Certified Reliability Engineer (CRE)

Ch.1 Reliability Management.

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Industrial Engineering and Management System Research Center.

Definition of Reliability.

[CRE Primer Ⅱ 47-60]

- **The probability that a product will perform its intended function satisfactorily for a pre-determined period of time and in a given environment.**

- **From the definition above, there are four key elements of reliability.**
  1. Probability.
  2. Intended Function.
  3. Time.
  4. Environment.

Failure and It's Classification.

[CRE Primer II 47-60]

■ Definitions and Classification of Failure.

- Definitions : The event, or inoperable state, in which any item or parts of an item does not, or would not, perform as previously specified.

- Failure rate : The total number of failures within an item population, divided by the total number of life units expended by that population, during a particular measurement interval under stated conditions.

- Four general classifications of failure
  1. Catastrophic Failure : The sudden and total failure of a unit.
  2. Degradation Failure : The gradual loss of the unit's output.
  3. Intermittent Failure : The sudden loss of operation.
  4. Drift Failure : Drift failure appears, at first, to be degradation failure in that the function is gradually lost. However, drift failure units are restored to full output by cycling (turning off and on) the unit.

Benefits of Reliability Engineering.

[CRE Primer Ⅱ 3-4]

■ Benefits of Reliability Engineering.

- Matching the capabilities of product design with the customer's application environment and performance expectations.
- Avoiding wasted time used to unanticipated failure in products or services through reliability and availability management concepts.
- Optimizing product run-in or burn-in times and conditions may be achieved, thereby inventory carrying costs, tooling costs, and energy requirements.
- Minimizing distribution system costs for transportation and logistic support of any given item including spare part stocks and service labor.
- Optimizing warranty costs determined by providing the best value to both manufacturing and customer in the warranty length and features offered.
- Reducing injuries and loss of life related to product failure or liability.
- Reduce the loss of property due to equipment failure.
- Staffing the development program team with qualified reliability professionals that ensure the design effort will focus on those areas that will reduce expensive redesign and rework costs.

Benefits of Reliability Engineering.

[CRE Primer Ⅱ 3-4]

■ Reliability Program and Its Tasks.

Design Objectives	R&M Tasks Contributing to Objectives
Determine feasibility of meeting design goals	**Predictions**
Understand the impacts on design performance - Single point feature, Key design parameter, Predominant failure modes/mechanisms.	**Design review, FMEA, FRACAS, Design of Experiment, TAAF, Thermal Analysis**
Use Proper parts and apply correctly	**ESS, Parts Control.**
Address all sources of components, materials, etc.	**Vendor/Supplier control**
Validate the design	**Qualification Testing.**

Role of the Reliability Function.

[CRE Primer Ⅱ 7-9]

■ Top management.

- Crucial to the success of a reliability program.
- Ensuring that the issues identified during product development by the reliability organization are adequately addressed.
- Reliability policy.
  - Should be initially defined and later refined as an organization develops.
  - This policy should be consistent with the objectives in the company's business and marketing plan, keeping in mind that customer goodwill and reliability/warranty performance are closely correlated.

Role of the Reliability Function.

[CRE Primer Ⅱ 7-9]

■ Reliability engineer and it's organization.

- A reliability engineer should seek opportunities to remain current and exchange ideas with other engineers.

- Role of reliability organization
  1. Completely analyze all failure.
     : When or where they occur in development.
     : Identifying the root cause of failure.
     : Determine the necessary corrective action, including redesign and revision of analytical tools.

Role of the Reliability Function.

[CRE Primer Ⅱ 7-9]

■ Reliability engineer and it's organization.

2. Developing efficient reliability demonstrated testing.

   : If required, demonstrations should focus on new components or assemblies, or the integration of old items in a new way.

   : Emphasizing engineering development testing to understand and validate the design process and models.

   : Accelerated testing should be used to age high reliability items and to identify their failure mechanisms.

3. Assign responsibility for reliability to a product development team.

   : Giving the team the authority to determine the reliability requirements, and to select the design, analysis, test, and manufacturing activities needed to achieve that reliability.

Role of the Reliability Function.

[CRE Primer Ⅱ 7-9]

■ Reliability Manual.

- Most organizations that deal with reliability create a manual that outlines reporting structure, specific procedures and standards and other documents to ensure continuity in purpose of execution of the program requirements.

- As a minimum, the reliability manual should include :
  1. A statement of reliability policy.
  2. Specific reliability procedures as well as references to appropriate standards and specifications.
  3. Design review and test procedures.
  4. Responsibility for specific programs, projects, procedures, etc.

Designing for Reliability.

[CRE Primer II 18-24]

- **Designing for reliability is often into phases such as concept, design and development, full scale development, operational and disposal.**

- **Concept Phase.**
  - The first phase or the earliest part of the reliability.
  - The designers work with customers to develop a product that meet the needs of the perceived customer in terms of ease of use, special training needs, special power requirements, complexity of design, support, etc. . .

- **Design & Development Phase.**
  - The stage when the issues such as ergonomics, maintainability, safety and other major design considerations become a "product on paper."

Designing for Reliability.

[CRE Primer II 18-24]

Full Scale Development.

- The design is basically complete and prototype(pre-production) runs of final build are occurring.
- Changes during this phase are very costly and in many cases are not done in order to meet some other goal or target.

Operational Phase.

- The use of the item in the field.
- The ease of use and ease of maintenance have a significant impact on the reliability of a product.

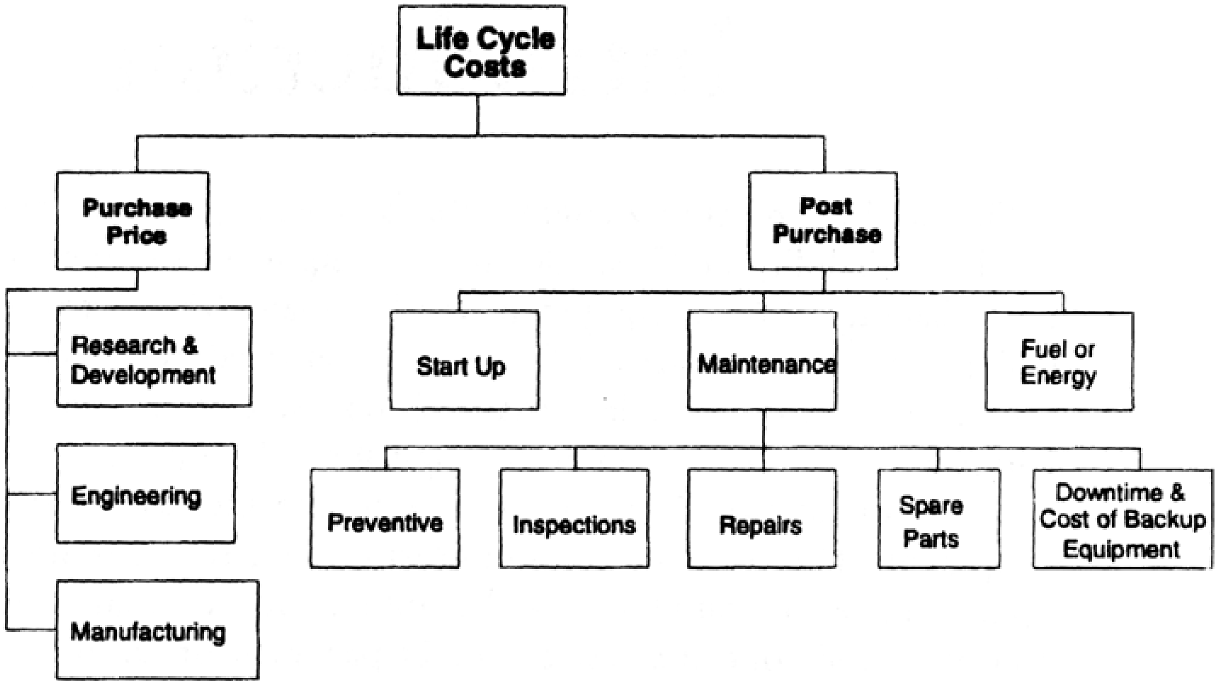
Disposal.

