Glossary of Reliability, Availability, and Maintainability Terms, Acronyms, and Abbreviations

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Preface

Given the plethora of terminology in the areas of reliability, availability, maintainability, and related disciplines such as logistics and quality control, it is important to use this terminology in a standard and consistent manner. This document supplements the use of time-honored standards such as MIL-STD-721C, adding numerous terms, more in-depth treatment, and using diagrams and equations where needed to explain concepts.

Various sources have been consulted to insure that these definitions are consistent with standard usage. Variant definitions are given where there is no single standard. A complete list of references is provided at the end of the document.

Reader comments are welcome, sent to dcollins@compuserve.com.

Defined terms, and cross-references to other terms in this glossary, are in **boldface**.

A

a   Greek letter alpha. May symbolize the **shape parameter** for a **Weibull distribution** (though β is more common); the **significance level** in **hypothesis testing**; or the probability of a **type I error**.

Abs   The name for the **absolute value** function in many computer languages; i.e., Abs(x) returns the absolute value of x.

Abscissa   The *x*-coordinate in a two-dimensional Cartesian (rectilinear) coordinate system, normally plotted on the horizontal axis of a graph. The *y*-coordinate is the **ordinate**.

Absolute value   The magnitude of a number, without regard to sign. Symbolized with vertical bars: $| x | = x$ if $x \geq 0$, $| x | = -x$ if $x < 0$.

Accelerated test   Or "accelerated life test". A test or testing process that attempts to uncover latent failures by operating equipment under conditions more severe than would be encountered in the intended environment of use. This testing is "accelerated" in the sense that less test time is needed to detect a given number of failures or failure modes. For example, equipment might be operated under temperature extremes, vibration levels, or **duty cycles** beyond its design point. Note that accelerated testing is intended to detect normal failure modes faster, not to uncover failure modes that would not occur in normal operation.

Acceptable quality level   The maximum percentage or proportion of defective items in a batch, tested by **sampling**, which can be accepted as a process average.

Acceptance number   The maximum number of defective items in a batch, tested by **acceptance sampling**, that will allow the batch to be accepted without further testing. Compare **rejection number**. Acceptance number is always less than rejection number; if, for a particular sample, acceptance number < number of defects < rejection number, then further inspection and/or testing will be required to make an accept/reject decision.

Acceptance sampling   **Sampling** from incoming batches to determine whether to accept them, according to a **sampling plan**. See also **acceptance number**.

Accessibility   The ease with which operators and service personnel can access controls, components, etc., required to keep a unit operational or repair it after a failure. Normally applied to physical accessibility, but could also relate to non-physical issues such as the ease-of-use of a computerized interface to test equipment.

Achieved As in "achieved reliability"; an attainment verified by measurement under stated conditions; compare **predicted**.

Active maintenance time The amount of time spent, during a corrective maintenance action, on diagnosis, adjustment, part replacement, etc.; as opposed to preparation time (gathering tools, traveling to the site of the failure, etc.) and delay or **logistics time** (waiting for parts or tools to arrive at the failure site).

Age replacement policy The policy, for replaceable components of a repairable unit, of replacing the components on failure or when they reach a predetermined age, whichever occurs first. Compare **failure replacement policy**, **block replacement policy**.

Age-specific death rate See h**azard rate**. This term is used primarily in actuarial and medical studies.

Age-specific failure rate See h**azard rate**.

Aggregate A variable, or the value of a variable, defined as the sum of other variables. For example, when subjecting units to several different environmental tests, "total failures" would be an aggregate variable summing the number of failures on individual tests.

AGREE Advisory Group on Reliability of Electronic Equipment. A joint industry/defense group set up by the **DoD** and the electronics industry in 1952. Their report, subsequently published as MIL-STD-781, is credited with helping to establish reliability engineering as a discipline.

Alignment 1. The process of adjusting a mechanical or electronic component in order to restore correct or optimum functioning to a unit. 2. The condition of being aligned correctly.

