



Voting System Standards

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Volume II, Appendix C

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Appendix C: Qualification Test Design Criteria

C.1 Introduction

This appendix describes the guiding principles used to design the voting system qualification testing process conducted by ITAs.

Qualification tests are designed to demonstrate that the system meets or exceeds the requirements of the Standards. The tests are also used to demonstrate compliance with other levels of performance claimed by the manufacturer.

Qualification tests must satisfy two separate and possibly conflicting sets of considerations. The first is the need to produce enough test data to provide confidence in the validity of the test and its apparent outcome. The second is the need to achieve a meaningful test at a reasonable cost, and cost varies with the difficulty of simulating expected real-world operating conditions and with test duration. It is the test designer's job to achieve an acceptable balance of these constraints.

The rationale and statistical methods of the test designs contained in the Standards are discussed below. Technical descriptions of their design can be found in any of several books on testing and statistical analysis.

C.2 Approach to Test Design

The qualification tests specified in the Standards are primarily concerned with assessing the magnitude of random errors. They are also, however, capable of detecting bias errors that would result in the rejection of the system.

Test data typically produce two results. The first is an estimate of the true value of some system attribute such as speed, error rate, etc. The second is the degree of certainty that the estimate is a correct one. The estimate of an attribute's value may or may not be greatly affected by the duration of the test. Test duration, however, is very

important to the degree of certainty; as the length of the test increases, the level of uncertainty decreases. An efficient test design will produce enough data over a sufficient period of time to enable an estimate at the desired level of confidence.

There are several ways to design tests. One approach involves the preselection of some test parameter, such as the number of failures or other detectable factor. The essential element of this type of design is that the number of observations is independent of their results. The test may be designed to terminate after 1,000 hours or 10 days, or when 5 failures have been observed. The number of failures is important because the confidence interval (uncertainty band) decreases rapidly as the number of failures increases. However, if the system is highly reliable or very accurate, the length of time required to produce a predetermined number of failures or errors using this method may be unachievably long.

Another approach is to determine that the actual value of some attribute need not be learned by testing, provided that the value can be shown to be better than some level. The test would not be designed to produce an estimate of the true value of the attribute but instead to show, for example, that reliability is at least 123 hours or the error rate is no greater than one in ten million characters.

The latter design approach, which was chosen for the Standards, uses what is called Sequential Analysis. Instead of the test duration being fixed, it varies depending on the outcome of a series of observations. The test is terminated as soon as a statistically valid decision can be reached that the factor being tested is at least as good as or no worse than the predetermined target value. A sequential analysis test design called the "Wald Probability Ratio Test" is used for reliability and accuracy testing.

C.3 Probability Ratio Sequential Test (PRST)

The design of a Probability Ratio Sequential Test (PRST) requires that four parameters be specified:

- H0, the null hypothesis
- H1, the alternate hypothesis

- a, the Producer's risk
- b, the Consumer's risk

The Standards anticipate using the PRST for testing both time-based and event-based failures.

This test design provides decision criteria for accepting or rejecting one of two test hypotheses: the null hypothesis, which is the Nominal Specification Value (NSV), or the alternate hypothesis, which is the MAV. The MAV could be either the Minimum Acceptable Value or the Maximum Acceptable Value depending upon what is being

tested. (Performance may be specified by means of a single value or by two values. When a single value is specified, it shall be interpreted as an upper or lower single-sided 90 percent confidence limit. If two values, these shall be interpreted as a two-sided 90 percent confidence interval, consisting of the NSV and MAV.

In the case of Mean Time Between Failure (MTBF), for example, the null hypothesis is that the true MTBF is at least as great as the desired value (NSV), while The alternate hypothesis is that the true value of the MTBF is less than some lower value (Minimum Acceptable Value). In the case of error rate, the null hypothesis is that the true error rate is less than some very small desired value (NSV), while the alternate hypothesis is that the true error rate is greater than some larger value that is the upper limit for acceptable error (Maximum Acceptable Value).

C.4 Time-based Failure Testing Criteria

An equivalence between a number of events and a time period can be established when the operating scenarios of a system can be determined with precision. Many of the performance test criteria of Section Volume II, Section 4, *Hardware Testing*, use this equivalence.

System acceptance or rejection can be determined by observing the number of relevant failures that occur during equipment operation. The probability ratio for this test is derived from the Exponential probability distribution. This distribution implies a constant hazard rate. Therefore, two or more systems may be tested simultaneously to accumulate the required number of test hours, and the validity of the data is not affected by the number of operating hours on a particular unit of equipment. However, for environmental operating hardware tests, no unit shall be subjected to less than two complete 24 hour test cycles in a test chamber as required by Volume II, Subsection 4.7.2. of the Standards.