- Designers are new required to take the disposal of the product into consideration of the design.
- In the design for disassembly it is important that performance is not degraded.

Designing for Reliability.

[CRE Primer II 18-24]

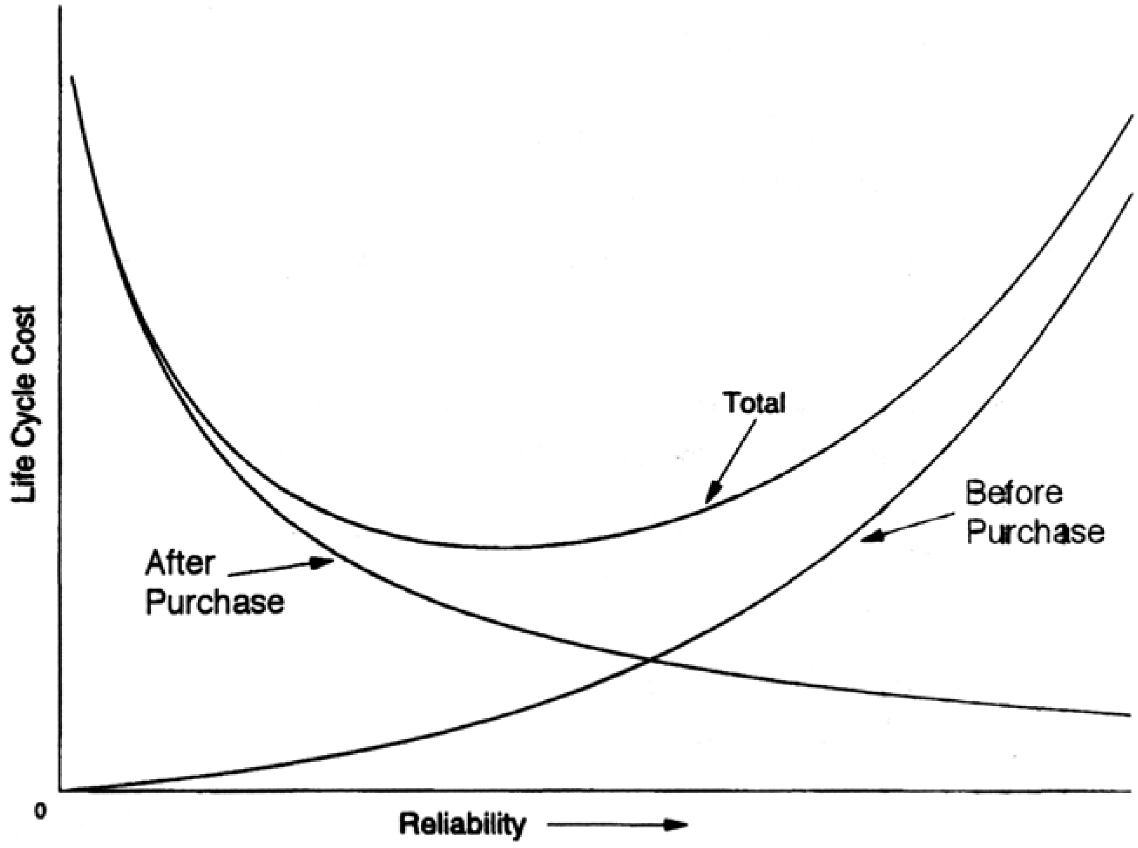
- ## Life Cycle Cost



Designing for Reliability.

[CRE Primer II 18-24]

- **Life Cycle Cost vs. Reliability.**



Designing for Reliability.

[CRE Primer II 18-24]

■ Life Cycle Cost vs. Reliability.

Product Cycle	Reliability Focus
I. Conceptual Design	· Formulate ideas, estimate resource, and financial needs. · Identify risks requirements. · Program objective.
II. Preliminary & Detailed Design	· Identify and allocate needs and requirements. · Propose alternate approaches. · Design and test the product. · Develop manufacturing, operating, repair/maintenance tasks.
III. Production/Manufacturing	· Refine and implement manufacturing procedures. · Finalize product equipment. · Establish quality processes. · Build and distribute the product.
IV. Operation/Repair	· Implement operating, installation, and training procedures. · Provide repair and maintenance service. · Repair warranty items. · Provide for performance feedback.
V. Wearout/Disposal	· Implement refurbishment and disposal tasks. · Resolve potential wearout issues.

Customer Needs Assessment.

[CRE Primer Ⅱ 25-31]

■ Reliability Requirement.

- Reliability requirement may be specified by the customer or generated by the design team. Obviously, the simplest alternative is to have the requirements specified. This frequently happens in military contracts.

  However, the more common situation is to have "implied" rather than specific requirements. Implied requirements come from customer expectations and must be discovered and incorporated by the design team.

■ Methods for Needs Assessment.

1. Market Surveys.
2. Benchmarking.
3. Prototyping.
4. Quality Function Deployment.

Customer Needs Assessment.

[CRE Primer II 25-31]

■ Quality Function Deployment (QFD).

- Quality function deployment is a tool that is sometimes referred to as the "voice of the customer", or as the "house of quality".
- QFD has been described as a process to ensure that customers' wants and needs are heard and translated into technical characteristics.
- The technical characteristics are handled through a cross functional team that includes sales, marketing, design engineering, manufacturing engineering, and operation.

