An Integrated RAM Approach to System Design and Support

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Challenge

"The operations and support phase of the system life cycle is the time during which the products of the system development and production phases perform the operational functions for which they were designed. In theory, the tasks of systems engineering have been completed. In practice, however, <u>the operation of modern complex systems is never without incident</u>."

Kossiakoff, A., Sweet, W., *Systems Engineering Principles and Practice*

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Reliability, Availability, Maintainability

- The most important aspect of O&S design
- Directly influences:
  - Operational effectiveness
  - Safety
  - Supply support
  - Maintenance planning
  - Manpower and personnel
  - Cost
- Indirectly influences:
  - Management of the Supply Chain
  - Technical Data
  - Facilities
  - Support Equipment

Failure Due to a Bad Design

Tacoma Narrows Bridge
07 November 1940

Tacoma Narrows Bridge
2006

Failure Due to Multiple Factors

Interstate 35 Bridge, Minneapolis, MN, 01 August 2007

-Excessive loads – using the bridge in an unintended environment

-Undersized gusset plates – poor design

-Corrosion – improper maintenance

-Design – geometric failure (bowing of the U10 joint)

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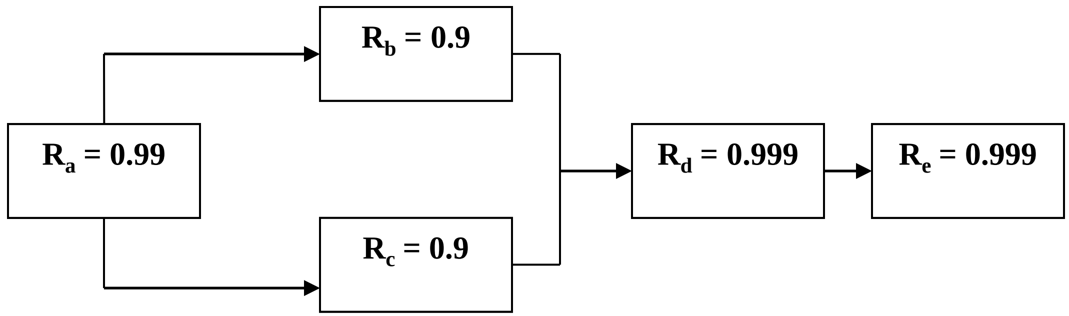
Program Failure Waiting to Happen

- "The reliability for the ABC system shall be 0.97 and it is listed in the Capabilities Development Document as a Key Performance Parameter."
- "How did you arrive at 0.97? Was it derived mathematical based on similar systems, what current technology can allow, or on requirements for mission success?"
- "None of the above - 0.97 is what the user thinks he can live with."

