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Probabilistic Simulation of the Human Factor in Structural Reliability

Christos C. Chamis
Lewis Research Center
Cleveland, Ohio

and

Surendra N. Singhal
Sverdrup Technology, Inc.
Lewis Research Center Group
Brook Park, Ohio

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National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

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Surendra N. Singhal
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Brook Park, Ohio 44142

Summary

The formal approach described herein computationally simulates the probable ranges of uncertainties for the human factor in probabilistic assessments of structural reliability. Human factors such as marital status, professional status, home life, job satisfaction, work load, and health, are studied by using a multifactor interaction equation (MFIE) model to demonstrate the approach. Parametric studies in conjunction with judgment are used to select reasonable values for the participating factors (primitive variables). Subsequently performed probabilistic sensitivity studies assess the suitability of the MFIE as well as the validity of the whole approach. Results show that uncertainties range from 5 to 30 percent for the most optimistic case, assuming 100 percent for no error (perfect performance).

Introduction

Structural failures have occasionally been attributed to human factors in engineering designs, analyses, maintenance, and fabrication processes. A recent article (ref. 1) addresses the issue of human errors in engineering judgment. Every facet of the engineering process (planning, designing, manufacturing, inspection, maintenance, communication, and coordination between different engineer-ing disciplines) is heavily governed by human factors and the degree of uncertainty associated with them (ref. 2). Societal, physical, professional, psychological and many other factors introduce uncertainties that significantly influence the reliability of human performance. Such factors are called primitive variables. Quantifying the effect of human factors and associated uncertainties in structural reliability requires (1) identification of the fundamental factors that influence human performance and (2) models that describe the interaction of these factors.

The human factor has long been a subject of study. Traditionally, there have been two approaches to quantifying the effect of the human factors: (1) qualitatively describing its effects on a certain outcome and, (2) curve-fitting the data obtained through surveys. Abundant references can be found on such approaches (refs. 3 and 4). There is a clear need for quantifying the fundamental factors (primitive variables) that influence human behavior and its subsequent effects on the probabilistic assessment of structural reliability and risk. In this present study the authors propose an initial formal approach, is based on probabilistic concepts and a multifactor interaction equation (MFIE) of product form. For the initial simulation, the fundamental factors assumed to affect human performance are (1) health, (2) home life, (3) marital status, (4) work load, (5) job satisfaction, and (6) professional status. The impact of remuneration is not mentioned specifically but it is implied in all six factors. It is ludicrous to presume that these are the only factors that influence human performance; however, they constitute a reasonable initial set of factors which are very important in both professional and personal fulfillment (refs. 5 and 6). Since these factors vary tremedously with time, human performance inherits the associated uncertainty. Therefore, it is appropriate to simulate human performance from a probabilistic standpoint. The objective of this paper is to describe our initial formal approach for quantifying the human factor in structural reliability.

Fundamental Considerations and MFIE Model

We start with the premise that if we are to quantify the range of uncertainties of probable human errors, we need a description of human behavior. In this context, it is reasonable to consider that human behavior constitutes an n-dimensional space (Human Behavior Space (HBS)) where each dimension represents a specific aspect of human behavior. It is further reasonable to assume that HBS can be described by an assumed interpolation function. One convenient interpolation function is a polynomial of product form because mutual interactions can be represented by the overall product, and can include those cross products in common algebraic polynomials. In this investigation, HBS is assumed to be described by the following multifactor interaction equation (MFIE):

$$\frac{P}{P_o} = \prod_{i=1}^{N} A_i^{m_i} \tag{1}$$

Where P is the performance of the analyst being evaluated that probabilistic assessment. P_0 corresponds to the analyst's best performance (taken as 100 percent), A_i represents the ith factor that influences the analyst's behavior, and mi is an exponent.

The form of factor A is taken to be

$$A_i = \left(1 - \frac{B}{B_o}\right)_i \tag{2}$$

Here B represents a specific cause for behavior (for example, professional status), and B_0 is the corresponding reference (final) value. This concept is represented in figure 1. Values for B_0 and m_i for specific behavior are selected either from known behavior or more likely from a best judgment in conjunction with consultations with seasoned professionals and first level supervisors.

By representing the HBS with the MFIE of product form (eq. (1)), we gain another distinct advantage. The behavior factors, B, can also be represented by another level of MFIE or progressive substructuring of equation (1). This progressive substructuring leads to a multitier representation of the HBS that permits intrinsic lower tier behaviors to influence more than one factor at the next higher tier. In other words, the observed specific behavior (B_i) may depend on another set of lower tier elemental behaviors. Further, the behavior factors in this lower set of specific behaviors may depend on yet another next lower tier of elemental behaviors. That is, there are usually sets and subsets of specific behaviors that hierarchically influence the higher level behaviors. When this is done, N can be limited (to 6, for example), but the number of factors influencing human behavior at the next lower tier will increase exponentially as N^j where j is the number of that tier. For example, when j = 1 the number of factors is 6; when j = 2, N = 36; when j = 3, N = 216, and so forth. This representation is natural for multiparallel processing computers where the tiers are programmed with different granularities. Obviously, then, the motivation for selecting such a form is for computational efficiency and convenience. Another reason for selecting an MFIE of product form is the success we had in two other investigations: (1) nonlinear complex behavior in high temperature materials (refs. 7 and 8), and (2) wind loads for buildings (ref. 9).