Alternative hypothesis The hypothesis that contradicts the **null hypothesis**. For example, the null hypothesis for the **t-test** is that $\mu_0 = \mu_1$; the alternative hypothesis is that $\mu_0 \neq \mu_1$ for a **two-tail test**, or either that $\mu_0 < \mu_1$ or $\mu_0 > \mu_1$ for a **one-tail test**.

American Society for Quality Or ASQ**.** The leading quality improvement organization in the U. S. ASQ publishes books and journals related to the management of quality and reliability, and sponsors various certifications in these areas. Their web site can be accessed at www.asq.org.

AMSAA method Named for the Army Materiel Systems Analysis Agency; one of a class of methods called **power law models**. A method for analysis of **reliability growth**, described in MIL-HDBK-781 and MIL-HDBK-189. This method assumes that failures during a development phase are modeled by a **nonhomogeneous Poisson**

process (nonhomogeneous because the failure rate will change as a result of design changes). The **intensity function** (**rate of occurrence of failures**) for the process is assumed to be a function of the form $\lambda\beta t^{\beta-1}$, where $\lambda > 0$ and $\beta > 0$ are parameters determined by estimation, and t is cumulative test time. The graphical **Duane method** is simpler and more commonly used, but the AMSAA method allows for statistical estimates such as **goodness of fit** and **confidence intervals**, which the Duane method does not.

Analysis of variance Or ANOVA. A method for testing the **null hypothesis** that several samples are drawn from populations with identical means. Though the test is for equality of **means**, it operates indirectly, by comparing **variances**. The test is normally carried out when there are more than two groups, since for pairs there are simpler tests such as the **t-test**.

The most common ANOVA procedure, called one-way analysis of variance, is for testing one experimental factor, applied to several groups. It relies on the assumption that groups are randomly and independently sampled from **normal** populations, and that the populations have equal **variances**. These assumptions may be relaxed somewhat if the groups are large; if the assumptions cannot be satisfied, the **Kruskal-Wallis test** can be used instead.

Suppose we have baseline data from five tests of a certain type of unit. Each test runs for a fixed length of time with a fixed number of units, and the test statistic is the number of failures that occurred. Two design changes are proposed and implemented, with subsequent retesting. The data are as follows (E_0 is the baseline data, and E_1, E_2 are the test data with the two design changes):

	E_0	E_1	E_2
Test 1	2	1	2
Test 2	3	0	2
Test 3	2	2	2
Test 4	4	0	0
Test 5	2	0	2
E_i mean	$\overline{x_0} = 2.60$	$\overline{x_1} = 0.60$	$\overline{x_2} = 1.60$
E_i sample variance	$s_0^2 = 0.64$	$s_1^2 = 0.64$	$s_2^2 = 0.64$
E_i sum of squares	3.2	3.2	3.2

Note that the sample variances (and therefore the standard deviations) are equal, satisfying the assumption above. The "sum of squares", $\sum_j (\overline{x_i} - x_{ij})^2 = n_i s_i^2$, is the variance multiplied by the number of data points in the group.

The basis for ANOVA is that the variance of the entire set of data has two components: The variance *within* each group, and the variance *between* the groups, relative to the "grand mean" of all the data. If we accept the null hypothesis, the between-groups variance is due to sampling error, and should approximately equal the within-groups variance. The test statistic is the **F ratio**, the ratio of the between-groups variance to the within-groups variance. The computations are as follows:

	Degrees of freedom	Sum of squares (SS)	Mean sum of squares (variance)
Between groups	2	10	5
Within groups	12	9.60	0.8
Total	14	19.60	

The between-groups **degrees of freedom** (df) is the number of groups minus 1; within-group df is $\sum_i (n_i - 1)$, the sum of the df for each group. The total sum of squares is $\sum_{i,j} (\bar{\bar{x}} - x_{ij})^2$ for all the data points without respect to grouping ($\bar{\bar{x}}$ is the grand mean of all the values); within-group sum of squares is the grand sum of the group sums of squares. It can be shown algebraically that

Total SS = Between-groups SS + Within-groups SS

which allows computation of the between-groups SS, given that we have computed the other two. As a check, the between-groups SS can also be computed as $n\sum_j (\bar{\bar{x}} - \bar{x}_i)^2$, where n is the number of groups.