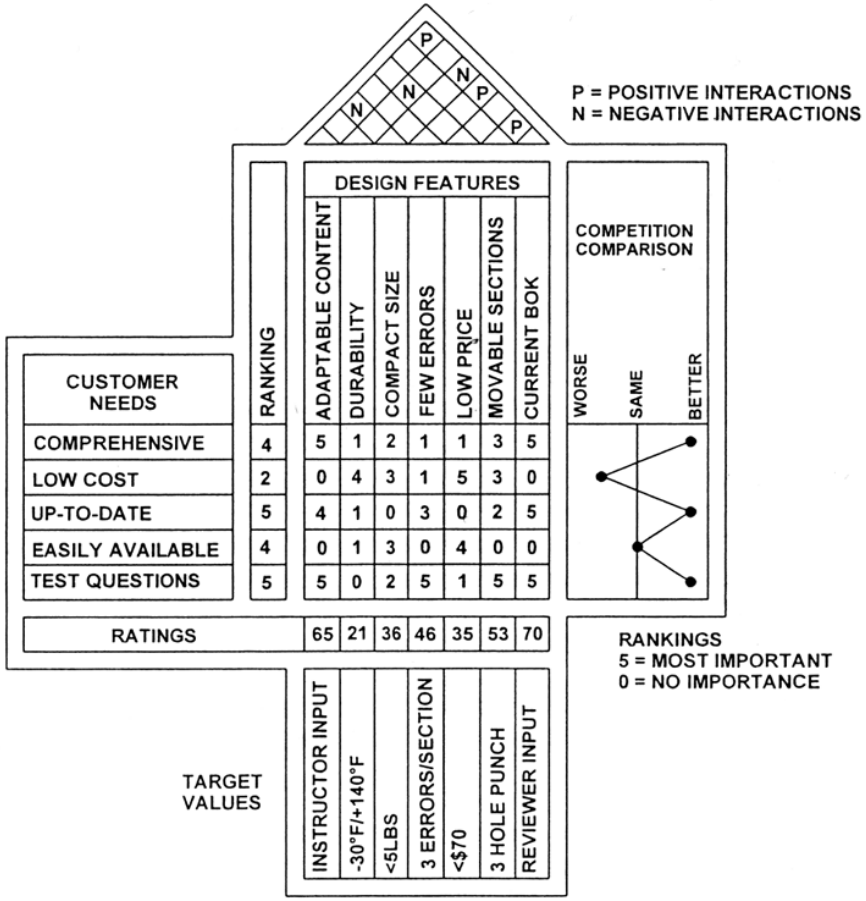
Customer Needs Assessment.

[CRE Primer II 25-31]

■ Quality Function Deployment (QFD).

- The possible benefits for using the QFD process.

1. Creates a customer driven environment.
2. Reduces the cycle time for new products.
3. Uses concurrent engineering methods.
4. Reduces design to manufacture costs.
5. Increases communication through cross functional teams.
6. Creates data for proper documentation of engineering knowledge.
7. Establishes priority requirements and improves quality.

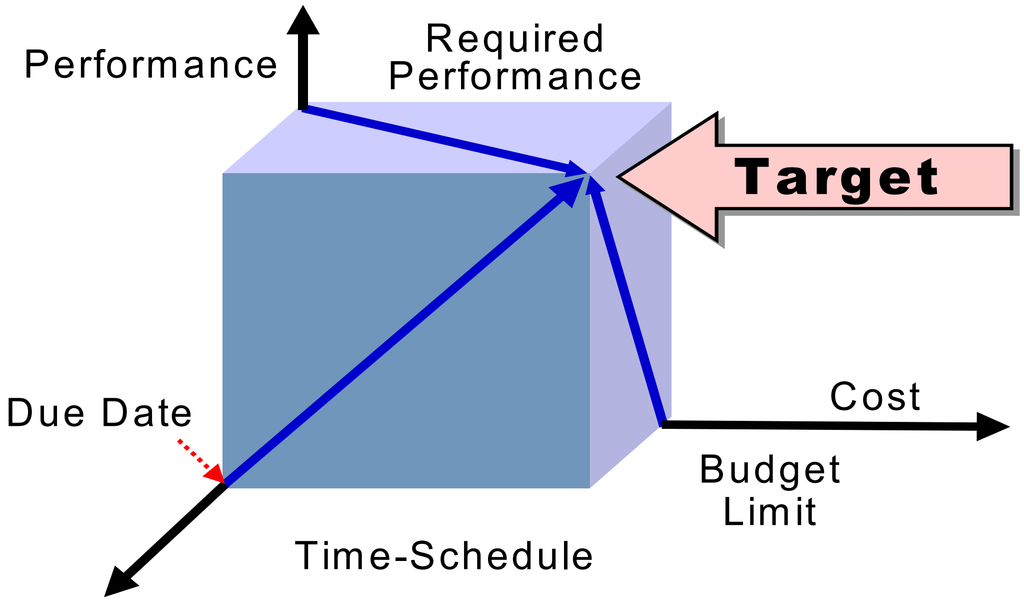


Project Management.

[CRE Primer II 32-46]

■ Definition of Project.

- A temporary/one-time endeavor with a specific objective to be met within the prescribed time and dollar limitations and that has been assigned for definition or execution.



Project Management.

[CRE Primer II 32-46]

■ Project Organization.

- **The Project Director or Leader.**

  The project director a member of upper management who serves as the sanctioning point for any project and who oversees its activities. The role of this individual is to facilitate accessibility to top management and provide an executive sounding board to the project team.

- **The Project Sponsor.**

  The person chartering the project may be a supervisor, functional leader, or someone else who has a substantial interest in the project. This individual or group within the performing organization provides the financial resources for project.

Project Management.

[CRE Primer II 32-46]

■ Project Organization.

- **The Project Manager.**

  The individual who has the ultimate accountability and responsibility for a project's success or failure. After the customer defines their expectations, it is the project manager's job to achieve these expectations related to quality, cost and schedule through the effective use of available resources.

  To bring the project to completion successfully, the project manager should possess expertise in several areas such as adaptive leadership behavior, knowledge of motivation techniques, interpersonal and organizational communication skills, decision-making and team-building skills, formal and informal authority, flexible management style, ability to plan, direct, and control a project implementation.

Project Management.

[CRE Primer II 32-46]

■ Project Organization.

- **Project Team.**

  The project team consists of the project manager and other who have the responsibility for project. The essence of the team is common commitment to the identified end product.

  The team can then translate their common purpose into specific performance goals.

  The selection of the team should begin early in the process while creating the initial project documentation because that is when the skills required for the project are most clearly investigated and identified.

Project Management.

[CRE Primer II 32-46]

■ Documents for Projects.

- **Statement of Work (SOW).**

  A project such as new product design/development starts out as a statement of work (SOW). The SOW may be a written description of the objectives to be achieved, with a brief statement of the work to be done and a proposed schedule specifying the start and completion dates.

