ASQ Certified Reliability Engineer.

Ch.7 Maintainability & Availability.

中国可靠性
KekaoXing.com

中国最专业、最有影响力的可靠性行业网站

Industrial Engineering & Management Systems Research Center.

Maintainability Planning.

[CRE Primer Ⅷ p2-3]

Definition of Maintainability.

- Maintainability is the measure of the ability of a system to be restored to a specified level of operational readiness within defined intervals with the use of prescribed personnel, facility, and equipment resources.

Maintainability Planning.

[CRE Primer Ⅷ p2-3]

Needs for Maintainability Engineering.

- To achieve ease of maintenance through design, reducing maintenance time and cost.
- To estimate maintenance and equipment downtime. This will determine the need for redundancy, in order to increase availability.
- To estimate system availability by combining maintainability data with reliability data.
- To estimate labor, hours, time, and other resources for proper maintenance.

Maintainability Planning.

[CRE Primer Ⅷ p2-3]

Establishing a Maintainability Program.

- Prepare program plan.
- Perform maintainability analysis.
- Prepare inputs to maintenance concept and plan.
- Establish maintainability design criteria.
- Perform design trade-offs.
- Predict maintainability parameter values.
- Incorporate maintainability requirements in subcontractor specs.
- Integrate other items.
- Participate in design reviews.
- Establish data collection, analysis and corrective action system.
- Demonstrate achievement of maintainability requirements.
- Prepare maintainability status reports.

System Effectiveness.

[CRE Primer Ⅷ p4]

Definition.

- A measure of the degree to which an item or system can be expected to achieve a set of specific mission requirements, and which may be expressed as a function of availability, dependability and capability.

Three Components of System Effectiveness.

- **Availability.** A measure of the degree to which an item or system is in the operable and committable state at the start of the mission, when the mission is called for at an unknown point in time.
- **Dependability.** The probability that an item will (a) enter any one of its required operational modes during a specified mission, and (b) perform the functions associated with those operational modes.
- **Capability.** A measure of ability of an item or system to achieve mission objectives given the conditions during the mission.

System Effectiveness.

[CRE Primer Ⅷ p4]

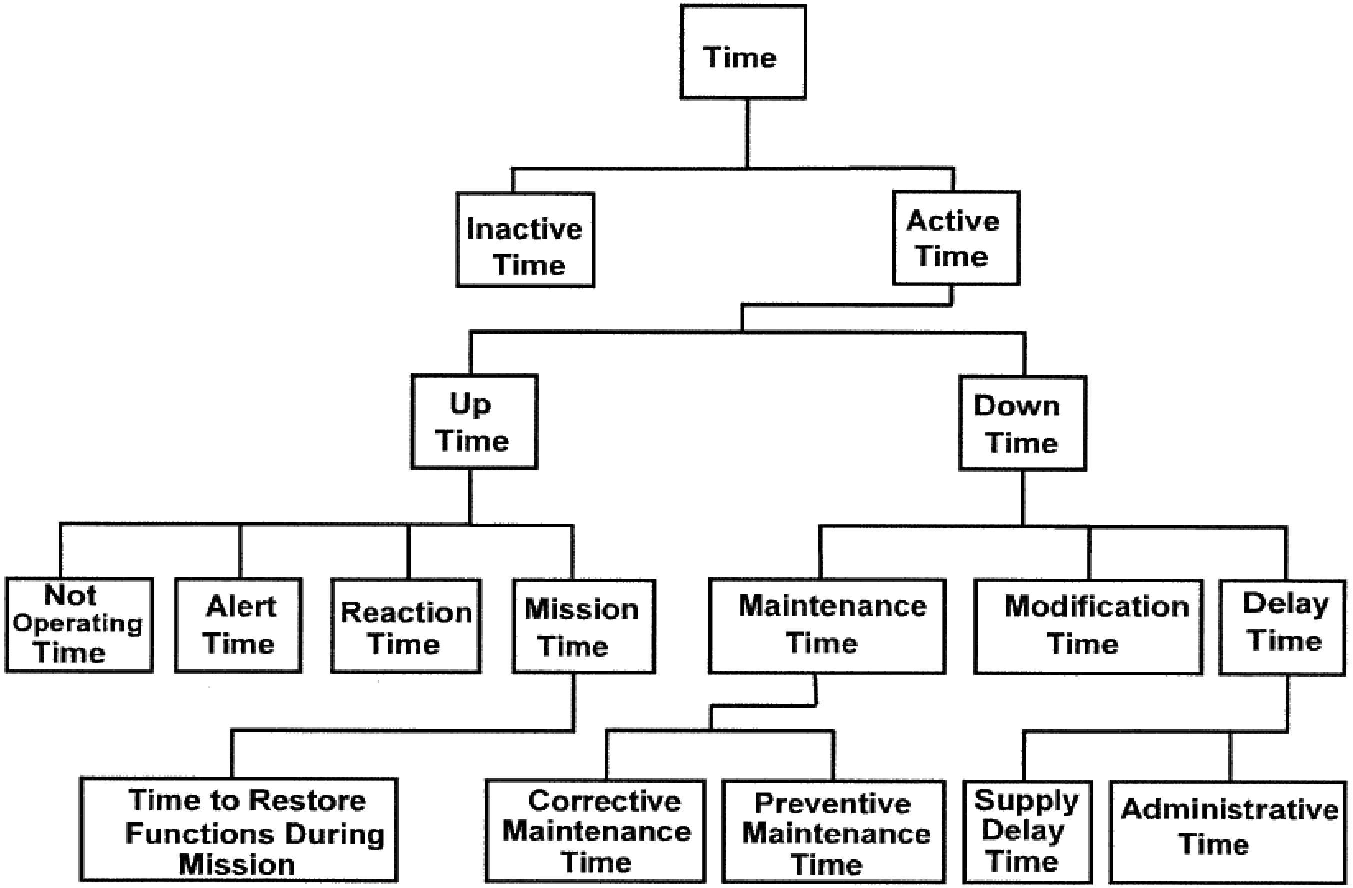
System Effectiveness Formula.