Finally, the ratio of the mean between-groups SS to the mean within-groups SS gives us the F statistic, 5/0.8 = 6.25 (the means are the sums of squares divided by the df). For a significance level of 0.95, consulting a table of the **F-distribution** for 2 df in the numerator, 12 df in the denominator, the value is 3.89. For a significance level of 0.975, the F-distribution value is 5.10. Thus we can reject the null hypothesis at the 97.5% level and conclude that at least one of the design changes made a significant difference. Determining which design has the most significant effect requires further pairwise testing of the means. See **t-test**, **Tukey's paired comparison procedure**.

See also **factorial designs**, **fractional factorial designs**, **two-way analysis of variance**.

Anderson-Darling statistic A **goodness of fit** test used for assessing the fit of an **empirical CDF** to either another set of empirical data, or an exact **CDF**. Its use and computation vary depending on the context. For testing the fit to a **Weibull distribution**, a common usage, the statistic is computed as

$$A^2 = -2\sum_i \hat{\mathrm{F}}(t_i)\{\log F(t_i) + \log[1 - F(t_i)]\} - n$$

where $\hat{\mathrm{F}}$ is the empirical CDF, F is the model Weibull CDF, and $t_1, \ldots, t_n$ are the observed failure times. For small samples, a correction factor is suggested:

$$A^2_{Corr} = \left(1 + \frac{0.2}{\sqrt{n}}\right) A^2 .$$

A^2_{Corr} greater than the value in this table is required to reject the null hypothesis (that the empirical CDF is drawn from the model CDF) at the given significance level:

a **(significance level)**	**Critical value of** A^2_{Corr}
0.10	0.637
0.05	0.757
0.025	0.877
0.01	1.038

ANOVA **Analysis of variance**.

Apportionment The process of allocating an overall reliability objective for a product or system among its components. This process may be applied recursively—for example, if a system has a reliability objective of 0.99 for a mission time of 100 hours, and consists of three identical modules in series, module reliability of 0.9967 is required. This can, in turn, be apportioned among the components of the module.

AOQ **Average outgoing quality**.

AOQL **Average outgoing quality limit**.

AQL **Acceptable quality level**.

Arithmetic mean The result of dividing the total of a set of numbers by the cardinality (number of members) of the set. More precisely, for a set of n numbers x_i, the arithmetic mean is

$$\left(\sum_{i=1}^{n} x_i\right) / n \,.$$

For a set of numbers x_i, where each x_i occurs with frequency f_i,, the arithmetic mean is

$$\left(\sum_{i=1}^{n} f_i x_i\right) / \left(\sum f_i\right).$$

For example, the arithmetic mean of {1,2, 2, 3, 4, 4, 5}, computed with either formula, is 3. See also **average**, **mean**.

Arrhenius model Named after Svante Arrhenius, Swedish chemist. A mathematical model for the influence of temperature on failure rate for electronic components:

$$l = K \exp\left(\frac{-E}{kT}\right)$$

Where l is the failure rate, K is Boltzmann's constant (1.38 x 10^{-23}J K^{-1}), E (eV) is the process activation energy, T is the absolute temperature, and k is an empirically determined constant.

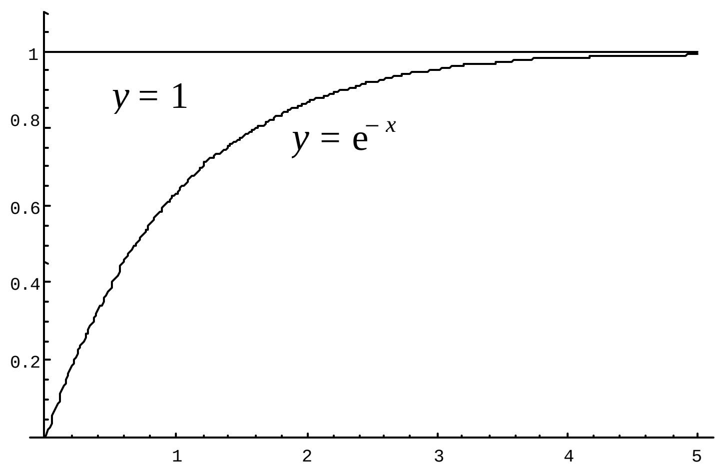
Arrival rate The **rate** at which some event occurs; typically used as a parameter of the **Poisson distribution**, and symbolized λ. For example, we might model the arrival of trucks at a warehouse as a Poisson process, with the arrival rate λ being the number of trucks arriving per time unit; if the occurrence of failures is modeled as a Poisson process, arrival rate is synonymous with **failure rate**.

