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# **AN UNAVAILABILITY MODEL FOR ERRORS MADE DURING SURVEILLANCE TESTING**

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## **INTRODUCTION**

Periodic testing or examination is conducted routinely for some critical standby equipment or instrumentation, in an attempt to increase its availability. This is often called "surveillance testing." There is a finite probability that tested equipment will be left in a degraded or nonfunctioning state because of an error, and this important type of human error is often called a "restoration error" in probabilistic safety analysis (PSA) parlance. One would expect a trade-off between the reduction in unavailability gained by surveillance testing and the increase in unavailability incurred by surveillance testing errors. In this paper, a mathematical model of the effect of errors made during surveillance testing on equipment unavailability is described.

## **TYPES OF SURVEILLANCE TESTING**

The simplest surveillance test involves an inspection that does not take the tested equipment out of service. This is called a "nonintrusive test" in our work. An example of nonintrusive testing is a visual check of valve stem position to determine valve seat position. In contrast, an intrusive surveillance test involves taking a piece of equipment out of operation to perform a test with dummy inputs, a detailed inspection, or an operational run. An example of intrusive testing is taking an instrument off-line and introducing a test voltage to check its response.

## **SURVEILLANCE TESTING ERRORS**

Two types of surveillance testing errors are treated in this model: testing error and restoration error. The failure of the tester to detect an existing unavailability is a testing error. Failure to return equipment that has been taken out of service for testing to an operating status is a restoration error.

Several performance shaping factors affect the probability of failure to restore. The most important of these is often the presence or absence of alerting factors. An alerting factor serves to remind to maintainer to take some action. For example, if one of a series of instru-

ments is discovered with an out-of-calibration setting, most maintainers will be especially vigilant in testing the remaining instruments.

The unavailability model reported in this paper includes restoration-error and testing-error probability estimates. We assume that human error probabilities can be estimated using some Human Reliability Analysis (HRA) methodology such as Technique for Human Error Rate Prediction (THERP)<sup>1</sup> or Human Error and Reduction Technique (HEART),<sup>2</sup> or by expert opinion solicitation.<sup>3</sup>

## SURVEILLANCE TESTING UNAVAILABILITY MODEL

The unavailability of equipment is represented in our model as the fraction of total operating time that the equipment is unavailable. The total operating time for the equipment is divided into intervals of length  $T$  called "operating periods." The component is serviced at the end of each operating period, and it emerges into a new maintenance interval with a probability,  $p_f$ , of being unavailable. In our model,  $p_f$  is an initial condition on the unavailability function. During an operating period, the component is subjected to  $q$  surveillance tests at regular intervals. Therefore, the operating interval,  $T$ , is divided conveniently into  $(q + 1)$  equal intervals called "surveillance intervals." The component will emerge from each surveillance test in either an available or unavailable state. The probabilities of emerging in each state are assumed to be a function of a surveillance testing error probability,  $p_x$ , and the restoration error probability,  $p_s$ . For simplicity, we assume a constant random failure rate during all operating periods, so the probability of a random failure in any surveillance interval is a constant  $p_r$ . We also assume no recovery of unavailable components between surveillance tests and constant human error probabilities. The probability of a component being unavailable at the start of the  $k + 1$ st surveillance interval of an operating period is given by the recursion relationship

$$P_{k+1} = P_k p_x (1 - p_s) + p_s .$$

The probability of an unavailable component in each surveillance interval is dependent on the previous interval and on the surveillance error probabilities. The total time that the component is unavailable for the operating period is the sum of the probability of being unavailable for each surveillance interval multiplied by the length of each maintenance interval. The unavailability of the component for the operating period is the unavailable time divided by the length of the operating period. The unavailability equation involves sums that are geometric progressions and can be evaluated in closed form. The resulting equation for the unavailability  $U$  is<sup>4</sup>

$$U = \frac{p_a}{q} \left( \frac{1 - \pi^q}{1 - \pi} \right) + \frac{p_b}{1 - \pi} \left[ 1 - \frac{1}{q} \left( \frac{1 - \pi^q}{1 - \pi} \right) \right] ,$$

where  $\pi = p_x(1 - p_s)$ ,  $p_a = p_f + p_r$  and  $p_b = p_r + p_s$ .

## APPLICATIONS OF THE MODEL

The model described above was applied using the probability values in Table 1 for a base case. These parameters are based on reasonable values encountered in a number of PSAs. Variations of these parameters model different maintenance situations.

The value of the restoration error probability,  $p_s$ , can be used to model some situations of interest. When  $p_s$  is zero, nonintrusive surveillance is modeled. Nonintrusive surveillance testing always reduces the unavailability of a component because standby failures can be discovered and corrected, but no new unavailability is introduced. However, such testing may be much less likely to discover component standby failures or faults than more invasive testing. When  $p_s$  is greater than zero, intrusive surveillance testing is modeled. If the instrument is not returned to service after the test, it is unavailable for performing its intended function after the test, even if it was working before the test.