The interpretation of B_0 is that it represents a scale, whereas mj represents a shape or path. For example, $(1 - B/B_0)^{m_i}$ where $1 > B/B_0$ and $+\infty < m_i < -\infty$, covers the whole space as is illustrated in figure 2. The inclusiveness of this particular form, combined with its simplicity, makes it very attractive for a computational simulation.

Probabilistic Simulation

An MFIE can be adapted to simulate the uncertainties of human performance because the uncertainties in factor A have their own range of uncertainties. As was already mentioned, the product terms in an MFIE can be expanded to include as many effects as are judged appropriate at the time of the simulation. The procedure used to perform the probabilistic simulation is similar to that in reference 7, which consists of the following steps: (1) Assume probabilistic distributions for the primitive variables B_i and mi in each factor A_i in the MFIE. Note that the distributions can be different for B and m and different for different terms. (2) Decide on the ranges of probable uncertainties in these distributions. (3) Probabilistically select values for each primitive variable from these ranges. (4) Substitute these values in the MFIE and calculate a corresponding value for P. (5) Repeat the process until sufficient values of P have been obtained to generate a reasonable probabilistic distribution for P. (6) Use statistical inference methods to generate the probabilistic distribution for P and to derive conclusions. The process is significantly expedited by using fast probability integration (FPI) (ref. 10) for steps 5 and 6. The use of FPI has an added advantage in that it calculates the probable sensitivities while it calculates values for the probable distribution. The significance of the sensitivities will be described later. Since we had no measured data and since the exponents significantly affect the path (fig. 2), four different ranges were selected (0 to 1, 0 to 3, 0 to 5, and 0 to 10) based on the author's judgment. Using different exponent ranges allows the assessment of the human performance of different individuals with individual-specific human behavior factors.

Tables I through IV list assumed mean values and ranges (scatter or coefficients of variation) of different primitive variables in the MFIE, for the four different intervals previously described. For convenience, the probability distributions for all primitive variables are assumed to be normal. However, the procedure can handle any probability distribution. Also, for convenience, the coefficient of variation for the reference values B_0 (eq. (2)) of all the factors is assumed to be zero.

Both Monte-Carlo simulation and FPI (ref. 10) were used to simulate the range of uncertainties in human performance (P in eq. (1)) and to quantify their respective sensitivities. Typical results obtained and their respective interpretations are discussed in the next section.

Results and Discussion

Cumulative distribution functions (CDF's) were generated for the various exponent ranges (0 to 1, 0 to 3, 0 to 5, 0 to 10). Since the CDF represents the probability of a response (performance in this report) being less than a given value for each exponent range, these results show the range of uncertainty for human performance in each exponent range. For example, figure 3 illustrates that human performance is most likely 30 to 70 percent of maximum. The mean performance for this range is about 50 percent. One probable interpretation is that the mean performance is about 50 percent of the best we can do and can be as low as 30 percent.

Comparable CDF results for exponents in the other three intervals are shown in figures 4, 5, and 6. These indicate that as the interval of the exponent is expanded, the range of uncertainty in the human performance decreases rapidly. Their respective means are about 3.5, 0.2, and 0.02 percent. These ranges indicate very low performance that could probably be associated with, for example, poor health or low morale.

Sensitivities can be evaluated to assess the influence of the exponent at a specific probability of human performance. Results are shown in figure 7 for a probability of 0.1 or 10 percent for all four exponent ranges. It is interesting to note that the exponent range from 0 to 1 is the most dominant contributor. Two additional points can be inferred from these results: (1) there is little interaction between the exponent in the 0 to 1 range with the exponents in the other three ranges, while there appears to be some interaction among the other three, and (2) the exponent range 0 to 1 appears to be a reasonable representation (author's judgment) of human behavior.

Comparable results for a probability of 0.5 (50 percent) are shown in figure 8 and for 1.0 (99 percent) are shown in figure 9. The results in these two figures show trends similar to those in figure 7.

General Comments

It is prudent to keep in mind the following qualifiers about an investigation like this one.

(1) It is a first attempt to provide a formal means for obtaining some quantifiable measure of the uncertainty of the human factor in probabilistic structural reliability analysis.

(2) Its relevance to a real situation can be judged only from on-the-job observations. For example, some reference value for a particular analyst may be estimated over a time period. Fluctuations about this reference may then be used to select exponent ranges from table V. If, for example, this particular analyst has obtained results judged to be reasonable for, 100 different problems, then his performance can be set at 0.9 or 90 percent. The exponent and reference value B_0 (eq. (2)) in the various factors can be adjusted so that combinations will give 0.9 performance at a probability of 0.95. The interpretation is that this analyst is expected to perform with 90-percent accuracy in 95 percent of the analyses he conducts. This probability is then used to judge the accuracy of his results.

(3) Multitier factors can be added as more observations become available when more analyses are performed.

(4) Each analyst will have a unique MFIE much in the same way as specific materials have unique analyses and tests.

(5) The quantification described herein can also be viewed as being parallel to subjective judgments that are used to evaluate individual performance such as outstanding, above average, average, below average, poor, and unsatisfactory. Instead of these qualifiers, performance uncertainties will be assigned with probability levels. The results of a hypothetical case, illustrated in table V, might lead the observer to devise alternatives.

