Reliability Concepts

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Definition of Reliability

"Probability that a system or product will perform in a satisfactory manner for a given period of time when used under specified operating condition"

Reliability - 4 main elements

1. **Probability** – numerical representation - number of times that an event occurs (success) divided by total number trials
2. **Satisfactory performance** – criteria established which describe what is considered to be satisfactory system operation

3. **Specifed time** – measure against which degree of system performance can be related - used to predict probability of an item surviving without failure for a designated period of time
4. **Specified operating conditions** expect a system to function - environmental factors, humidity, vibration, shock, temperature cycle, operational profile, etc.

LIFE CYCLE CURVE

- typical life history curve for infinite no of items – 'bathtub curve'
- comparison of **failure rate** with **time**
- 3 distinct phase – debugging , chance failure and wear-out phase

Life Cycle (Bath Tub) Curve

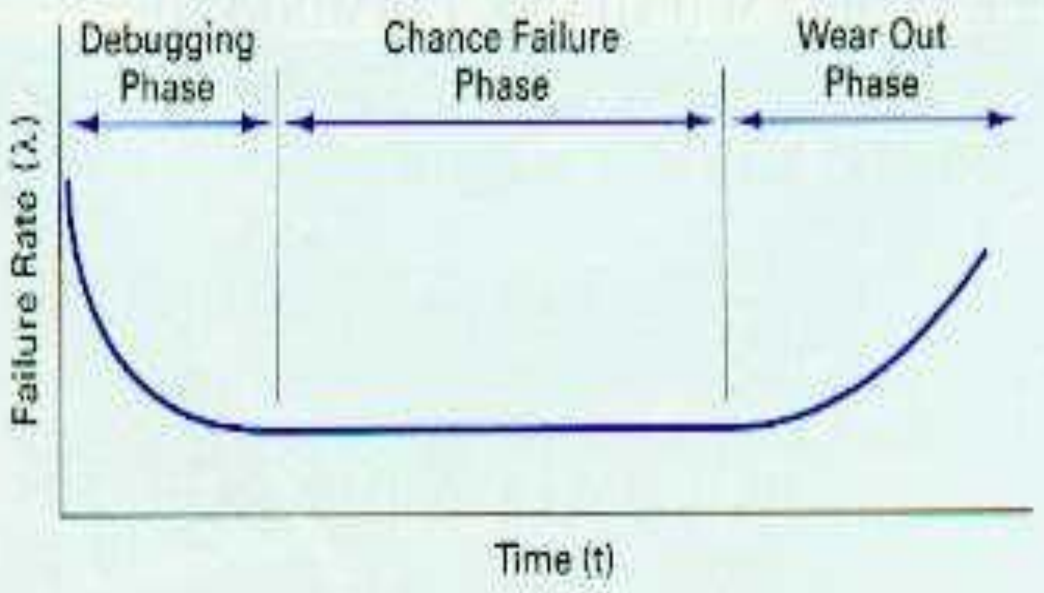
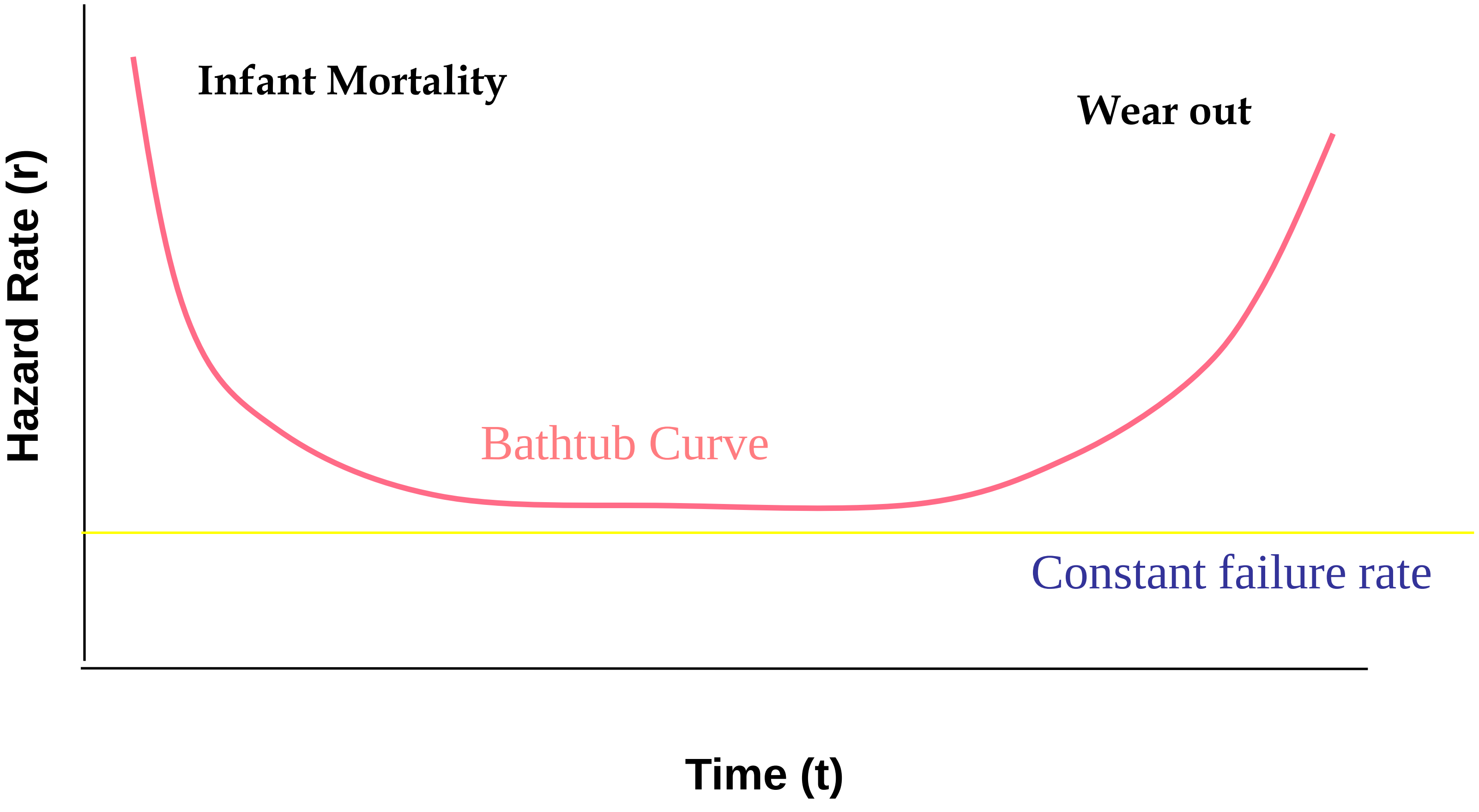


