Building on Reliability: Reliability Test Planning

By Stephen N. Luko and Dean V. Neubauer

Q What is reliability demonstration testing?

A Many industries require some kind of reliability demonstration testing for their products. Recall from a previous Data Points article[1] that reliability is a probability statement about a product's survivability under certain conditions, generally as a function usage or time. This can apply to raw materials, components, devices, and entire systems.

Demonstration methodology may need to occur in evaluating a supplier: during various phases of product development, as a quality audit, or as a validating measure of an existing product improvement. In each case, some kind of testing protocol is used to demonstrate product reliability. Here we start the development of the key concepts of demonstration testing. In a future article, we will look at several more specific cases and examples.

RELIABILITY DEMONSTRATION PLANNING

Demonstration testing is about how long the life of a product will be under certain conditions of use. In a demonstration test, there are two ways that any test unit can conclude: a) the unit is tested and failure occurs at some time; or b) a unit is tested for a specific time or number of cycles, then stopped. In the latter case, we say that the sample test value was censored at the test truncation time.

Censored values are also called "suspensions" or "runouts" in that the true failure time is unknown but is in the future. There are multiple types of censoring: left-, interval-, and right-censoring. In this discussion, the truncated test times are right-censored, that is, the true unmeasured failure time is in the future. The conditions of the test should also be considered, and in practice, the sample size is also important. In actual practice, some combination of both a) and b) may occur.

In some industries, where censoring is concerned, the critical truncation test time is referred to as a "bogey" value and the test called a "bogey test." In addition, a statistical distribution may be assumed such as the Weibull or lognormal. When the test is a bogey-type test and a distribution is assumed, we also usually assume a parameter of the assumed distribution. In the case of the Weibull, the assumed parameter is the Weibull shape parameter or "slope," β. In the case of the lognormal, the scale parameter σ is assumed. We can also have a nonparametric-type test where no distribution is assumed. A bogey-type test plan uses a sample size, *n*, and a maximum number of failures, *r*, allowed by the plan. Additionally, a level of confidence in the final result is required as an input to any plan. What is being demonstrated in any test plan is typically a stated life for which a desired reliability is specified.

In stating a life requirement to be demonstrated, there are several terms that are commonly used. The most general way to state a requirement is to specify a life value and the associated reliability at that value. For example, if the requirement is 10,000 cycles of use with a reliability of 90%, that means that the reliability at 10,000 cycles is 90%. It also means there is a 10% failure probability at 10,000 cycles. Reliability engineers abbreviate this using the "B_p life notation." In this example, we would say that the life to be demonstrated is a B_{10} life of 10,000 cycles. The "10" simply means 10% failure probability (or 90% reliability) at 10,000 cycles. To "demonstrate" implies to show with confidence that some statistical confidence coefficient holds for the plan. Confidence plays into the test plan as a means of minimizing the risk of being incorrect in the stated final result. The confidence coefficient is typically 90, 95, or 99%, but other values are also used.

Another common way that reliability and confidence are captured in one representation is to use the "*RC*" notation, where "*R*" stands for reliability and "*C*" for confidence. For example, *R*90*C*90 stands for 90% reliability with 90% confidence.

In our previous illustration, if we wanted 95% confidence, we would say that the requirement of 10,000 cycles is *R*90*C*95. Still another way to specify a requirement is to use the service life of a product. A "service life", *s*, is one lifetime, at the end of which, the product is expected to be retired/replaced. One must state the product reliability at the service life, and this is often 99%, particularly where safety is of concern. This is useful when a distribution, such as a Weibull model, is used as an assumption.