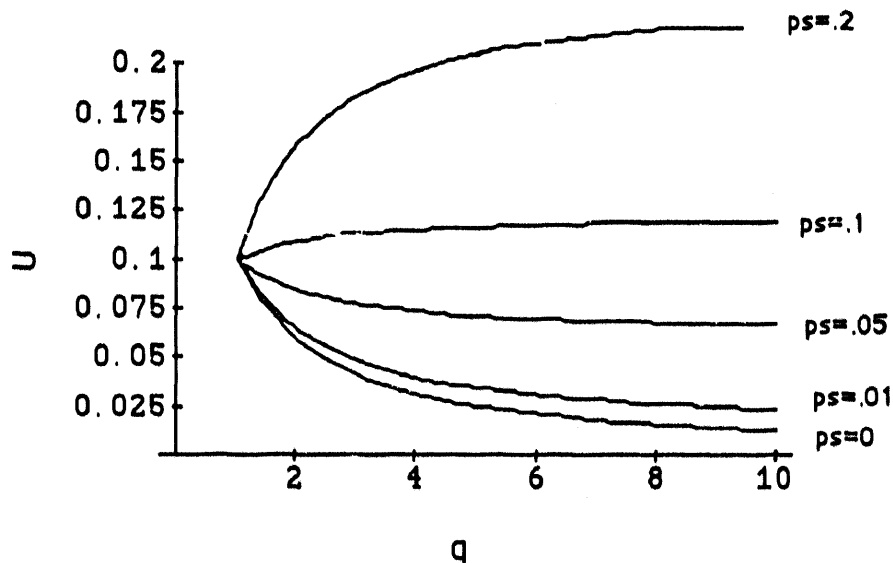
**Table 1.** Unavailability model parameters.

Parameter	Value
$p_x$	0.2
$p_s$	0.1
$p_f$	0.1
$p_r$	0.01

Our model includes the effects of alerting factors and second checkers on failure-to-restore errors as a refinement to the failure-to-restore model. Because of the finite probability of failing to restore a component after surveillance testing, intrusive surveillance testing can result in increasing unavailability for a given component. This unavailability growth will occur if the gain in availability arising from the discovery and correction of standby faults is relatively smaller than the unavailability introduced by errors in restoration after surveillance testing. Figure 1 is a plot of unavailability  $U$  as a function of the number of surveillance tests per operating period for various values of  $p_s$ .

Another interesting class of results can be generated by examining the derivative of the unavailability  $U$  with respect to different parameters. Figure 2 is a plot of the derivative of  $U$  with respect to the surveillance error probability,  $p_x$ , as a function of  $p_x$  when the random failure rate is very low. A parametric family of curves for different values of surveillance testing frequency represented by  $q$  is generated. In this plot, one can see that increasing the number of surveillance tests increases the importance of the surveillance error probability in determining the unavailability. The importance of the surveillance error probability also increases as its value increases. Both trends are intuitively reasonable.

Other uses of this model include evaluating the cost-effectiveness of surveillance testing. A surveillance test often will result in a reduction in unavailability for all testing frequencies. However, a cost is associated with each performance of the surveillance testing based on the operator time required to prepare, perform, second-check, and restore the component. A corresponding change in component unavailability is associated with each surveillance test. As more frequent surveillance tests are performed, the cost of performing them rises linearly, whereas the reduction in unavailability decreases exponentially. A point of diminishing returns for increasing the frequency and efficiency of surveillance tests is soon reached, where a unit reduction in unavailability achieved by increased surveillance testing is bought at an increasingly higher price.



**Figure 1.**  $U$  vs surveillance frequency  $q$  ( $p_s$  as a parameter).

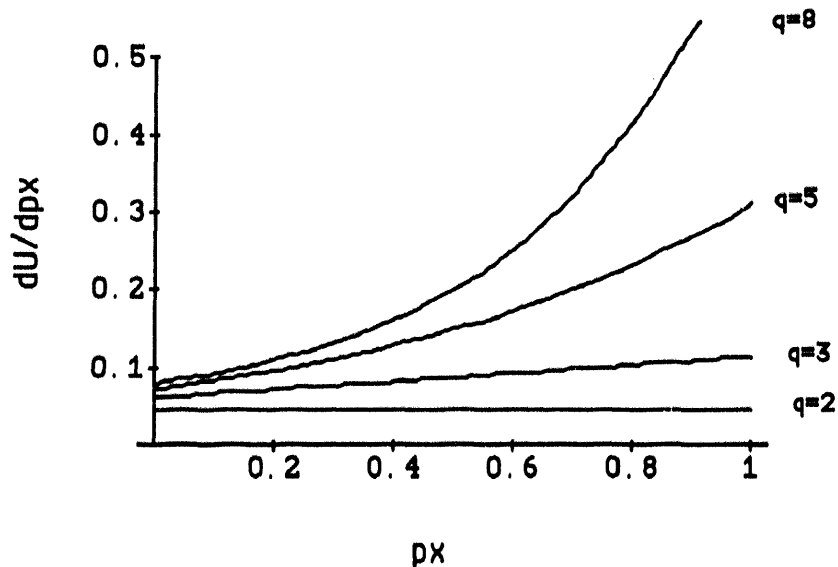


Figure 2.  $\partial U/\partial p_x$  vs surveillance error probability  $p_x$ .

## CONCLUSIONS

We have developed an unavailability model for surveillance testing of standby components that includes testing characteristics such as restoration error probability and failure to discover component unavailability error probabilities. This model includes the effects of surveillance tests and unavailability introduced by the tests themselves. It also includes maintenance and surveillance frequencies, random failure probabilities, and human error probabilities for failing to restore and failing to discover unavailable components during testing. The model includes the effect of alerting factors on surveillance restoration errors.

If surveillance is nonintrusive, it will always decrease unavailability. If surveillance is intrusive, unavailability can either decrease if surveillance restoration error probability is low enough or increase if this error probability is too high. An example of the cost-effectiveness of surveillance testing shows that the frequency and the efficiency of surveillance tests strongly affects costs but affects unavailability less strongly. Thus, a point of diminishing returns for increasing the frequency and efficiency of surveillance tests is quickly reached.

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