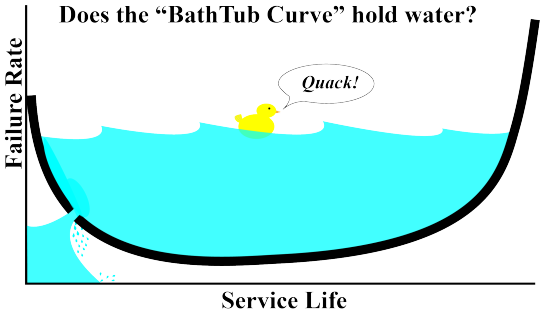
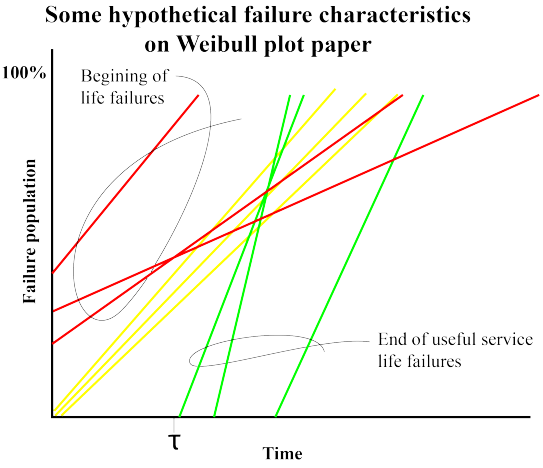
Thoughts on the Bathtub Curve

A friend once told me "all failures are due to wearout" (except something like blunt force trauma). After hearing him say it, I gave it some thought; particularly the implications of this revolutionary (well, to some maybe) statement that we throw out the first third of well-known and pervasively referenced "bathtub curve"!



Depiction of a hypothetical bathtub curve with the three failure rate characteristics, DFR, time-independent failure rate, and IFR. Only equipment exhibiting IFR can be managed with preventive maintenance policies.

It seems there can not be DFR[1] if all failures are wearout. ***BUT DFR is observed when equipment data are collected*** so what is going on? DFR is simply the result of "mixed" failure modes, combined with effective root cause analysis and followed up with effective maintenance policies. Failures due to manufacturing flaws, inadequate training, design inadequacies leading to early breakdown, and so forth, are eliminated by the organization interested in avoiding production losses or liability claims due to protective system breakdowns. Early breakdowns are eliminated by high-performing organizations that use cost-effective maintenance strategies. By this process, only the end of useful service life failures remain and the bulk of service life is made relatively free of corrective maintenance.[2]



While observation of DFR is good for installed equipment, it is unhelpful for maintenance planning; although it is possibly helpful in equipment purchase decisions. Eliminating early service life breakdowns is more costly than without them, and the prudent engineer is wise to avoid equipment exhibiting this characteristic. On the other hand, the manufacturer is unlikely to indicate the equipment for sale is subject to immediate breakdown. The only way practicing engineers are likely to identify DFR a priori is experience with the equipment or from reported experience from outside their organization. Practicing engineers would like to have equipment with with characteristics as shown in green in the figure to the right; equipment that only exhibits IFR[3] after a reasonably long failure-free service life. Given τ, they can effectively plan for almost failure-free operation by replacement(s) prior to expected failure at time τ.

It is interesting that (primarily) organizations with effective equipment management strategies would observe DFR (assuming no a priori equipment failure characteristic knowledge). And it could be said that organizations having ineffective maintenance strategies would tend to see failure characteristics similar to those shown in yellow in the figure above. In-service failures at random times put equipment in charge of the maintenance program rather than the other way around. In such organizations, costs rise due to maintenance staffing levels needed to support emergent repairs and for expediting commodity deliveries. CBM[4], a close second-cousin to age-based planned maintenance, is implied by realizing "green characteristic" equipment performance in the figure above. CBM is effective if there is sufficient lead time before failure for maintenance to schedule parts and labor on a non-expedited basis. In this case, CBM would again produce a bathtub curve characteristic assuming root cause is addressed effectively.

[1] Decreasing Failure Rate

[2] More formal discussion is in Klutke, G. A., P. C. Kiessler, and M. A. Wortman (2003, March). *A critical look at the bathtub curve*. IEEE Transactions on Reliability 52(1), 125Ð 129.

[3] Increasing Failure Rate

[4] Condition-Based Maintenance