Introduction to Maintainability

- The concept of maintainability encompasses:
 - An operational measure of effectiveness
 - A characteristic of design
 - An engineering specialty that supports design
 - A cost driver
 - A planned activity in each stage of product life-cycle

Introduction (cont)

- <u>Maintainability</u> is the ability of an item to be maintained; this ability stems from the aggregate of all design features which promote serviceability.
- <u>Maintenance</u> is a series of actions of appropriate character (content, timing, quality) to restore or retain an item in an operational state.
- Contrast:
 - Reliability is time to failure, probability of no failure
 - Maintainability is time to diagnose and repair a failure or time to prevent future failure

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Maintainability is Inherently a Probabilistic Measure

- Detection, diagnosis, repair, check-out all involve uncertainty
- Human skill and learning are involved
 - Differences due to individuals
 - Differences due to experience
- Consider other definitions of maintainability:

The probability that:

- Item will be restored to operational status in T hours
- Maintenance will not be required more than X times per time period

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- Maintenance cost will not exceed \$Z per time period

Maintainability in the System Life-Cycle

- The <u>Maintainability Plan</u> is developed during conceptual design, reviewed internally and by customer, and includes:
 - Functions to be performed (p.391-393)
 - Standards/ Procedures/ models to be used
 - Schedule
 - Documents/ Reports
 - Organization, responsibilities, interfaces within your company and with customer, supplier

Maintainability in the System Life-Cycle

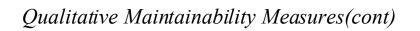
• The <u>Systems Engineering Plan</u> has a major section devoted to integration of the engineering specialties into the design process. The SE is responsible for assuring adequate participation, influence, visibility, etc. is granted to maintainability, and others.

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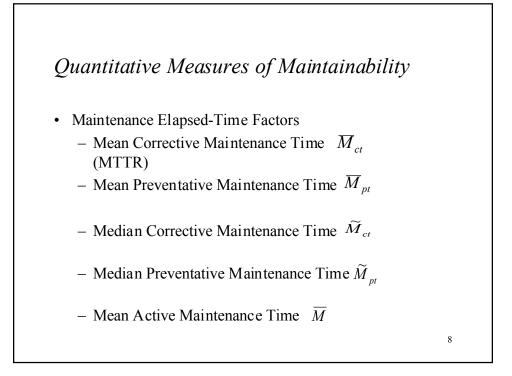
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Qualitative Maintainability Measures

- Especially important early in design when limited data exist
- Examples:
 - Skill level reduction
 - Ease of access
 - Simplicity of task
 - Identification, markings, coding
 - Standardization
 - Safety during maintenance
 - Clearly written, easy to follow instructions
 - Ease of fault isolation



- Some ways these get incorporated into design
 - Management emphasis
 - Experienced maintenance "chiefs" on each team
 - Checklists (see handout)
 - Degree to which quantitative measures/ models are sensitive to these



Quantitative Measures of Maintainability

- Maintenance Labor-Hour Factors
 - Maintenance labor-hours per operating cycle
 - Maintenance labor-hours per cycle
 - Maintenance labor-hours per month
 - Maintenance labor-hours per maintenance action
- Maintenance Frequency Factors
 - Meantime between maintenance = MTBM
 - Unscheduled (corrective) and Scheduled (preventive)
 - Meantime between replacement = MTBR

Maintainability Function

- Definition: Let T = Repair Time Random Variable. The Maintainability Function M(t) is defined by M(t) = P(T≤t)
 - Example: Suppose T is exponential with repair rate λ . Mean time to repair:

$$MTTR = \frac{1}{\lambda}$$
$$M(t) = 1 - e^{-\lambda t} = 1 - e^{\frac{-t}{MTTR}}$$

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Other Distributions Used

- Normal Simple, remove and plug in.
- Lognormal complex repair; multiplicative degradation model.
- Weibull Variety of situations...most versatile. A generalization of the exponential, which has constant failure rate. Often used for "worst link" or "first of many flaws to produce a failure."

