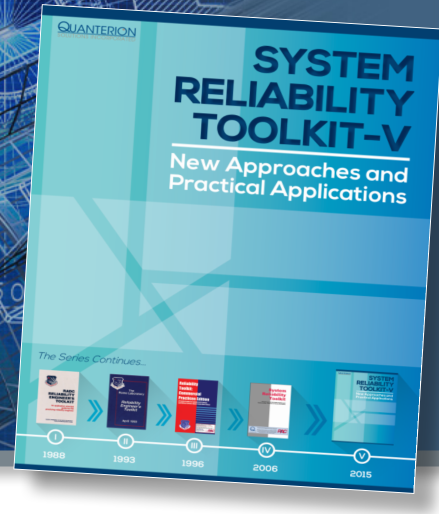
Lessons In

System Reliability

FROM THE QUANTERION

SYSTEM RELIABILITY TOOLKIT-V



The important topics included in this short publication are shared here from the popular Quanterion Solutions' 900+ page System Reliability Toolkit-V. Please give us a call if you need help in any reliability engineering need (315-732-0097).

This second edition includes one Toolkit topic: Topic 1.4: Availability and Operational Readiness.

Topic 1.4: Availability and Operational Readiness

In a general sense, availability is defined as the ability of a product (or service) to be ready for use when the customer wants to use it - it's available if it's in the customer's possession and it works whenever it is turned on or used. If the product is "in the shop" for repair/fix, or it is in the customer's possession but doesn't work, then it is not available.

An acceptable level of operational availability should be strictly dependent on the application of the product. Consider, as an example, that an operational availability of 99.9% means that 1 out of 1000 times that a product is used, or a service is requested, it will not work. Consider also that there may be 100,000 of these products used, or services requested, 4 times every day. This means that 400 times per day (i.e., 400,000 demands x .001) this product will not operate or service will not be available when someone tries to use it. Is 99.9% operational availability considered acceptable in the following circumstances:

- Turning on a lamp
- Starting your car
- Using medical equipment in an emergency
- Flying in an airplane
- Making a 911 telephone call
- Automated safety check in a nuclear power plant
- Operation of a smoke detector

Availability measures are mutually dependent on Uptime and Downtime. This concept is illustrated in Figure 1.4-2. As a result, the same level of availability can be achieved with different values of reliability and maintainability, because reliability is a measure of how often a product fails and maintainability is a measure of how quickly it can be repaired/fixed.

The quantitative measures of availability, as listed in Table 1.4-1, represent the percentage of time that a product or service is in the customer's "possession" and works when it is turned on or used, over the period of time that the product is owned.

Note that the first three equations are time independent, so the value yielded by each equation is the same whether the period of performance being considered is 1 hour or a year. However, the last equation is not time independent and the period of performance is

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very important. Consider the following example. A product has an MTBF of 100 hours and an MTTR of 0.5 hours. Using the equation for inherent availability, the availability is 99.5%, regardless of the time period of interest. Now, if a failure occurs in the first 25 hours of operation and requires one hour to correct, the uptime/total time ratio is 24/25 = 0.96, or 96% availability. If operation then continues failure free for another 25 hours, the availability for the first 50 hours is 49/50 X 100% = 98%. See Figure 1.4-2 on the following page.

The first three equations are actually steady state equations. See also Table 1.4-1 on the page 4. The equation for inherent availability, for example, is the steady state equation derived from the following, as time approaches infinity:

$$A = \frac{MTBF}{MTBF + MTTR} + \frac{MTTR}{MTBF + MTTR} e^{-\left(\frac{1}{MTBF} + \frac{1}{MTTR}\right)t}$$

When possible, confidence limits should be stated for an estimate of availability using steady state equations. Consider the situation in which the observed failures and recorded repair/fix times are assumed to follow independent exponential distributions, and for which MTBF and MTTR are are each chi-squared distributed. In this situation, exact confidence intervals and bounds are readily obtainable upon observing that:

$$A_o = \frac{MTBF}{MTBF + MDT} = \frac{1}{1 + \frac{MDT}{MTBF}} = \frac{1}{1 + R}$$

where R, the ratio of two independent, chi-squared random variables, is a standard F-distribution. Then,

$$LCL_{(\text{on the measured variable})} = \frac{MTBF_{Measured}}{MTBF_{Measured} + MTTR_{Measured}(F)}$$

where F is the F-statistic for a given risk at (2 x number of failures), (2 x number of repairs/fixes) degrees of freedom.

