risk, and to allow comparison with other HRAs.

Support analysis of contributing factors to risk - Scientists well trained in the scientific method at best, raise a suspicious eyebrow, and at worst, scream "patently ridiculous" when confronted with the phrase "root cause". Some might point to the Big Bang as the cause of modern events, but the aforementioned scientists would suggest those holding that view have not investigated enough. However, scientific inquiry may discover important correlations between events, and scientific and less rigorous methods may suggest contributing factors and precursors to events. The usefulness of an HRA is enhanced if it contains the appropriate information to extend the identification and analysis of contributing factors to risk beyond that inherent and required for the HRA process.

Well documented function, task, timeline, link, and human vulnerability analyses (supplemented by relationships discovered and documented in the HRA process) contain the raw material useful for identifying or investigating contributing factors to undesirable situations or events having potential risk impact. Well executed and documented analyses, presenting or suggesting a taxonomy of qualitative information are helpful in identifying relationships among contributing factors, and in assessing the magnitude of their contributory relationships to risk.

Results comparable with other analyses - The value of HRA results, quantitative or qualitative, is enhanced if the results can be meaningfully compared to results from other HRA efforts. Such comparisons facilitate examination of HRA related issues of possible relevance across systems or facilities not originally included in a single analysis. Careful, standardized, and meticulously documented use of accepted HRA techniques is necessary for meaningful comparisons of results from separate HRA efforts. HRA results are very context specific. Any valid combining or comparison of results must include rigorous comparisons and matching of the variables and influences identified and used to estimate the HRA results. The process, assumptions, and methodologies employed must also be carefully considered to determine valid comparisons of HRA results.

Appropriately detailed and well documented function, task, timeline, link, and human vulnerability analyses are the linchpin of a highly traceable HRA, to provide the minimum information to determine the validity and meaningfulness of HRA results, and comparing these results with other HRAs.

Iterative Process for Doing Function, Task, Timeline, Link and Human Vulnerability Analyses

The iterative process presented below can provide a sound technical base for responding to each of the HRA requirements outlined in the previous section of this paper. The document review gives the analyst an overview of the facility and an understanding of the human actions and action sequences that are actually used by the staff. The open-ended interviews, along with the facility's operating procedures are of great help in developing an outline of the functions, tasks, and subtasks that should be performed as part of each operating procedure. Once the outline of the functions, tasks, and subtasks has been completed, directed interviews help fill in any gaps in the understanding of the human actions and action sequences that make up the function/tasks/subtasks and help the analyst to understand the performance shaping factors (PSFs) that measurably impact either positive or negative performance of the functions/tasks/subtasks. Direct observations and table-top discussions are very useful in showing the interactions between individuals responsible for each function/task/subtask and furthering the understanding of the PSFs. Organizing resulting function/task/subtask information on a time grid, and presenting pictorially the interfaces among personnel, actions, and equipment, and their frequency, help the analyst visualize circumstances where institutional factors (e.g., management, organizational culture) might have their greatest impact on performance. Finally, screening for error vulnerability provides the analyst a rank ordering of human task actions and action sequences for consideration during later segments of the HRA.

Information for these analyses is sought from a wide variety of sources to ensure a complete and accurate picture of how functions and tasks are actually performed. Frequently, facility documentation is incomplete or out of date, and/or personnel have differing perceptions of how the functions and tasks of interest are supposed to be executed.

Only by sampling all, or at least a representative mix of, facility information sources, can credible representations of these functions and tasks be achieved.

Function/Task Analysis - The function analysis characterizes human involvement within the content of a total event sequence. It is a step-by-step representation of an event using flow chart diagrams and narrative descriptions. As such, it is much like a systems analysis used for facility equipment. The focus of the analysis is the event sequence. Equipment and human tasks (e.g., activate pump, open/close valve) and conditions under which these tasks are performed, are described in the sequence in which they occur. There is no attempt to breakdown human actions below the task level. For HRA, human tasks become the top events of more detailed task analysis. The follow-up task analysis is a step-by-step representation of a human task action sequence also using flow chart diagrams and narrative descriptions. The focus of the analysis is the human task. It is broken down into sub-tasks, and in some cases, hierarchical elements of those sub-tasks. [6]

Table 1 contains questions that must be answered in order to fully understand all the factors surrounding the function/task being analyzed.