Table 1 — Sample Size Requirement, Zero Failure Plans, Reliability and Confidence Specified

	Reliability, *R*									
C	**0.9000**	**0.9500**	**0.9600**	**0.9700**	**0.9800**	**0.9900**	**0.9950**	**0.9973**	**0.9987**	**0.9990**
0.500	7	14	17	23	35	69	139	257	514	693
0.550	8	16	20	27	40	80	160	296	592	799
0.600	9	18	23	31	46	92	183	339	679	916
0.650	10	21	26	35	52	105	210	389	778	1,050
0.700	12	24	30	40	60	120	241	446	892	1,204
0.750	14	28	34	46	69	138	277	513	1,027	1,386
0.800	16	32	40	53	80	161	322	596	1,192	1,609
0.850	19	37	47	63	94	189	379	702	1,405	1,897
0.900	22	45	57	76	114	230	460	852	1,705	2,302
0.950	29	59	74	99	149	299	598	1,1109	2,218	2,995
0.990	44	90	113	152	228	459	919	1,704	3,409	4,603
0.995	51	104	130	174	263	528	1,058	1,960	3,923	5,296
0.999	66	135	170	227	342	688	1,379	2,555	5,114	6,905

One of the most popular and simplest of test plans is the zero-failure plan. Such a plan requires that the test results in zero failures at the test bogey truncation time. Zero-failure test plans are conservative in that the product reliability has to be much better than the requirement to have a reasonable chance of passing the test. A zero-failure plan that is the most conservative of these types of plans is based on the binomial distribution where the formula is found in numerous sources.[2-3] The sample size for an "*RC*" plan where the test truncation time is equal to the required B_p life is computed as:

$$n = \frac{\ln(1-C)}{\ln(R)}$$

In Equation 1, the *C* (confidence level) and *R* (reliability) are each expressed as a decimal. Note that $R = 1 - P/100)$ where "*P*" $(0 < P < 100)$ is attached to the B_p life we are trying to demonstrate. This formula is the nonparametric case. When *n* units are tested to time *t* and zero failures result, then what is demonstrated is $B_p \geq t$ with confidence *C*. For example, when $P = 10$ (90% reliability) and $C = 0.9$ (90% confidence), then Equation 1 requires $n = 22$ units be tested. So testing 22 units to a time *t* without failure demonstrates that the B_{10} life is at least *t* with 90% confidence.

The sample size $n = 22$ is commonly found in engineering/quality requirements because *R*90*C*90 is a common reliability requirement for numerous products. Further, there is no assumption of a distribution implied in this formula, and that removes the uncertainty associated with assuming a distribution. Such a test is considered conservative because with 90% confidence, if the true B_{10} life were in fact equal to the test time *t*, then the probability of passing this test would be $1 - C$, or 10% in this case. Thus, when we use a zero-failure plan, it is hoped that the true B_p life is in reality much better than the test time.

Table 1 was created using Equation 1 for selected values of *R* and *C*.

For a more detailed review of non-parametric cases of zero failure sampling, see the practice for setting an upper confidence bound for a fraction or number of non-conforming items, or a rate of occurrence for non-conformities, using attribute data, when there is a zero response in the sample (E2334). In part two on this topic, we will discuss plans where the Weibull distribution is an assumption. ■

REFERENCES

1. Luko, Stephen, N., "What is Reliability – Key Concepts and Terminology," Data Points, *ASTM Standardization News,* Jan./Feb. 2018, pp. 28-29.
2. Schenkelberg, Fred, "Success Test Formula Derivation," *Accendo Reliability,* accendoreliability.com/success-testing-formula-derivation.
3. Ireson, W.G., and Coombs Jr., C.F., *Handbook of Reliability Engineering and Management,* McGraw-Hill, 1966.

Stephen N. Luko is a retired fellow and statistician at United Technologies Corp/Collins Aerospace. Chair of the reliability subcommittee (E11.40) in the committee on quality and statistics (E11), he is an ASTM International fellow, Harold F. Dodge Award recipient, and a former E11 chair.

Dean V. Neubauer, the Data Points column coordinator, is engineering fellow and chief statistician, Corning Inc. A member at large on the executive subcommittee of the committee on quality and statistics (E11), he is an ASTM International fellow, a Harold F. Dodge Award winner, and a past chair of the E11 committee.

Erratum

In his Sept./Oct. 2020 *SN* Data Points article, "Probability Models for Epidemics and Materials," Peter Fortini is discussing progeny distribution:

> "With mean greater than one, once the number of individuals in a generation is high enough, the growth is for practical purposes exponential with:
>
> number of individuals in *n*-th generation = $k \exp(\mu n)$."

The equation should be: *n*-th generation = $k \exp(n \log(\mu))$ or $k\,\mu^n$.