Using this formula with an assumed measured MTBF of 100 hours, a measured MDT of one hour, and 10 failures and repairs/fixes, at a 10% risk, the measured availability and the LCL on the measured operational availability are:

$$A_o = \frac{MTBF}{MTBF + MDT} = \frac{100}{100 + 1} = 0.9901$$

F for $\alpha = 0.1$ and $\nu_1 = \nu_2 = 20$ is 1.7938. Therefore, $LCL = \frac{100}{100 + 1(1.7938)} = 0.9824$

Now, consider the equation for Ai. If a product never failed, the MTBF would be infinite and Ai would be 100%. Or, if it took no time to repair/fix the product, MTTR would be zero and again the availability would be 100%.

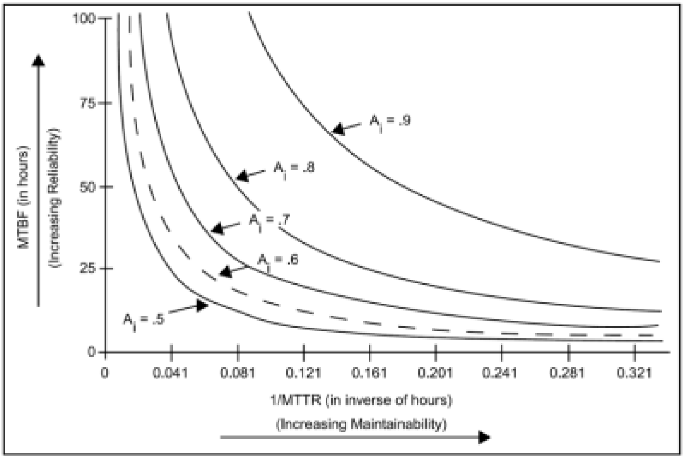


Figure 1.4-1. Different Combinations of MTBF and MTTR Yield the Same Inherent Availability

