What Is Reliability?

Key Concepts and Terminology

By Stephen N. Luko

Q What does the field of reliability involve?

A The ASTM International committee on quality and statistics (E11) recently created a new subcommittee on reliability, E11.40. This subcommittee is tasked to develop standards on reliability topics, including:

- General reliability,
- Systems reliability,
- Repairable systems,
- Test planning,
- Risk analysis, and
- Failure forecasting, among other topics.

The subcommittee is now working on its base document, a guide to general reliability, and expects to ballot the document in early 2018. Some of the essential concepts of reliability — useful to engineers, scientists, and managers — are covered here as related to materials, components, systems, and processes.

Reliability Concept

Reliability is defined as the probability that a component, device, product, process, or system will function or fulfill a function after a specified duration of time or usage under specified conditions.

Related concepts include dependability, availability, and risk.

Reliability can apply to situations where a simple material is being used, for example, a road surface material, or a complex system, for example, a jet engine. There are many types of processes, including manufacturing processes and business processes. At a high level of interpretation, a process is just a sequence of repeated steps designed to deliver an output product or service. A reliable process is one that delivers over and over again.

Whether a material, a fabricated component, a simple device, a large system, or a process, the way each can fail is called its failure mode. In many cases there may be more than one failure mode, and these may be competing, or a mixture or combination of these.

The task of reliability is to define/study failure modes and to estimate the probability of "life" continuance as a function of some usage unit such as operating time, cycles of use, calendar time, demand cycles, or a function of these. The results may be used by decision makers on key items such as maintenance schedules, replacement intervals, warrantee and life cycle costs, and inventory planning.

Reliability is a key dimension of quality of goods and services.

In thinking about the science of reliability more generally, there are three important sub-areas. First, there is mathematical reliability that studies the theoretical aspects of reliability and heavily depends on probability and statistics for most of its results. This enables the applied portions of the second arm – reliability engineering. Reliability engineering attempts to create robust and reliable products by engineering methods. This approach generally applies to complex systems and processes where there might be design opportunities that focus on the long-term reliability of the system/process. Finally, there is reliability management, which attempts to steer the activity of reliability engineering as well as manage customer feedback and develop metrics that measure reliability performance.

Failure Modes and Reliability Calculations

Various metrics used by engineers and management are associated with reliability; these help track and gage reliability performance. The "failure rate" is a key metric. When a product fails, we can usually associate the failure rate with some specific failure mode, which carries units of "failure events" per unit time. The failure mode is just the way in which the product fails. Specific failure modes depend on the type of product or service being studied, but generally they fall into three types:

- Random,
- Wear out, and
- Early failures.

The last classification is known in industry as failures of the "infant mortality" type – a term borrowed from the biological sciences.

The three major classes of failure modes can be thought to model an entire product life cycle from development to retirement/completion. In the development or early introduction stage of a product, some failures may occur that are due to unforeseen design or development issues. These failure modes may be severe in some units and relaxed in others, causing the former to fail early. This is a classic case of infant mortality, or IM; some units fail early and others last essentially for the entire design life.

During continued improvement, failure modes are found, fixed, and removed over time, improving the failure rate as time passes. The failure rate typically drops during this period, and eventually the product life cycle falls into the random period of failure. In this period, units fail due to random causes at a constant rate. Such failures may be related to numerous external as well as internal causes and are often rare.

As a population continues to age, units will accumulate age-related damage and begin to show signs of wear. Failures tend to occur more rapidly as usage increases. In this wear-out period, failures may be driven by prolonged chemical, thermal, electrical, or mechanical type actions that impart damage to the product over time. All of this is depicted in the so-called bathtub curve shown in Figure 1.

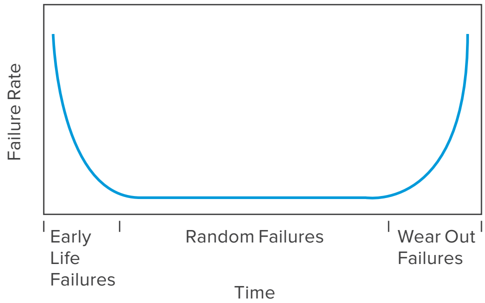

Figure 1 — The “Bathtub” Curve

The figure shown depicts a general trend for a product life cycle. Its shape does not necessarily represent all types of products, and not every product will experience an infant mortality or even a wear-out period. An important period of this life cycle is the random period over which there is a constant failure rate. The reliability function at time *t* over this period follows the exponential distribution with failure rate λ. That function is Equation 1.

$$R(t) = e^{-\lambda t} \qquad (1)$$

Conversely, the failure probability at time *t* is Equation 2.

$$F(t) = 1 - e^{-\lambda t} \qquad (2)$$

Often, and this may depend on the industry, the reciprocal of the failure rate is used. This is θ = 1/λ, where θ is known as the mean time between failure, or MTBF. This metric is useful for systems that are repaired (repairable systems) or for single-use systems that fail randomly over the life cycle. Random failure rates are not age dependent. Failures depend only on how much time a unit has seen and not on the starting time. Suppose for example, that a fleet of many units has a total operational time of 15,000 hours, and this fleet has experienced 17 failures. For the random case, it does not matter if the failures were repaired units or new units. Under these conditions, the failure rate is estimated as: 17/15,000 = 1.133E-3 failures per hour; the MTBF is 15,000/17 = 882.4 hours. The reliability at *t* = 50 hours is, using Equation 1, 0.945.

For random type failures, we can model either the time between failures using the exponential distribution, or the number of failures on an interval *t*, using the Poisson distribution. We can also calculate confidence bounds on the parameters λ or θ or on specific reliability values or quantiles. We can also predict what future frequency of occurrence is expected to happen, given stable conditions of the failure rate. This type of analysis is fairly straightforward.

When the failure mode is infant mortality (IM) or wear out (WO), the Weibull distribution is often an adequate model. In fact, the exponential distribution is a special case of the more versatile Weibull model. In the case of IM, the failure rate is actually a decreasing function of time. For a WO, the failure rate increases with time. Other statistical models such as the lognormal model can also be used for these two types of failure. Generally, for design reliability calculations, the random model is typically assumed. WO and IM are usually special cases of problem behavior when they apply to field performance or development activity. The random model in reliability can be useful on many fronts and should be a staple of the engineer’s overall tool box.

For more information on these topics, see any of the works provided in the references.

REFERENCES

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