- **Work Breakdown Structure (WBS).**

  A work breakdown structure (WBS) is created to define the work that needs to be done. It is the primary planning tool for organizing work.

[CRE Primer II 32-46]

■ Project Scheduling Method : CPM

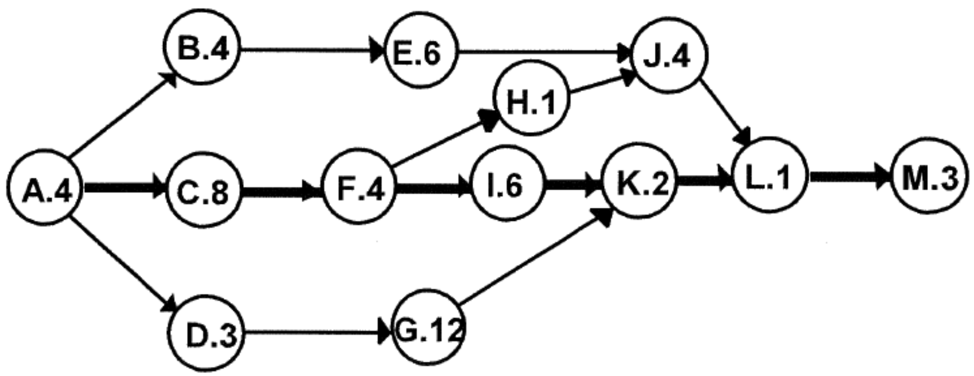
- A network planning technique for the deterministic analysis of a project's completion time, used for planning and controlling the activities in a project.

- Unique features of CPM include :
  - The emphasis is on activities.
  - The time and cost factors for each activity are considered.
  - Only activities on the critical path are contemplated.
  - Activities with the lowest crash cost (per incremental time saving) are selected first.
  - As an activity is crashed, it is possible for a new critical path to develop.

Project Management.

[CRE Primer II 32-46]

■ Project Scheduling Method : CPM



TASK	ACTIVITY	DURATION weeks		COST $		COST/ WEEK
0	ISO 9001 Certification	normal	crash	normal	crash	CRASH
A	Planning	4	3	2,000	3,000	1,000
B	Select Registrar	4	3	1,000	1,200	200
C	Write Procedures	8	6	12,000	15,000	1,500
D	Contact Consultant	3	1	500	700	100
E	Schedule Audit	6	5	200	1,000	800
F	Write Quality Manual	4	3	800	1,200	400
G	Consultant Advising	12	9	9,600	14,400	1,600
H	Send Manual to Auditor	1	1	100	100	-
I	Perform Training	6	4	9,000	12,000	1,500
J	Auditor Review Manual	4	3	1,000	1,250	250
K	Internal Audits	2	1	600	750	150
L	ISO Audit	1	1	10,000	10,000	-
M	Corrective Action	3	2	1,600	2,000	400
10	Certification	Milestone		48,400		

Project Management.

[CRE Primer Ⅱ 32-46]

■ Project Scheduling Method : PERT

- The PERT can be used for estimating completion times. PERT is basically an extension of CPM, which incorporates variabilities in activity duration(time estimates) into the network.

- PERT incorporates the potential uncertainties in activity duration by using three time estimates and variance for each activity. Three time estimates are
  - The Optimistic, The Pessimistic, Most likely.
  - The expect time and the standard deviation t_e

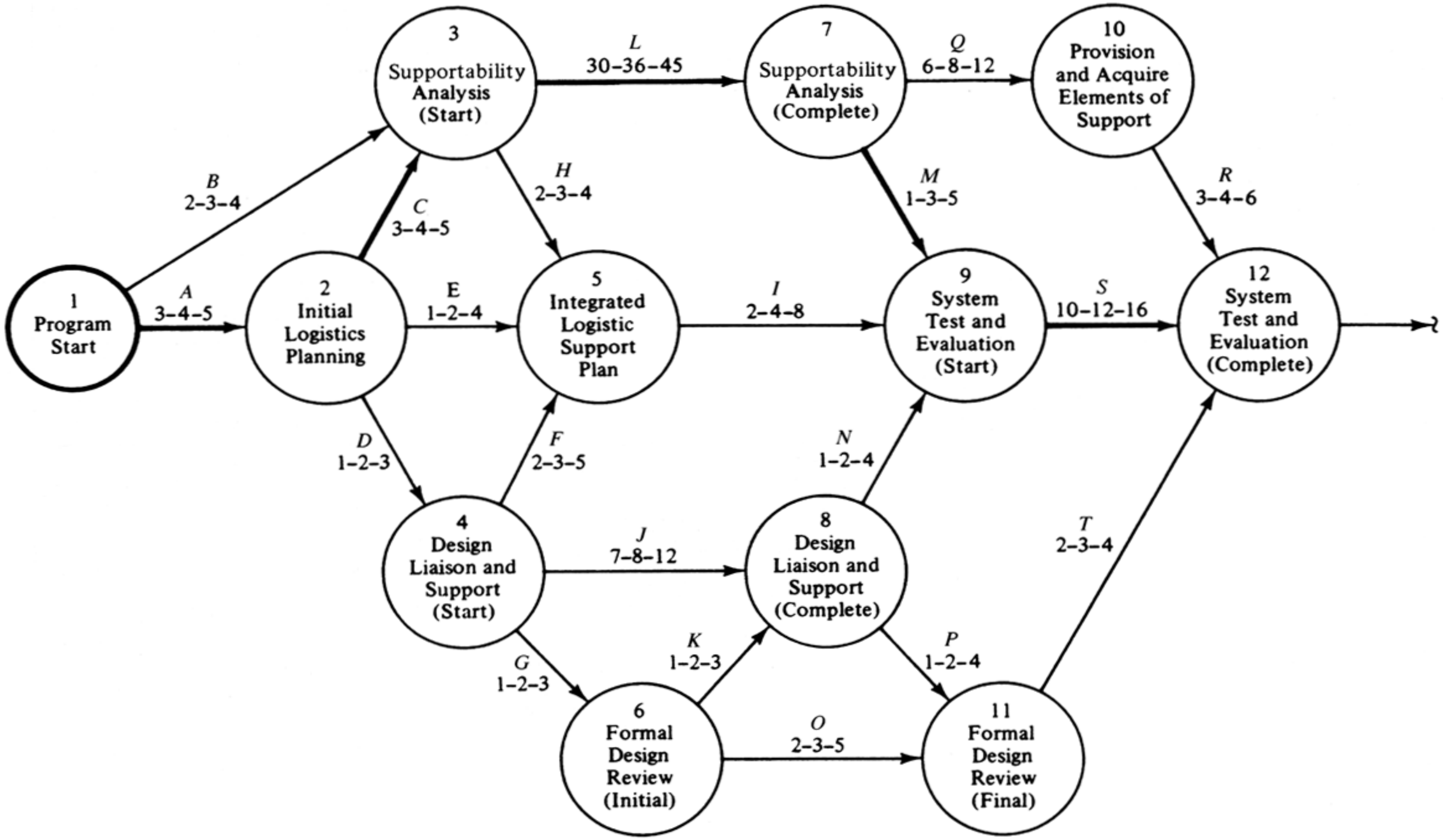
1. $t_e = \dfrac{t_o + 4t_m + t_p}{6}$

2. $\sigma_t = \dfrac{t_p - t_o}{6}$

Project Management.

