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# Quantification of the Effects of Dependence on Human Error Probabilities*



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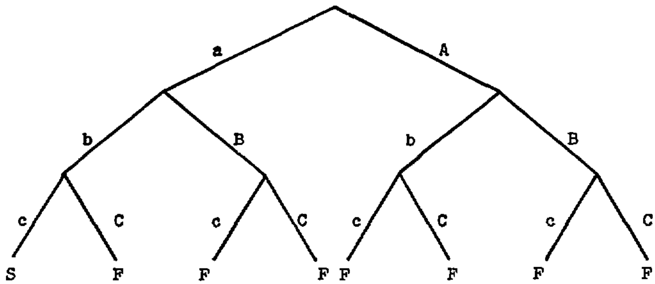
In estimating the probabilities of human error in the performance of a series of tasks in a nuclear power plant, the situation-specific characteristics of the series must be considered. A critical factor not to be overlooked in this estimation is the dependence or independence that pertains to any of the several pairs of task performances. In discussing the quantification of the effects of dependence, the event tree symbology described in Figure 1 will be used.

The performances of two tasks, "A" and "B," are independent if the probability of correct performance of "B" is unaffected by the performance of "A." If performance (or nonperformance) of Task "A" results in a change in the basic human error probability (BHEP) for Task "B," the two performances are dependent. The effects of dependence are not unidirectional. The effect can be positive, as when success on "A" increases the probability of success on "B" and failure on "A" increases the probability of failure on "B," or negative, as when success on "A" increases the probability of failure on "B" and failure on "A" increases the probability of success on "B." Negative dependence will not be discussed in this document because of its questionable applicability to nuclear power plant operations. In any series of tasks, the only dependence considered for quantification in this document will be that existing between the task of interest and the immediately preceding task. Tasks performed earlier in the series may have some effect on the end task, but we consider this effect negligible.

We identify two types of dependence: direct and common cause. Direct dependence between two events implies that the actual performance of the first task (whether correct or incorrect) has a relational effect on the probability of correct performance of the second task. Common cause dependence implies that some set of circumstances or some single performance shaping factor has an overall effect on all tasks to be performed which alters the human error probabilities (HEPs) of all the tasks.

* The theory, method, and terminology presented here is taken from the Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications, A. D. Swain and H. E. Guttmann, NUREG/CR-1278, U.S. Nuclear Regulatory Commission, Washington, D.C., September 1980.




"A" - the event in question

A - failure (or the probability of failure) on "A"

a - success (or the probability of success) on "A"

("S" and "F" are not used to designate events)

S (or F) - success (or failure) for that application

Figure 1. Event Tree Diagramming

The extent of the dependence effect can vary from situation to situation. The "level" or "degree" of this dependence can be estimated for each series of tasks. The level of dependence can be thought of as a continuum. The effects of dependence between Tasks "A" and "B" range from zero dependence (complete independence) to complete dependence. As defined above, zero dependence between Tasks "A" and "B" pertains when the probability of correct performance on Task "B" is the same regardless of the performance on Task "A." Complete dependence between "A" and "B" implies success on "B" given success on "A" or failure on "B" given failure on "A" in all cases. Complete dependence between performances on two tasks is rare, but it is not as rare as zero dependence.

The preferred method for estimating the effects of dependence is to gather data on the error probabilities of the tasks in question and to determine empirically the conditional probabilities involved. In most cases, such data is not presently available, and the time and economic considerations involved in collecting the data preclude the use of this method.

Another method employed in the estimation of dependence effects is a judgmental assessment of the effect of the performance of one task on the probability of correct performance of another. Such judgments should only be made by qualified professionals trained in the conducting of human reliability analyses. Certain assumptions as to the natures of the tasks involved as well as to the human performance requirements and responses will have to be made prior to such judgments.

