Human Error and Available Time in SPAR-H

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ABSTRACT

The purpose of this paper is to introduce recent efforts to quantify temporal factors contributing to human error. These efforts apply to a broad range of human factors in nuclear power plant operations, including human-machine interaction and human-computer interaction. The purpose of attending this workshop is to allow other workshop attendees to evaluate the way temporal factors are modeled in a safety critical system. It is also the authors' intention to learn about other attempts to classify temporal factors in work, ultimately informing a richer data basis for estimating human error probabilities.

Author Keywords

Human reliability analysis, time, work, human-computer interaction

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

INTRODUCTION TO HUMAN RELIABILITY ANALYSIS

Following the incident at Three Mile Island, the US Nuclear Regulatory Commission increased efforts to document the reliability and risk of nuclear power plants (NPPs). A major initiative was undertaken to develop Probabilistic Risk Assessment (PRA) models for NPPs. Since a large contributing factor to plant risk is human error, PRA models incorporated both human error probabilities and physical system error probabilities [1].

Unfortunately, modeling human error probabilities is fraught with difficulty, especially because actual performance or reliability data are not available for many operations. A series of methods was sought to generate reliable and valid estimates of human error probabilities. Seaver and Stillwell [4] addressed this need by outlining methods for using expert judgments to arrive at these probabilities. These approaches explicated paired comparison, ranking and rating, direct numerical estimation, and indirect numerical estimation techniques applied to error estimation, with a particular emphasis on aggregating the estimates from multiple experts. Subsequent efforts have formalized and refined the methods to estimate error probabilities (e.g., THERP [5] and SPAR-H [2]) and generalized estimation techniques beyond NPPs (e.g., handling high-level radioactive waste).

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Early human reliability analysis methods based human error probability almost exclusively on time, whereby reliability was modeled as having a curvilinear Wiebull distribution with respect to the time available to complete a task. While these methods provided consistent metrics of human error probabilities, the values were not always defensible in light of non-temporal contributing factors to human errors [1,2].

The Idaho National Engineering and Environmental Laboratory (INEEL), among other US Department of Energy National Laboratories, was tasked by the US Nuclear Regulatory Commission to develop a simple method for estimating the human error probabilities associated with operator and crew actions and decisions in response to critical events at commercial US NPPs. The Standardized Plant Analysis Risk Human Reliability Analysis (SPAR-H) method was developed to support plant-specific probabilistic modeling across a range of performance shaping factors in addition to time [2].

THE SPAR-H METHOD

Based on review of human reliability analysis methods, the SPAR-H method assigns human activity to one of two general task categories: *action* or *diagnosis*. Examples of action tasks include operating equipment, conducting calibration or testing, and other activities performed during the course of following plant procedures or work orders. Diagnosis tasks consist of reliance on knowledge and experience to understand existing conditions, planning and prioritizing activities, and determining appropriate courses of action. Operational research suggests that for cognitively engaging tasks such as diagnosis, people tend to exhibit a base human error rate equal to 1.0×10^{-2}. This means that people have about a 1 in a 100 chance of making a diagnosis error. For tasks that are more action oriented, the base human error rate is equal to about 1.0×10^{-3}, suggesting about a 1 in a 1000 chance of making an error. Base error rates for the two task types associated with the SPAR-H method were calibrated against other human reliability analysis methods. The calibration revealed that the SPAR-H human error rates fall within the range of rates predicted by other methods [2]

The SPAR-H method incorporates eight performance shaping factors (PSFs) that serve as multipliers to base human error rates These factors include:

- *Available time*—refers to the time available to complete a task, often in the context of the time to complete a corrective action to prevent an abnormal operating event in NPPs;
- *Stress and stressors*—broadly defined to describe negative (or sometimes positive) arousal that impacts human performance;
- *Experience and training*—included in this consideration are years of experience of the individual, specificity of training, and amount of time since training;
- *Task complexity*—refers to how difficult the task is to perform in the given context;
- *Ergonomics (including human-machine interaction)*—refers to the equipment, displays and controls, layout, quality and quantity of information available from instrumentation, and the interaction of the operator with the equipment to carry out tasks;
- *The quality of operating procedures*—refers to the existence and use of formal operating procedures or best practices for the tasks under consideration;