[CRE Primer II 32-46]

■ Project Scheduling Method : PERT



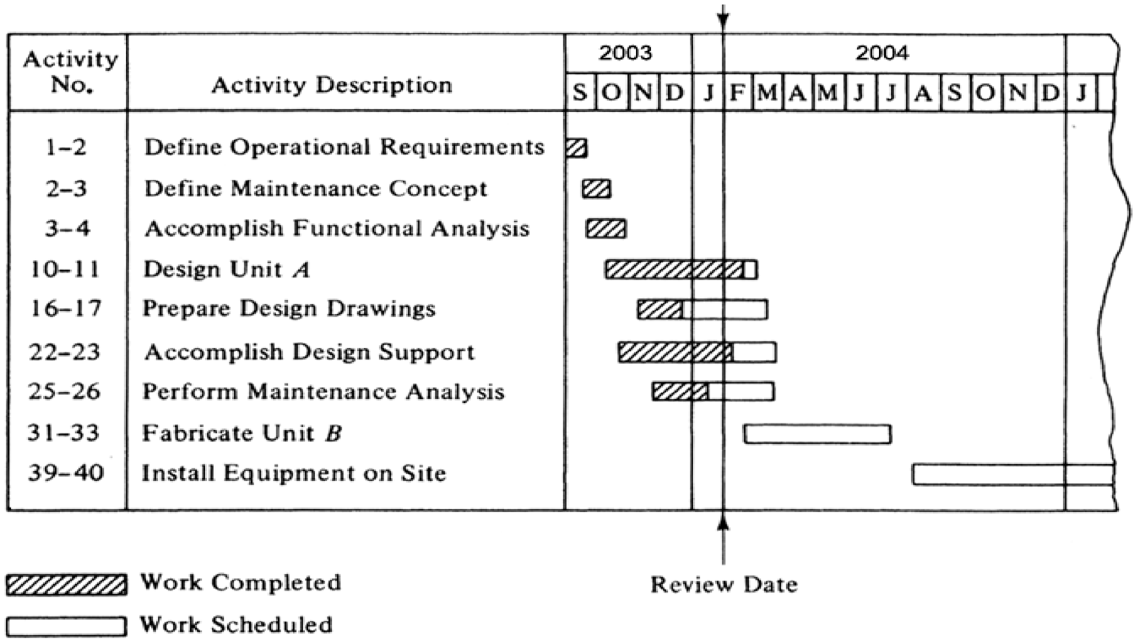
Project Management.

[CRE Primer Ⅱ 32-46]

■ Project Scheduling Method : Gantt Chart.

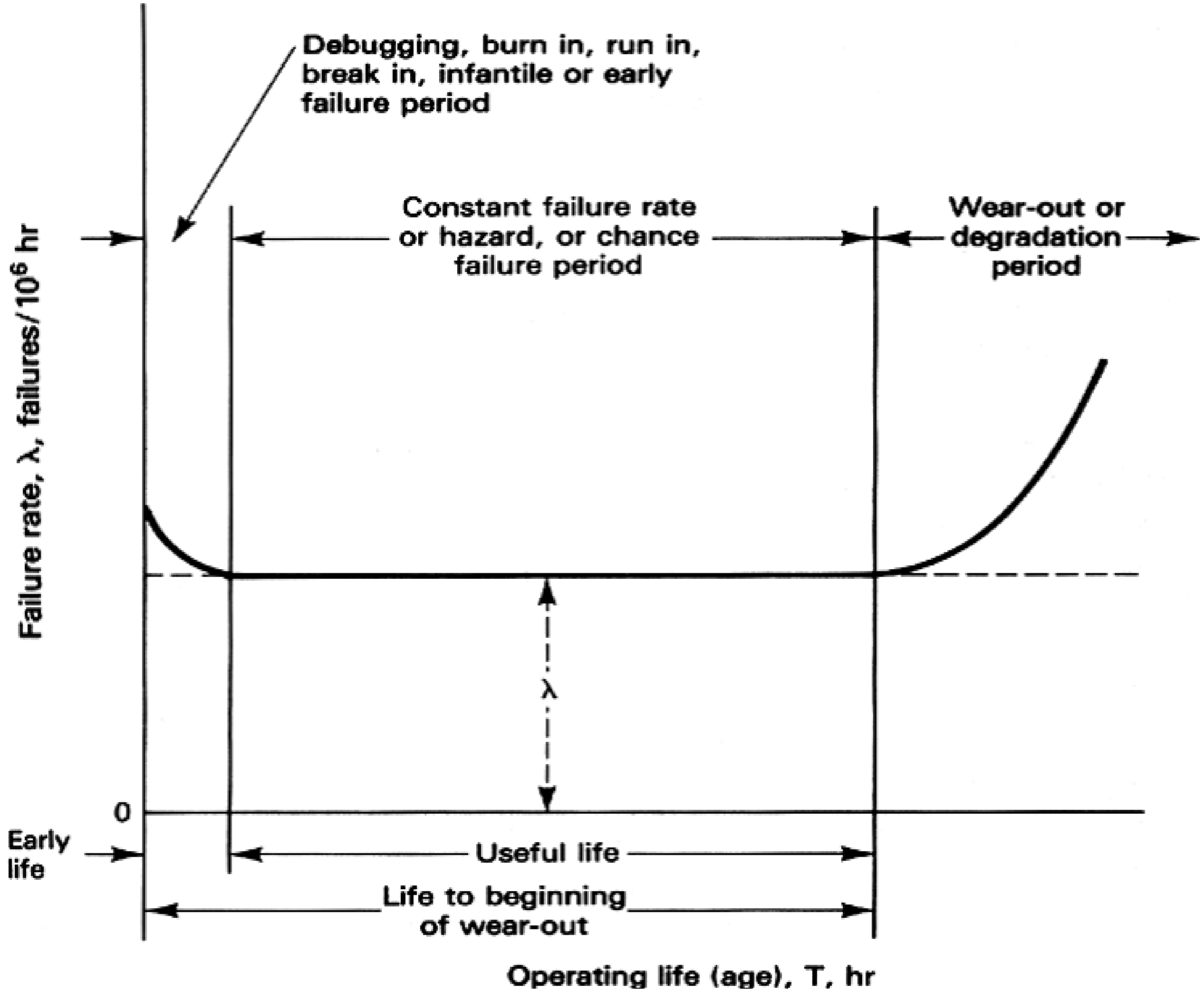
- The earliest and best-known type of planning and control chart, especially designed to show graphically the relationship between planned performance and actual performance over time.