TABLE 1
Questions to Answer when Performing a
Function Analysis

Concerning the Function and its Related Tasks:

- [1] What is the function/task, its product, and importance?
(This must be defined in detail)
- [2] What tasks are to be performed in order for the facility to progress from the current state to the goal state?
- [3] How critical is the task in order to achieve the goal state?
- [4] In what sequence do the tasks need to be accomplished?
- [5] What information is required by the task performer?
- [6] What control activations are required?
- [7] What performance requirements are important?
- [8] Is coordination with other tasks or personnel required?
- [9] What errors are possible and how likely are they?
- [10] How many people are needed to perform the task/job?
- [11] What skill level is required to perform the task/job?
- [12] Is function/task to be performed within the capability of the operator?
- [13] Do task characteristics impose excessive demands on the operator(s) (cognitive, psychomotor, or physical)?
 - Concurrent multitask requirements
 - Task duration
 - Frequency of task performance
 - Information feedback
 - Accuracy

Table 1 (cont'd)

- Error probability
- Error criticality
- Strength

Concerning the Function/Task Environment:

- [1] Events requiring operator response
 - Speed of occurrence (too fast?)
 - Number (too many?)
 - Persistence (too short-lived?)
 - Movement (excessive?)
 - Intensity (too weak to perceive?)
 - Patterning (unpredictable?)
- [2] Physical effects
 - Temperature, humidity, noise, vibration (excessive?)
 - Lighting (inadequate?)
 - Safety (problems?)

Concerning the Function/Task Equipment:

- [1] Display information requirements
 - The amount of information available (too much or too little?)
 - Quality of the information?
 - Operator response required?
 - Human memory requirements?
- [2] Control requirements
 - Manipulations required?
 - Force required?
 - Response time?
 - Number to do?

To answer these questions the function/task analysis should fully exploit five iterative steps. They include: (1) Reviewing pertinent facility documents, (2) Conducting non-directed/open-ended interviews with subject matter experts, (3) Conducting directed interviews with operators, (4) Directly observing the function/task, and (5) Organizing the information in a consistent, usable fashion. Terminology and illustrations presented in the following paragraphs are common to U.S. Department of Energy (DOE) nuclear facilities.

(1) Review pertinent facility documents.

[a] Operating procedures provide a starting point for the new procedures. If the current procedures are verbal, then interviews should be set up with the individuals using the procedures in order to document them as thoroughly as possible.

[b] Facility policies, guidance documents, and standards provide information about the safety and administrative requirements to which the facility needs to conform.

[c] Documents related to the administration of the facility (e.g., policy statements and organizational charts) provide information concerning how the facility is operated and who controls the various organizations within the facility.

[d] Operation and Maintenance Logs provide information about how the facility actually operates and provides information about the frequency of the function/task of interest. Also, these documents show how the facility has been maintained and whether maintenance has had an impact on the frequency or severity of the event.

[e] Accident/Incident Reports provide information about the events the facility has had related to the function/task of interest, and how they were handled.

[f] PRAs provide information on the function/task and the inherent risks associated with the facility. Also, a large amount of information concerning the tasks that are accomplished and a good understanding of the quality of the current procedures can be obtained by reviewing the HRA, if it was done as part of a PRA.

[g] Piping and instrumentation diagrams provide an overview of the equipment that is in the facility. The most up-to-date drawings should be selected. As-built drawings should be reviewed by system experts and updated prior to using.

[h] Other sources of information

- o Approved vendor information.
- o Other procedures that describe similar function/tasks, including procedures from outside organizations, if necessary.
- o Technical literature, such as textbooks.
- o Engineering documents, such as engineering drawings or analysis reports.
- o Records of the basis for, and development of, methods and calculations.
- o Analyses of the function/task.
- o User feedback reports.
- o Event reports, root cause analyses, and lessons-learned documents relevant to the procedure.
- o Results of design verification, qualification test and functional tests.
- o Other information relevant to procedure requirements, such as letters of

commitment, contracts and other documents that should also be reviewed and incorporated into the technical basis.

Initial flow chart diagrams and narratives describing the function/task are the products of this step. The flow chart diagram shows the flow of the function/task and the respective states of the facility. An example of a typical flow chart diagram that can be used for this purpose is shown in Figure 1. The function/task narrative is a written description of the function/task. Contained in this narrative are the answers to the questions contained in Table 1. The flow chart diagram and function/task narrative are revised and refined after each succeeding step of the function/task analysis.

(2) Conduct non-directed/open-ended interviews with subject matter experts.

The individuals (subject matter experts) that are most important to interview include:

- [a] Function performers (operators of the systems involved)
- [b] System designers
- [c] Maintenance personnel
- [d] System/process engineers.