A third method proposed for the quantification of dependence effects is a model developed by human factors personnel at Sandia National Laboratories. They postulate that this dependence model can be used if it is not appropriate to use the above-described methods. This model is the result of several others that have been considered over the past 4 years. It has been selected for use because it results in estimates of human reliability that are believable in the light of what is known about human performance on nuclear power plant tasks. In the proposed model, the continuum of dependence is divided into five discrete points as shown in Figure 2. These points are labelled zero, low, moderate, high, and complete dependence (ZD, LD, MD, HD, and CD). ZD is fixed as the BHEP, B, for Task "B," and CD is fixed at 1.0. The intermediate levels of dependence were selected so that they are 5, 15, and 50% of the distance between ZD and CD for LD, MD, and HD, respectively. The specific values for LD, MD, and HD are the result of human factors considerations. Using this dependence model, the conditional probabilities can be determined from the following equations (see p. 5):


Figure 2. Continuum of Dependence Represented by Five Discrete Points

$$\Pr[B|A|ZD] = B$$

$$\Pr[B|A|LD] = \frac{1 + 19B}{20}$$

$$\Pr[B|A|MD] = \frac{1 + 6B}{7}$$

$$\Pr[B|A|HD] = \frac{1 + B}{2}$$

$$\Pr[B|A|CD] = 1.0$$

For BHEPs of .01 or smaller, the use of the above equations will result in conditional probabilities very close to .05, .15, and .5 for LD, MD, and HD. It is suggested that these values be used as approximations for the conditional probabilities when dealing with BHEPs of less than .01 for the second task.

For an example of the three methods, assume that three valves must be operated in the order specified by the plant's written procedures as follows:

1. Open valves 1216A and B
2. Inspect ...
3. Record ...
4. Verify ...
5. Open MOV 1344

The tasks of interest, "A," "B," and "C," are the manipulations of the three valves. The intervening inspection and recording tasks are disregarded here. Given that these tasks are in the same set of procedures, an error of omission on "A" amounts to failure to initiate the task, thus making errors of omission on the other two tasks certainties. Errors of omission will be disregarded in this example. Errors of commission only (e.g., closing a valve instead of opening it) will be considered here.

The following assumptions are made. The procedures treat the manipulations of valves 1216A and B in one step. Therefore, we consider there to be at least a high level of dependence between them. The manipulation of MOV 1344 is treated separately and occurs after a number of intervening activities. We will also assume, for the purposes of this example, that these operations are to be performed by an auxiliary operator. We assume that he is highly motivated to perform his job correctly, and that the procedures are adequate for his needs. The task is to be performed under normal operating conditions -- there are no unusual demands placed on the operator, and the level of stress is optimal.

As previously mentioned, one method for estimating conditional probabilities is to use actual data. In using actual data to determine the conditional probabilities B|A and C|B, suppose we know from plant records or from studies based on this particular procedure that the manipulation of valves of the type of "A" and "B" has an error probability of .003, that this HEP is raised by a factor of 200 to .6 for B|A, and that the manipulation of valves of the type of "C" always has an error probability of .005. We can use these figures directly in the computation of the probability of system failure. In other words, the joint HEP for "A," "B," and "C" is:

$$A \times B|A \times C = .003 \times .6 \times .005 = .000009 \approx 10^{-5}.$$

If we wish to use the method that estimates the conditional probabilities directly using our judgment as human factors specialists, we first have to state certain assumptions regarding the performance shaping factors for this case, such as those stated in the introduction to this example. Then, let us assume that the BHEP for "A" and for "B" is .003 and that the BHEP for "C" is .005. Given the assumptions stated, we judge that if the operator fails to manipulate 1216A correctly (if he fails to open 1216A), he will fail to manipulate 1216B correctly 90% of the time; that is, B|A is .9. We judge that, since a similar manipulation is required for MOV 1344 and since it and 1216A and B are in the same set of procedures, the HEP for the manipulation of "C" is .30 given an error on "B;" that is, C|B is .3. The joint HEP for these tasks now becomes:

$$A \times B|A \times C|B = .003 \times .9 \times .3 = .00081.$$

For the method using the dependence model, let us assume that there is CD between Tasks "A" and "B" and that there is LD between Tasks "B" and "C." The equations listed earlier (or, rather, the approximations given) can be used to determine the joint HEP of

$$A \times B|A|CD \times C|B|LD = .003 \times 1.0 \times .05 = .00015.$$

These three sets of calculations illustrate the use of each of the three methods. Since each method employed different assumptions about the dependence relations between Tasks "A," "B," and "C," different values for the joint HEP were obtained. We recommend the method that uses actual data for estimating the appropriate probabilities as best. In practice, the performance of a human reliabili . analysis may be required on a complex system for which the performance data is incomplete and for which inadequate information regarding performance shaping factors has been provided. The analyst can use combinations of all three methods in such a case to address the variety of conditions that would be encountered.