- Roles of Gantt Chart.
  - For machine loading.
  - For monitoring job progress.



Failure Modes & Mechanisms.

[CRE Primer Ⅱ 61]



Failure Modes & Mechanisms.

[CRE Primer Ⅱ 61]

■ Infant Mortality.

- These failures are generally the result of components that do not meet specifications or workmanship that is not up to standard.
- There are not design related issues, but quality related issues.
- The infant mortality period is noted by a decreasing failure rate. The Weibull distribution is commonly used to determine when the infant mortality period is over.

■ Constant Failure Rate.

- This is called the random failure rate period.
- We can only predict the probability of a failure in a certain interval, but not a specific failure at a specific time.
- The constant failure rate period is the most common time frame for making reliability predictions, where the exponential distribution is utilized.

Failure Modes & Mechanisms.

[CRE Primer II 61]

■ Constant Failure Rate (continued).

- For exponential data, the failure rate of a product can calculated from test data.

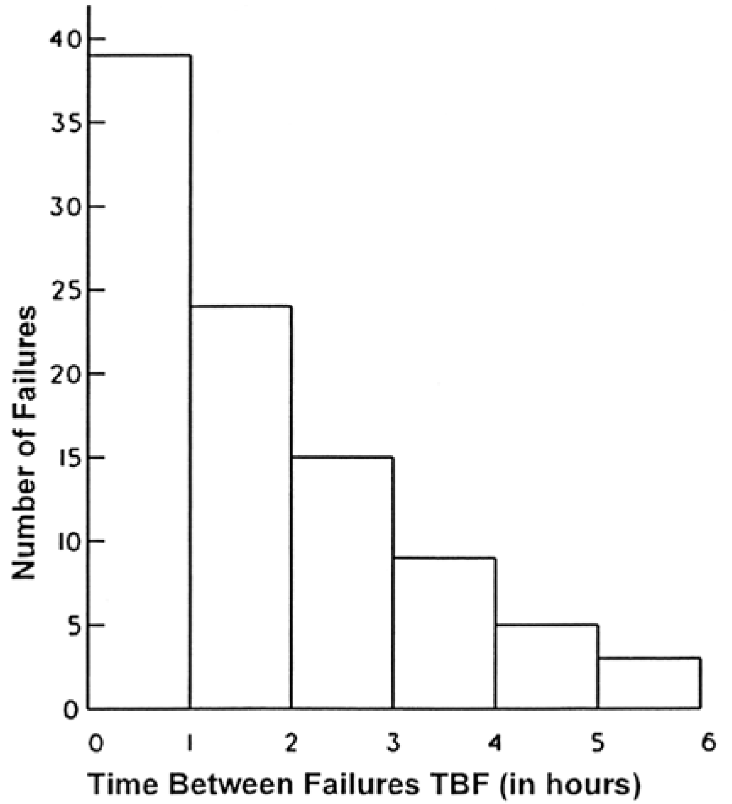
- Failure Rate & MTBF.

$$\lambda = \text{Failure rate} = \frac{\text{No. of items failed}}{\text{Total test time}}$$

$$\text{MTBF} = \frac{\text{Total test time}}{\text{No. of items failed}} = \frac{1}{\lambda}$$

- Example. If seven items are tested for 50 hours each and three item fail at 20, 38, and 42 hours respectively, item ?

$$\lambda = \frac{3}{20 + 38 + 42 + (4) \times (50)} = \frac{3}{300} = 0.01/\text{hr}$$



Failure Modes & Mechanisms.

[CRE Primer II 61]

■ Wearout Period.

- As time goes on, we see failure occurring more and more frequently to a point where it may not longer be practical to continue operating the system.
- Several distributions may be appropriate to model the wearout period.

Reliability Program Elements.

[CRE Primer Ⅱ 62-63]

■ Definition of the reliability program.

- Based on the integrated needs, objectives, and resources of the organization.

- Main considerations.
  - Defining what type of activities or tasks.
    - ⇒ Historic performance and market expectations are crucial elements.
  - Safety and liability issues associated with the product or service offering should be weighted heavily.
  - Effective use of cross-functional concurrent product and process development team.
  - Recalling that "analysis and optimization of full life-cycle cost impact"

- Results : The reliability plan and schedule.

Reliability Program Elements.

[CRE Primer Ⅱ 62-63]

- **Developing the reliability goals and requirements.**
  - Must understand the expectations of the customer and translate those expectations into realistic reliability goals.
  - The system-level goals can be allocated to subsystem level,
  - The development team can use the allocated reliability values to define component level performance and procurement specifications.

- **Design for reliability.**
  - Identifying an effective design process to meet the requirements that have been derived from customer expectations of failure-free performance.
  - Must ensure the timely delivery of a reliable end item within technological and budget constraints.
  - The application environment should be characterized and considered.
  - The manufacturing process interaction on the design must be evaluated as well.
  - The modeling and prediction techniques identified.

Reliability Program Elements.

[CRE Primer Ⅱ 62-63]

■ Assessing reliability programs.

- An iterative design activity.
- The same models and tools used to design for reliability apply to this step.
- In additions, the results of design reviews, test results, and historic product performance data are applicable.
- Reliability growth concept are useful in quantitative defining progress toward reliability goals.

■ Measuring reliability.

- The reliability of products may be measured through :
  - The analysis of test results and
  - The interpretation of actual performance data.
- The confidence level should be considered in the measurement process.
- By ensuring that a high confidence in the measured value assigned to reliability is achieved, we provide a solid basis for decision making.

Reliability Program Elements.

[CRE Primer Ⅱ 62-63]

■ Ensuring reliability performance.

- It is the step achieving customer satisfaction and "optimization of full life-cycle cost impact"
- The effective implementation of a well designed reliability program will ensure that :
  - The immediate product design will attain its reliability goals,
  - Successive related product designs will benefit from the lessons learned.
- Failure Reporting, Analysis and Corrective Action System (FRACAS).
  - A method for implementing feedback mechanisms.
  - Tracking all contribute to ongoing reliable performance.

Reliability Program Elements.

[CRE Primer II 62-63]

- **Important elements of a reliability program.**
  1. Failure reporting, Analysis and Corrective Action System (FRACAS).
  2. Design Review.
  3. Sub/Vendor Controls.
  4. Parts Control.
  5. Failure Mode, Effects, and Critical Analysis (FMECA).
  6. Reliability Qualification Testing (RQT).
  7. Predictions.
  8. Test Analyze and Fix (TAAF).
  9. Thermal Analysis.
  10. Environmental Stress Screening (ESS).

Reliability Training Program

[CRE Primer II 75-79]

■ Consideration for Training Program.

