Mean Time Between Failure (MTBF) And Availability – A Primer

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Technical Paper

This paper provides an overview of Mean Time Between Failure (MTBF) and Availability as they relate to electronic products such as RAID controllers and RAID subsystems. There are many misconceptions about MTBF, the importance of MTBF, and the relevance of MTBF to Availability that this paper will clarify.

Mean Time Between Failure

Mean Time Between Failure is the mean (or average) time expected between failures of a given device and is normally measured in hours. It is a statistical value meant to be applied to a large sample over a long period of time. MTBF calculations can be used to predict behaviors of very large, or entire populations, not the behavior from a particular site or smaller subset of the population. Although MTBF also serves a valuable role as a measurement tool in assessing the empirical reliability of a product, for purposes of this paper, MTBF will be explored as a predicative tool, not as a measurement tool.

Ideally, MTBF should be used only in reference to repairable items, while MTTF (Mean Time To a Failure) should be used for non-repairable items. In practice, however, MTBF is commonly used for both repairable and non-repairable items.

With electronic products, such as RAID controllers or disk drives, it is an industry assumption that the parts have constant failure rates during the useful operating life period. For constant failure rate systems, MTBF is the inverse of the Failure Rate (FR), or MTBF = 1/FR. The detailed calculations of Failure Rate, MTBF, and probability-of-failure are not only complex, but a science unto itself. However, most people who use MTBF values normally don't calculate them, but only need to understand the values so they can be used for analytical purposes.

It is not unusual for a hard drive manufacturer to advertise an MTBF of 1,000,000 hours for a modern SCSI or Fibre Channel disk drive. 1,000,000 hours equates to over 114 years. But what does this mean? MTBF is a statistical value, quantified in hours. It is neither a guarantee nor a prediction of how long any specific disk drive will last before failing. It is, however, a critical element in determining the probability-of-failure of a specific disk drive. Probability is a ratio, normally quantified as a percentage. Therefore, the question is not how long will this specific drive last, for that is unknown, but instead, what are the chances this drive will last a particular (T) number of hours.

To determine the probability a device will perform without failure over a specific period of time, a mathematical formula has been created. In mathematics, certain numbers find their way into many different uses. The most famous would be π (pi). Although one might not remember, most learned in high school geometry that π is the ratio of a circle's circumference to its diameter and has the approximate value of 3.14. Another number represented by the symbol ***e***, is used throughout mathematics in connection with natural logarithms. It has found many uses, especially in the exponential world of statistics and probabilities. ***e*** has an approximate value of 2.718. With that said, the probability a device will perform without failure over a specific period of time is determined by finding ***e*** to the power of the negative value of the period of time divided by the MTBF. In other words, $R(T) = e^{(-T/MTBF)}$.

Example: Given the MTBF for a disk drive is 1,000,000 hours, what is the probability the disk will operate without failure for five years? To answer this question, divide five years, 43,800 hours, by the MTBF (43,800/1,000,000 = .0438). Then find the value of ***e*** raised to the power of the negative value of that number ($e^{-.0438} = .9571$). Since probability is a percentage, there is a 95.71% probability that the disk drive will not fail in a five-year period. Hint: MS Excel™ has a standard EXP function that makes this calculation easy.

If the timeframes in the example above are changed, the probability of no failure in only half the time, 2 ½ years, becomes 97.83%, while 10 years is 91.61%. It is now easier to see that these values are not linear, but exponential, and that when the amount of time is changed, it will have an exponential effect on the probability.

An interesting element of MTBF is based in a common misunderstanding of the word "mean." If a product has an MTBF of 43,800 hours (five years), what percentage would one expect to be operational after 43,800 hours? Intuition (misled by the statistical word mean) suggests the answer is 50%, i.e., that after five years there would be an equal chance of the product failing as not failing. In reality, the probability of the product being operational is much lower. The answer is only 36.79%. This is due to the failure rate being based on the exponential distribution.

Why do manufacturers spend so much money on these extremely high MTBFs, especially when the products will never be in use that long? The answer is in the numbers, more specifically, in the way that combining items together result in overall MTBF.

In today's data-intensive information-age world, users no longer have just one disk drive, they have many, perhaps even hundreds in large installations. How is the MTBF for multiple products calculated? Once the Failure Rate (inverse of MTBF) is determined, MTBF for multiple products (or components) is easily calculated as the inverse of the sum of each component's failure rate.

$$MTBF = \frac{1}{FR_1 + FR_2 + FR_3 + \ldots FR_n}$$

FR is the failure rate of each component of the system up to n, all components.

The MTBF of a system and the decreased reliability of having multiple components are best illustrated by example. Using the same 1,000,000-hour MTBF disk drive, calculate the MTBF of a system using 112 disk drives, a number not uncommon for a customer site today. The MTBF of the system (112 disk drives) drops to 8,929 hours, or just over one year. Losing a 73 GB disk drive, even once a year, is probably not acceptable for most applications, thus the concept of RAID, but that's a different paper!

Now, consider an even larger site with 448 disk drives installed. Again, not uncommon for larger companies. The MTBF plunges to 2,232 hours, or less than three months. How does losing four 73 GB disk drives a year affect an operation? What is likely to happen in a five-year period? These examples demonstrate that multiple components can have a very dramatic effect on overall reliability, even when the individual items themselves are very high MTBF. That is why manufacturers must drive toward higher and higher individual MTBFs, so that overall reliability is acceptable when they are used together in numbers.

Failure Rate Calculation Models

There are two commonly used failure rate models used for performing reliability predictions on electronics. The names are MIL-HDBK-217 and Bellcore. Both are accepted standards, developed over several years. Both include mathematical equations for determining the failure rate (and in turn, the MTBF) of various components (such as integrated circuits, transistors, diodes, resistors, and capacitors).

