PREVENTIVE MAINTENANCE ANALYTICS

Kishan Jainandunsing, PhD
Senzo Labs

Abstract

Operations and maintenance personnel are commonly interested in measuring MTBF, MTBR, MTBA, MDT and MUT for machines and parts they are responsible for. These concepts play an important role in preventive maintenance of machines. And although they are very familiar concepts to operations and maintenance personnel, it is worthwhile to revisit the mathematics behind them and the implications when effectively or ineffectively used.

Introduction

Each of these statistical quantities provides crucial information for scheduling maintenance preventively. Moreover, they are crucial key performance indicators (KPIs) for a machine or part, regardless of industry; i.e., machines in a manufacturing workflow, POS terminals in a supermarket, bedside monitoring equipment in a hospital ward, static and moving parts in jet engines, street lamps in a city, etc.

The stochastic variables of the probability distributions underlying these KPIs are by no means time-invariant, but may tend to change over time. In general the change can be divided in two periods of the lifecycle of the machine or part. In the first period the variables are changing as more data becomes available, causing the KPIs to evolve. In the second period the variables remain constant, causing the KPIs to settle around specific values and vary only within fixed ranges around these values.

Definitions

MTBF stands for Mean-Time-Between-Failures, i.e., the average time between failures. In mathematical form MTBF is expressed as a time-dependent function as follows:

$$MTBF(t) = \frac{\sum_{t_0}^{t}(start\ of\ failure\ time - start\ of\ up\ time)}{\sum_{t_0}^{t} failure}$$

MTBR stands for Mean-Time-Between-Repairs, i.e., the average time between repairs. In mathematical form MTBR is expressed as a time-dependent function as follows:

$$MTBR(t) = \frac{\sum_{t_0}^{t}(start\ of\ repair\ time - start\ of\ up\ time)}{\sum_{t_0}^{t} repair}$$

MTBA stands for Mean-Time-Between-Assists, i.e., the average time between assists. In mathematical form MTBA is expressed as a time-dependent function as follows:

$$MTBA(t) = \frac{\sum_{t_0}^{t}(start\ of\ assist\ time - start\ of\ up\ time)}{\sum_{t_0}^{t} assist}$$

MDT stands for Mean-Down-Time, i.e., the average down time. In mathematical form MDT is expressed as a time-dependent function as follows:

$$MDT(t) = \frac{\sum_{t_0}^{t}(start\ of\ up\ time - start\ of\ failure\ time)}{\sum_{t_0}^{t}(failure) + \sum_{t_0}^{t}(repair) + \sum_{t_0}^{t}(\ assist)}$$

$$+\frac{\sum_{t_0}^{t}(start\ of\ up\ time - start\ of\ repair\ time)}{\sum_{t_0}^{t}(failure) + \sum_{t_0}^{t}(repair) + \sum_{t_0}^{t}(\ assist)}$$

$$+\frac{\sum_{t_0}^{t}(start\ of\ up\ time - start\ of\ assist\ time)}{\sum_{t_0}^{t}(failure) + \sum_{t_0}^{t}(repair) + \sum_{t_0}^{t}(\ assist)}$$

MUT stands for Mean-Up-Time, i.e., the average up time. In mathematical form MUT is expressed as a time-dependent function as follows:

$$MUT(t) = \frac{\sum_{t_0}^{t}(start\ of\ failure\ time - start\ of\ up\ time)}{\sum_{t_0}^{t}(up)}$$

$$+\frac{\sum_{t_0}^{t}(start\ of\ repair\ time - start\ of\ up\ time)}{\sum_{t_0}^{t}(up)}$$

$$+\frac{\sum_{t_0}^{t}(start\ of\ assist\ time - start\ of\ up\ time)}{\sum_{t_0}^{t}(up)}$$

In the above expressions t_0 is the point in time measured from the time the machine is first turned on for measurement of the KPIs.

MTBF

A typical plot for the MTBF time-dependent function is shown in Figure 1, for the case where the intervals between failures occur randomly.

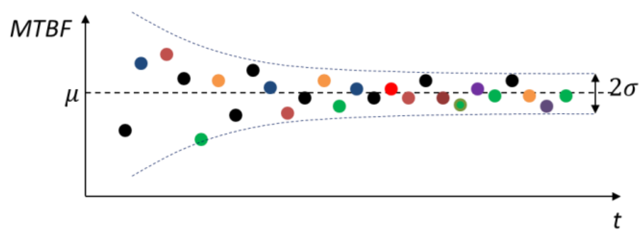

Figure 1: MTBF as a function of time

According to the Central Limit Theorem with each new data point the MTBF's probability distribution will more closely resemble a normal or Gaussian distribution $\aleph(\mu, \sigma^2)$ with the stochastic variables μ and σ^2 for the mean and variance, respectively. See Figure 2.

