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QUANTIFYING HUMAN PERFORMANCE FOR RELIABILITY ANALYSIS OF SYSTEMS[1]

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ABSTRACT

A general mathematical model of the probability of errorless human performance was derived and equated to human reliability for time-continuous tasks. The application of this model and the implications of the time-to-first-human-error (TTFHE) concept were tested with data collected using a laboratory vigilance task. The error data were ordered, and through classical inference theory the undelying density functions were isolated, and tested for goodness of fit. Weibull, gamma, and log-normal distributions emerged as relevant; normal, and exponential distributions were rejected. The relevant distribution parameter values were applied to the general mathematical model, and predictions were made of human performance reliability for the task. It was concluded that this is a feasible and meaningful way to quantify human performance for time-continuous tasks for use in reliability analyses of systems.

[1]Further reproduction is authorized to satisfy needs of the U. S. Government. The research reported in this paper is described in more detail in AMRL-TR-68-93, Mathematical Modeling of Human Performance Errors for Reliability Analysis of Systems, William B. Askren and Thaddeus L. Regulinski, 1968, Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio.

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INTRODUCTION

The state-of-the-art for incorporating human error data in reliability analyses of systems allows only approximations of the true effect of man's performance on the reliability of the total system, as indicated by the reviews of Askren (1967), Blanchard and Harris (1967) Leuba (1964), Meister (1964), and Williams (1967). Much research is needed to develop models, methodologies and data more reflective of the nature of human performance and more compatible with engineering analysis processes. The concern of this research was with the expressing of human performance data in a manner more compatible with the reliability analysis process.

Classical reliability analysis uses statistical inference to translate time of failure observations to a relevant model. The prediction of reliability is obtained then from the model via probability theory. This requires knowledge of some stochastic function, e.g., probability density function (PDF of the failures of the equipment with respect to time for the operations involved. Also, classical reliability modeling employs the first moment of the random variable which for the continuous case is time, and is known variously as mean-time-to-failure, mean-time-to-first-failure, and mean-time-between-failures (Sandler, 1963). The specific objective of this research, therefore, was to determine the feasibility of applying this classical method to the analysis of human performance.

PROCEDURE

The research involved four operations. First, a general mathematical function of human performance reliability was derived through which human error data could operate. Second, the appropriateness to human performance measurement of the first moment of the random variable "t" was established. Third, human error data were generated with the random variable "t" used as the measure. Fourth, stochastic functions descriptive of the error data were determined and the suitability of the general mathematical equation to handle the functions was tested.

RESULTS

A Generalized Human Performance Reliability Function

The human performance tasks that are most analogous to equipment operation in the time domain, and thus most amenable to classical reliability modeling are continuous operation tasks such as vigilance, monitoring and tracking. This seemed to be a proper starting point for modeling human error, although it was recognized that many human operations are not time-continuous. Consequently, a generalized reliability function was derived for human tasks of a continuous nature. This function is expressed as:

$$R(t) = \exp^{-\int_0^t e(t)\,dt} \qquad (1)$$

where R(t) is the reliability of human performance for any point in time, and e(t) is the error rate for the specific task. This equation is proposed as the generalized model for the reliability of human performance for continuous tasks.

Appropriateness Of The First Moment of The Random Variable "t" For Human Performance Measurement

In general, mean-time-to-failure (MTTF) is applied to components that are not repairable and are throw-away items, such as fuses and light bulbs, whereas mean-time-to-first-failure (MTTFF) and mean-time-between-failures (MTBF) are applied to equipment that are repairable. The three concepts are useful in dealing with human performance reliability. MTTF translates into mean-time-to-human-initiated-failure, and is used to describe when a system function could be expected to fail as a result of an error or an accumulation of errors by one or more persons performing tasks in that function, e.g., overpressurizing a missile fuel tank, undershooting an aircraft landing, or inadvertant actuation of an ejection seat.

MTTFF and MTBF translate into a language suitable for describing errors whose effects are correctable. Thus, MTTFF transforms into mean-time-to-first-human-error and is useful in treating errors that are highly critical, such that the first occurrence of an error would be costly, or establish hazardous conditions, e.g., failing to detect a target on a radar scope or not inserting an ejection seat safety pin prior to performing maintenance work. MTBF converts to mean-time-between-human-errors and is useful in treating errors of a less critical nature; this measure could be used, for example, to provide information regarding the frequency of production of defective parts, or an indication of the proficiency level of personnel. Of the three quantifiers, mean-time-to-first-human-error (MTTFHE) was the easiest to simulate in a laboratory environment, hence it was selected for use in this study.

Generation of Human Error Data

A 30 minute vigilance task was used with subjects required to observe a circular light display, and respond to a failed-light event by pressing a hand-held switch. The twenty lights of the display were programmed to flash sequentially at approximately one-second intervals and to fail randomly. The subjects, 51 male and female college and Air Force personnel were given a standardized oral briefing of expected task performance, and allowed a two minute practice period to minimize errors induced by initial learning. Miss and false alarm error data were collected. A miss error denoted that the subject did not detect the failed-light event. A false alarm denoted an error by anticipation where the subject responded as if a failed-light event occurred when in fact the event did not occur. The times of occurrence to first miss errors ranged from 2 to 1624 seconds, and to first false alarm errors ranged from 4 to 1537 seconds.

Stochastic Functions Of The Error Data And Suitability Of The General Mathematical Equation.

The observations of the times to first-miss-error, to first-false-alarm-error, and to combined-false-alarm-and-miss-error were ordered, and an incremental analysis of the data indicated that the error rate was not constant.

Hence, Weibull, gamma, normal and log-normal distributions were examined to ascertain the relevant paradigm. The exponential distribution, which requires a constant rate was also tested as a further check on the nature of the data.

The data were tested for fit with Weibull both graphically and by computer analysis. The Weibull graph plots show a straight line fit indicating that this distribution is relevant. Computer analyses confirmed this fit yielding parameter values given in Table 1. These values are significant at the .10 level

Insert Table 1 - About Here

using the Kolmogorov-Smirnoff (K- S) test. From Table 1 it can be determined that for Weibull the mean time to first-miss-error is 633.26 seconds, to first-false-alarm-error is 309.04 seconds, and to first-combined-error is 315.82 seconds.

The reliability of performance for any time period may be predicted by using the two parameter Weibull reliability function adaptation of the general equation:

$$R(t) = e^{-\left(\frac{t}{a}\right)^{b}} \qquad (2)$$

where a, and b are scale and shape values from Table 1. For example, if reliability of the vigilance task of this study is defined as the probability of performance precluding both miss and false alarm errors, the reliability for $t = 60$ seconds is predicted to be .70 by solving equation (2) using the values $b = .7$ and $a = 267.75$. Alternately, the reliability may be obtained by inspection of the Weibull graph plots.

The gamma and log-normal distributions were tested by computer analysis and also found to be relevant models at the .10 level using the K-S test. Parameter values are given in Table 1. The reliability of performance for any time period may be predicted also using gamma and log-normal reliability function adaptations of the general equation. The exponential and normal distributions were tested by computer analysis and were rejected at the .10 level using the K-S test. Parameter values for these distributions are also given in Table 1.

CONCLUSIONS

It is concluded that equation (1) is a useful general model of human performance reliability for time-continuous tasks, and that it is meaningful and feasible to determine the error rate term, e(t), by analysis of time-to-first-error data of a task. The human reliability function may now be defined as the probability of successful task performance within temporarily constraints, thus allowing predictions of task reliability for various time intervals. It is believed that quantifying human performance reliability in the mathematical language of the system analyst will prove useful in making man-machine system performance prognoses.

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