FIGURE 11-3 Typical life history of a complex product for an infinite number of items.

Bath Tub Curve



Debugging (Infant mortality) Phase

- rapid decrease in failure rate
- Weibull distribution with shape parameter $\beta < 1$ is used to describe the occurrences of failure
- Usually covered by warranty period

Chance failure phase

- Constant failure rate – failure occur in random manner
- Exponential and also Weibull with β =1 can be used to describe this phase

Wear-out phase

- Sharp rise in failure rate – fatigue, corrosion (old age)
- Normal distribution is one that best describes this phase
- Also can use Weibull with shape parameter $\beta > 1$

Weibull Interpretation

$b < 1$

- Implies infant mortality

$b = 1$

- Implies failures are random
- An old part is as good as a new part

$1 < b < 4$

- Occurs for:
  - Low cycle fatigue
  - Most bearing and gear failures
  - Corrosion or Erosion

$b > 4$

- Implies rapid wear out in old age
- Occurs for:
  - Wear-through

Maintainability

- Pertains to the ease, accuracy, safety and economy in the performance of maintenance actions
- Ability of an item to be maintained
- Maintainability is a design parameter, maintenance is a result of design

Measures of Maintainability

MTBM – mean time between maintenance, include preventive and corrective maintenance

MTBR – mean time between replacement, generate spare part requirement

$\overline{M}$ - mean active maintenance time

$\overline{M}_{ct}$ – mean corrective maintenance time or mean time to repair

$\overline{M}_{pt}$ – mean preventive maintenance time

- Frequency of maintenance for a given time is highly dependent on the reliability of that item
- Reliability ↑ frequency of maintenance ↓
- Unreliable system require extensive maintenance

Reliability function [R(t)]

- R(t) = 1 – F(t)
- F(t) = probability of a system will fail by time (t) = failure distribution function

  Eg. If probability of failure F(t) is 20%, then reliability at time t is

  R(t) = 1 – 0.20 = 0.80 or 80%

Reliability at time (t)

- $R(t) = e^{-t/\theta}$
- $e = 2.7183$
- θ = MTBF

$$\lambda = \frac{1}{\theta}$$

λ = failure rate

- So,

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

Failure Rate (λ)

- Rate at which failure occur in a specified time interval

$$\lambda = \frac{\text{number of failures}}{\text{total operating hours}}$$

- Can be expected in terms of failures per hour, % of failure per 1,000 hours or failures per million hours

Example 1

- 10 components were tested. The components (not repairable) failed as follows:

✓ Component 1 failed after 75 hours

✓ Component 2 failed after 125 hours

✓ Component 3 failed after 130 hours

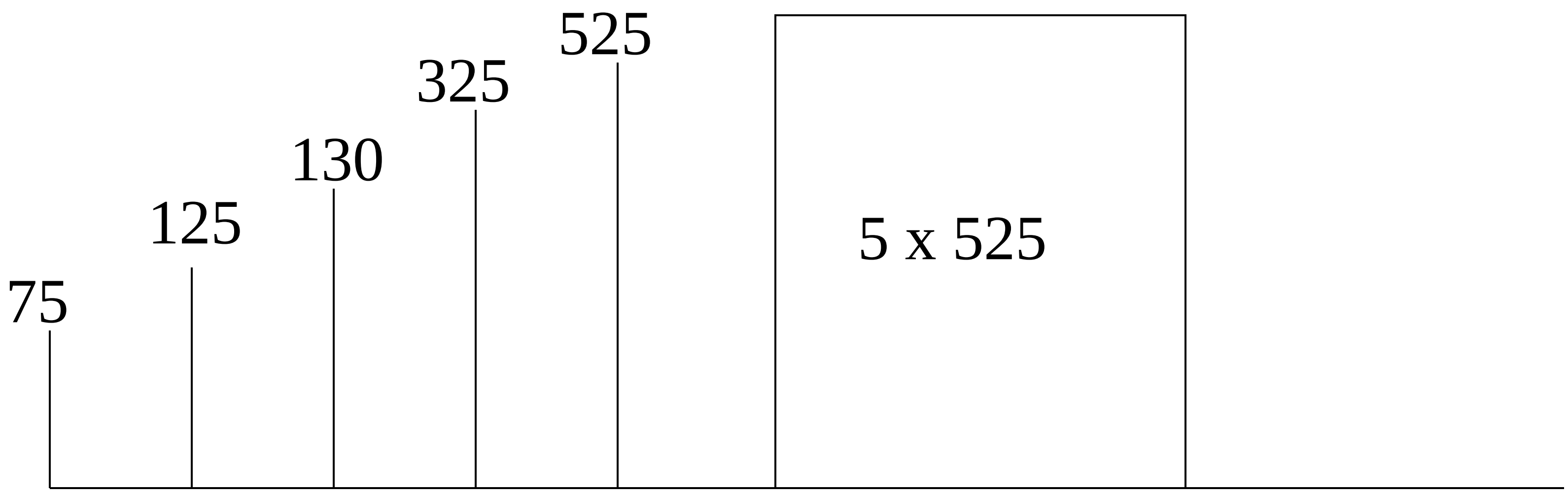
✓ Component 4 failed after 325 hours

✓ Component 5 failed after 525 hours

Determine the MTBF

Solution:

Five failures, operating time = 3805 hours



Solution

$\lambda = 5 / 3805 = 0.001314$

Example 2

The chart below shows operating time and breakdown time of a machine.