(6) Special experiments comparable to those that are used for intelligence are not desirable. However, we envision that multitier MFIE's can be structured to include generic factors as an evolutionary process resulting from adapting this approach to different analysts and under different circumstances.

(7) We illustrated the MFIE approach by using subjective human behavior factors, and we assumed that the analyst was functioning at an advanced knowledge level. Behavior can just as easily be evaluated in terms of factors such as (1) level of education, (bachelor, master, doctor), (2) extent of knowledge of fundamental principles of mechanics, (3) knowledge of computational methods, (4) familiarity with computer programming, (5) experience in using a specific code, and (6) experience gained on similar or closely related problems. Each of these factors can be substructured into lower tiers with technical or subjective factors influencing them.

Concluding Remarks

The results of this initial investigation of the use of probabilistic simulation to quantify the human factor in structural reliability are as follows:

1. A multifactor interaction equation (MFIE) of product form may be used to relate human performance to some easily identifiable factor that can influence it.

2. An initial assessment may include factors such as professional status, home life, job satisfaction, health conditions, marital satisfaction, and work load.

3. The range of uncertainty in the human factor can be evaluated probabilistically by assuming uncertainties in the values for each factor and its corresponding exponent in an MFIE.

4. Exponent intervals can be selected to yield reasonable values for the human factor.

5. A hypothetical table (similar to table 5) can be devised to convert qualitative performance evaluation to quantifiable ranges of uncertainty for specific probability.

6. An MFIE can be adapted to individual performance by observing an individual over a period of time and entering more specific data into the equation.

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TABLE I.—FUNDAMENTAL HUMAN FACTOR DISTRIBUTIONS WITH EXPONENTS BETWEEN 0 AND 1

Primitive variable	Mean	Coefficient of variation, percent
Professional status		
Reference	1.0	0.0
Current	.30	33.3
Exponent	.267	10.0
Home life		
Reference	1.00	0.0
Current	.25	20.0
Exponent	.013	10.0
Job satisfaction		
Reference	1.00	0.0
Current	.40	25.0
Exponent	.176	10.0
Health		
Reference	1.0	0.0
Current	.2	20.0
Exponent	.964	10.0
Marital status		
Reference	1.0	0.0
Current	.30	26.7
Exponent	.252	10.0
Work load		
Reference	1.0	0.0
Current	.35	22.9
Exponent	.466	10.0

TABLE II.—FUNDAMENTAL HUMAN FACTOR DISTRIBUTIONS WITH EXPONENTS BETWEEN 0 AND 3

Primitive variable	Mean	Coefficient of variation, percent
Professional status		
Reference	1.0	0.0
Current	.30	33.3
Exponent	1.85	10.0
Home life		
Reference	1.00	0.0
Current	.25	20.0
Exponent	1.691	10.0
Job satisfaction		
Reference	1.00	0.0
Current	.40	25.0
Exponent	2.703	10.0
Health		
Reference	1.0	0.0
Current	.2	20.0
Exponent	.099	10.0
Marital status		
Reference	1.0	0.0
Current	.30	26.7
Exponent	.852	10.0
Work load		
Reference	1.0	0.0
Current	.35	22.9
Exponent	1.005	10.0

TABLE III.—FUNDAMENTAL HUMAN FACTOR DISTRIBUTIONS WITH EXPONENTS BETWEEN 0 AND 5

Primitive variable	Mean	Coefficient of variation, percent
Professional status		
Reference	1.0	0.0
Current	.30	33.3
Exponent	4.007	10.0
Home life		
Reference	1.00	0.0
Current	.25	20.0
Exponent	1.923	10.0
Job satisfaction		
Reference	1.00	0.0
Current	.40	25.0
Exponent	1.926	10.0
Health		
Reference	1.0	0.0
Current	.2	20.0
Exponent	3.912	10.0
Marital status		
Reference	1.0	0.0
Current	.30	26.7
Exponent	2.897	10.0
Work load		
Reference	1.0	0.0
Current	.35	22.9
Exponent	3.597	10.0

TABLE IV.—FUNDAMENTAL HUMAN FACTOR DISTRIBUTIONS WITH EXPONENTS BETWEEN 0 AND 10

Primitive variable	Mean	Coefficient of variation, percent
Professional status		
Reference	1.0	0.0
Current	.30	33.3
Exponent	5.431	10.0
Home life		
Reference	1.00	0.0
Current	.25	20.0
Exponent	6.903	10.0
Job satisfaction		
Reference	1.00	0.0
Current	.40	25.0
Exponent	.518	10.0
Health		
Reference	1.0	0.0
Current	.2	20.0
Exponent	1.737	10.0
Marital status		
Reference	1.0	0.0
Current	.30	26.7
Exponent	3.301	10.0
Work load		
Reference	1.0	0.0
Current	.35	22.9
Exponent	6.826	10.0

TABLE V.—HYPOTHETICAL OBSERVED PERFORMANCE

Qualitative rating	Assumed parameters		
	Mean	Uncertainty range, percent	Probability of occurrence, percent
Outstanding	90	±5	95
Above average	80	±5	90
Average	70	±5	90
Below average	60	±7	90
Poor	50	±10	95
Unsatisfactory	40	±10	95