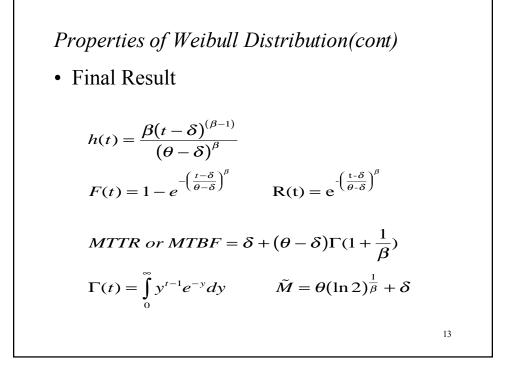
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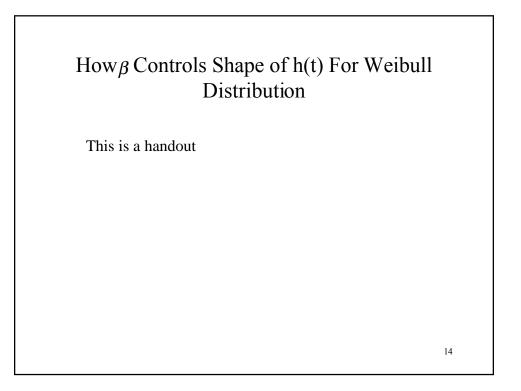
Properties of Weibull Distribution

- Invented in 1951; tried to create $h(t) = at^b, t \le 0$

Set, $H(t) = (\lambda t)^{\beta}$, β controls shape of h(t), $\beta = 1$ is exponential Then, $h(t) = \frac{dH(t)}{dt} = \beta \lambda (\lambda t)^{\beta-1}$ $F(t) = 1 - e^{-Ht} = 1 - e^{-(\lambda t)^{\beta}} = 1 - e^{-\left(\frac{t}{\theta}\right)^{\beta}}, \theta = \frac{1}{\lambda}$

Adjoin a third "shift" parameter $\delta \ge 0$, which shifts left ٠ endpoint of range of distribution: $[\delta_j + \infty]$. Require $\theta > \delta \ge 0$





Weibull Closure Property

- Recall for n exponential-life components with rates $\lambda_1, \lambda_2, ..., \lambda_n$ and a series system $\lambda_s = \sum_{i=1}^n \lambda_i$
- If a series system has:

- n independent parts, each Weibull with the same β

$$\theta_1 = \frac{1}{\lambda_1}, \theta_2 = \frac{1}{\lambda_2}, \dots, \theta_n = \frac{1}{\lambda_n}$$

The respective characteristic lives

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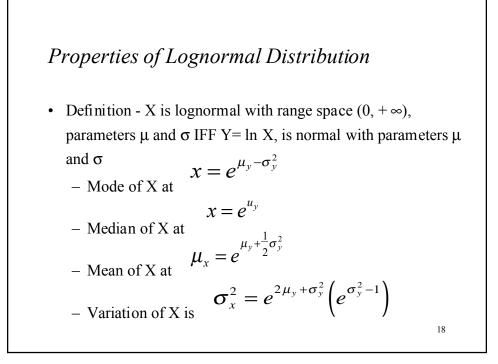
Example

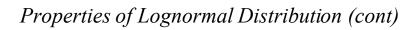
 5 Hoses in an Engine Cooling System have β=1.8, Respective θ1= 95, θ2= 110, θ3=130, θ4=130, θ5=150 months, then

$$O_s = \left(\frac{1}{95^{1.8}} + \frac{1}{110^{1.8}} + \frac{1}{130^{1.8}} + \frac{1}{150^{1.8}}\right)^{-\frac{1}{1.8}} = 48.6 \text{ months}$$

$$\tilde{R} = 48.6(\ln 2)^{\frac{1}{1.8}} = 39.6 \text{ months}$$

$$MTBF = 48.6\Gamma\left(1 + \frac{1}{1.8}\right) = 43.2$$





- Properties
- 1. If X₁ lognormal $(\mu_{y_1}, \sigma_{y_1}^2)$, X₂ lognormal $(\mu_{y_2}, \sigma_{y_2}^2)$ and X₁, X₂ independent; then W = X₁ * X₂ is lognormal with $(\mu_{y_1} + \mu_{y_2}, \sigma_{y_1}^2 + \sigma_{y_2}^2)$
- 2. If Xj, j=1,...,n are lognormal (μ_y, σ_y^2) and independent, then the geometric mean $(\prod_{j=1}^n x_j)^{\frac{1}{n}}$ is lognormal $(\mu_y, \frac{\sigma_y^2}{n})$