20.2	2.5	6.1	7.1	24.4	4.2	35.3	1.8	46.7

- Operating time (green)
- Down time (yellow)

a) Determine the MTBF.

Solution:

Total operating time = 20.2 + 6.1 + 24.4 + 4.2 + 35.3 + 46.7

= 136.9 hours

Solution

$\lambda = 4 / 136.9 = 0.02922$

Therefore;

- $\theta = MTBF = 1/\lambda = 34.22$ hours

b) What is the system reliability for a mission time of 20 hours?

$R = e^{-\lambda t}$ $t = 20$ hours

$R = e^{-(0.02922)(20)}$

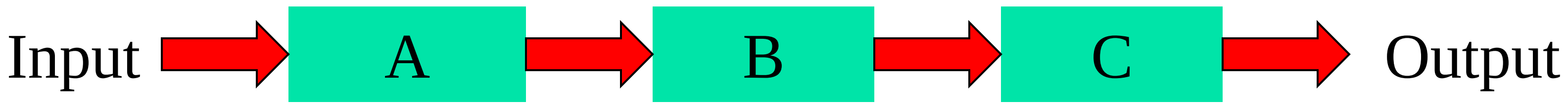
R = 55.74%

Reliability Component Relationship

- Application in series network, parallel and combination of both

Series Network

- Most commonly used and the simplest to analyze



All components must operate if the system is to function properly.

$$R = R_A \times R_B \times R_C$$

- If the series is expected to operate for a specified time period, then
- $R_s\ (t) =\ e^{-(\lambda_1+\lambda_2+\lambda_3+\ldots+\lambda_n)t}$

Example

- Systems expected to operate for 1000 hours. It consists of 4 subsystems in series, $MTBF_A$ = 6000 hours, $MTBF_B$ = 4500 hours, $MTBF_C$ = 10,500 hours, $MTBF_D$ = 3200 hours. Determine overall reliability.

  $\lambda_A = 1 / MTBF_A = 1/6000 = 0.000167$

  $\lambda_B = 1/MTBF_B = 1/4500 = 0.000222$

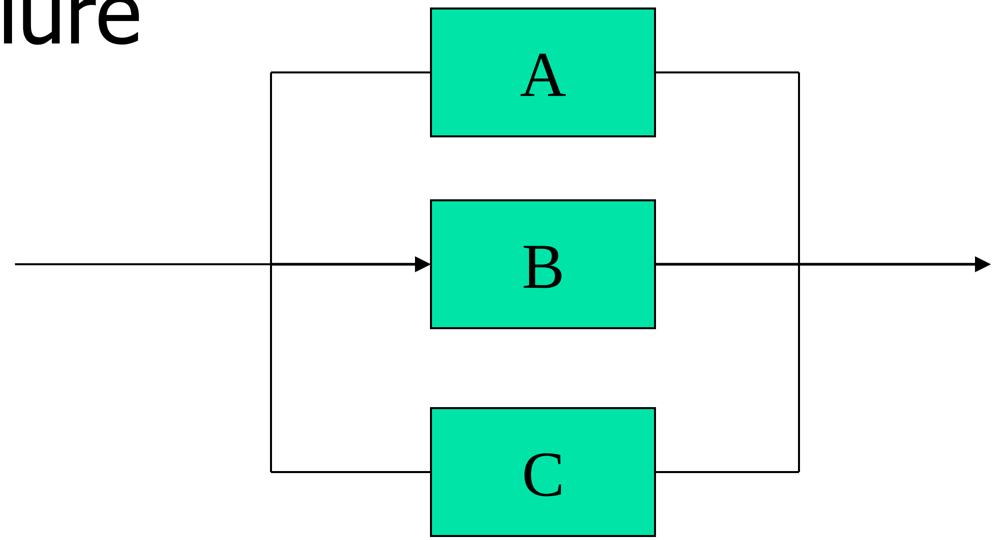
  $\lambda_C = 1/MTBF_C = 1/10500 = 0.000095$