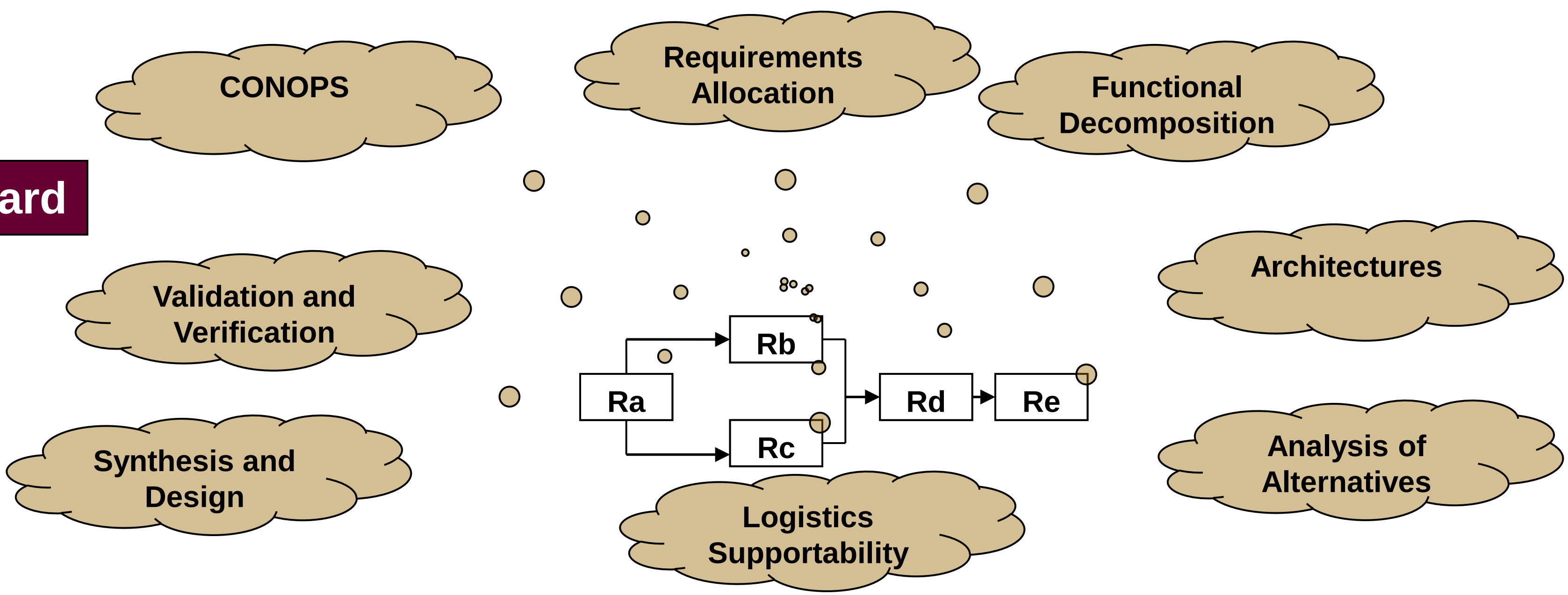
Calculating Reliability

System Schematic