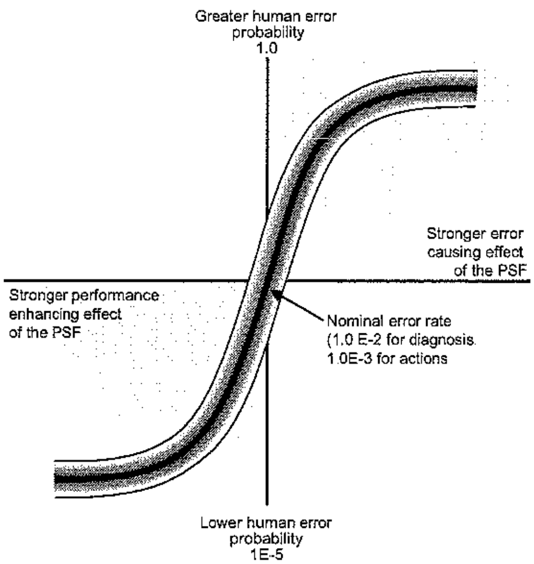

Figure 1. Mean human error probability as a function of PSF influence.

- *Operator fitness for duty*—refers to whether or not the individual performing the task is physically and mentally fit to perform the task at that time;
- *Work processes*—refer to aspects of doing work, including inter-organizational, safety culture, work planning, communication, and management support and policies

PSFs work to increase the error rate due to situational characteristics If, for example, the person is experiencing considerable stress, his or her task performance will decrease proportionate to the level of stress. Conversely, if a person has extensive training and practice doing a task, that person's proficiency may mitigate the chance of human error While many contemporary human reliability analysis methods address PSFs in some form, the SPAR-H method is one of the few that addresses the potential beneficial influence of these factors. Figure 1 shows the influence of the PSF (*x*- axis) on mean human error probability (HEP) values (*y*- axis).

All eight PSFs are significant contributors to human error. Figure 2 depicts the interrelationship between the PSFs as well as their direct or indirect contribution to human performance. Available time as a PSF is influenced by the other PSFs as follows:

- *Stress and stressors*—amount of stress does not change the available time;
- *Experience and training*—greater experience means that less time is required for actions and decisions,
- *Task complexity*—can make the time available insufficient;
- *Ergonomics (including human-machine interaction)*—poor layout can result in increased reaction time, lessening the available time to respond;
- *The quality of operating procedures*—complex or poorly conceived procedures increase how much time one needs to act;
- *Operator fitness for duty*—illness or drug abuse may require increased time to decide or act; and
- *Work processes*—poor shift turnover of information can reduce time available

In turn, available time affects the other PSFs as follows:

- *Stress and stressors*—less time may increase stress;
- *Experience and training*—available time has little or no effect on experience and training;
- *Task complexity*—little time makes the task more complex;

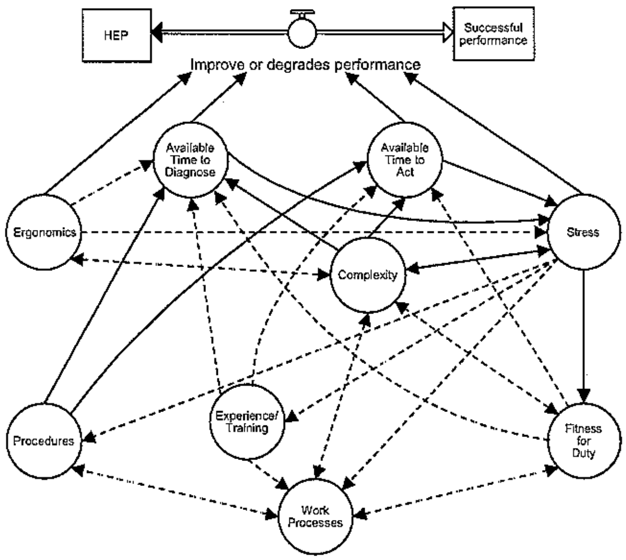

Figure 2. Path diagram showing relationships among PSFs (solid lines denote high degree of relationship, dashed lines denote medium degree of relationship).