  $\lambda_D = 1/MTBF_D = 1/3200 = 0.000313$

  Therefore; $R = e^{-(0.000797)(1000)} = 0.4507$

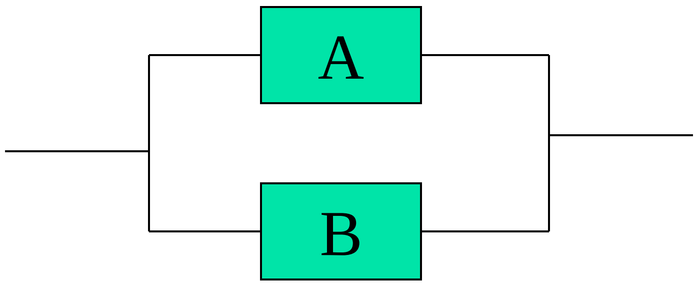
Parallel Network

- A number of the same components must fail order to cause total system failure



Example

- Consider two units A and B in parallel. The systems fails only when A and B failed.



$$F_s(t) = F_a(t)\, F_b(t)$$

$$= [1-R_a(t)][1-R_b(t)]$$

$$= 1-R_a(t)\, R_b(t) + R_a(t)\, R_b(t)$$

$$R_s(t) = 1- F_s(t)$$

$$= R_a(t) + R_b(t) – R_a(t)\, R_b(t)$$

- If A and B are constant failure rate units, then:
- $R_a(t) = e^{\lambda_a t}$ $R_b(t) = e^{-\lambda_b t}$

And $R_s(t) = \int_0^\infty R_s(t)dt = \frac{1}{\lambda_a} + \frac{1}{\lambda_b} - \frac{1}{\lambda_a + \lambda_b}$

θ_s = MTBF

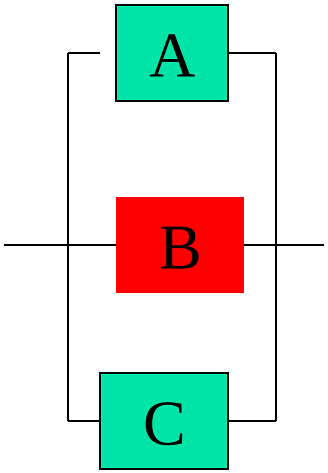
Consider 3 components in parallel

- $R_s = 1 – F_s$
- $F_a = 1- R_a$ $F_b = 1- R_b$ $F_c = 1- R_c$
- $R_s = 1 – (1-R_a)(1-R_b)(1-R_c)$
- If components A, B and C are identical, then the reliability,