ASQ See **American Society for Quality**.

ASQC American Society for Quality Control, now called **American Society for Quality**.

Assumptions Conditions that must be satisfied in order for an analysis to be valid. For example: use of the **t-test** with small samples assumes that the parent population is at least approximately **normal**; a two-sample t-test assumes that the parent populations of the samples have the same variance, as does the standard **analysis of variance** procedure. Such assumptions should be listed, and validated, in a complete analysis.

Asymptote A straight line which becomes tangent to a given curve, and whose perpendicular distance from the curve decreases to zero, as the curve goes to infinity. For example, the graph of $y = 1 - e^{-x}$ has as asymptote (is asymptotic to) $y = 1$:



Asymptotic 1. Approaching infinitely closely to a given value; see **asymptote**. 2. (Said of two functions) approaching one another infinitely closely as their arguments tend to infinity, or some other value; symbolized ~ (read "is asymptotic to"). For example, Stirling's approximation is asymptotic at infinity to the factorial function:

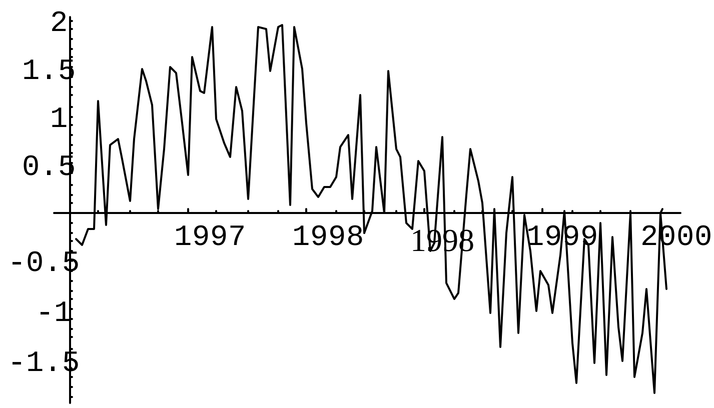
$$n! \sim \sqrt{2p\ n}\ n^n e^{-n}\ ,\ n \to \infty$$

Attributable risk A measure of the amount of risk attributable to a given factor being studied. This might be an absolute measure, or a proportion. For example, suppose in studying the effect of using certain equipment in a given climate, we find that the normal failure rate of 1/1000 hours goes to 2/1000 hours. Then the attributable risk is

1 failure per 1000 hrs., or .001 (the difference between the two rates). This term is primarily used in the literature on medical risks.

Attribute data Data measuring the presence or absence of an attribute, such as "operating" versus "failed". The data is a count, by attribute, of the items in a **sample** or **population**. Attributes are often binary, but in general may be *n*-ary, such as colors, item part number, etc. Compare **variable data**.

Autocorrelation Also called "serial correlation". A tendency, in a set of data points taken in sequence, for points close together in the sequence to be closer to one another than to points farther apart in the sequence. The example **time series** below illustrates autocorrelation.



In this case, the autocorrelation reflects a trend in the data. Autocorrelation analysis may also be applied to the **residuals** from a **regression** model; autocorrelation implies that an assumption of the model, that the residuals are independently distributed about the regression line, is not met.

Autocorrelation is calculated based on a particular *lag*, or interval between the observations that are compared; e.g., lag 1 implies that an observation is compared with the one immediately following it. The *lag k sample autocorrelation coefficient* is calculated as

$$r_k = \frac{\sum_i \left(y_i - \bar{y}\right)\left(y_{i+k} - \bar{y}\right)}{\sum_i \left(y_i - \bar{y}\right)^2} \quad .$$

This coefficient will be between −1 and +1 and is interpreted similarly to a **correlation coefficient**.

