Reliability Testing

Sample size and Test duration

- Test 1 sample
  - Low cost, low confidence
- Test 100 samples
  - High cost, high confidence
- Test 5 samples in series
  - Minimum equipment and personnel, production delayed
- Test 5 samples simultaneously
  - Maximum equipment and personnel, Production expedited

Problem:

- A system has 10 components in series. A reliability of 0.99 for a period of 1000hrs is required. What time will be required for testing this system?
- $0.99=e^{-\lambda*1000}$
- λ=1.005e-5/hr
- MTBF = 99491hrs
- = 113 yrs

Complete Testing

- Choose a sample of n items and wait for all n to fail
- Mean Time To Failure = Accumulated Test Time / Number of Failures

$$\hat{\mu} = \frac{T_r}{n}$$

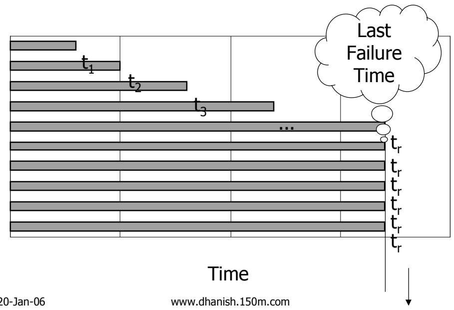
Partial Testing

- Take a large sample and test only part to failure
- Failure Terminated Test
- Time Terminated Test
- Sequential Reliability Test

Failure Terminated Test

- Tests terminated when a preassigned number of failures (r) occurs in the chosen sample (size n)
- Lot accepted if the estimated average life exceeds a preassigned value

Without replacement



Calculation:

Assuming constant failure rate

- If failed items are not replaced,

$$T_r = \sum_{i=1}^{r} t_i + (n-r)t_r \qquad \hat{\mu} = \frac{T_r}{r}$$

If failed parts are replaced with good ones,

$$T_r = nt_r \qquad \hat{\mu} = \frac{T_r}{r}$$

Confidence interval for failure terminated test

- The statistic $2T_r/\mu$ has a chi-squared distribution with 2r degrees of freedom. Thus a two-sided $100(1-\alpha)\%$ confidence interval for the mean life is given by

$$\frac{2T_r}{\chi^2_{\alpha/2,2r}} < \mu < \frac{2T_r}{\chi^2_{1-\alpha/2,2r}}$$

Problem:

- Life testing is conducted for a sample of 15 transistors, The time to failure for each is exponentially distributed. The test is terminated after four failures, with no replacement of the failed items. The failure time (in hours) of the four transistors are 400, 480, 610, and 660. Estimate the mean life of the transistors and the failure rate. Find a 95% confidence interval for the mean life.

Solution:

- Accumulated life = (400 + 480 + 610 + 660) + (15-4)660 = 9410h
- Estimated Mean Time to Failure =
- 9410/4 = 2352.5h
- Estimated failure rate = 1/2352.5 = 0.000425/h

Solution...

$$\frac{2T_r}{\chi^2_{\alpha/2,2r}} < \mu < \frac{2T_r}{\chi^2_{1-\alpha/2,2r}}$$

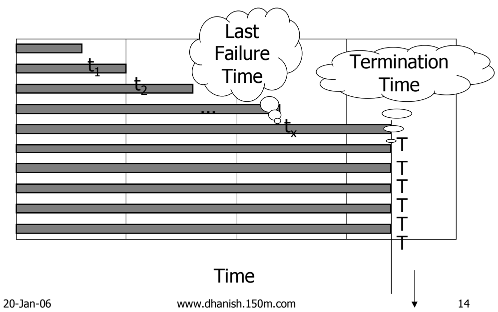
$$\frac{2(9410)}{17.53} < \mu < \frac{2(9410)}{2.18}$$

$$1073.588h < \mu < 8633.027h$$

Time-Terminated Test

- Terminated when a preassigned time T is reached
- Reject the lot if the observed number of failures exceeds a preassigned value
- Let x be the number of failures observed