- In the process of developing a training needs assessment, consideration should be given to the following items.
  - Consideration with the goals and objectives of an organization.
  - Prioritization for activities identified as critical to the organization's success.
  - Consideration of the participants' baseline education level, work experience, desires, learning styles and training history.

Reliability Training Program

[CRE Primer Ⅱ 75-79]

- ## Development of a Needs Assessment.

1. Identify, consolidate and document key skills dimensions.
2. Define the acceptable level of competency for each skill dimension.
3. Assess the competency of the individual in each skill dimension.
4. Perform a gap analysis.
5. Document individual training plan.

Reliability Training Program

[CRE Primer Ⅱ 75-79]

■ Key concepts to apply in planning Training Programs.

- Modularization of training programs allow flexibility in application.
- Combination of a variety of media and delivery techniques.
- In order to be most effective, training must be utilized shortly after receipt to reinforce and ingrain the newly developed skills.
- Inclusion of reinforcement process throughout the proper methods and techniques.
- Validation for effectiveness and participant feedback.

Product Safety and Liability.

[CRE Primer II 80-120]

■ Introduction.

- A new force exists in the economy known as consumerism. Consumers exist in large numbers, have voting power and advocates.
- In most modern industrialized countries, customers are increasingly demanding quality, product safety, non confusing pricing and manufacturer liability.

■ Company Programs to Improve Product Safety.

- **Top management.**
  1. Commits to make and sell only safe products.
  2. Mandates formal design reviews.
  3. Establishes guidelines for product traceability.
  4. Establishes claim defense guidelines.
  5. Establishes safety performance guidelines.
  6. Assures compliance vis audits.

Product Safety and Liability.

[CRE Primer II 80-120]

■ Company Programs to Improve Product Safety (continued).

- **Supplemental organization product safety structure.**
  1. A product safety committee.
  2. Safety engineers.
  3. Outside experts for advice and audit.

- **Other key product safety organizational responsibility centers.**
  1. Product Design.
  2. Manufacturing.
  3. Quality control.
  4. Marketing.
  5. Field service.

Product Safety and Liability.

[CRE Primer II 80-120]

■ Safety Related Data.

1. The date and time of the failure.
2. The operating and environmental conditions at the time of failure.
3. A description of the failure mode.
4. The necessary actions to repair the failure, necessary equipment, and repair time.
5. What was the active operating time of the equipment ?
6. The equipment operator, along with classification and skill level.
7. An initial failure cause determination.
8. Following the initial investigation.
9. Following the root cause determination.
10. The corrective action recommendation.
11. Implementation and follow up of the corrective action.

Product Safety and Liability.

[CRE Primer II 80-120]

■ The Goal of a Safety Program.

- Provide a process for designing, assembling, and delivering safe and effective products that deliver an expected level of performance.
- Provide a process for the evaluation of system safety conformance.
- Provide the user with the safety information needed to control the risk associated with the product.

Product Safety and Liability.

[CRE Primer II 80-120]

■ Risk Management Purpose.

- Eliminate or minimize loss of life, accidents, or injuries to people.
- Reduce damage to equipment, property or the environment.
- Save resources.

■ Risk Assessment.

- A large portion of risk management activities are the risk assessments that are performed throughout the design activity. Risk assessments can be quite comprehensive endeavors. However, risk assessments cover three areas as follows.
  1. Hazard identification.
  2. Rating the hazard.
  3. Hazard control.

Product Safety and Liability.

[CRE Primer II 80-120]

■ Hazard Identification.

- The purpose of hazard identification is to show the context of the potential hazard. This context includes identifying the setting (mission profile phase), the part, the object at risk, the contributing factors, and the hazard causing the risk.

- Hazard identification approaches.
  1. The mission profile.
  2. The bill of materials.
  3. The object at risk.
  4. Table of hazards.
  5. What if analysis.
  6. Delphi.
  7. Method Organization for a Systematic Analysis of Risks (MOSAR)
  8. Hazard and Operability Study (HAZOP).
  9. Others such FMEA, PRAT and FTA.

Product Safety and Liability.

[CRE Primer II 80-120]

■ Hazard Rating System.

- After hazards are identified, they must be rated. When a hazard is rated, its frequency and severity are taken account.

- Example.

Frequency	Severity			
	Catastrophic	Critical	Marginal	Minor
Frequent	I	I	I	II
Probable	I	I	II	II
Occasional	I	II	II	III
Remote	II	III	III	IV
Improbable	III	III	IV	IV
Incredible	IV	IV	IV	IV

Hazard level.

I. Intolerable. II. Undesirable.

III. Acceptable if state of the art. IV. Acceptable.

Product Safety and Liability.

[CRE Primer II 80-120]

■ Hazard Control.

- Once the hazard level is recorded, and the present hazard reduction actions are summarized, a judgement must be made as to the efforts to reduce it further.

- Risk control activities.
  1. Use inherently safe designs.
  2. Employ protective measures, including alarms.
  3. Provide the user with residual risk information.

Some Considerations for Reliability.

■ Cost Factors.

- Reliability engineers and design engineers must achieve optimum reliability, or else costs incurred throughout subsequent operations will be greater than necessary.

■ Environmental Factors.

- In system design, there are two categories of environmental with which the reliability engineer must contend.
  1. The first is the family environment in which the components must function as a system.
  2. The second is the environment in which the system must function.

■ Human Factors.

- Human factors such as hearing and visual acuities, sex, mental and physical capabilities, and compatibility of work methods with human anatomy all can be vital factors in achieving reliability objectives.

Some Considerations for Reliability.

■ Human Factors (continued).

- **A summary of some important human factors.**
  1. Dangerous or critical controls should be made obvious, be protected with a cover, and labeled.
  2. Knobs, levers and controls should be designed for easy access; they should not protrude to permit accidentally bumping.
  3. Foot controls are best applied from the sitting position.
  4. Conditions of the work area should be appropriate. (Light, temperature, noise, and odors should be considered.)
  5. If an operation can be inherently hazardous, it should be labeled accordingly.
  6. Age, dexterity, agility, physical condition, aptitude, skill level, hearing, eyesight, mental ability, and temperament, are important factors when designing equipment, and assigning work.

Some Considerations for Reliability.

■ Simplification.

- The smallest number of components should be used without compromising performance, particularly if the design of a system is a series design.

■ Redundancy.

- Redundancy is defined as the existence of more than one means for achieving a stated level of performance.
- As parallel elements are added to such a redundant system, the reliability increases because each new element provides a different "route" or "bypass".

■ Derating.

- Derating may be applied in structural design by designing a 10,000 lb. load capability into a device when the maximum specification is 1,000 lbs.
- System reliability can be increased by designing components with operating safety margins.

Some Considerations for Reliability.

■ Fail-safe.