Example 1 pp.395-398

- Assumes normal
- Takes \overline{X} s to be μ, σ . Is this ok?
- What's wrong with equation 14.1?

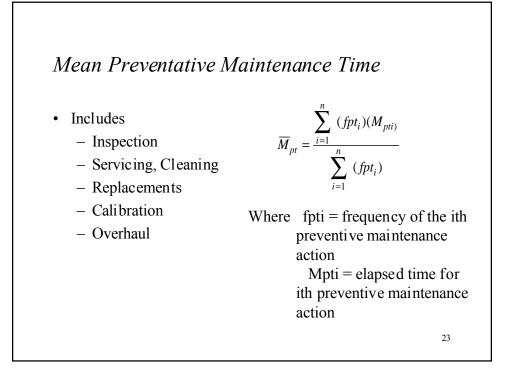
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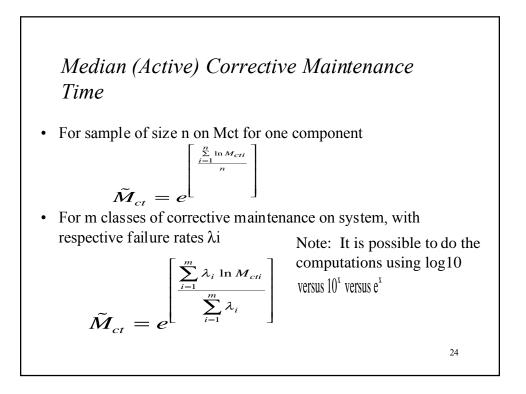
Example 2

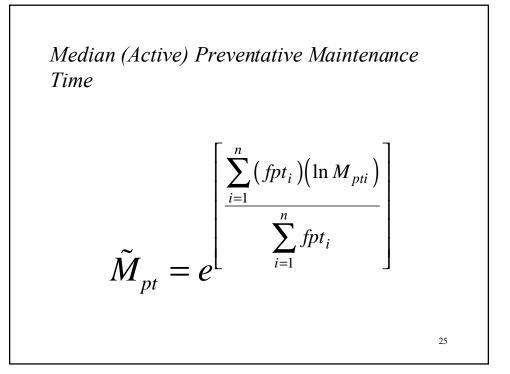
- Suppose n Components in series, each exponential with λI failure rate for component I; Let Mcti= time to repair system when ith component fails. Then $\overline{M}_{ct} = MTTR$ for system is estimated by (14.2) $\overline{M}_{ct} = \sum_{i=1}^{n} X_i M_{cti}$ Repair time/unit time Repair time per failure $\sum_{i=1}^{n} \lambda_i$ System failure/unit time
- If there are n_i of type i in the system, then use:

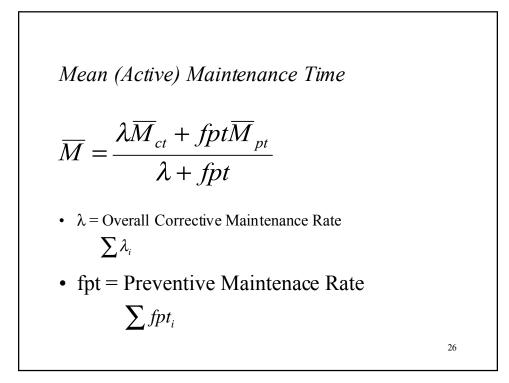
$$\overline{M}_{ct} = \frac{\sum_{i=1}^{n} n_i \lambda_i M_{cti}}{\sum_{i=1}^{n} n_i \lambda_i}$$