- *Ergonomics (including human-machine interaction)*—available time has little or no effect on ergonomics and human-machine interaction;
- *The quality of operating procedures*—available time has little or no effect on the quality of operating procedures;
- *Operator fitness for duty*—available time has little or no effect on the operator's fitness for duty; and
- *Work processes*—in some cases, time may enhance or compromise work processes

PSFs are characterized according to whether the task is cognitively engaging (i.e., a diagnosis task) or routinized (i.e., an action task). The PSFs are further classified according to whether they occur in a fault tolerant situation or a fault intolerant condition. In terms of NPPs, fault tolerance occurs during less critical operations, such as when an NPP is in shutdown mode. Fault intolerance occurs during critical operations, such as when an NPP is at power and the consequences of errors are high. In a human-computer interaction context, fault tolerance tends to equate to day-to-day activities such as routine word processing. Fault intolerance likely encodes into a more sensitive project, such as writing a conference paper shortly before deadline.

To demonstrate how PSFs shape human error, we present a small subset of PSF modeling below using available time in a fault intolerant condition. For a cognitively engaging (i.e., diagnosis) task, available time may be modeled as follows:

- *Inadequate time*—If the operator cannot perform the task in the amount of time available, no matter what s/he does, then failure is certain. (HEP=1.0)
- *Barely adequate time*—Two-thirds of the average time required to complete the task is available. (HEP=0.1)
- *Nominal time*—On average, there is sufficient time to diagnose the problem. (HEP=0.01)
- *Extra time*—The time available is between one to two times greater than the nominal time required (HEP=0.001)
- *Expansive time*—The time available is greater than two times the nominal time required. (HEP=0.0001)
- *Insufficient information*—If you do not have sufficient information to choose among the other alternatives, assign this PSF level. (HEP=0.01).

For routinized (i.e., action) tasks, available time may be modeled as follows:

- *Inadequate time*—If the operator cannot execute the appropriate action in the amount of time available, no matter what s/he does, then failure is certain (HEP=1.0)
- *Time available is equal to the time required*—There is just enough time to execute the appropriate action (HEP=0.01)
- *Nominal time*—There is some extra time above what is minimally required to execute the appropriate action. (HEP=0.001)
- *Time available is greater than or equal to five times the required time*—There is an extra amount of time to execute the appropriate action (i.e., the approximate ratio of 5:1). (HEP=0.0001)
- *Time available is greater than or equal to fifty times the required time*—There is an expansive amount of time to execute the appropriate action (i.e., the approximate ratio of 50:1). (HEP=0.00001)
- *Insufficient information*—If you do not have sufficient information to choose among the other alternatives, assign this PSF level. (HEP=0.001)

Note that PSFs can be combined. In the case where more than one PSF is being considered, absolute HEP values are computed by adding individual PSF multipliers. This would be the case, for example, if available time and stress contributed to a human error.

In the event of multiple concurrent tasks, as is common in most real-world scenarios, the HEP values may also be combined. If two events must occur together for an error to occur, the HEP values are multiplied together to create a logical *AND* relationship. For example, loosing a word processed document requires the user *both* to fail to save