Without replacement



Calculation

Assuming constant failure rate

If failed items are not replaced,

$$T_x = \sum_{i=1}^{x} t_i + (n - x)T \qquad \hat{\mu} = \frac{T_x}{x}$$

If failed parts are replaced with good ones,

$$T_x = nT \qquad \hat{\mu} = \frac{T_x}{x}$$

Confidence interval for time terminated test

- The statistic $2T_x/\mu$ has a chi-squared distribution with 2(x+1) degrees of freedom. Thus a two-sided 100(1-α)% confidence interval for the mean life is given by

$$\frac{2T_x}{\chi^2_{\alpha/2,2(x+1)}} < \mu < \frac{2T_x}{\chi^2_{1-\alpha/2,2(x+1)}}$$

Problem:

- A sample of 12 electronic components is tested for 1000h, with no replacement of failed components. The time to failure is exponentially distributed. Three components failed within the prescribed test time, the failure times being 650, 680, and 720h. Estimate the mean time to failure and the failure rate. Find a 90% confidence interval for the mean time to failure

Solution:

- Accumulated life = (650+680+720) + (12-3)1000 = 11050h
- Estimated MTTF = 11050/3 = 3683.33h
- Estimated failure rate = 0.00027/h

$$\frac{2(11050)}{15.51} < \mu < \frac{2(11050)}{2.73}$$

$$1424.887h < \mu < 8095.238h$$

Problem:

- Twenty small generators were put under test for a period of 1500h. One generator failed at 400h and was replaced by a new one. A second failed at 500h and was also replaced. A third and fourth failed at 550h and 600h, respectively, and were removed from testing, but were not replaced.

Contd...

- A fifth malfunctioned at 700h, was immediately repaired, and was put back into test. A sixth malfunctioned at 800h, but was kept in test. Later analysis showed this failure was due to governor malfunction. Estimate the failure rate of the generators. What assumptions did you make?

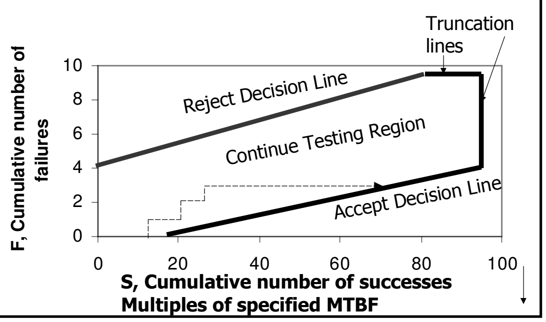
Solution:

- T_x=550+600+18*(1500)=28150
- x=5
- μ = 5630hr
- λ =0.0017762/hr = 1.56/yr

Sequential Testing

- Combination of Failure terminated and Time terminated

Sequential Testing Procedure



Sequential Testing

- R_d = Desired or specified reliability
- R_m = Minimum acceptable reliability
- α = Producer's risk
- β = Consumer's risk

$$\text{Accept}: F \ln\frac{1-R_m}{1-R_d} + S\ln\frac{R_m}{R_d} = \ln\frac{1-\beta}{\alpha}$$

$$\text{Reject}: F \ln\frac{1-R_m}{1-R_d} + S\ln\frac{R_m}{R_d} = \ln\frac{\beta}{1-\alpha}$$

Partial Test to Failure

- Better: Choose a sample of n items, n>r and terminate the test after r of these have failed; remaining is m=(n-r)