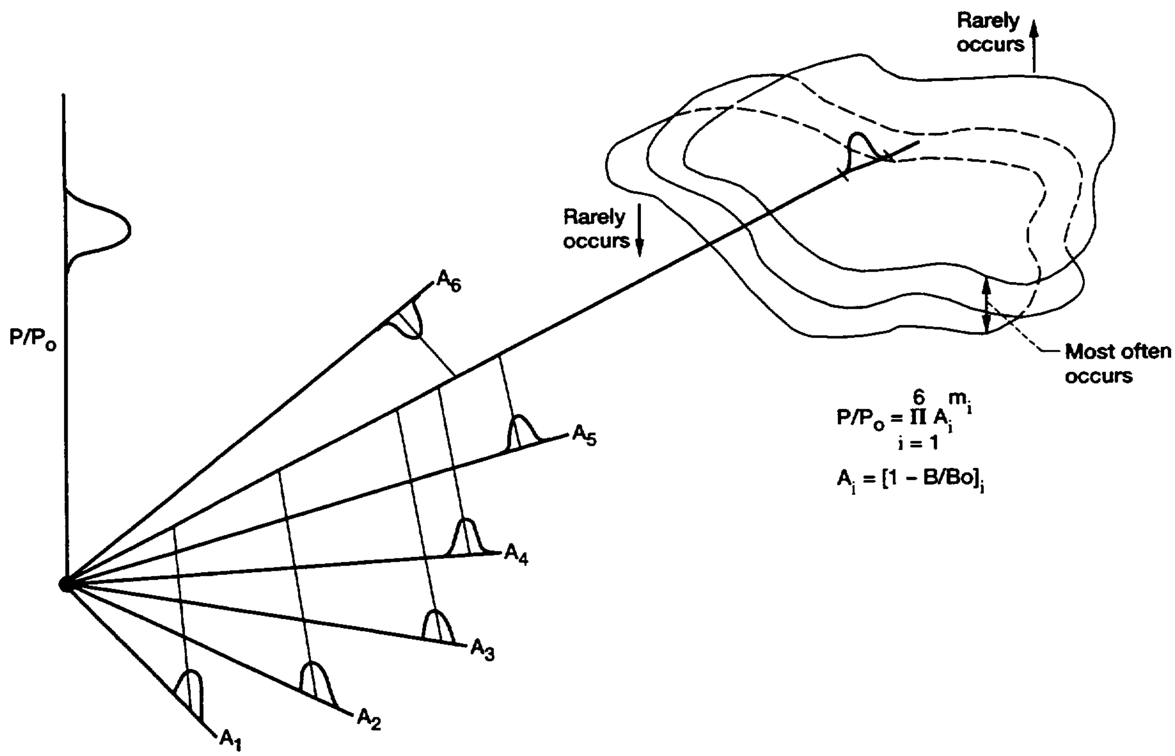

Figure 1.—Human behavior space (assuming six uncertainty factors (N = 6)).

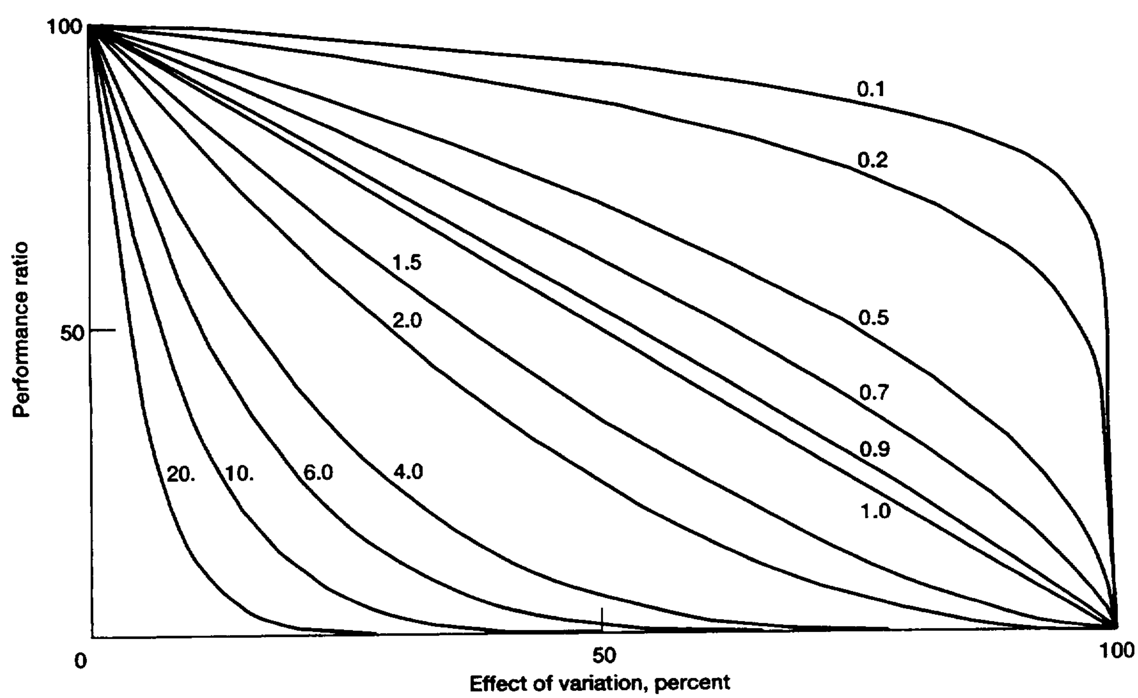

Figure 2.—Effect of variation in the exponent.