- SE = Mission Reliability × Operational Readiness × Design Adequacy.

Reliability Time Relationships

[CRE Primer Ⅷ p5]

Reliability, Maintainability and Availability.



Reliability Centered Maintenance.

[CRE Primer Ⅷ p7-10]

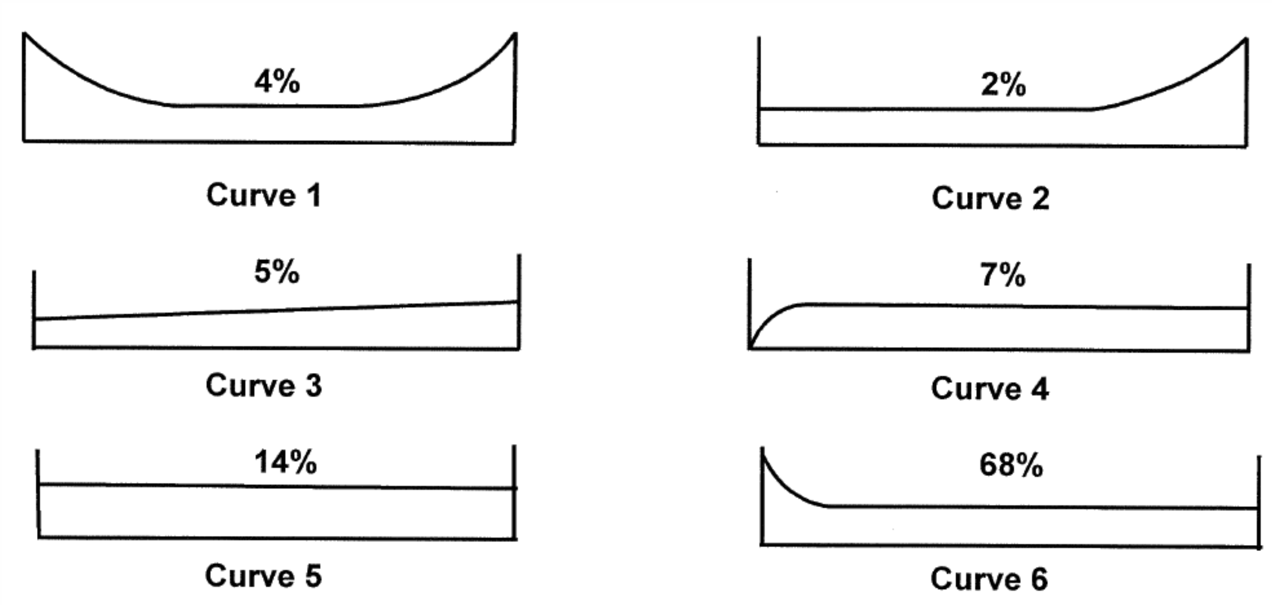
Introduction.