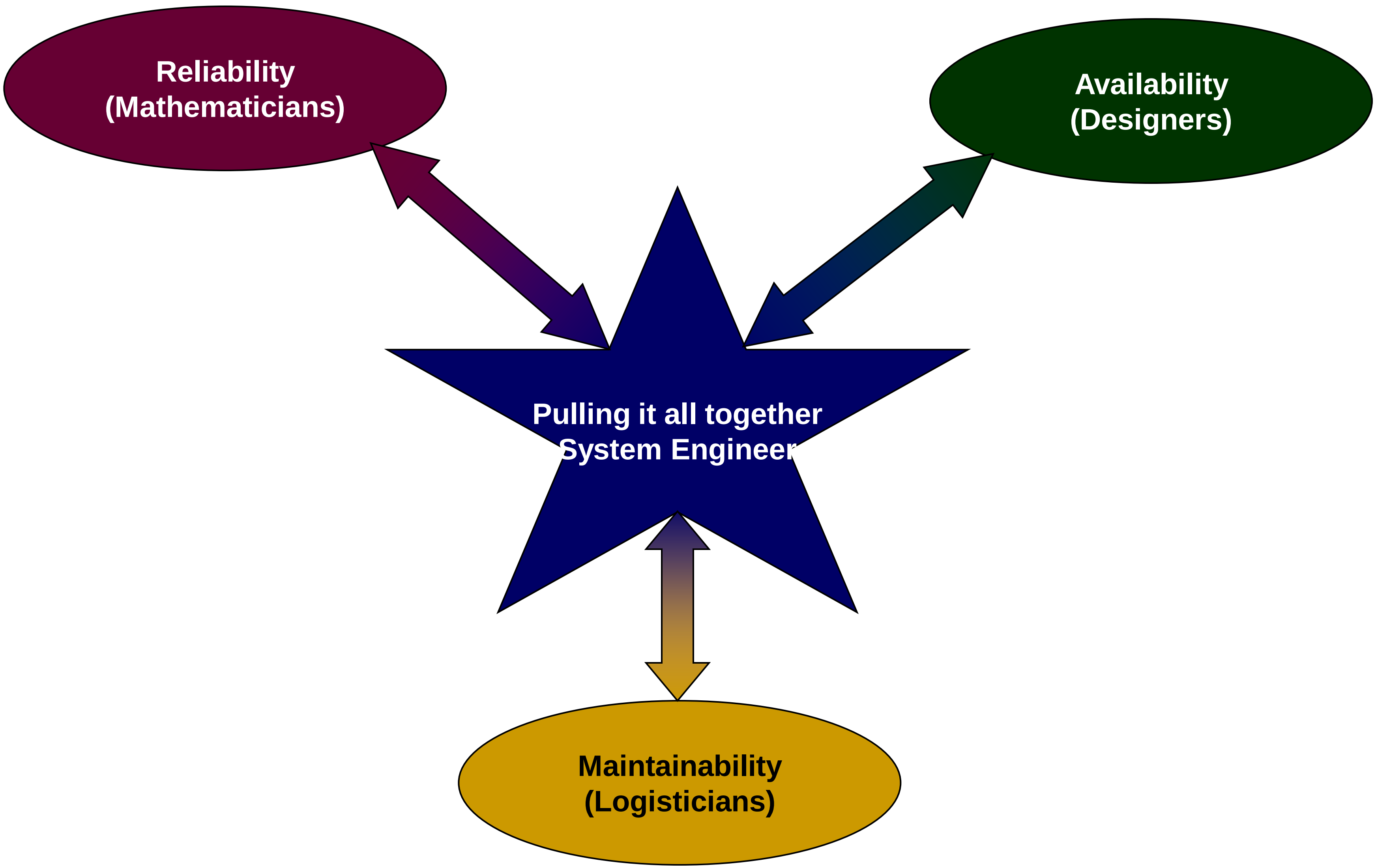
Easy



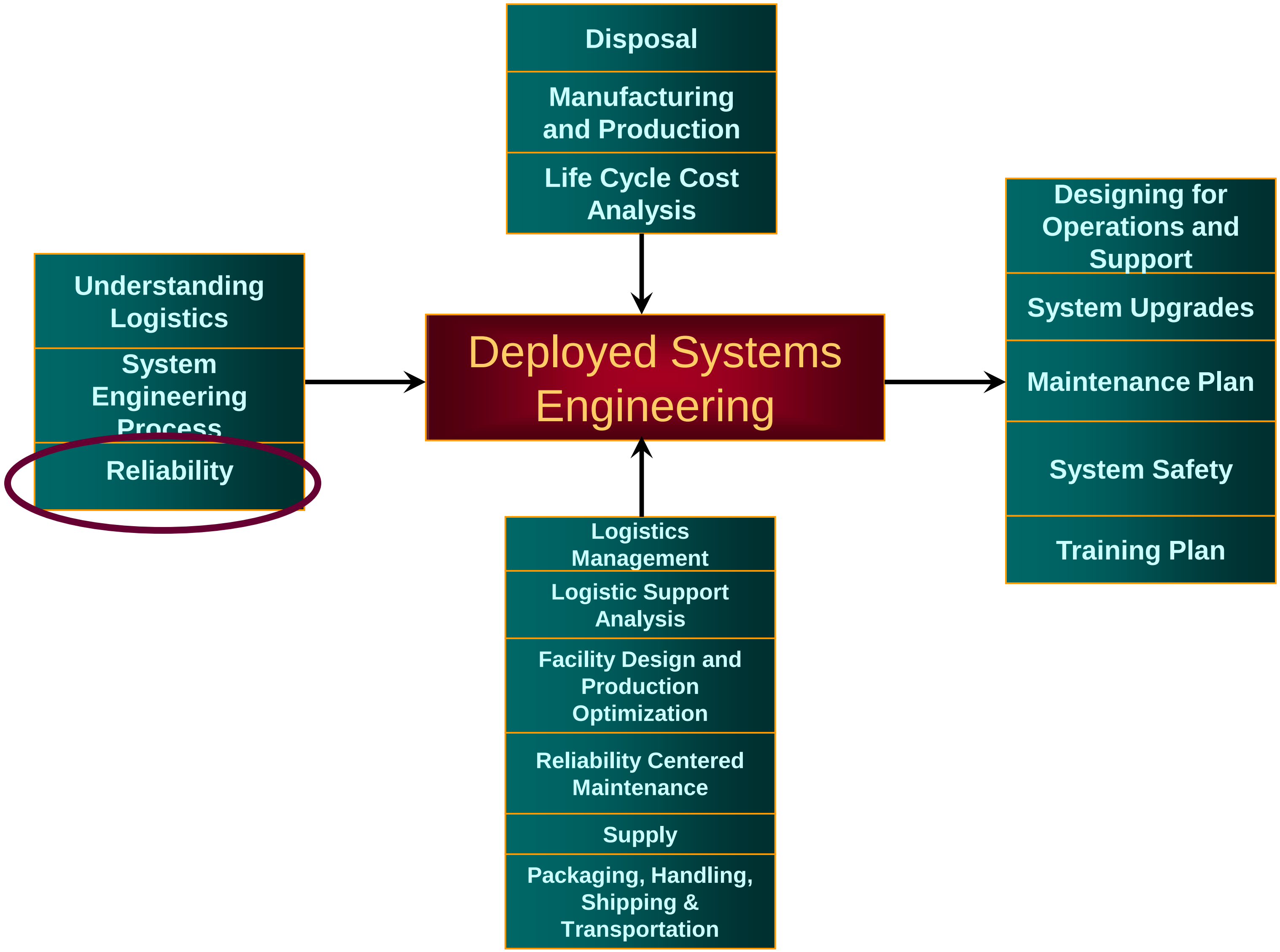
Hard



What’s Behind the RAM?