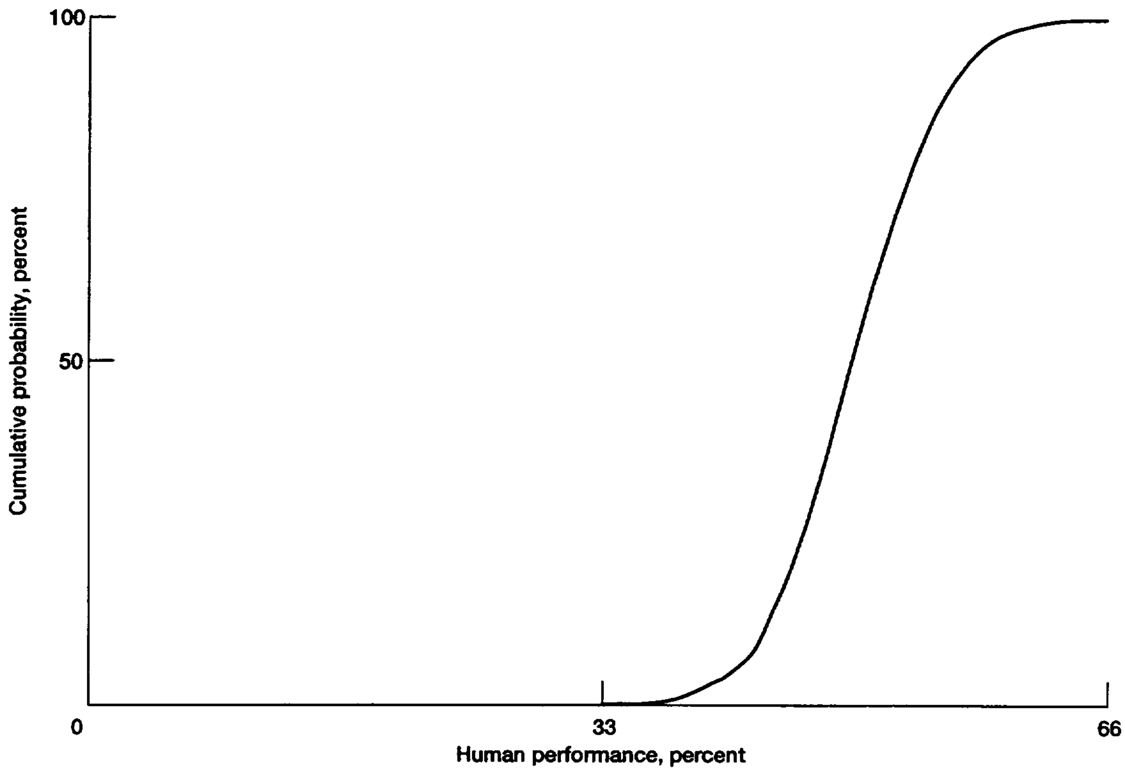

Figure 3.—Cumulative distribution function of human performance (with random exponents between 0 and 1).