- RCM analysis indicates that studies should be performed on key equipment to determine which failure curve apply. Once enough data has been gathered and analyzed to determine the failure patterns, the engineer can place equipment under the proper curve.

Reliability Centered Maintenance.

[CRE Primer Ⅷ p7-10]

Six Types of Reliability Curves : Example.



- For the maintenance engineer, the constant failure rate areas mean that overhaul actions do little to enhance the equipment.

Reliability Centered Maintenance.

[CRE Primer Ⅷ p7-10]

Steps for a RCM Program.

1. Design for maintainability.
2. Perform functional FMEAs.
3. Categorize the failure distributions.
4. Determine maintenance task intervals.
5. Package all tasks into a plan.
6. Optimize results with data collection.
7. Analyze results for potential corrective action.

Total Productive Maintenance.

[CRE Primer Ⅷ p11-13]

Introduction.

- TPM involves the sharing of equipment maintenance and upkeep with the plant floor operators and dedicated maintenance craftsmen. The operators are trained to share responsibility for daily and routine duties in the area of inspection, cleaning, maintenance, and minor repairs.

- The effect is to increase productivity, improve quality, lower machine downtime, enhance equipment life cycle costs, and develop operator and maintenance personnel's knowledge and skills.

- The goals of TPM are zero breakdowns and zero defects. If breakdowns and defects are eliminated, costs go down, quality goes up, productivity improves, and equipment utilization increases.

Total Productive Maintenance.

[CRE Primer Ⅷ p11-13]

Six Big Losses.

- **Downtime.**
  1. Equipment failure due to breakdowns.
  2. Setup and adjustments.

- **Speed Losses.**
  3. Idling and minor stoppages.
  4. Reduced speed.

- **Defects.**
  5. Process defects.
  6. Reduced yield upon startup.

Calculating Maintainability.

[CRE Primer Ⅷ p17-19]

Mean Time To Repair (MTTR).

- $$MTTR = \frac{\sum_{i=1}^{n} (\lambda_i)\ (t_i)}{\sum_{i=1}^{n} \lambda_i}$$

- $$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (t_i - MTTR)^2}{n-1}}$$

where n = number of subsystems.

λ_i = failure rate of the i^{th} system

t_i = time to repair the i^{th} unit.

Calculating Maintainability.

[CRE Primer Ⅷ p17-19]

Probability of Repair Within the Allowable Downtime.

- To calculate the probability of performing a maintenance action within an allowable time interval use :

$$M(t) = 1 - e^{-t/MTTR}$$

- Example. What is the probability of completing an action within 5 hours if the MTTR = 7 hours ?

Sol.) $M(t) = 1 - e^{-t/MTTR} = 1 - e^{-\frac{5}{7}} = 1 - 0.4895 = 0.5105$

Maintainability Allocation.

[CRE Primer Ⅷ p14-16]

Maintainability Allocation.

- Maintainability allocation is a top down application of the requirements for the system. The individual equipment maintainability requirements must be derived from the required total system maintainability criteria.

- The MTTR equation for the allocation factor.

$$MTTR = \frac{\sum_{i=1}^{n} (\lambda_i)(KMTTR_i)}{\sum_{i=1}^{n} \lambda_i}$$

where K = The allocation factor.

λ_i = The failure rate of the i item.

$MTTR_i$ = The original estimate of the MTTR for the i item.

$KMTTR_i$ = The adjusted $MTTR_i$

Availability.

[CRE Primer Ⅷ p20-24]

Availability.

- The measure of the degree to which an item is in the operable and committable state at the start of a mission, when the mission is called for at an unknown(random) time.

- The three common measures of availability.

Inherent Availability (A_i) : This is the ideal state for analyzing availability. The only considerations are the MTBF and the MTTR. This measure does not take into account the time for preventive maintenance and assumes repair begins immediately upon failure of the system.

$$A_i = \frac{MTBF}{MTBF + MTTR}$$

MTTR : Mean time to repair.