Structured Analysis for Deployed Systems Engineering



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Limitations/Constraints

- Availability of data
  - Historical, analogy, parametric analysis
- Use of the correct reliability prediction model
  - Do you have a clear understanding of system?
- Understanding/modeling of operational environment
  - Will not account for all of the factors that affect system reliability
- Accounting for operation of the system itself
  - User may not employ the system as designed

100% reliability does not exist because of cost, acceptability of failure, and in truth…it is impossible to obtain

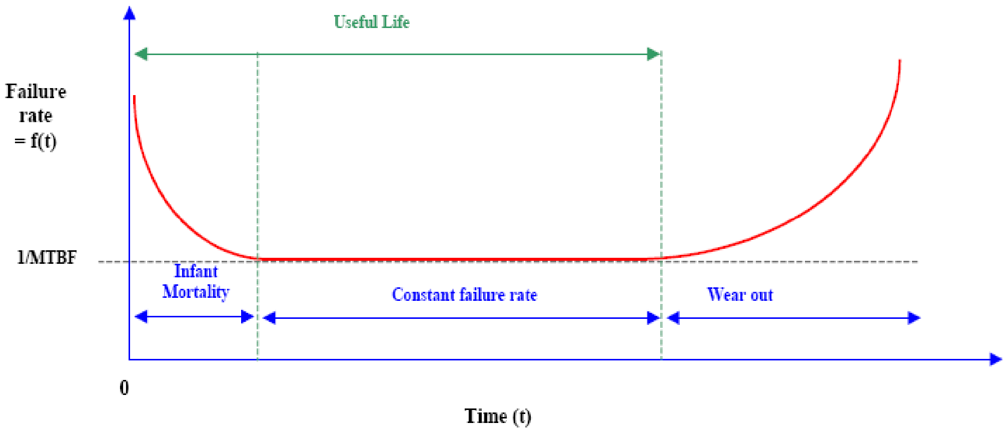
Stakeholders/Contributors

- Similar systems in a similar environment
  - Data can help determine the reliability of the new system
- System designers
  - Account for reliability throughout the design
- Evaluators
  - Assess if the system meets reliability requirements
- Manufacturers
  - Affects system assembly <u>and</u> quality control
- Product introduction team
  - Early barometer of system’s reliability
- Product support team
  - Best assessment of reliability in system design
- Users and maintainers
  - Ultimately affects system performance; perhaps more than any other measure

Do’s and Don’ts in Reliability Applications and Analysis

Addressing Reliability

- Do you truly understand the problem at hand?
  - Environment, requirements, CONOPS
- Have you set the boundary conditions?
  - Assumptions, limitations
- Have you correctly assumed equilibrium?
  - Modeling
- Can you solve for the unknowns?
  - Design and verification



- This can be a typical behavioral model for an organic and inorganic system – looks fairly benign
- In reality, randomness, environmental effects, catastrophic events, etc., will skew the outcome

Failure Due to a Bad Design

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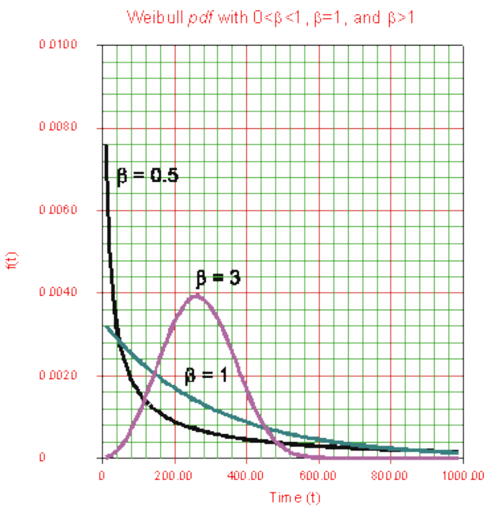
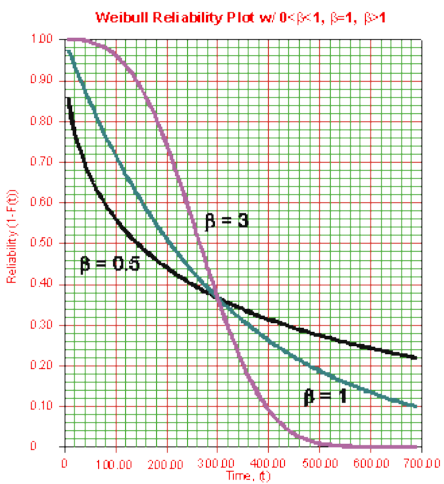
Some Basics