In this case, the null hypothesis is that the Mean Time Between Failure (MTBF), as defined in Subsection 3.4.3 of the Standards, is at least as great as some value, here the Nominal Specification Value. The alternate hypothesis is that the MTBF is no better than some value, here the Minimum Acceptable Value.

For example, a typical system operations scenario for environmental operating hardware tests will consist of approximately 45 hours of equipment operation. Broken down, this time allotment involves 30 hours of equipment set-up and readiness testing and 15 hours of elections operations. If the Minimum Acceptable Value is defined as 45 hours, and a test discrimination ratio of 3 is used (in order to produce an acceptably short expected time of decision), then the Nominal Specification Value equals 135 hours.

With a value of decision risk equal to 10 percent, there is no more than a 10 percent chance that a system would be rejected when, in fact, with a true MTBF of at least 135

hours, the system would be acceptable. It also means that there is no more than a 10 percent chance that a system would be accepted with a true MTBF lower than 45 hours when it should have been rejected.

Therefore,

H0: MTBF = 135 hours
H1: MTBF = 45 hours

a = 0.10
b = 0.10

and the minimum time to accept (on zero failures) is 163 hours.

It follows, then, that the test is terminated and an ACCEPT decision is reached when the cumulative number of equipment hours in the second column of the following table has been reached, and the number of failures is equal to or less than the number shown in the first column. The test is terminated and a REJECT decision is reached when the number of failures occurs in less than the number of hours specified in the third column. In the event that no decision has been reached by the times shown in the last table entries, the test is terminated, and the decision is declared as indicated.

<u>Number of Failures</u>	<u>Accept if Time Greater Than</u>	<u>Reject if Time Less Than</u>
0	163	Continue test
1	245	Continue test
2	327	Continue test
3	409(1)	82
4	1635	245(2)

- (1) Terminate and ACCEPT
- (2) Terminate and REJECT

The ACCEPT/REJECT criteria of this time-based test accommodate the inclusion of partial failures in the following manner. A graph is drawn, consisting of two parallel lines through the sets of numbers of failures and time values shown in the table. These lines are plotted against the total number of failures on the vertical axis, and the elapsed time on the horizontal axis. They become "ACCEPT" and "REJECT" boundaries. As an illustration, Figure C-1 below has been constructed using the values from the previous table.

