New Concepts in Human Reliability Models

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ABSTRACT

This paper presents a new approach to the analysis of human reliability and the prevention of human errors in mechanized/automated systems. A theoretical framework is presented to integrate and convert a combination of human performance, environmental, and task response signals (input), into a conditional probability of success or failure (availability or human error -- output), in real-time.

1. INTRODUCTION

Human operators typically work within a highly dynamic environment where both external stress variables (e.g. workload, time pressure, environmental variables, etc.) and internal stress variables (attention, fatigue, frustration, etc.) are continuously changing. In addition, individuals performing a particular task vary widely in capabilities and in their response to different stress variables. Given this situation, the system reliability of a hybrid man-machine system is more accurately viewed as a time-varying function – as opposed to a single value. The ability to build a time-varying model to predict this function has significant safety and system reliability implications. The clearest of these implications is the ability to replace human operators that are substantially decreasing the reliability of the system, as a whole, before a failure occurs.

2. HUMAN RELIABILITY MODELS - REVIEW

The principle objective of human reliability analysis (HRA) is to describe the likelihood of human error under different circumstances (preferably in quantitative terms) and to propose means to reduce that likelihood. A list of models available to do HRA is presented in Table 1 [1]. The models listed use a variety of approaches to accomplish the goals of HRA. Many attempt to quantify the probabilities associated with the potential human errors using tabulated values of error rates [2], or expert opinion. Several of the models also attempt to incorporate possible changes in individual performance shaping factors (PSFs) which modify the probability of error for personal and task related conditions such as fatigue, stress, and environmental conditions.

Unfortunately, contemporary methods such as those listed in Table 1 are characterized by static models -- removed from the immediate work place and task at hand. These models make use of traditional reliability theory -- they are usually based on actuarial statistics and/or expert opinion. As such, they lack timeliness and immediacy, regarding the task and environment as well as the human's current condition.

3. HUMAN RELIABILITY MODELS – NEW CONCEPTS

In most cases, humans become integral parts of complex systems – where humans are called upon to deal with unexpected situations. Figure 1 depicts a situation-performance flow where a combination of task environment, task application, equipment and interfaces, and the individual human interact to produce a performance resultant. Here, each situational component is represented by a range of reasonable exposure, as well as an unreasonable range. On the performance side, robustness of response, as well as safety, reliability, maintainability, and system integrity are issues. The human is positioned in the middle of the situation, and is many times called upon to compensate for environmental, application, and equipment variation. A priori human reliability/human error models and analysis methods, as reviewed previously, address this basic situational structure. Although they add significantly to design content, they are limited in their ability to contribute to real-time operations in prevention of human errors and/or recovery therefrom.

In order to address real-time human reliability/mistake-proofing models, several needs are apparent:

1. Ability to tailor models to specific situations.
2. Ability of models to self-generate and evolve with respect to situational change.
3. Ability of models to offer timely information relevant to operational decisions.

The purpose of this paper is to address operational human reliability models – which can be embedded within the situation, in a real-time or near real-time manner. To this end, several characteristics of human activity present critical issues:

1. Person to person performance variation resulting from abilities and skills.
2. Personal performance variation over time associated with vigilance and fatigue factors.
3. Personal knowledge/training/ability to assess situations and take counteraction.

A block diagram of a generic situational human reliability model is depicted in Figure 2. Here, task requirements serve as the basis or benchmark for application performance calibration. They are translated into quantifiable performance characteristics compatible with quantitative modeling formats. The situation is sensed or calibrated through a series of sensors linked into the environment, equipment/interface, and/or human, in terms of physical/physiological characteristics. Sensors/sensing is matched in terms of situational characteristics and timeliness needs as reflected through the conditional reliability model.

The model itself is tailored to respond to critical situational/requirement needs. Kolarik [11] provides a basic development of conditional reliability/survival,

$$R(t_2|t_1) = \exp - \int_{t_1}^{t_2} \lambda(\zeta)d\zeta = \frac{R(t_2)}{R(t_1)}, \quad t_2 > t_1 \quad (1)$$

where $\lambda(\zeta)$ represents a failure hazard function, expressing an instantaneous failure rate.

Assuming the nature of the real-time conditional reliability model is such that it can forecast the physical parameters sensed, projections of future performance are obtained. These projected performances are compared against benchmark requirements and a resulting probability of success/survival for a time increment, Δt, is developed, $R(\Delta t_i)$. Now assuming independence over time, probabilities of success/survival are projected into the future for m time periods,

$$R(t|t+m\Delta t)=\prod_{i=1}^{m}R(\Delta t_i) \qquad (2)$$

Within this general framework, research questions naturally focus on forecasting and comparison techniques. Previous research has shown feasibility in physical modeling [12]. Techniques such as exponential smoothing, time series, and neural network models have been investigated. Extensions of these techniques to more complex modeling requirements and situations, such as those in human reliability, pose challenges in both forecasting and comparison techniques.

4. CONCLUSIONS

A priori design phase reliability models for human performance/human error risk assessment and failure mitigation have been widely used over the past several decades. Their contributions have been significant. Counterpart situational models for in-process operations are feasible. With the advent of more plentiful computation power and advances in sensor technology, real-time human reliability/mistake-proofing development is expected to accelerate.