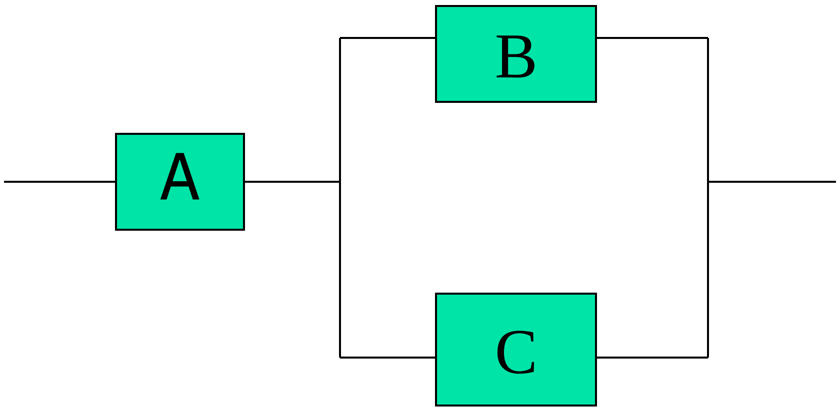
$$R_s = 1 – (1 – R)^3$$

- For a system with n identical components,

$$R_s=1- (1-R)^n$$

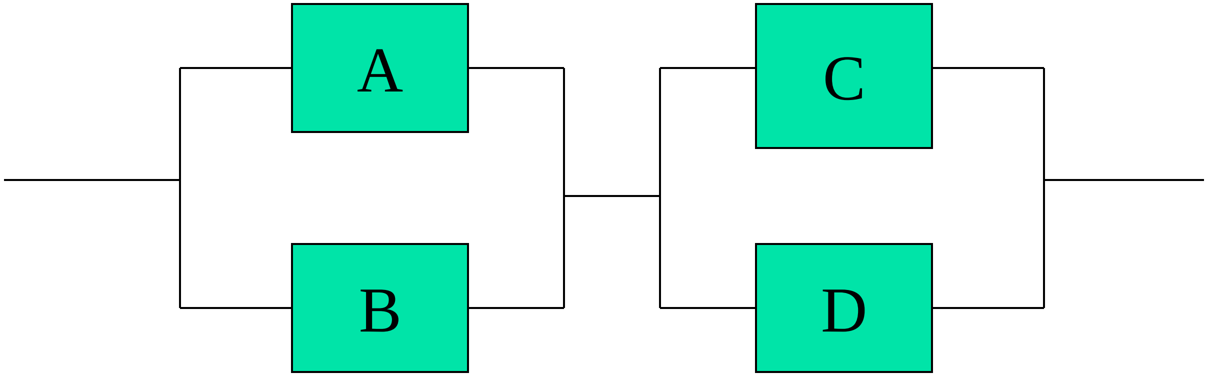


Combined series parallel network



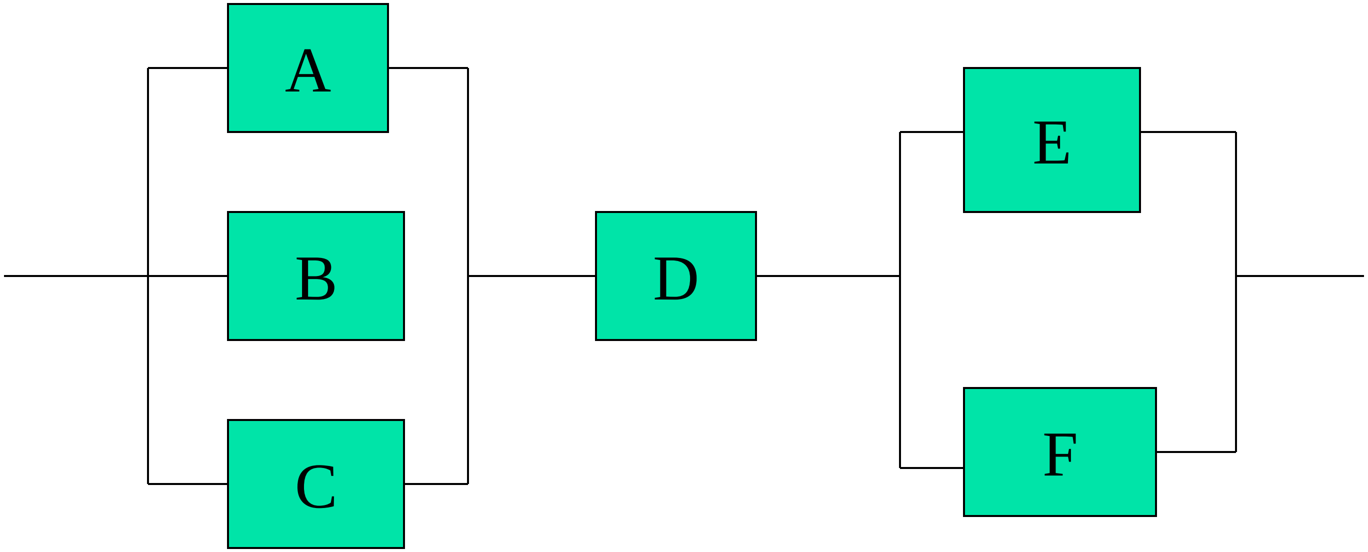
$$R_s = R_A\,[R_B + R_C - R_B R_C]$$

Combined series parallel network



$$R_s = [1-(1-R_A)(1-R_B)][1-(1-R_C)(1-R_D)]$$

Combined series parallel network



$$R_s=[1-(1-R_A)(1-R_B)(1-R_C)][R_D] \times [R_E+R_F-(R_E)(R_F)]$$

Combined series parallel network

- For combined series-parallel network, first evaluate the parallel elements to obtain unit reliability
- Overall system reliability is determined by finding the product of all series reliability

THANK YOU