Plan for the Session

- Guest lecture by Eric Feron (1 hour)
- Quiz on Design of Dynamic Systems (15 minutes)
- Review of Reliability Improvement Case Study -- Router Bit Life (35 minutes)

Learning Objectives

- Introduce some basics of reliability engineering
- Relate reliability to robust design
- Practice some advanced construction techniques for orthogonal arrays
- Introduce analysis of ordered categorical data
- Practice interpreting data from robust design case studies

Reliability Terminology

- Reliability function $R(t)$ -- The probability that a product will continue to meet its specifications over a time interval
- Mean Time to Failure *MTTF* -- The average time *T* before a unit fails

$$MTTF = \int_0^\infty R(t)dt$$

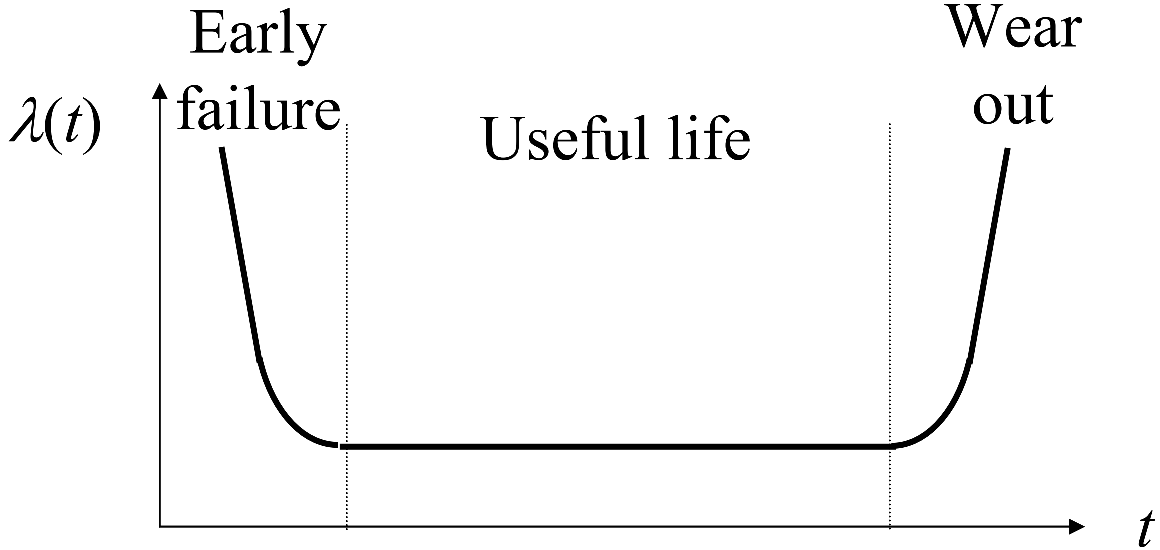
- Instantaneous failure rate $\lambda(t)$

$$\lambda(t) = \Pr(\text{System survives to } t + dt \mid \text{System survives to } t)$$

$$R(t) = e^{-\int_0^t \lambda(\xi)d\xi}$$

Typical Behavior

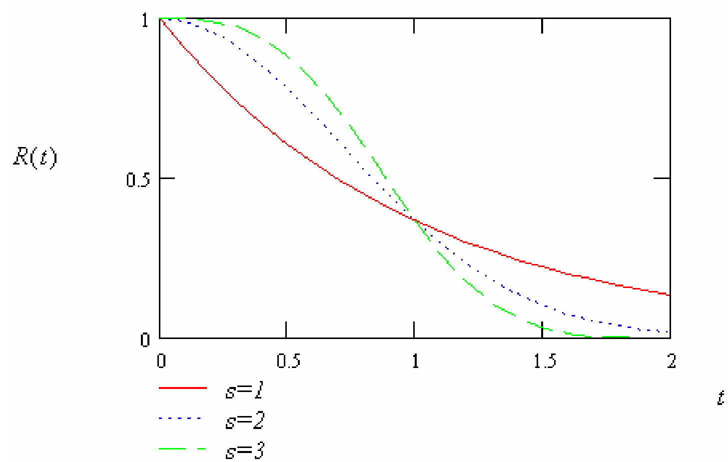
- Early failure period often removed by "burn-in"
- Wear out period sometimes avoided by retirement
- What will the reliability curve $R(t)$ look like if early failure and wear out are avoided?



Weibull Distributions

- Common in component failure probabilities (e.g., ultimate strength of a test specimen)
- Limit of the minimum of a set of independent random variables

$$R(t) = e^{-\left(\frac{t-t_o}{\eta}\right)^s}$$



System Reliability

- Components in series (system fails when *any* subsystem fails)

$$R_{SYST} = \prod_i R_i$$

- Components in parallel (system fails only when *all* subsystems fail)

$$F_{SYST} = \prod_i F_i$$

Router Bit Life Case Study

- Printed wiring boards cut to size by a routing operation
- Router bit rotated by a spindle
- Machine feeds spindle in X-Y plane

Taylor Tool Life Equation

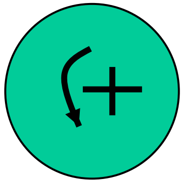
$$VT^n = C$$

- V - cutting speed
- T - time to develop a specified amount of flank wear
- C and n - experimentally determined constants for cutter material / workpiece combinations

n=0.08-0.2	High speed steel
n=0.2-0.5	Carbide

Noise factors

- Out of center rotation of spindle



- Router bit properties
- PWB material properties
- Spindle speed

Noise Factor in the Inner Array

- When can this be done?
- Why can this work?
- What are the advantages?