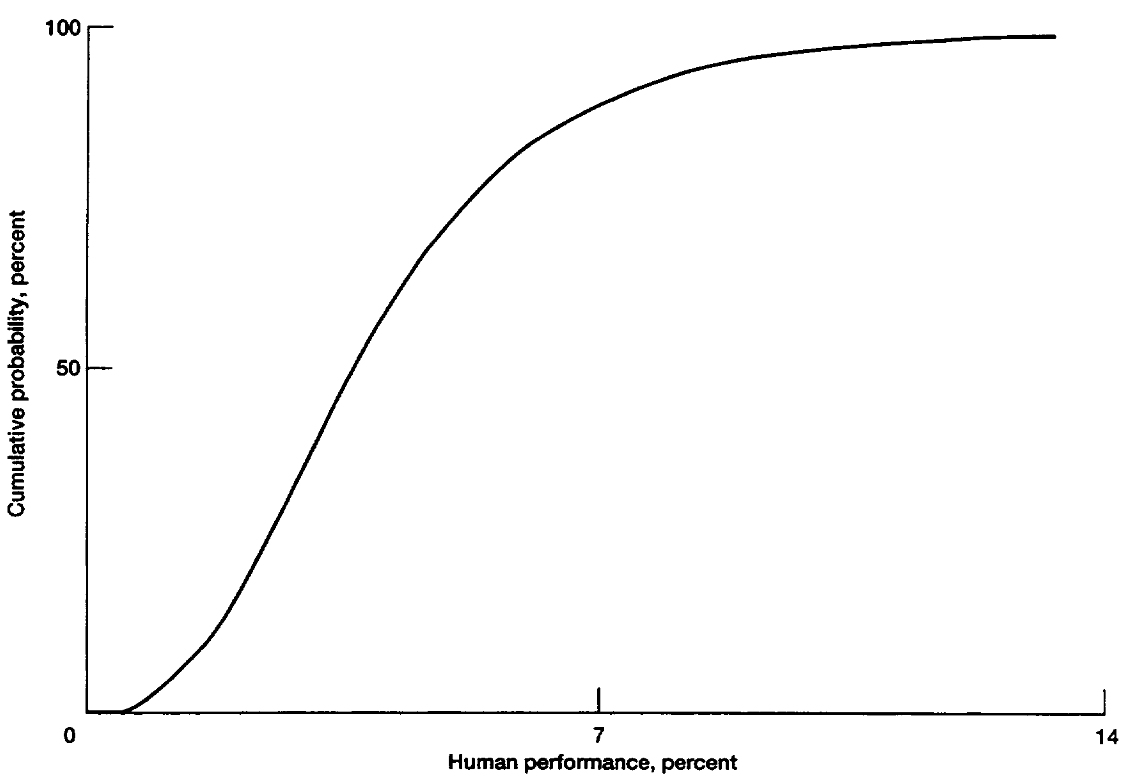

Figure 4.—Cumulative distribution function of human performance (with random exponents between 0 and 3).

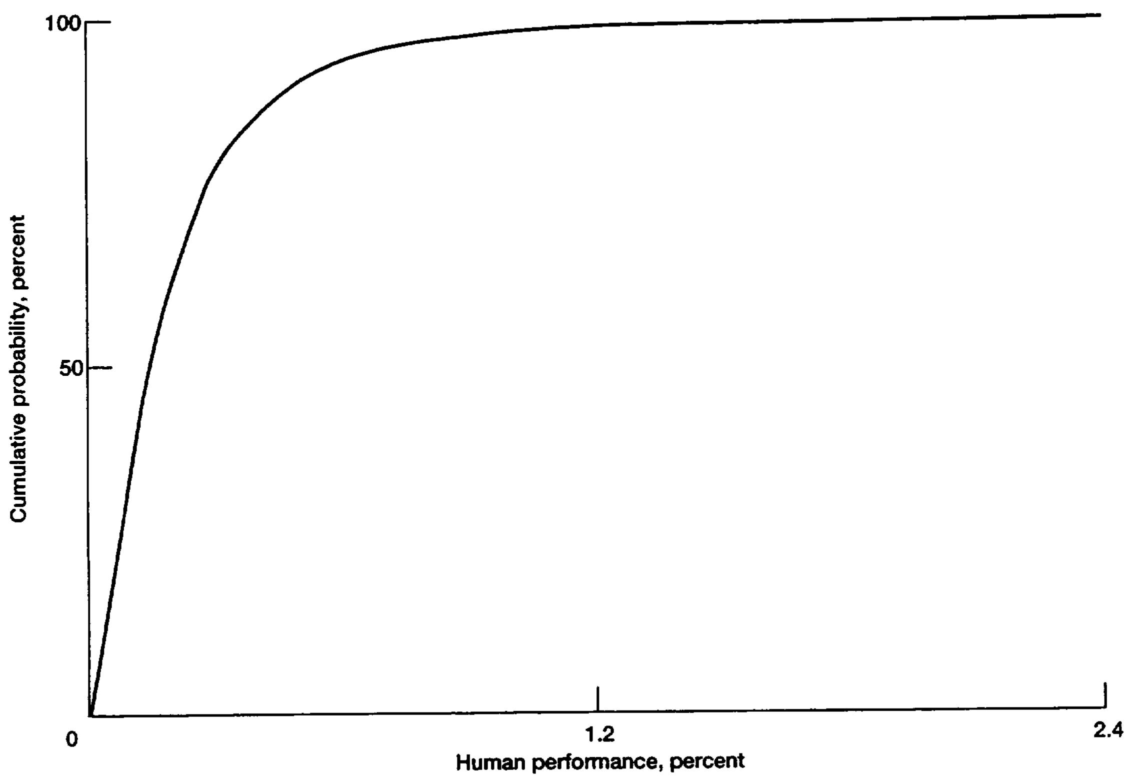

Figure 5.—Cumulative distribution function of human performance (with random exponents between 0 and 5).