Availability A measure of the degree to which a unit or system is operational when required. The most common measure of availability is the probability that the unit is operational. For non-repairable systems, this is simply the **reliability**. For repairable systems, the long-term availability = MTBF/(MTBF + MTTR). (See also **MTBF**, **MTTR**.)

Availability function A function *A(t)*, which yields the probability that a unit, operating since time $t_0 = 0$, will be operational at time t. Such a function would normally exist only for a theoretical model, though an empirical approximation might be constructed for a real device or system.

Availability, instantaneous The probability that a unit is available at a given time t.

Availability, steady state Or "long-term availability". The probability that a unit will be available when availability has reached a steady state. In terms of the availability function, this is the limit, as $t \to \infty$ of the **availability function** *A(t)*, if the limit exists. In practice, steady state availability is measured as MTBF/(MTBF + MTTR).

Average In ordinary language, "average" is often used to refer to a "typical" member of a group. As used by engineers and statisticians, "average" most often refers to
1. The **arithmetic mean** of a group of numbers.
2. The **expected value** of a **random variable** described by a **probability distribution**.
These two definitions are equivalent in the following sense: If a discrete (finite or countable) set of numbers is sampled repeatedly (using **sampling with replacement**), and the probability of obtaining each number is computed, a probability distribution is obtained. As the number of samples becomes larger, the expected value of the distribution converges to the arithmetic mean of the numbers.

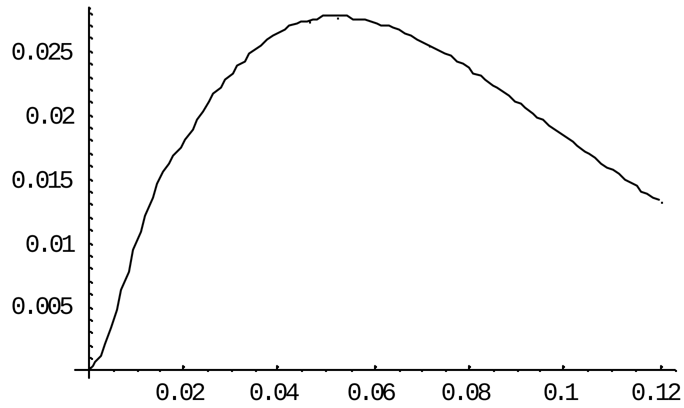
Since "average" may be used in various contexts to denote any measure of central tendency in a group, more precise terms should be used where precision is warranted. See **arithmetic mean**, **geometric mean**, **harmonic mean**, **mean**, **median**, **mode**, **root mean square**.

Average outgoing quality The long-run proportion of defective items of a given type shipped by a manufacturer, or produced by a manufacturing process. Usually used in the context of **acceptance sampling**. See also **average outgoing quality curve**.

Average outgoing quality curve A graphical representation of outgoing versus incoming quality, for a particular **sampling plan**. The AOQ curve is based on the same analysis as the **operating characteristic curve**, which graphs (for a given sampling plan) P_a, the probability of accepting an incoming lot, versus p, the percent defective in the incoming lots. Depending on lot size, P_a, is computed using the **hypergeometric distribution** (small lots, sampling without replacement), **binomial distribution** (for large lots, approximates the hypergeometric), or **Poisson distribution** (approximation to the binomial for large lots, small p). Average outgoing quality is computed as

$$\text{AOQ} = pP_a \frac{N-n}{N},$$

where N is lot size and n is sample size. For $n \ll N$, this is approximately pP_a. The graph below shows a sample AOQ curve for $N = 5000$, $n = 30$, and **acceptance number** 1. Incoming quality (proportion defective) is on the x-axis, and outgoing quality (proportion defective) is on the *y*-axis. The maximum point on this curve is the **average outgoing quality limit**.



Average outgoing quality limit Or AOQL. The highest value of **average outgoing quality** that will be tolerated without taking some action to bring the value back below AOQL. See also **average outgoing quality curve**.

Remainder of glossary pages have been removed

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In addition to the listed references, various Internet resources were used, such as the web sites of U.S. Government organizations and non-government professional societies.

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