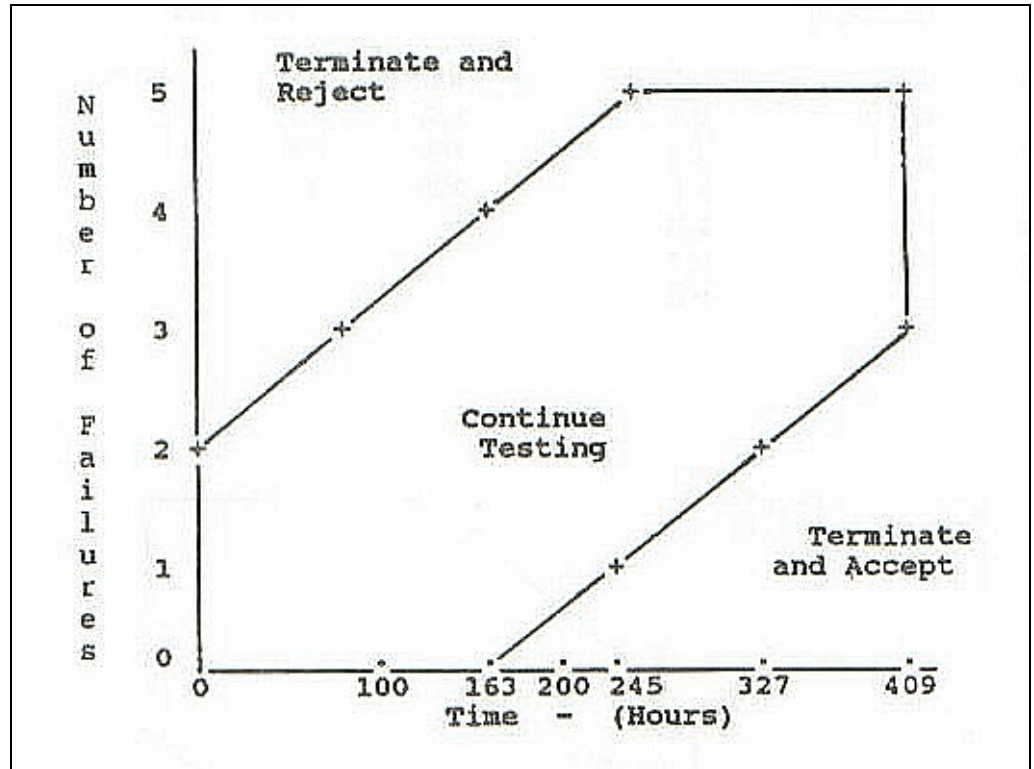


Figure C-1

As operating time is accrued, the horizontal line is extended from the origin to the current value of time. If a total or partial failure occurs, the value of the cumulative failure score is plotted at the time when the failure occurred. A vertical line is drawn between this point and the horizontal trace. The test is resumed and the horizontal trace is continued at the level of the cumulative failure score.

The test is terminated and the equipment is accepted whenever this horizontal line intersects the lower of the two parallel lines. If the vertical line drawn to connect the horizontal trace to the new cumulative failure score intersects the upper of the two parallel lines, the test is terminated and the equipment rejected.

The test is terminated and the equipment is rejected if a total score of 5.0 or more is reached. If after 409 hours of operation the cumulative failure score is less than 5.0, then the equipment is accepted.

An example is illustrated in Figure C-2. For this example, assume that System R experienced a sequence of partial failures as shown in the table below. The system would be rejected after the sixth failure event because its operating trace intersected the upper boundary. Similarly, System A would be accepted when its operating trace intersected the lower boundary at 220 hours.

<u>System R</u>			<u>System A</u>		
Time	Score	Cum. Score	Time	Score	Cum Score
34	0.5	0.5	123	0.5	0.5
45	0.8	1.3	189	0.2	0.7
78	0.5	1.8	220	-	0.7
89	0.5	2.3			
101	0.8	3.1			
123	0.5	3.6			