In general

t_i is the time to failure of the ith item

$t_1 \le t_2 \le \cdots \le t_i \le \cdots \le t_n$

Accumulated Test Time $T_r = \sum_{i=1}^{n} t_i + \sum_{j=1}^{m} t_j$

$$\hat{\mu} = \frac{T_r}{n}$$

If all items fail, then $\hat{\mu}$ is the arithmetic mean of failure times

If the test is terminated after a specified number of hours, t^* when some have failed and others have not, ie $t^* > t_r$

$$\hat{\mu} = \frac{\sum_{i=1}^{n} t_i + (n-r)t^*}{r}$$

If some items are withdrawn before failure (censored), but failures are replaced and censored items not replaced

$$\hat{\mu} = \frac{\sum_{j=1}^{c} t_j + (n-c)t^*}{r}$$

If neither failures nor censored items are replaced

$$\hat{\mu} = \frac{\sum_{i=1}^{r} t_r + \sum_{j=1}^{c} t_j + (n-r-c)t^*}{r}$$

Accelerated Testing

- Sudden-death testing
- Magnifying the load
- Highly accelerated testing

Sudden death testing

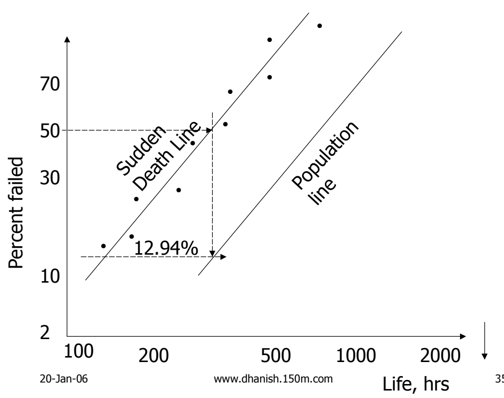
- Suitable for a large number of inexpensive units
- Suppose fifty specimens are available for testing.
- The fifty are randomly divided into ten sets of five items each.
- Each set of five is run simultaneously until one item in the set fails.
- After failure, the rest is removed from test.
- Continue till all ten sets are tested

Analysis:

- Each number represents separate estimates of the life of the weakest 12.94% of population
- Plot the ten numbers on Weibull paper using the rank column for a sample of ten
- A straight line is obtained which describes the distribution of the 12.94% life

Analysis: ...

- As a best estimate of the 12.94% life point, the median 50% life is taken.
- This is located at the 50 % level of the straight line obtained
- This is just as reliable as one obtained from testing all 50 specimens



Magnified Loading

- Reduces testing time, and no of items required
- Problem is correlation
- Stress-Life models
  - Exponential Model, Power Model, Exponential Power model, Arrhenius model, Eyring linear & non-linear models

Fatigue

- N_1 is the failure life in the laboratory at a given stress intensity factor, N_2 is the field life, k is between 6.5 and 7.0 for steels

$$N_2 = N_1 \left(\frac{\sigma_1}{\sigma_2} \right)^k$$

Problem:

- An electrical insulator is rated for normal use at 12kV. Prior tests of a sample have suggested this insulator will operate over 30kV and a stress-life exponent of the power model was found to be k=5.5. How long must one run an accelerated life test at 30kV to demonstrate an equivalent time to 10 per cent life (based upon voltage only) if the 10% life at 12kV is desired to be at least 25 years?

Solution

$$N_2 = 25\left(\frac{12}{30}\right)^{5.5}$$

$$N_2 = 0.16191 yr$$

$$= 1418.3 h$$

Ref: O'Connor, Patrick D., Practical Reliability Engineering Fourth Edition, 2002, John Wiley & Sons

HALT

- Highly Accelerated Life Testing
- No attempt to simulate the service environment
- No limit to type and level of stress
- Apply whatever stresses that might cause failures to occur as soon as practicable

Justification

- Causes of failures that will occur in the future are very uncertain
- The probabilities of and durations to failures are also highly uncertain
- Time spent on testing is expensive
- Finding causes of failure during development and preventing recurrence is far less expensive

Benefits

- Time compression of test programme
- Increased effectiveness
- NO reliability values can be obtained by HALT

Reliability Testing

- Difficult but a necessity