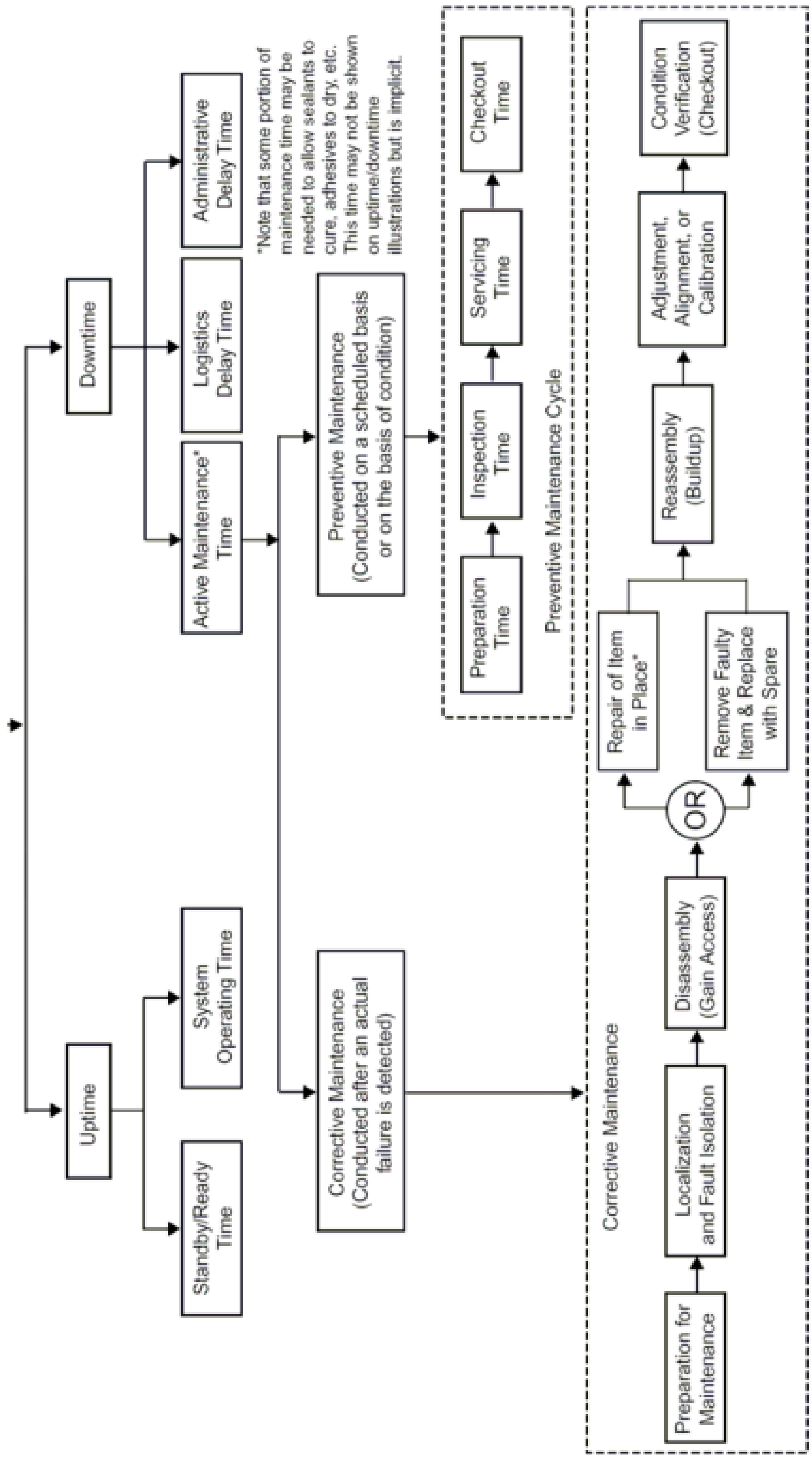


Figure 1.4-2: Composite View of Uptime/Downtime Factors

Measure	Equation	Description
Inherent Availability	$A_i = \frac{MTBF}{MTBF + MTTR} * 100\%$	• Where MTBF is the mean time between failure and MTTR is the mean time to repair (corrective only) • Reflects the percent of time a product would be available if no delays due to maintenance, supply, etc. (i.e., not design-related) were encountered
Achieved Availability	$A_a = \frac{MTBM}{MTBM + MTTR_{Active}} * 100\%$	• Where MTBM is the mean time between maintenance (preventive and corrective) and $MTTR_{Active}$ is the mean time to accomplish preventive and corrective maintenance tasks • Similar to A_i except that preventive and corrective maintenance are included
Operational Availability	$A_o = \frac{MTBM}{MTBM + MDT} * 100\%$	• Where MTBM is the mean time between maintenance (preventive and corrective) and MDT is the mean downtime, which includes $MTTR_{Active}$ and all other time involved with downtime, such as delays • Similar to inherent availability but includes the effects of maintenance delays and other non-design factors. • A_o reflects the totality of the inherent design of the product, the availability of maintenance personnel and spares, maintenance policy and concepts, and other non-design factors, whereas A_i reflects only the inherent design.
Uptime Ratio	$A = \frac{Uptime}{Uptime + Downtime} * 100\%$	• Uptime is the time that the product is in the customer's possession and works; downtime is the total number of hours that the product is not operable/usable • Uptime Ratio is time-dependent; the time period over which the measurement is made must be known

Table 1.4-1. Quantitative Measures of Availability

Now, consider the equation for Ai. If a product never failed, the MTBF would be infinite and Ai would be 100%. Or, if it took no time to repair/fix the product, MTTR would be zero and again the availability would be 100%.