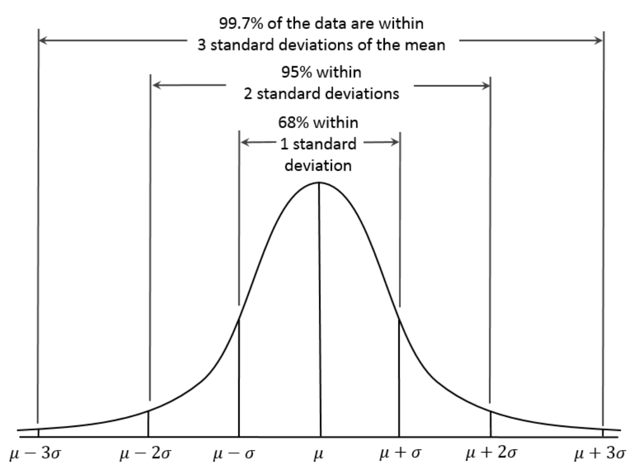

Figure 2: Normal distribution

The mathematical expression for the normal distribution is given by:

$$f(x|\mu,\sigma^2) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\frac{(x-\mu)^2}{\sigma^2}}$$

The implication of Figure 1 is that MTBF should be calculated constantly over large enough periods of time in order to arrive at the true MTBF of a machine or type of machine. An equivalent method to determine the MTBF of a machine is to have access to a relatively large number of the specimens of same type of machine (or part), as is common for a large manufacturer, which may have 100 specimens of machine type A, either in a single location or spread out geographically across the country or across the globe. In this case $MTBF(t)$ is calculated by having all machines start at the same time, record the failure time for each machine, followed by applying the expression for $MTBF(t)$ on this data dataset as if it represents a single specimen.

TIP: Once the MTBF has been established, maintenance of any specimen of the same type of machine or part can be scheduled deterministically.

The normal distribution plot in Figure 2 reveals how continuous calculation of the MTBF can be used to spot trends in a worsening condition of the machine or part:

- The mean of the distribution starts shifting towards the left, i.e., failures of the machine or part trend towards more frequent occurrences.
- The standard deviation tends to increase, i.e., the operation of the machine or part becomes less predictable.
- A combination of these two phenomena.

The above means that one cannot assume that the stochastic variables of the underlying probability distribution are time-invariant.

Tip: Monitor trends in mean and standard deviation of the MTBF's probability density function in order to predict when to schedule repairs or part replacements**.**

MTBR

The above can be used to predict when it's time to conduct a repair on the machine or to replace a part. I.e., being able to compute MTBR form this data. The same method of large number of specimens of the same type of machine or part can be applied in this case as in the MTBF case. The Central Limit Theorem applies in this case as well.

TIP: Once the MTBR has been established, repair of any specimen of the same type of machine can be scheduled deterministically.

Similar to the MTBF case, the mean and standard deviation of the MTBR probability density function can move over time. However, the meaning is different in the MTBR case:

- Shifting of the mean towards the left. This may be due to a lower quality part or the repair quality assurance standard being too loose.
- Shifting of the mean towards the right. This may be due to a higher quality part or a change towards a stricter repair quality assurance standard.
- Increase of the standard deviation. This may be due to inconsistent replacement part quality or inconsistent adherence to the repair quality assurance standard.
- Decrease of the standard deviation. This may be due to improved consistency in adherence to the repair quality assurance standard.

TIP: Monitor trends in mean and standard deviation of the MTBR's probability density function in order to adjust part and repair quality assurance standards and training.

MTBA

The MTBA probability density function is not guaranteed to be a normal distribution, since assists may be caused by events that are not failures in nature.

An interesting case is where the MTBA exhibits a Poisson distribution. A Poisson distribution is an appropriate model if the following assumptions are true:

- An event occurs k times in an interval, where k is an integer value.
- Event occurrences are independent of each other.
- The rate at which the events occur is the same for all intervals.
- Events cannot occur at the same instant.

See Figure 3 for examples of Poisson distributions for different values of λ which is the expected number of occurrences. In case of the yellow plot the probability of one occurrence ($k = 1$) per interval is the highest. In case of the purple plot the probability of 4 occurrences ($k = 4$) per interval is the highest. And in case of the blue plot the probability of 10 occurrences ($k = 10$) per interval is the highest.

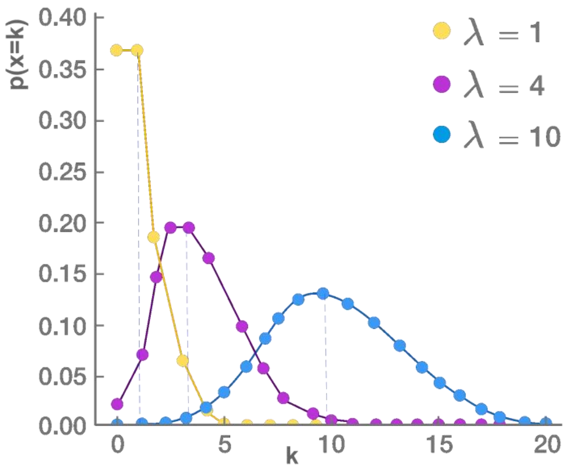

Figure 3: Poisson distributions for different expected number of occurrences

An example of a Poisson distribution is the loading of a reel of resistors of a particular value in a PCB assembly pick-n-place machine for manufacturing of an electronic device in high volume. If the machine operates at a constant rate and an empty reel is swapped out in a fixed time interval, then the rate of empty reel swap-out occurrences is expected to be constant and independent of the intervals.

Tip: Monitoring how the expected number of occurrences λ or the rate k of occurrences, changes in the Poisson distribution of a process is an indication of a random or systematic problem.

MDT and MUT

Since the MDT and MUT are composites of MTBF, MTBR and MTBA, their probability density functions are rather complex than simple. These KPIs are therefore mostly useful in spotting overall trends, but rely on looking at the MTBF, MTBR and MTBA to drill down to the probable cause or causes of a trend.

Conclusions

MTBF, MTBR, MTBA, MDT and MUT are very useful statistical quantities and KPIs in the operation of machinery. These are valuable tools and if applied correctly can improve overall productivity and quality significantly.