The process for conducting the interviews is as follows:

- [a] Interviews are done with only one interviewee at a time.
- [b] Each interviewee is given a new set of flow chart diagrams, which are the function/task narrative and piping and instrumentation drawings (P&IDs), that he/she can mark up.
- [c] The individual should be allowed to select particular diagrams he/she wishes to annotate (non-directed/open-ended).
- [d] As each interview is completed the annotated diagrams and function/task narrative should be collected for comparison and consolidated with those of other interviewees.
- [e] Informal walk-downs of the system can help to resolve any questions personnel might bring up during the interview function/task.
- [f] If a consensus on a particular flow chart diagram and associated function/task narrative sheet cannot be achieved, it may be necessary to convene a meeting with some of the interviewees to force a consensus.

Figure 1: Flow Chart Diagram

[g] The flow chart diagrams and function/task narrative are modified to reflect the information gained from the open-ended interviews.

Refined flow chart diagrams, narratives, and task list are the products of this step.

(3) Conduct directed interviews with users and performers of the function/task.

The process for conducting the interviews is as follows:

[a] The interviewee should have a copy of the revised flow chart diagram(s) and associated function/task narrative, for specific functions for which he/she is responsible.

[b] The interviewee is asked specific questions concerning the completeness and accuracy of the flow chart diagrams and function/task narrative. These questions should be developed from inconsistencies noted between flow chart diagrams and function/task narrative developed from the documentation reviews and from the non-directed interviews.

[c] The interviewee should also be asked (if possible) to supply information about what could happen to the function/task state if the human actions were done incorrectly or if the actions were ineffective. This information will also be used in the human vulnerability analysis described below.

[d] If a consensus on a particular flow chart diagram and associated function/task narrative cannot be achieved, it may be necessary to convene a meeting with some of the interviewees to force a consensus.

The products of this step are flow chart diagrams and function/task narratives, modified and expanded as necessary to reflect the findings from the directed interviews.

(4) Directly observe the function/task being performed using walk-downs, simulator runs, and table-top discussions.

Walkdowns should be conducted as follows:

[a] Groups of appropriate personnel, rather than individuals, should be brought together to walk-down each function utilizing, correcting and expanding affected flow chart diagrams and the function narrative emerging from earlier directed interviews.

[b] Analysts should be stationed in the control room (if any), in the facility, and with any other groups walking down the function/task narrative, to ensure no loss of information.

[c] The walkdown should be conducted as if the function/task was being performed.

[d] The personnel walking down the flow chart diagrams and function/task narrative should also note equipment labels, equipment locations, lighting, ancillary equipment needed to perform the action, special safety precautions, and equipment actuation indicators.

[e] Equipment labels should be checked against control room labels to determine if any mismatches exist.

[f] Any problems found during this process should be noted and corrected before continuing.

Simulator runs should be conducted on facility simulators and entail observing simulations of the function/task of interest. There should be a number of simulator runs for this scenario including runs that are "real-time" and runs in which the alarm event scenario is "stepped through." The following function/task information should be collected.

[a] Information about how the operating crews interact physically, (does the crew physically run into each other) and communicate, (is it clear who in the crew does what) can be gained from "real-time" runs.

[b] At the end of the run, the observer should ask the crew about their performance in terms of problems the crew had in getting the plant to the goal state and to allow the crew to voice concerns about the steps of the procedure.

Table-top discussions should be conducted as follows:

[a] Operating crews and others responsible for performing each function/task are assembled and provided copies of the refined flow chart diagrams and narratives.

[b] Crews and others are then asked to discuss the alarm event as if they were responding to it in real life.

[c] Information gained from table-top discussions of the event is not as in-depth as that gained from simulator runs because the information about crew physical interactions is not available.

The products of this step are revised flow chart diagrams and function/task narratives; modified and expanded as necessary to reflect the findings from the direct observations, simulator sessions, and table-top discussions.

(5) Organize the function/task information in a consistent, usable fashion.

At this point flow chart diagrams and narratives should be organized to illustrate: (1) the juxtaposition of functions, tasks, and subtasks along a time grid, and (2) interfaces among personnel, actions, and equipment responsible for each, and the strengths (frequency) of these interfaces.