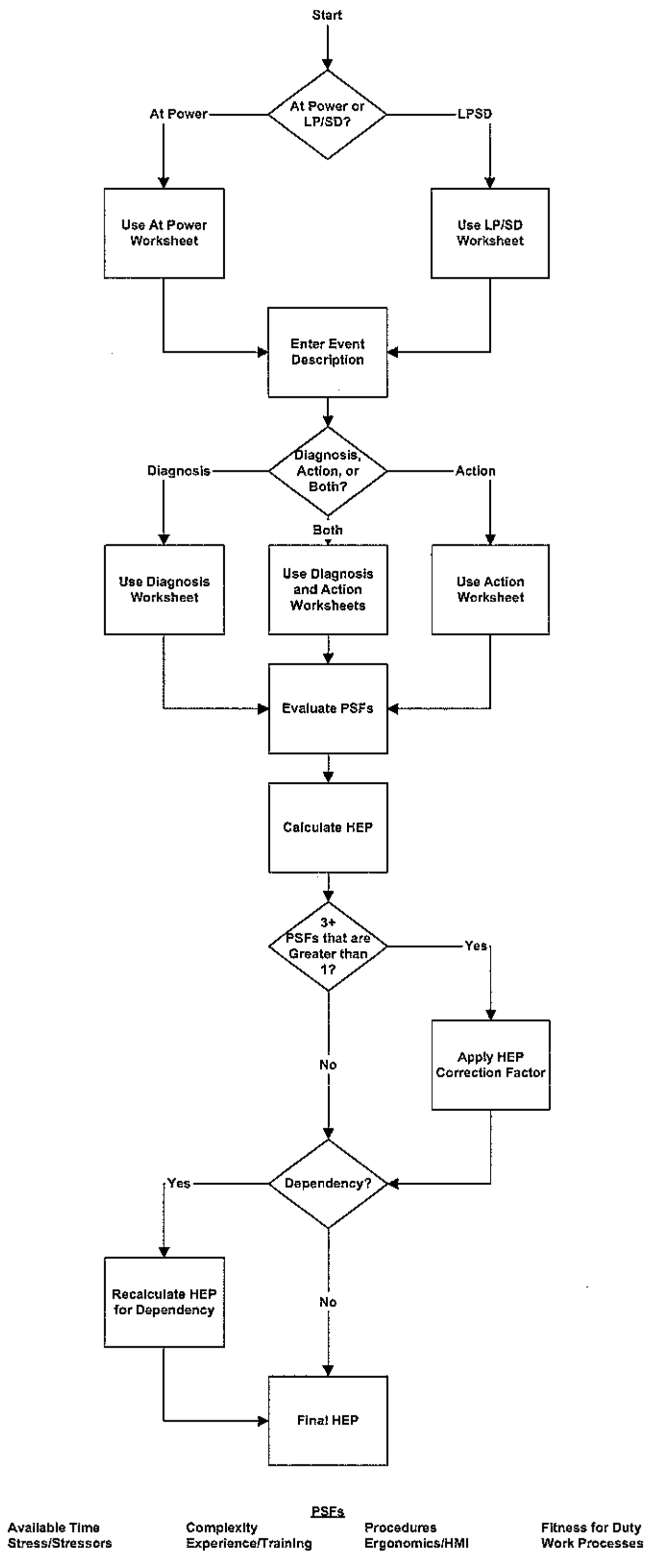

Figure 3. Basic flow diagram for completing a SPAR-H analysis of a task.

the document *and* to quit the word processing program If, however, errors are not in any way related to one another, the two task HEP values are added together to create a logical *OR* relationship For example, a person may not be able to log in to a computer *either* by forgetting his or her computer password *or* by failing to type the password in the correct CapsLock case

The complete process of calculating an HEP for a particular task is shown in Figure 3. Calculating an HEP first involves determining the appropriate level of fault tolerance (i.e., fault intolerant is equivalent to "At Power" in NPPs, while fault tolerance is equivalent to "Low Power/Shutdown" in NPPs). Then, the level of cognitive engagement must be determined (i.e., cognitively engaging tasks are equivalent to "Diagnosis Tasks," while routinized tasks are equivalent to "Action Tasks"). The individual PSF multipliers are applied to the base error rate to produce an HEP If there are multiple PSFs with a negative influence, an adjustment factor is applied to realign the HEP with established human error rate distributions Finally, if the task under consideration is part of a sequence of tasks, the HEP is modified to reflect task dependency The multiple steps in computing a SPAR-H HEP are explicated in [2]

IMPLICATIONS FOR HUMAN-COMPUTER INTERACTION

The previous sections describe the SPAR-H method for estimating human error rates. This method was specifically developed for the context of NPPs, but its applicability to other work domains is currently being explored The field of human-computer interaction (HCI) is one area that is of particular interest in generalizing the SPAR-H method, because the SPAR-H method already incorporates ergonomic and human-machine interaction components as PSFs While task decomposition methods such as task analysis are common in HCI [3], they do not typically decompose tasks in terms of their contribution to user errors It is hoped that modeling tasks in terms of PSFs, especially available time, will provide useful metrics to HCI while simultaneously providing insights that may inform future iterations of the SPAR-H method

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