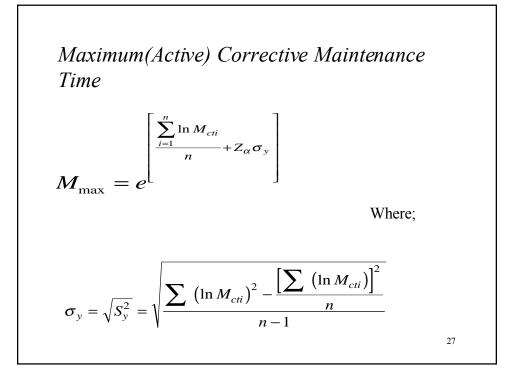
i	n _i .	$\lambda_{i} * 10^{3}$ hrs	M _{cti} (hr)	Repair Time per	10 ³ hr
Assemblies	Component	S		$n_{i}\lambda_{i}M_{cti}$	
1	4	10	.1	4.0	
2	6	5	.2	6.0	
3	2	8	1.0	16.0	
4	1	15	.8	7.5	
5	5	12	.5	30.5	
		161		63.5	

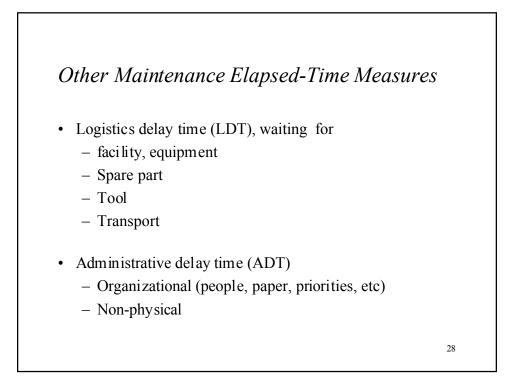


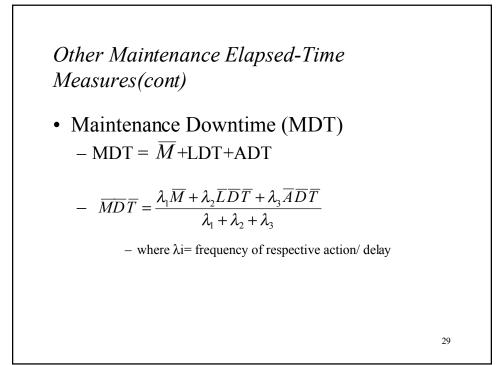


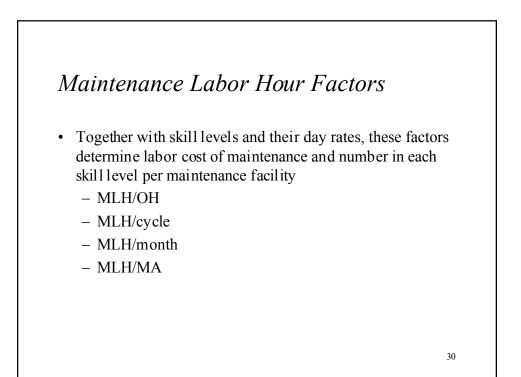


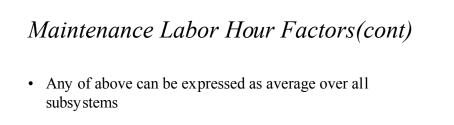












- Can apply to corrective, preventive, pr total active
- Can apply to total maintenance downtime
- Conceptually, want to select skill levels and maintenance difficulty to minimize maintenance costs

Maintenance Frequency Factors • Meantime Between Maintenance (MTBM) $MTBM = \frac{1}{\frac{1}{MTBM_{u}} + \frac{1}{MTBM_{s}}}$ MTDM is approximately MTDE the

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MTBM_u is approximately MTBF, the reliability factor, although in general MTBF ≤ MTBM_u

Maintenance Frequency Factors(cont)

- Meantime Between Replacement (MTBR)
 - A part, component, or a subsystem must be replaced by a spare part from inventory. Major link between maintenance actions and logistics support system