The MIL-HDBK-217, also known as the Military Handbook for "Reliability Prediction of Electronic Equipment", is published by the Department of Defense, based on work done by the Reliability Analysis Center and Rome Laboratory at Griffiss AFB, NY. The latest version of MIL-HDBK-217 is MIL-HDBK-217F, Notice 2 (217F-2).

The non-military alternative to MIL-HDBK-217 is Bellcore. The Bellcore reliability prediction model was originally developed by AT&T Bell Labs. Bell Labs modified the equations from MIL-HDBK-217 to better represent what their equipment was experiencing in the field. The most recent revision of the Bellcore Reliability Prediction Procedure, TR-332, is Issue 6.

While the main concepts between MIL-HDBK-217 and Bellcore are similar, MIL-HDBK-217 is targeted for military applications, and tends to be somewhat pessimistic when used for commercial quality products. Bellcore adds the ability to take into account burn-in, field, and laboratory testing. These added abilities have made the Bellcore standard very popular with commercial organizations. And even though MIL-HDBK-217 is widely used by both commercial and military companies, many companies making products such as computers, telecommunications systems, medical systems, and power supplies, are choosing to use the Bellcore handbook for their reliability predictions, reporting that their predicted MTBF is consistent with their actual field experience. Because of this, the Bellcore model should be the expected model when predicting MTBF for most commercial applications.

Redundancy

A common strategy for increasing the MTBF of a system is to add redundant components in parallel. Industry standards have determined that redundant components increase the MTBF by 50%. Component redundancy is the definition of RAID, and the value of RAID can be justified with the simplest of examples. If a storage system employed disk mirroring, or RAID 1 and each disk drive had an MTBF of 1,000,000 hours, then disk drives in a RAID 1 redundant configuration would have an MTBF of 1,500,000 hours. Such is also common strategy for power supplies, fans, controllers, and many other items that have high uptime requirements.

Thus, a RAID 1 set with a disk drive failure would be expected to continue operation for an extensive period of time before a failure of the redundant disk drive would render it inoperable (MTBF of a redundant pair is 1,500,000). In practice, however, the failed disk drive would be replaced in a reasonably short period time, perhaps hours, restoring full redundancy to the system. The use of redundancy techniques improves MTBF considerably, and introduces the need for a broader concept to look at reliability. The result is the metric of Availability.

Availability

Availability is the probability that a system is operational when called upon to perform its function. It is quantified as a percentage. Availability calculations take into account both the failures and the repairs of the system, which result in “downtime” or non-operational time. Availability is calculated by dividing the MTBF by the sum of the MTBF and any additional downtime (in hours). The equation is: A = MTBF/(MTBF + Downtime). Therefore, if a device has not failed, the downtime is 0, so the availability would be 1 or 100%.

Once again, RAID systems exemplify the value of redundancy, not only for increasing MTBF but Availability as well. Consider a RAID system configured with redundant controllers, power supplies and fans. However, every component still requires the system be shut down (downtime) for replacement including firmware updating. Because of the redundancy, assume the configuration has an MTBF of 250,000 hours. It is then determined that FRU replacements and firmware updates would amount to 26 hours of downtime over the planned life of the installation. Availability = 250,000/(250,000 + 26) = .99989 or 99.989%. It’s good, but not great, and certainly not 1 (100 percent). As a point of reference, an industry measurement of goodness in Availability is referred to as “Five Nines”, or 99.999 percent. In the immediate example above, only 2.5 hours of downtime in the five year period could be incurred to meet 99.999 percent.

Availability and Hot Plug Technology

Now consider a system utilizing both redundancy and hot replacement of redundant components. Hot replacement allows for the swapping of components without having to power down the system or interrupt its performance. With redundant modules, in the event of a failure of a module, system operation continues. Should a failed component not be replaced, the system will continue to function until the remaining redundant component fails or some other non-redundant element of the system fails.

Therefore, a system with fully redundant, hot replaceable components essential to operation, that also does not require downtime for maintenance actions such as cleaning or the updating of firmware, the downtime would be zero, and the availability of the system would be 1 or 100%. Therefore, should any failure occur, the system would continue to perform its intended function without degradation.

It should be noted that in the example above, if the downtime is reduced to zero, availability changes to 1 or 100% regardless of the MTBF.

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Summary

Reliability measurements, like MTBF and Availability can be useful metrics for evaluating products and configurations. Unfortunately, some companies have chosen to exploit the complexities of MTBF and Availability to make product claims of reliability that are unsubstantiated. When using MTBF and Availability data to make product choices and decisions, lots of questions should be asked. One should never take a published value, especially very favorable ones, at face value. Here are some questions to ponder:

1. Is the quoted MTBF number predictive or measured (empirical)?
2. If the quoted MTBF number is predictive, what methodology and assumptions were used to calculate it? Are details available?
3. What elements of the system are redundant?
4. Are all critical operating elements covered with redundancy?
5. Does the system provide for hot-replacement of all serviceable elements, including software and firmware?

The accurate answers to the questions above will be valuable in understanding the real differences in products or alternatives. Remember the following:

MTBF predicts the rate at which failures can be expected. Availability predicts the percentage of time the system can be expected to perform its' intended purpose with its' inherent MTBF. High MTBF values are inherently good, but the real measure of product usefulness is its Availability. The ideal product would never break, but if it did, redundancy would maintain the operation. Although the ideal doesn't exist, the next best thing does. Products with high MTBFs and correspondingly low failure rates, coupled with high availability through redundancy ensure every element of the solution is oriented toward continuous access.