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SYST 302: Systems Methodology and Design II #10

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Design for Maintainability

- Concepts and Definition
- Measure of Maintainability
- Maintainability in System design
- Maintainability Evaluation

What is Maintainability

- **Maintainability:** **the ability of a product to be maintained, a design characteristic dealing with the ease, accuracy, safety, and economy in the performance of maintenance functions.**
  - **The probability that an item will be restored within a given period of time**
  - **The probability that maintenance will not be required more than x times a given period of time**
  - **The probability that the maintenance cost will not exceed y dollars in a given period of time**
- **Maintenance categories:**
  - **Corrective maintenance: unscheduled maintenance to restore a system to a specified level of performance**
  - **Preventive maintenance: scheduled maintenance to retain a system at a specified level of performance**

Measures of Maintainability

- **Maintenance Elapsed-Time Factors**
  - Mean corrective maintenance time (Mc)
  - Mean preventive maintenance time (Mp)
  - Mean active maintenance time (MT = Mc + Mp)
  - Logistic delay time (LDT)
  - Administrative delay time (ADT)
  - Maintenance down time (MDT=MT+LDT+ADT)
- **Maintenance Labor-Hour Factors**
  - Maintenance labor-hours per cycle, etc.
- **Maintenance Frequency Factors**
  - Mean time between maintenance
- **Maintenance Cost Factors**
  - Maintenance cost per system operating period, etc.

Mean Corrective Maintenance Time

- Compute mean and STD given historical data
- Time includes failure detection, fault isolation, disassembly, repair, etc.

$$\overline{M}_{CT} = \frac{\sum_{i=1}^{n} M_{CT\,i}}{n} \qquad \sigma = \sqrt{\frac{\sum_{i=1}^{n} \left(M_{CT\,i} - \overline{M}_{CT}\right)^2}{n-1}}$$

- **Normal distribution**
  - simple maintenance and repair (remove and replace)
- **Exponential distribution**
  - constant repair rate (part substitution methods)
- **Log-normal distribution**
  - most maintenance tasks and repair actions (several sub tasks of unequal frequency and time duration)

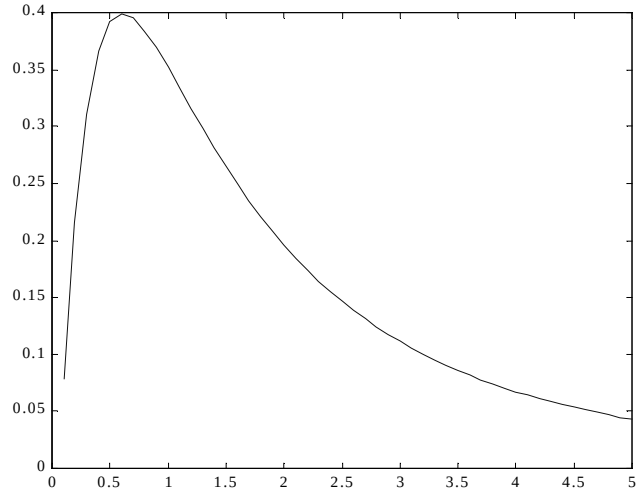
Log-Normal Distribution

If y is normally distributed with mean μ and variance σ^2, then $x = e^y$ $(y = \ln x)$ follows the lognormal distribution with density function

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{\left[-(\ln x - \mu)/2\sigma^2\right]}, x > 0$$

where $\bar{x} = e^{\mu + \sigma^2/2}$,

and $\sigma_x^2 = e^{2\mu+\sigma^2}(e^{\sigma^2} - 1)$



Mean Preventive Maintenance Time

Time includes periodic inspection, servicing, scheduled replacement of critical items, calibration, overhaul, etc.

$$\overline{M}_{pt} = \frac{\sum (ftp_i)(M_{pt_i})}{\sum ftp_i}$$

ftp_i : frequency of the ith preventive action per unit time period

M_{pt_i} : elapsed time required for the action

Ex: Auto preventive maintenance:

(1) Oil Change every 3 months, 1 hr

(2) Minor tune-up every 6 months, 2 hrs

(3) Major tune-up every 12 months, 4 hrs

$$\overline{M}_{pt} = \frac{(\frac{1}{3})(1\,hr) + (\frac{1}{6})(2\,hrs) + (\frac{1}{12})(4\,hrs)}{(\frac{1}{3}) + (\frac{1}{6}) + (\frac{1}{12})} = \frac{12}{7}\ hrs$$

$$\text{MTBM}_{\text{S}} = \frac{1}{(\frac{1}{3}) + (\frac{1}{6}) + (\frac{1}{12})} = \frac{12}{7}\ months$$

Mean Corrective Maintenance Time

Time includes failure detection, fault isolation, disassembly to access, repair, etc.

$$\overline{M}_{ct} = \frac{\sum(\lambda_i)(M_{ct\,i})}{\sum \lambda_i}$$

λ_i : failure rate of the ith item

Ex: Auto corrective maintenance:

(1) Flat tire, 1 per year, 1 hr

(2) Battery, 0.5 per year, 1 hr

(3) Starter, 0.1 per year, 2 hrs

(4) Transmission, 0.2 per year, 3 hrs

(5) Others, 2 per year, 1 hr

$$\overline{M}_{ct} = \frac{(1)(1\,hr) + (0.5)(1\,hr) + (0.1)(2\,hrs) + (0.2)(3\,hrs) + (2)(1hr)}{1 + 0.5 + 0.1 + 0.2 + 2} = \frac{4.3}{3.8}\ hrs$$

$$\text{MTBM}_{\text{U}} = \frac{1}{1 + 0.5 + 0.1 + 0.2 + 2} = \frac{1}{3.8}\ years = \frac{12}{3.8}\ months$$

Mean Active Maintenance Time

Time includes scheduled (preventive) and unscheduled (corrective) maintenance

$$\overline{M} = \frac{(\lambda)(\overline{M}_{ct}) + (fpt)(\overline{M}_{pt})}{\lambda + fpt}$$

$\lambda = 1/MTBM_U$: corrective maintenance rate

$fpt = 1/MTBM_S$: preventive maintenance rate

Ex: Auto active maintenance:

$$\overline{M} = \frac{\left(\frac{3.8}{12}\right)\left(\frac{4.3}{3.8}\right) + \left(\frac{7}{12}\right)\left(\frac{12}{7}\right)}{\frac{3.8}{12} + \frac{7}{12}} = \frac{16.3}{10.8}\ hrs$$

Mean Time between Maintenance

Average time between all maintenance actions (corrective and preventive)

$$MTBM = \frac{1}{1/MTBM_u + 1/MTBM_s}$$

$MTBM_u$: mean interval of unscheduled (corrective) maintenance

$MTBM_s$: mean interval of scheduled (preventive) maintenance

Ex: Auto mean time between maintenance:

$$MTBM = \frac{1}{\frac{3.8}{12} + \frac{7}{12}} = \frac{12}{10.8} \ months$$

What is Availability

Availability: **the probability that a system, when used under stated conditions, will operate satisfactorily at any point in time**

- **Inherent Availability (ideal condition)**

$$A_i = \frac{MTBF}{MTBF + \overline{M}_{CT}}$$

- **Achieved Availability (ideal condition)**

$$A_a = \frac{MTBM}{MTBM + \overline{M}}$$

- **Operational Availability (actual)**

$$A_o = \frac{MTBM}{MTBM + MDT}$$

Maintainability Allocation

Example: **Given inherent availability requirement of 0.9989, a MTBF of 450 hours, design Mct allocation**

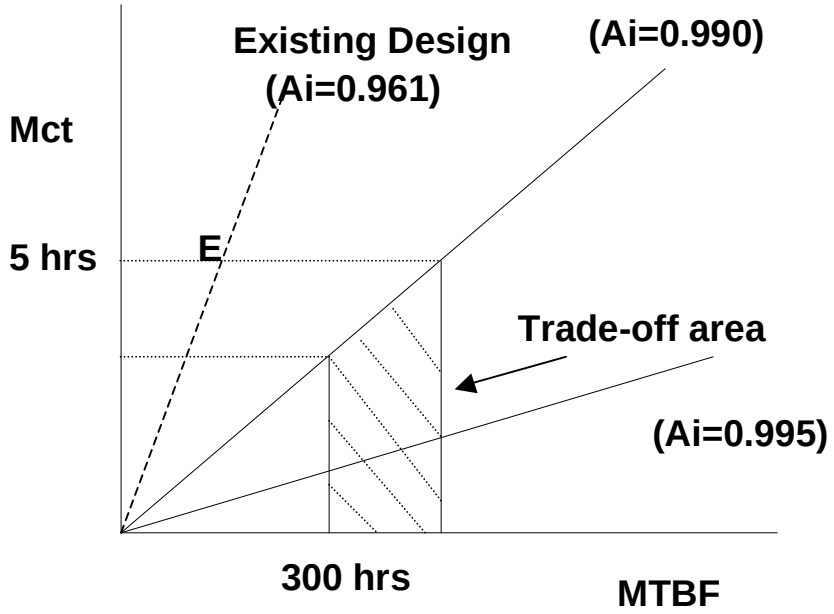
$$\text{Since } A_i = \frac{MTBF}{MTBF + \overline{M}_{ct}}$$

$$\Rightarrow \overline{M}_{ct} = \frac{MTBF(1 - A_i)}{A_i}$$

$$= \frac{450(1 - 0.9989)}{0.9989} = 0.5hr$$

Reliability-Maintainability Trade-Off Evaluation

- **Goal:** **to select the best alternative based on cost**



Conf.	A_i	$MTBF$	$\overline{M}_{CT}$
Existing	0.961	125	5.0
Alt.A	0.991	450	4.0
Alt.B	0.990	375	3.5
Alt.C	0.991	320	2.8

Choose the configuration with minimum total R&D, manufacturing, and O&M costs which satisfies the requirements of Ai>0.99, MTBF>300, and Mct<5.0