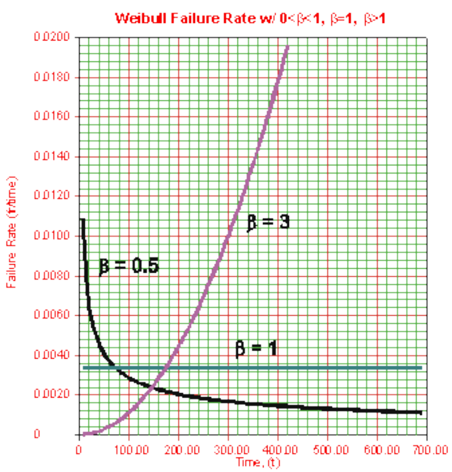
- Select the correct probability distribution function
  - Exponential
    - Constant failure rate model for continuously operating systems
    - Probability of failure for some time period in the future is independent of age (i.e., “memorylessness”)
  - Normal
    - Summing of random effects
    - Assumes independence between events
    - Events equally weighted (or no one which is dominant)
- Look at component interactions and interfaces
  - Conditional probability
- Consider redundancy in design
  - Be careful!
- Don’t be afraid of Weibull

Weibull Distribution

- Most widely used in reliability calculations
  - Appropriate use of parameters can model a variety of failure rate behaviors (2 and 3 parameter distributions)
- Used to calculate wear in and wear out phenomena as well as constant failure rates
  - Take on shape of other distribution functions by varying its shape parameter







Why Weibull?

- Exponential assumes all units are being utilized in exactly the same manner and are exposed to the same stresses
- However…
  - Failure characteristics vary depending on their usage
  - Failure distributions are different for different types of systems (e.g., mechanical versus electronic)
- Normal, Lognormal and Weibull distributions are time dependent
  - That is, reliability of a device is a strong function of its age
  - Require at least two parameters
- Weibull looks at historical data or data from a similar system being used in a similar manner to make predictions on behavior and failures

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Applying FMECA

1. Define System Requirements
2. Accomplish Functional Analysis
3. Accomplish Requirements Allocation
4. Identify Failure Modes
5. Determine Causes of Failures
6. Determine Effects of Failure
7. Identify Failure Detection Means
8. Rate Failure Mode Severity
9. Rate Failure Mode Frequency
10. Rate Failure Mode Detection Probability
11. Analyze Failure Mode Criticality

Upfront SE processes are required if the analysis is to be successful

Blanchard, Benjamin S., "Logistics Engineering and Management (Sixth Edition)"

Failure Interactions

- Best analyzed through Markov Analysis and state diagrams

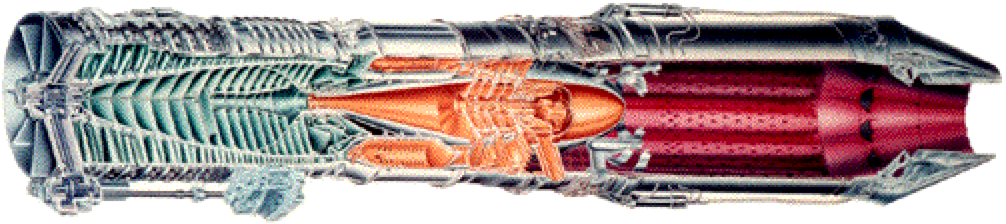
- Calculates reliability for the following scenarios
  - Independent components
  - Load-Sharing systems
  - Standby systems
    - Idealized system
    - Failures in standby state
    - Switching failures
    - Primary system repair
  - Multi-component systems
  - Combination of systems

- Availability
  - Standby redundancy
  - Shared repair crews

Example

Systems Approach to Reliability

- Reliability can only be increased if:
  - Component reliability is increased through design optimization
  - Component redundancy is built into the system
  - Interactions between the components are understood to a very high degree



Is a single engine failure an independent event?
If not, do you understand the collateral effects?
How do you model them to predict single engine failure?

Summary

- Requirements
  - Understand early in system development the reliability expectations
  - Determine if they are achievable
- Functional analysis and allocation and its effects on reliability
  - Best accomplished through a FMECA
- Synthesis
  - Build reliability into the design via component/subcomponent design, minimization of component interactions and redundancy
- Feedback
  - Predict component and system behavior via probability analyses (e.g., Weibull distribution function, M&S, etc.)
  - Determine if the initial design will meet performance and cost constraints; iterate and refine as required
- Verification
  - Ensure the test and evaluation activities address those areas that will provide the greatest visibility into system reliability; this is often overlooked
- Specification
  - Hold the manufacturer accountable for all aspects of reliability in the design