Quality Characteristic

- We want to maximize useful life of the bit
- Phadke chose to measure **inches cut prior to excessive dust production**
- Does this meet the guidelines for additivity?
- What other choices would you suggest?

Control Factors

- Suction (1 in Hg, 2 in Hg)
- XY feed rate (60”/min, 80”/min)
- In-feed (10”/min, 50” in/min)
- Bit type (four types)
- Suction foot (solid ring, bristle brush)
- Stacking height (3/16”, 1/4”)
- Backup slot depth (0.06”, 0.1”)
- Spindle speed (30K rpm, 40K rpm)

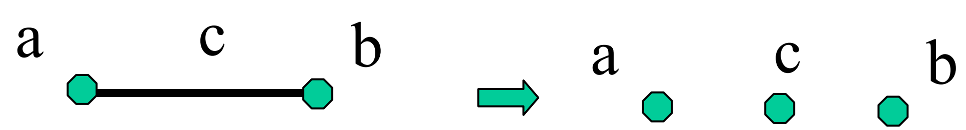
Do these meet the definition of a control factor?

Reqts of the Matrix Experiment

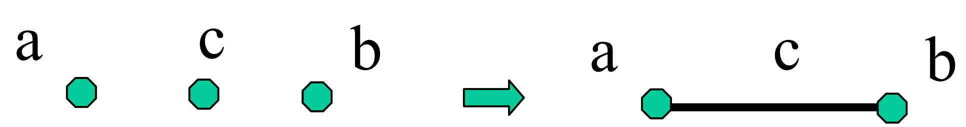
- Two 4 level factors
- Seven 2 level factors
- Interactions
  - XY feed X speed
  - In-feed X speed
  - Stack height X speed
  - XY feed X stack height
- Compute required DOF

Linear Graphs and Experimental Design

- Draw the **required** linear graph
- Compare with **standard** linear graphs
- Modify the standard linear graph to suit using modification rules
  - Breaking a line



  - Forming a line



Speed Assigned as an Outer Factor

- Guarantees that all interactions with all other factors can be computed
- Doubles the experimental effort (for a two level outer factor)

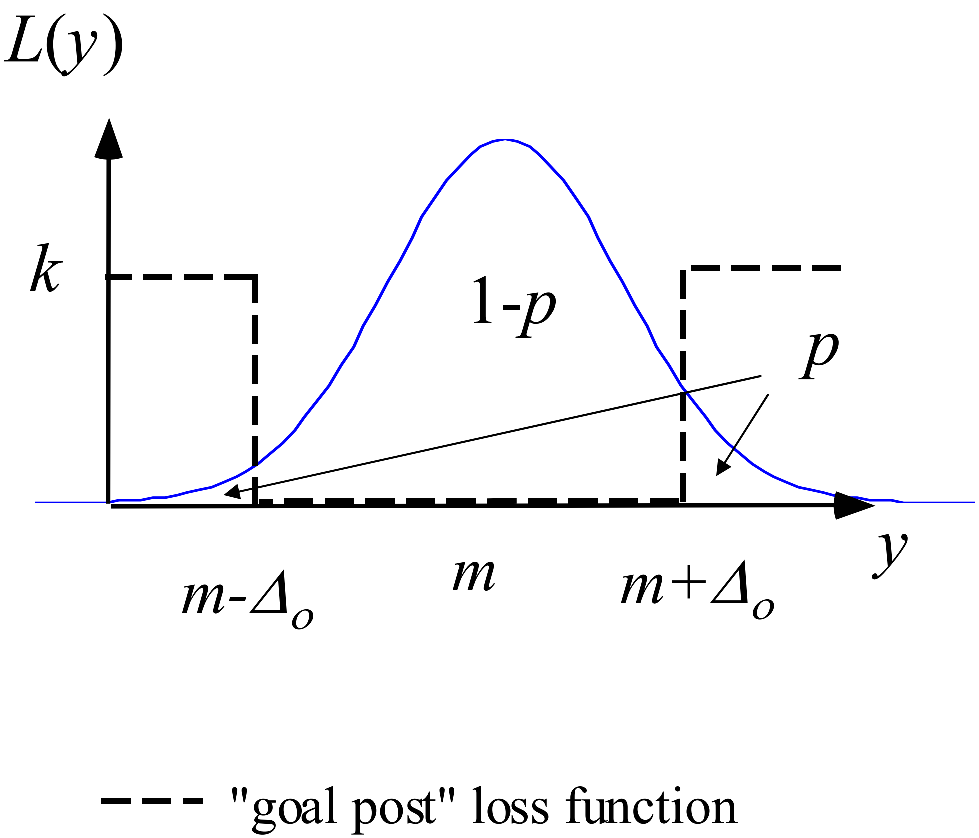
S/N for Fraction Defective

- Average quality loss in passing products

$$Q = k\frac{p}{1-p}$$

- Signal to noise

$$\eta = -10\log_{10}\left[\frac{p}{1-p}\right]$$



Ordered Categorical Data

- The response of the system is summarized by membership in discrete categories
- The categories have an unambiguous ordering
- For example, survey data often takes the form:
  - Poor
  - Fair
  - Good
  - Excellent

Router Bit Life Conclusions

- Two fold increase in bit life realized while maintaining throughput
- Robust design can be used to improve life
  - Life as larger the better
  - Probability of failure as ordered categorical
- Noise can be induced in inner array
- A control factor can be used in an outer array to study interactions

Next Steps

- Homework #8 due 8 July
- Next session Wednesday 8 July 1:05-3:55
  - Quiz on reliability and robust design
  - Mid deck active control experiment case study
- Last on-campus session 9 July 1:05-3:55 - Review session for final exam
- Each student may resubmit up to three quizzes and/or home works by Monday 13 July (grades will be averaged with the original grades)