[a] Timeline Analysis organizes a function/task analysis along a time grid (including plant response times) to highlight sequential and parallel ordering of tasks or lower level units of analysis, and timing between those units of analysis. [7] Time line analysis charts are usually constructed with time on the horizontal axis and the listing of tasks on the vertical axis. The time estimates associated with a task are indicated by bar graphs beginning at the start of the task and ending when the tasks are completed. For the purposes of producing a function/task narrative, a time line analysis can be used to determine whether there is sufficient staff to perform the procedure, when various tasks will start and be completed, and when staff will be available to perform other tasks. Figure 2 shows a segment of a timeline analysis for a medical application of nuclear technology.

[b] Link Analysis organizes a function/task analysis as a network diagram showing interfaces between and among tasks or lower units of analysis, and frequency with which those interfaces take place. [7] The interactions include the communication links among personnel, the sensory or motor relationships among personnel and/or personnel and equipment, and relationships of equipment. Link analysis is important in the development of a function/task narrative because it illustrates where personnel need to be, their sources of information, and whether there are sources of confusion for the operators performing their functions. Figure 3 shows a segment of the link analysis for a medical application of nuclear technology.

Human Vulnerability Analysis - is similar to a Failure Modes and Effects Analysis, that is, it uses results of function, task, timeline, and link analyses, to screen (rank order) human actions and action sequences listed therein on their relative likelihoods of precipitating a human error. The range of human actions analyzed in subsequent phases of the HRA depends on relative error likelihood and depth of analysis being pursued. [7]

A human vulnerability analysis should be conducted in order to annotate the function/task analysis flow chart diagrams and function/task narratives, and to screen (rank order) human actions and action sequences according to their potential vulnerability to error.

Figure 2: Time-Line

Figure 3: Link Analysis

A human vulnerability analysis should be conducted as follows:

[a] A team of facility operators, system engineers, and others with a great depth of knowledge about the function/task are assembled, and provided copies of the completed function/task flow chart diagrams and narratives.

[b] The team screens likelihoods (e.g., assigns rough error probability estimates, rank orders relative to one another) that human errors that could be committed across all human task actions and action sequences are identified as part of the function/task analysis. The three basic types of human errors that should be considered are:

- o Errors of omission. Examples of this class of error are:
 - Operators skip a step in a procedure
 - Operators forget to open a valve, start a pump, or close a breaker.
- o Errors of commission. Examples of this class of error are:
 - Operators select the wrong procedure
 - Operators close the wrong valve, start the wrong pump, or close the wrong breaker.

- o Cognitive errors. Examples of this type of error are:

- Operators read a display and interpret the results incorrectly
- Operators think they closed a valve, however, they only partially closed it.

[c] For each task action and action sequence the following information is documented:

- o Function/task human action or action sequence identifier.
- o Purpose of the human action or action sequence.
- o Potential human error.
- o Effect of the error on the system or facility.
- o Method of detecting the error.
- o Any environmental conditions that can influence the human error.
- o Contingency actions that can be taken to mitigate the effects of the human error.

Figure 4 shows how human vulnerability analysis information can be documented in tabular form. The information can also be displayed in narrative form.

Task Identifier	Purpose of the Task	Potential Human Error	Effect of the Error of the System	Method of Detecting Error	Environmental Conditions	Mitigating Actions
Close breaker E-23	Energizes Bus 670-23-E	Select wrong breaker	Energize wrong bus Delay in energizing correct bus Battery backup could be drained	Local indication on breaker Status lights for emergency pump 670-M-11 will not light	No unique situations	Energize correct bus
		Improperly close breaker	Delay in energizing correct bus Battery backup could be drained	Local indication on breaker Status lights for emergency pump 670-M-11 will not light	No unique situations	Check breaker for closure

Figure 4: Human Error Process Vulnerability Analysis

CONCLUSIONS & RECOMMENDATIONS

This paper has examined the potential contributions that detailed analyses can make in achieving quantitative and qualitative HRA results which are: (1) credible, in that they minimize uncertainty, (2) auditable, in that they link quantitative results and qualitative information from which the results are derived, (3) capable of supporting root cause analyses on human reliability factors determined to be major contributors to risk, and (4) capable of repeated measures and being combined with similar results from other HRAs to examine issues transcending individual systems and facilities. Based on experience analyzing test and commercial nuclear reactors, and medical applications of nuclear technology, an iterative process is suggested for doing detailed function, task, timeline, link and human vulnerability analyses using documentation reviews, open-ended and structured interviews, direct observations, and group techniques. Finally, detailed analyses done in this manner by knowledgeable human factors practitioners can contribute significantly to the credibility, auditability, causal factor analysis, and combining goals of the HRA.

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