5. REFERENCES

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Table 1. List of recent human reliability analysis (HRA) methods with an associated reference. Based on Gertman and Blackman (1994).

Method	Citation
Confusion Matrices	Sugnet et al., 1984 [3]
Expert Estimation	Stillwell et al., 1982 [4]
Human Cognitive Reliability (HCR)	Hannaman et al., 1985 [5]
Maintenance Personnel Performance Simulation (MAPPS)	Siegel et al., 1984 [6]
Success Likelihood Index Method - Multiattribute Utility Decomposition (SLIM-MAUD)	Embrey et al., 1984 [7]
Sociotechnical Assessment of Human Reliability (STAHR)	Phillips, 1982 [8]
Technique for Human Error Rate Prediction (THERP)	Swain and Guttman, 1983 [2]
Sandia Recovery Model (SRM)	Weston et al., 1987 [9]
Operator Reliability Calculation and Assessment (ORCA)	Dougherty and Fragola, 1988 [10]

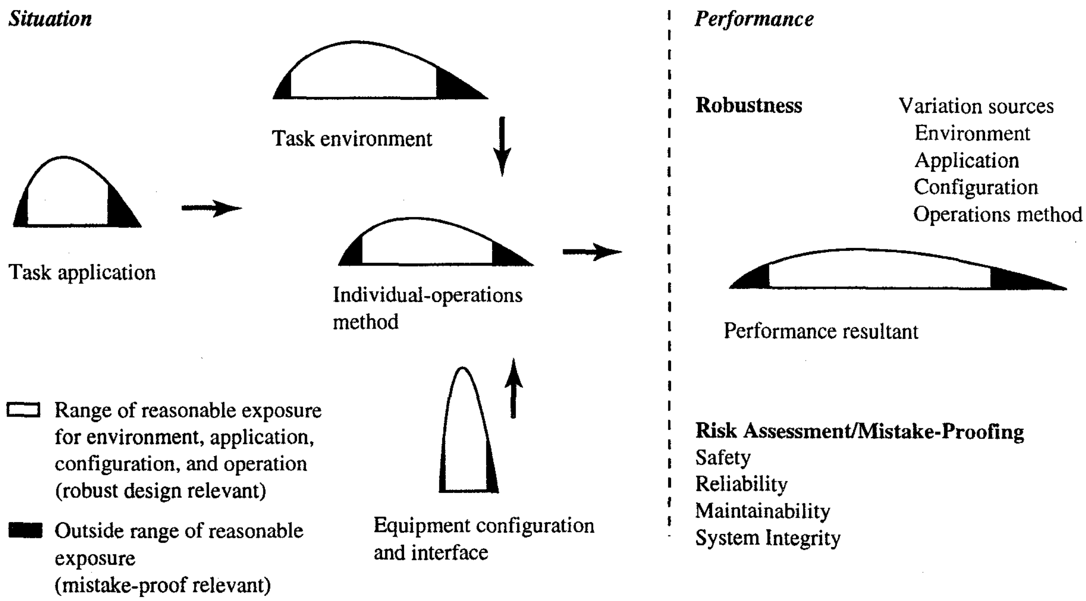

Figure 1 Situation-performance variation.

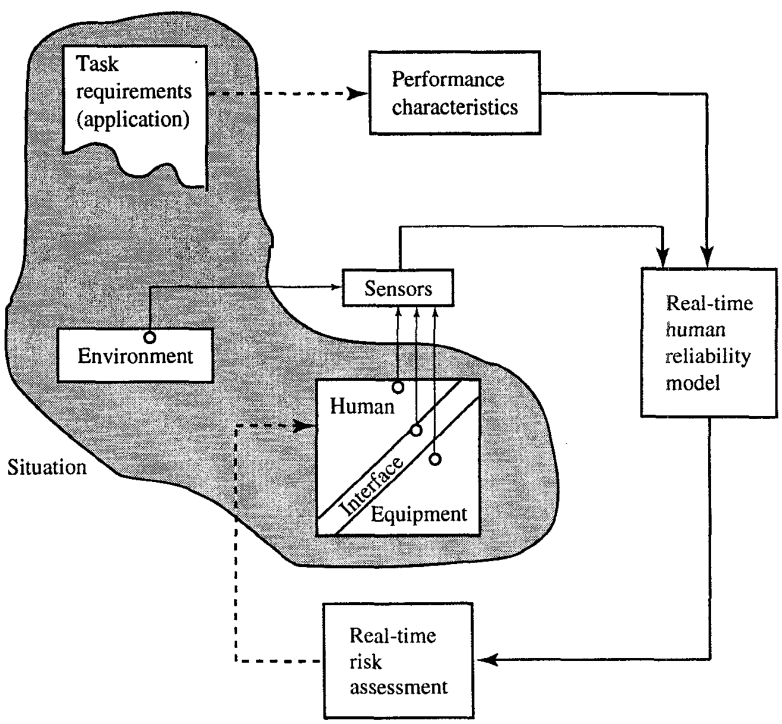

Figure 2 Real-time human reliability/risk assessment model concept.