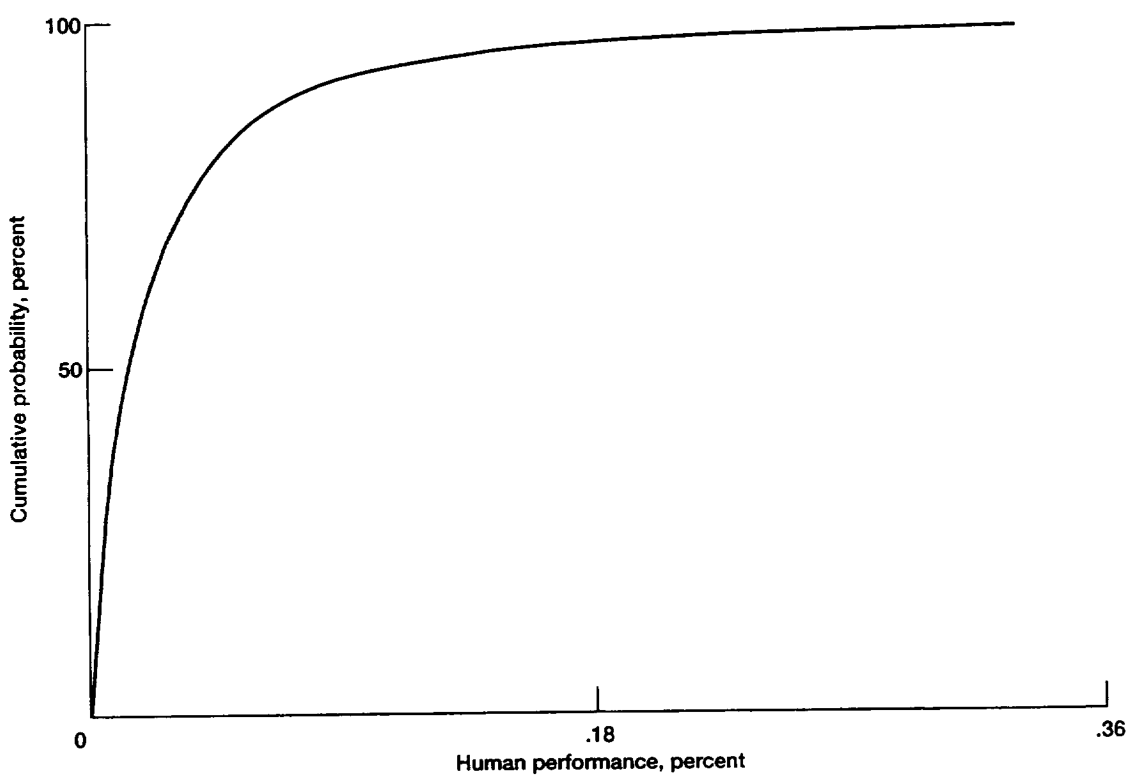

Figure 6.—Cumulative distribution function of human performance (with random exponents between 0 and 10).

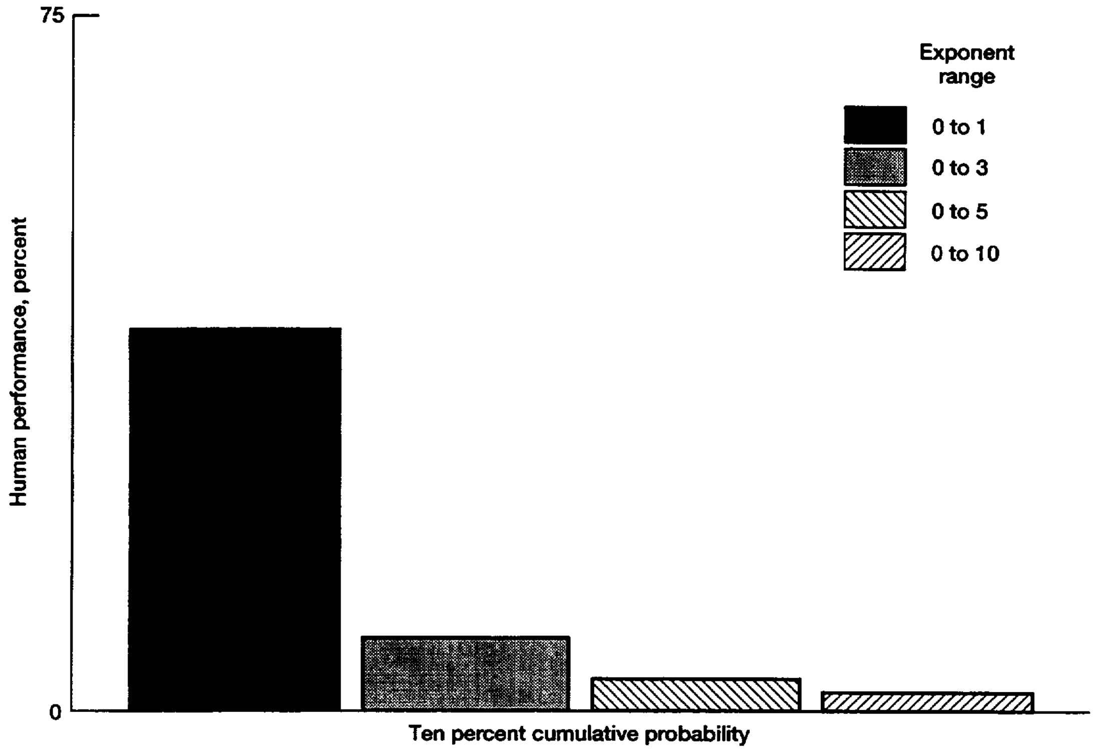

Figure 7.—Sensitivity of human performance on exponent uncertainties.