Availability.

[CRE Primer Ⅷ p20-24]

Availability.

Achieved Availability. (A_A**)** : This is somewhat realistic in that it takes preventive maintenance into account, as well as corrective maintenance.

$$A_A = \frac{\text{MTBMA}}{\text{MTBMA} + \text{MMT}}$$

MMT : Mean Maintenance Action Time.

Operational Availability (A_o**)** : This is what generally occurs in practice. Operational availability takes into account that the maintenance response is not instantaneous, parts may not be in stock for repair, as well as, other logistics issues.

$$A_o = \frac{\text{MTBMA}}{\text{MTBMA} + \text{MDT}}$$

MDT : Mean Down Time.

Preventive Maintenance Analysis.

[CRE Primer Ⅷ p33-37]

Types of Maintenance.

- **Corrective Maintenance.**

  The unscheduled actions, initiated as a result of failure, that are necessary to restore a system to its required level of performance.

  Corrective maintenance cannot be planned, but can be determined by reliability. The mean time to repair (MTTR) is applicable for such items. The time to repair has three elements to it

  1. Preparation Time : locating people, traveling to the site, obtaining tools, parts and instruments.
  2. Active Maintenance Time : studying the charts, performing the repair, and verifying the repair.
  3. Delay Time : the wait time involved in such activities as locating charts, waiting a the stores counter, waiting on production to clear the area, and awaiting personnel to verify repairs.

Preventive Maintenance Analysis.

[CRE Primer Ⅷ p33-37]

Types of Maintenance.

- **Preventive Maintenance.**

  The scheduled actions necessary to retain a system at a specified level of performance.

  Preventive Maintenance has the function of the prevention of failure via planned or scheduled efforts. PM can be based on : scheduled service for cleaning, service for lubricating, detection of early signals of problems, length of use, or based on other failure in service.

Preventive Maintenance Analysis.

[CRE Primer Ⅷ p33-37]

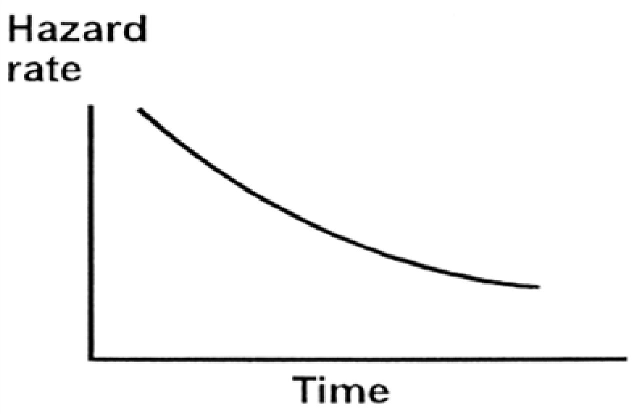
Maintenance Level.

- Organizational Maintenance : Where parts are repaired through the least skilled maintenance needs.
- Intermediate Maintenance : Where parts are beyond a basic level of repair, so the need is at a slightly higher level of skill.
- Depot Level : When highly specialized skills are required and possibly at a more central location with specialized equipment.

Preventive Maintenance Analysis.

[CRE Primer Ⅷ p33-37]

Preventive Maintenance Strategy : Decreasing Hazard Rate.



Decreasing Hazard Rate.

Schedule maintenance will return the part to the top of the curve.

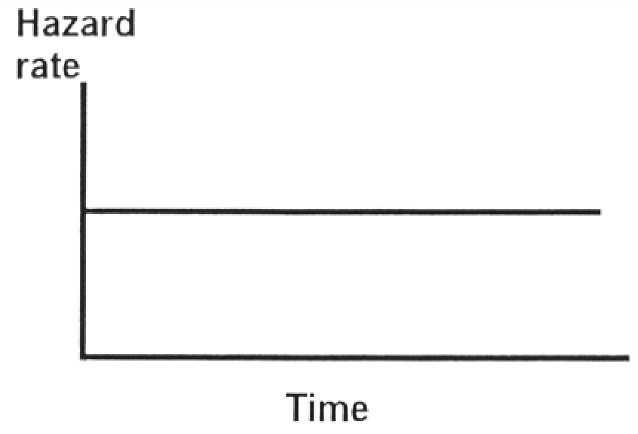
- Given a decreasing hazard rate, it is best to not replace the part.
- If these failures cannot be prevented, a burn-in of the part should be implemented before it is installed and put into service.
- Various causes of infant mortality.