- If failure of the water circulation system can overheat an X-ray machine, then the machine can be designed to stop as soon as water circulation is interrupted.
- When failure to operate a product can lead to fatality or substantial financial loss, a fail-safe type design should be adopted.

■ Producibility.

- Products must be designed not only for performance, but also so that they can be produced with quality.

■ Maintainability.

- Products should be designed such that weak or marginal parts can be replaced conveniently, normal maintenance can be conducted effectively, and a field representative or user can effect planned maintenance economically without sacrificing reliability.

System Effectiveness.

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.

■ System Effectiveness Formula.

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

Reliability Functions.

[Other Resouces]

Reliability : $R(t)$

Failure Rate : $\lambda(t)$

Mean Time Between(or To) Failure : MTBF, or MTTF

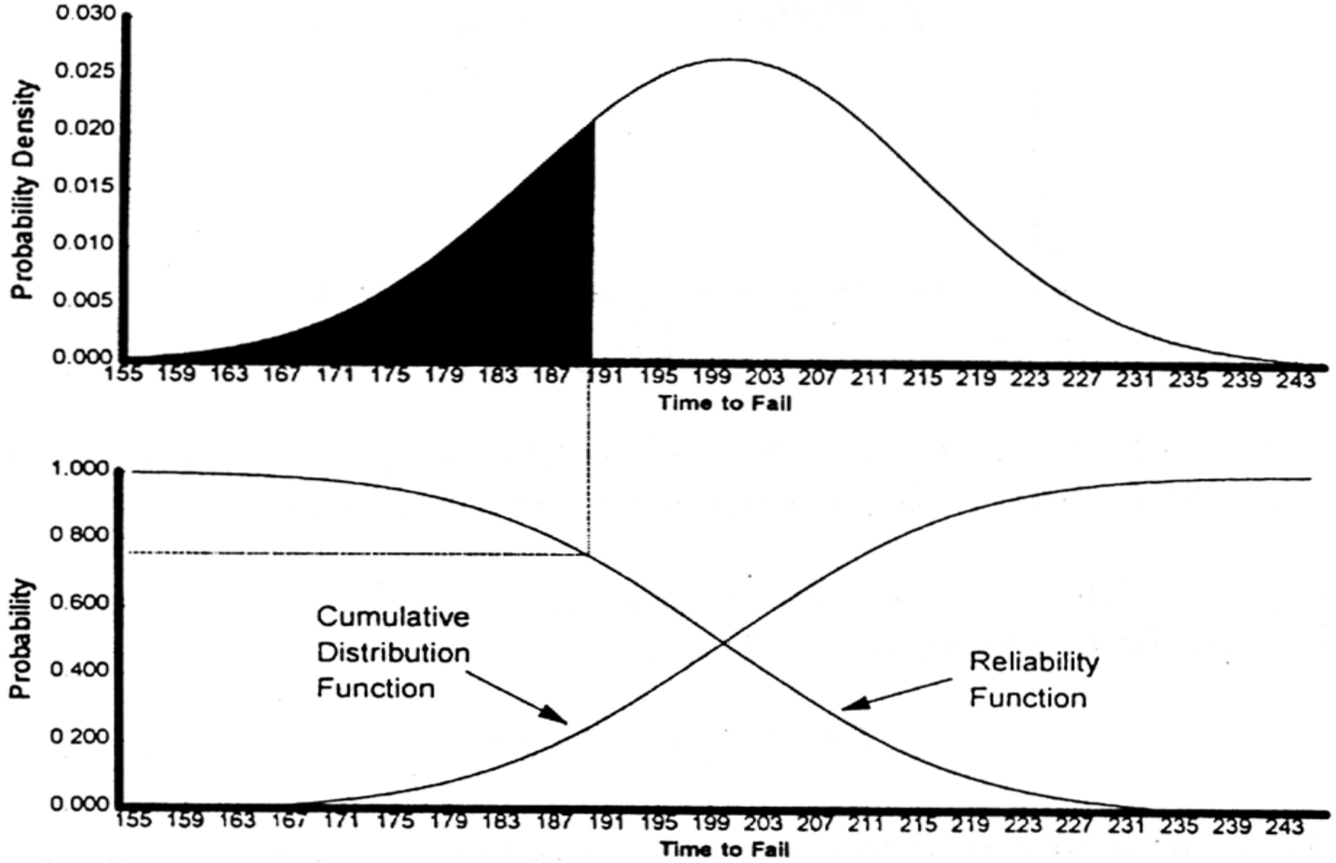
Notations.

- $R(t)$: The reliability functions.
- $F(t)$: The failure cumulative functions.
- $f(t)$: The failure density functions.
- $\lambda(t)$: The hazard functions - The instantaneous failure rate.
- N_0 : A number of identical items at time $t=0$.
- $N_s(t)$: A number of survived items at time t
- $N_f(t)$: A number of failed items at time t

Reliability Functions.

[Other Resouces]

Reliability Functions and Relationships.



Reliability Functions.

[Other Resouces]

Reliability Functions and Relationships.

1. $$R(t) = \frac{N_s(t)}{N_0} = \frac{N_0 - N_f(t)}{N_0} = 1 - \frac{N_f(t)}{N_0} = 1 - F(t)$$

2. $$f(t) = \lim_{\triangle t \to 0}\left[\frac{1}{N_0}\frac{N_s(t) - N_s(t+\triangle t)}{\triangle t}\right] = -\frac{1}{N_0}\frac{d}{dt}N_s(t)$$ (where $N_s(t) = N_0 R(t)$)

$$= -\frac{d}{dt}R(t) = \frac{d}{dt}F(t)$$

3. $$\lambda(t) = \lim_{\triangle t \to 0}\left(\frac{1}{\triangle t}\right)\left[\frac{\nu\text{mber of failure} \in (t, t+\triangle t)}{\nu\text{mber of survivors at } t}\right]$$

$$= \lim_{\triangle t \to 0}\left[\frac{1}{N_s(t)}\frac{N_s(t) - N_s(t+\triangle t)}{\triangle t}\right] = -\frac{1}{N_s(t)}\frac{d}{dt}N_s(t)$$

$$= \frac{N_0 f(t)}{N_s(t)} = \frac{f(t)}{R(t)}$$

Reliability Functions.

[Other Resouces]

Reliability Functions and Relationships.

4. $\lambda(t) = \frac{f(t)}{R(t)} = \frac{-\frac{d}{dt}R(t)}{R(t)} = -\frac{d}{dt}[\ln R(t)]$

$$\ln R(t) = -\int_0^t \lambda(t)dt + c$$

(where $t=0$, $R(t)=1$, then $c=0$)

$$\therefore \quad R(t) = e^{-\int_0^t \lambda(t)\,dt}$$

5. $f(t) = \lambda(t) \cdot R(t) = \lambda(t) \cdot e^{-\int_{-\infty}^t \lambda(t)\,dt}$