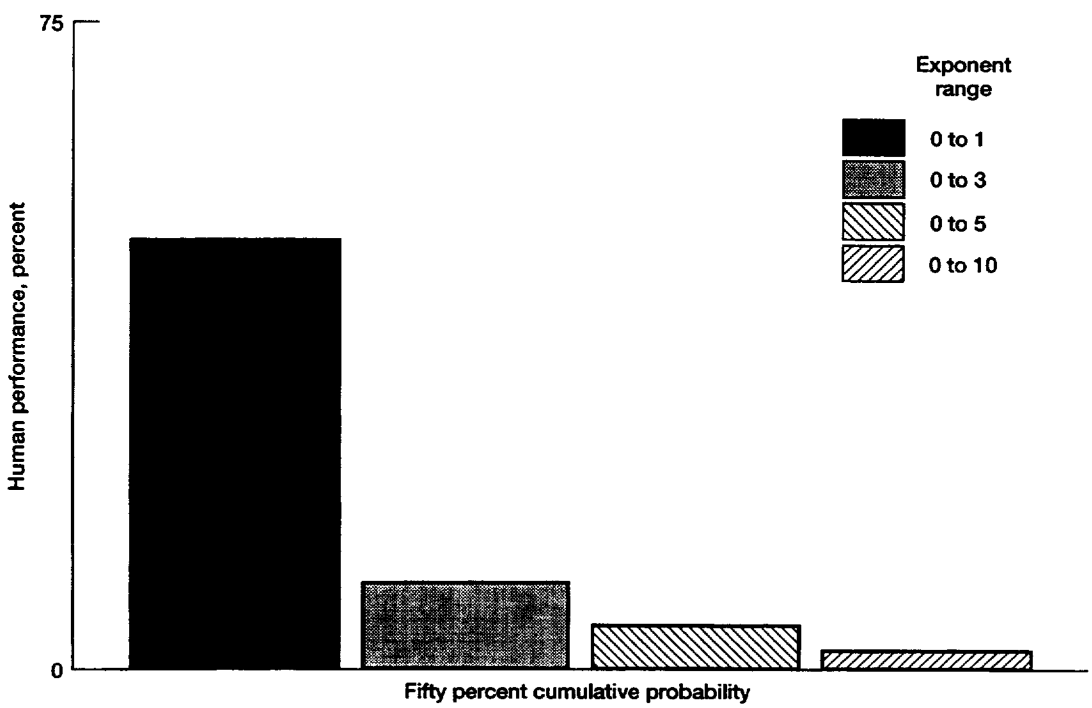

Figure 8.—Sensitivity of human performance on exponent uncertainties.

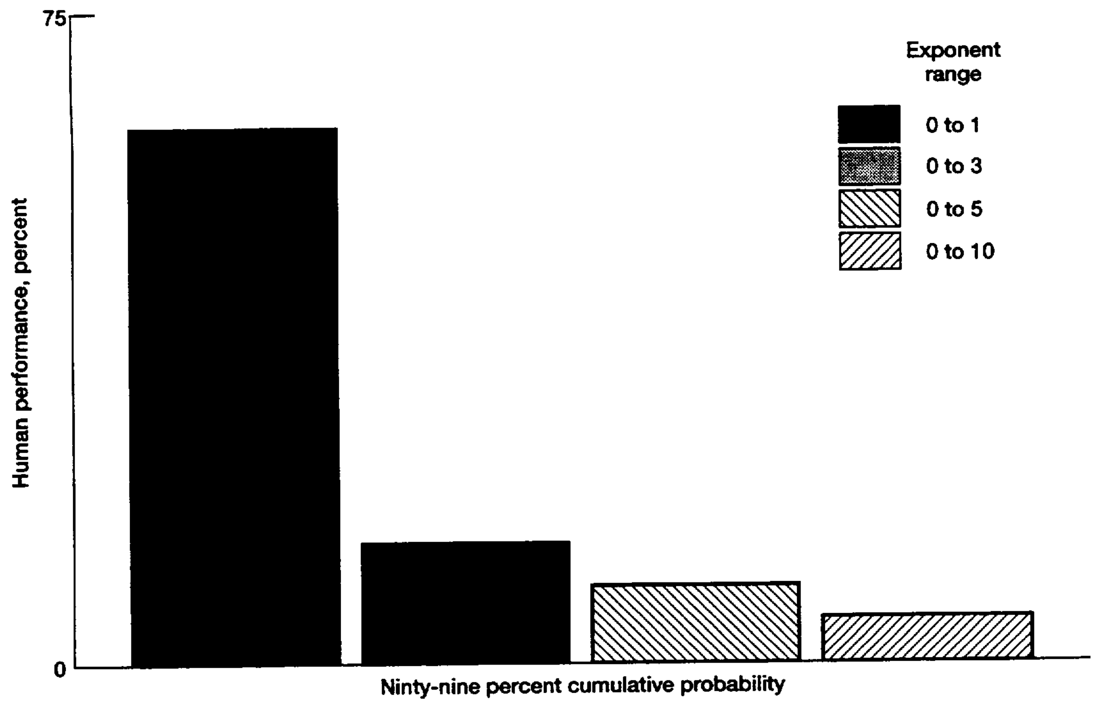

Figure 9.—Sensitivity of human performance on exponent uncertainties.

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Christos C. Chamis, NASA Lewis Research Center, and Surendra N. Singhal, Sverdrup Technology, Inc., Lewis Research Center Group, Brook Park, Ohio 44142 (work funded by NASA Contract NAS3-25266), presently at NYMA, Inc., Engineering Services Division, 2001 Aerospace Parkway, Brook Park, Ohio 44142. Responsible person, Christos C. Chamis, organization code 5200, (216) 433-3252.

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13. ABSTRACT ***(Maximum 200 words)***

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