  Improper use, Improper installation, Inadequate materials, Poor quality conformance, Over-stressing, Power surges, Improper set up, Handling damage.

Preventive Maintenance Analysis.

[CRE Primer Ⅷ p33-37]

Preventive Maintenance Strategy : Constant Hazard Rate.



Constant Hazard Rate.

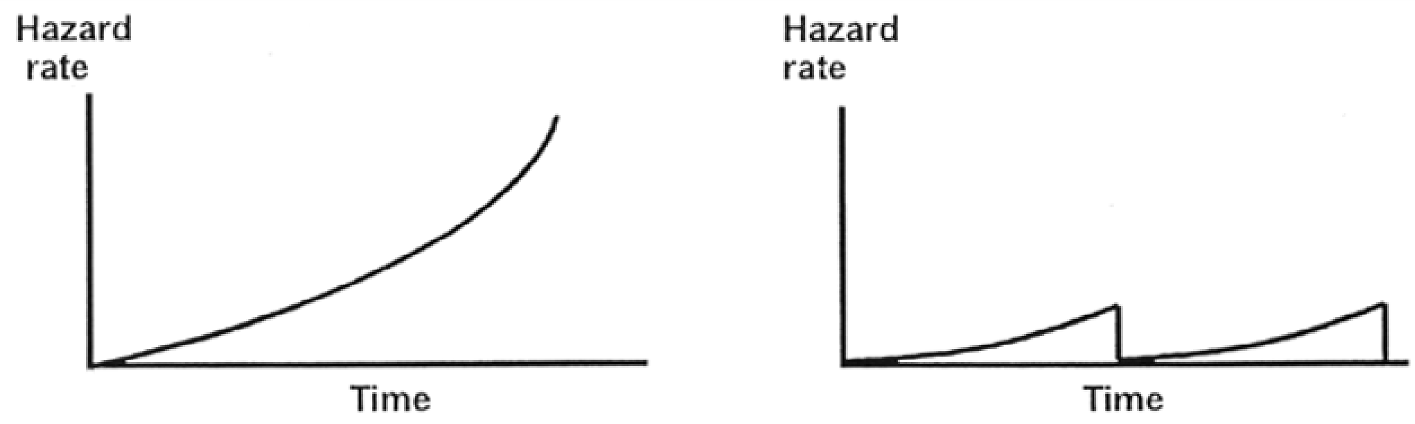
Replacement of a part will result in the same probability of failure as before.

- Given a constant hazard rate, part replacement does not reduce failure rates.

Preventive Maintenance Analysis.

[CRE Primer Ⅷ p33-37]

Preventive Maintenance Strategy : Increasing Failure Rate.



- Given a increasing hazard rate, scheduled replacement reduces failure rates.
- Given a nearly failure free, but increasing hazard rate, scheduled replacement will provide a near zero failure rate.

Designing for Maintainability and Availability.

[CRE Primer Ⅷ p39-40]

Preventive Maintenance Strategy : Increasing Failure Rate.

- **Standardization** : Look for compatibility of mating parts and minimize the number of different parts in the system.
- **Modularization** : Have standards on sizes, shapes, modular units. This will allow for standardized assembly and disassembly procedures.
- **Functional Packaging** : Place all needed components of an item into a kit or package.
- **Interchageability** : This refers to plug-in devices where spares are instantly interchangeable with failed parts. One part can be used in other units.
- **Accessibility** : A part should be easy to get to and to replace. Good parts should not be removed to gain access to failed parts.

Designing for Maintainability and Availability.

[CRE Primer Ⅷ p39-40]

Preventive Maintenance Strategy : Increasing Failure Rate.

- **Malfunction Annunciation** : Provide a means to notify the operator when the unit fails.
- **Fault Isolation** : A malfunction can be isolated. This is the most time consuming task of all maintenance work. This problem could be minimized by preventive maintenance procedures, built-in test equipment (BITE), simplicity in design of parts, and by trained personnel.
- **Identification** : Have a unique identification of all components and a method of recording corrective and preventive maintenance.