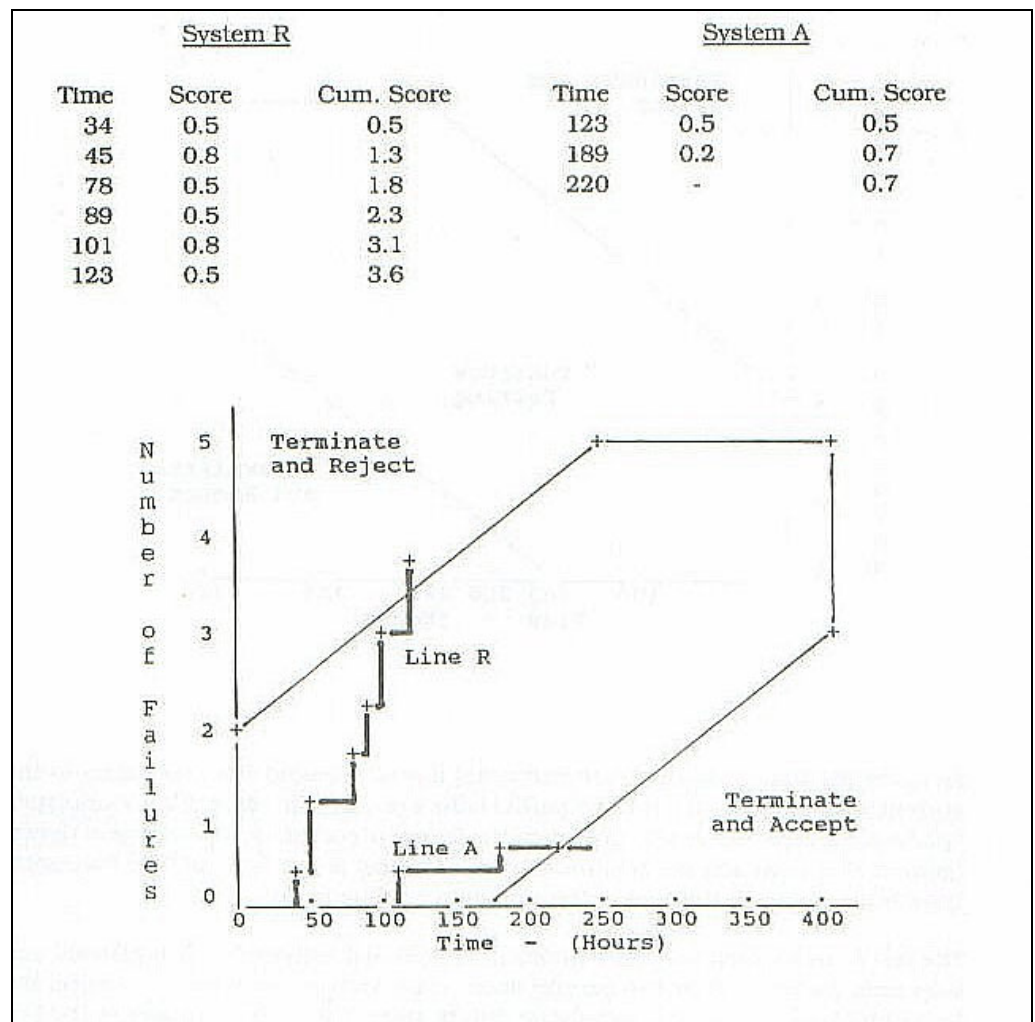


Figure C-2

C.5 Event-based Failure Testing Criteria

Some voting system performance attributes are tested by inducing an event or series of events, and the relative or absolute time intervals between repetitions of the event has no significance. Although an equivalence between a number of events and a time period can be established when the operating scenarios of a system can be determined with precision, another type of test is required when such equivalence cannot be established. It uses event-based failure frequencies to arrive at ACCEPT/REJECT criteria. This test may be performed simultaneously with time-based tests.

For example, the failure of a device is usually dependent on the processing volume that it is required to perform. The elapsed time over which a certain number of actuation cycles occurs is, under most circumstances, not important. Another example of such an attribute is the frequency of errors in reading, recording, and processing vote data.

The error frequency, called “ballot position error rate,” applies to such functions as process of detecting the presence or absence of a voting punch or mark, or to the closure of a switch corresponding to the selection of a candidate.

Qualification and acceptance test procedures that accommodate event-based failures are, therefore, based on a discrete, rather than a continuous probability distribution. A Probability Ratio Sequential Test using the binomial distribution is recommended. In the case of ballot position error rate, the calculation for a specific device (and the processing function that relies on that device) is based on:

HO: Desired error rate = 1 in 10,000,000

H1: Maximum acceptable error rate = 1 in 500,000

a = 0.05

b = 0.05

and the minimum error-free sample size to accept for qualification tests is 1,549,703 votes.

The nature of the problem may be illustrated by the following example, using the criteria contained in the Standards for system error rate. A target for the desired accuracy is established at a very low error rate. A threshold for the worst error rate that can be accepted is then fixed at a somewhat higher error rate. Next, the decision risk is chosen, that is the risk that the test results may not be a true indicator of either the system's acceptability or unacceptability. The process is as follows:

- The desired accuracy of the voting system, whatever its true error rate (which may be far better), is established as no more than one error in every ten million characters (including the null character).

- If it can be shown that the system's true error rate does not exceed one in every five hundred thousand votes counted, it will be considered acceptable. (This is more than accurate enough to declare the winner correctly in almost every election.)
- A decision risk of 5 percent is chosen, to be 95 percent sure that the test data will not indicate that the system is bad when it is good or good when it is bad.

This results in the following decision criteria:

- If the system makes one error before counting 26,997 consecutive ballot positions correctly, it will be rejected. The vendor is then required to improve the system.
- If the system reads at least 1,549,703 consecutive ballot positions correctly, it will be accepted.
- If the system correctly reads more than 26,997 ballot positions but less than 1,549,703 when the first error occurs, the testing will have to be continued until another 1,576,701 consecutive ballot positions are counted without error (a total of 3,126,404 with one error).

C.6 Resolving Discrepancies During Data Accuracy Testing

Data accuracy criteria for qualification tests are intended to demonstrate that the system meets at least the minimum accuracy requirements established by the Standards. Ballots for this test may be of any format that is capable of generating a large number of voting marks in each counting cycle. Ballot reading logic capability is not exhaustively tested by the procedure.

In the event of discrepancy among the totals for any ballot position obtained on each of the ballot-counting cycles, or among the sums of the totals for all of the ballot positions, the following procedure shall apply:

- Step 1: For each ballot position, compute the difference between the largest and the smallest totals.
- Step 2: Sum the differences for all ballot positions.
- Step 3: Sum the totals for all ballot positions on each counting cycle.
- Step 4: Compute the sum of all ballot positions on all counting cycles.
- Step 5: Compute the ratio of the sum of the differences from Step 2 to the sum of all votes from Step 4.

- Step 6: If the ratio from Step 5 is less than $1/1,500,000$, then accept the system and terminate the test; otherwise proceed to Step 7.
- Step 7: If the ratio from Step 5 is equal to or greater than $1/27,000$, then reject the system; otherwise proceed to Step 8.
- Step 8: If the testing agency and the vendor agree that the cause of the discrepancy can be identified and corrected, and if this corrective action is taken, then repeat the test in its entirety; otherwise, reject the system.