As shown in Figure 1.4-1, a given level of availability can be achieved with different values of R&M. As reliability decreases, better maintainability is needed to achieve the same availability and vice versa. Table 1.4-2 illustrates the impact that reliability (as one element of uptime) and maintainability (as one element of downtime) can have an operational availability. The table presents R&M factors that should be considered for specific parameters having an effect on Ao, and, therefore, provides the user with alternatives to obtain greater designed-in operational availability, or solutions for unacceptable operational availability, in the customer's field environment.

Operational Readiness. Closely related to the concept of operational availability but broader in scope is operational readiness. Operational readiness is defined as the ability of a military unit to respond to its operational plans upon receipt of an operations order. It is, therefore, a function not only of the product availability, but also of assigned numbers of operating and maintenance personnel, the supply, the adequacy of training, and so forth.

Although operational readiness has traditionally been a military term, it is equally applicable in the commercial world. For example, a manufacturer may have designed and is capable of making very reliable, maintainable products. What if he has a poor distribution and transportation system or does not provide the service or stock the parts needed by customers to effectively use the product? Then, the readiness of this manufacturer to go to market with the product is low.

The concepts of availability and operational readiness are obviously related. Important to note, however, is that while the inherent design characteristics of a product totally determine inherent availability, other factors influence operational availability and operational readiness. The maintainability engineer directly influences

Reliability Effect	Maintainability Effect	Impact on Operational Availability	R&M Considerations
Increase	No Change	Increase	Uptime can increase due to: • Improved design reliability (hardware and software) • More efficient screening tests at product manufacturer • Reduction in the number of induced failures • Reduction in the number of incidents where an apparent failure cannot be verified • Increased time between preventive maintenance actions
Decrease	No Change	Decrease	Uptime can decrease due to: • Design modifications having negative impact on reliability • Reduced efficiency of screening tests at product manufacturer • An increase in the number of maintenance-induced failures • An increase in the number of unverified failures • Shorter time between preventive maintenance actions
No change	Increase	Decrease	Downtime can increase due to: • Use of lower-skilled repair personnel • Increase in delays due to paperwork or unavailability of repair parts • Reduced efficiency in detecting and isolating failures during repair/fix • Improper correlation between product performance limits and test equipment measurement limits • induced failure caused by mishandling of the product during repair/fix
No change	Decrease	Increase	Downtime can decrease due to: • Increased training and/or learning by repair personnel • Readily available repair parts and reduction of paperwork • Increased efficiency in correctly verifying and isolating failures • Proper handling of product during repair/fix • Improved correlation between product performance limits and test equipment measurement limits

Table 1.4-2: Impact of R&M on Operational Availability

the design of the product. But, together with the reliability engineer, the maintainability engineer also can affect other factors by providing logistics planners with the information needed to identify required personnel, spares, and other resources. This information includes the identification of maintenance tasks, repair/fix procedures, and needed support equipment.

For More Information:

1. "Lower Confidence Limits and a Test of Hypotheses for System Availability," M. Thompson, IEEE Transactions on Reliability, R-15, No. 1, May 1966, pp. 32-36.

2. MIL-HDBK-338, "Electronic Reliability Design Handbook," 1984.

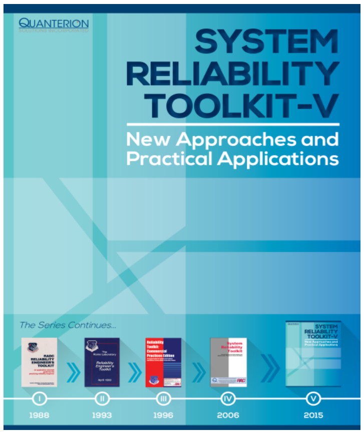
The next edition in the Lessons in Reliability series will cover Return on Investment (ROI) for reliability engineering.

Interested to learn about a particular reliability engineering topic? Let us know!

Email Qinfo@Quanterion.com with your feedback or questions.

This tech brief is the second article of a new, monthly series from Quanterion Solutions' System Reliability Toolkit-V.

The next article in the series is 1.5.2: Reliability Return on Investment (ROI).



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