Testability

[CRE Primer Ⅷ p41-44]

Introduction.

- A test strategy should be developed for performing measurements on a specific item or program. Test program usually occur at the end of development and production segments and are used to determine if the design requirements have been achieved.

- Some conditions requiring testing.
  - New development. (1st time designed)
  - Commercial off-the-shelf product (COTS).
  - Safety critical (Nuclear power plant vessel).
  - Dormancy (An item subjected to long term storage).
  - Long life (An item likely to be in service for a relatively long time such as a Hubble Telescope).
  - Harsh environment (High shock, rapid thermal cycling, etc.)
  - Software development.

Testability

[CRE Primer Ⅷ p41-44]

Some Guideline for Testability

- Have design documentation available.
- Use standard testable parts, modules, connectors, test point levels, etc.
- Provide access to system and data buses, critical nodes, test buses.
- Test redundant circuits independently.
- Provide disconnection from high and low power sections.
- Use standard test point impedance levels, of 50, 75, 130 ohm or > 1 megohm.
- Design to assist maintenance in isolation of faults.

Testability

[CRE Primer Ⅷ p41-44]

Built-in Test (BIT)

- The testing of complex electronic systems such as laboratory instruments, avionics, printed circuit boards, etc. are made easier with built-in-test (BIT) facilities or points.

- This design can consist of additional hardware and/or software, that will be used for carrying out functional test on the system. The operator can activate the testing, or the BIT can be made to perform periodic tests or monitor the unit continuously.

Spare Parts Strategy.

[CRE Primer Ⅷ p45-50]

Optimum Parts Replacement.

- It is generally assumed that the total cost of a maintenance failure is greater that the costs associated with a scheduled PM action. The prime assumption for PM actions. Replacing a worn brake shoe in a braking system is cheaper than waiting until the rotors are damaged by the brake shoe rivets.

Spare Parts Strategy.

[CRE Primer Ⅷ p45-50]

Optimum Parts Replacement Model.

- Minimizing the total cost per unit time.

$$C_T = \frac{C_p \int_T^{\infty} f(t)dt + C_f \int_0^T f(t)dt}{T\int_T^{\infty} f(t)dt + \int_0^T tf(t)dt}$$

where C_T = The total cost per unit time. C_f = The cost of a failure.

C_p = The cost of PM T = Time between PM actions.

- Assumptions.

1. The time to fail follows a Weibull distribution.
2. Preventive maintenance is performed on an item at time T, at cost of C_p
3. If the time fails before time = T, a failure cost of C_f is incurred.
4. Each time preventive maintenance is performed, the item is returned to its initial state, the item is "as good as new"

Spare Parts Strategy.

[CRE Primer Ⅷ p45-50]

Optimum Parts Replacement Model.

- The optimum time maintenance actions.

$$T = m\Theta + \delta$$

where m is a function of the ratio of the failure cost to the preventive maintenance cost, and the value of the shape parameter.

Θ is the scale parameter.

δ is the location parameter.

Spare Parts Strategy.

[CRE Primer Ⅷ p45-50]

Optimum Parts Replacement Model.

$$C_T = \text{PM Costs} + \text{Failure Costs}$$

$$= \left(\text{PM Actions x } \frac{\text{Cost}}{\text{PM}}\right) + \left[\text{PM Actions x Cost of a Failure x} \left(1 - \exp\left[-\left(\frac{t - \gamma}{\eta}\right)^{\beta}\right]\right)\right]$$

Software Maintenance

[CRE Primer Ⅷ p51-54]

Categories of Software Maintenance.

- **Corrective Maintenance. (17%)**

  When the customer or user deploys software, defects requiring changes will be uncovered. Corrective maintenance is defined as changes required to correct defects found during the operation of a software system or execution of a software application.

- **Adaptive Maintenance. (18%)**

  Over time, the original environment for which the software was developed will change. Adaptive maintenance results in modifications to the software to accomodate changes to its external or operating environment.

Software Maintenance

[CRE Primer Ⅷ p51-54]

Categories of Software Maintenance.

- **Perfective Maintenance. (65%)**

  Perfective maintenance extends the software beyond its original functional requirements. Perfective maintenance involves change made in response to user or customer requests to improve the efficiency and/or documentation.