Build4Scale
U.S. Department of Energy

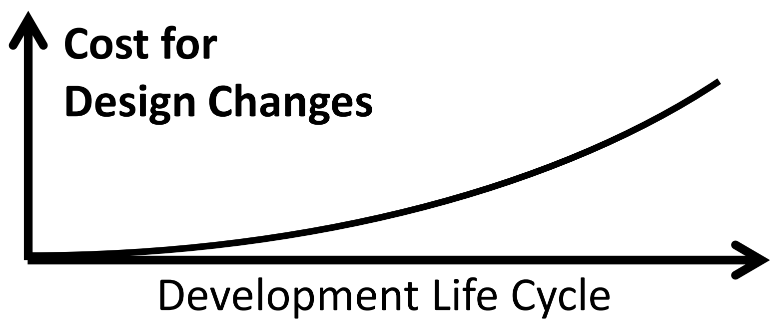
Design for Manufacturing, Assembly, and Reliability

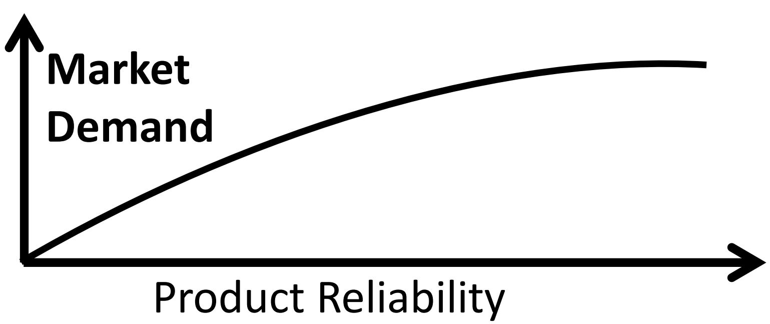
Module 3E Design for Reliability

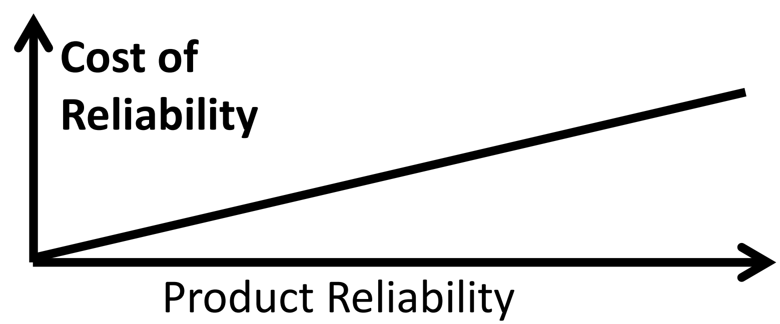
Motivation

Why is this module important?

- Product reliability problems are easier and cheaper to fix early in development lifecycle



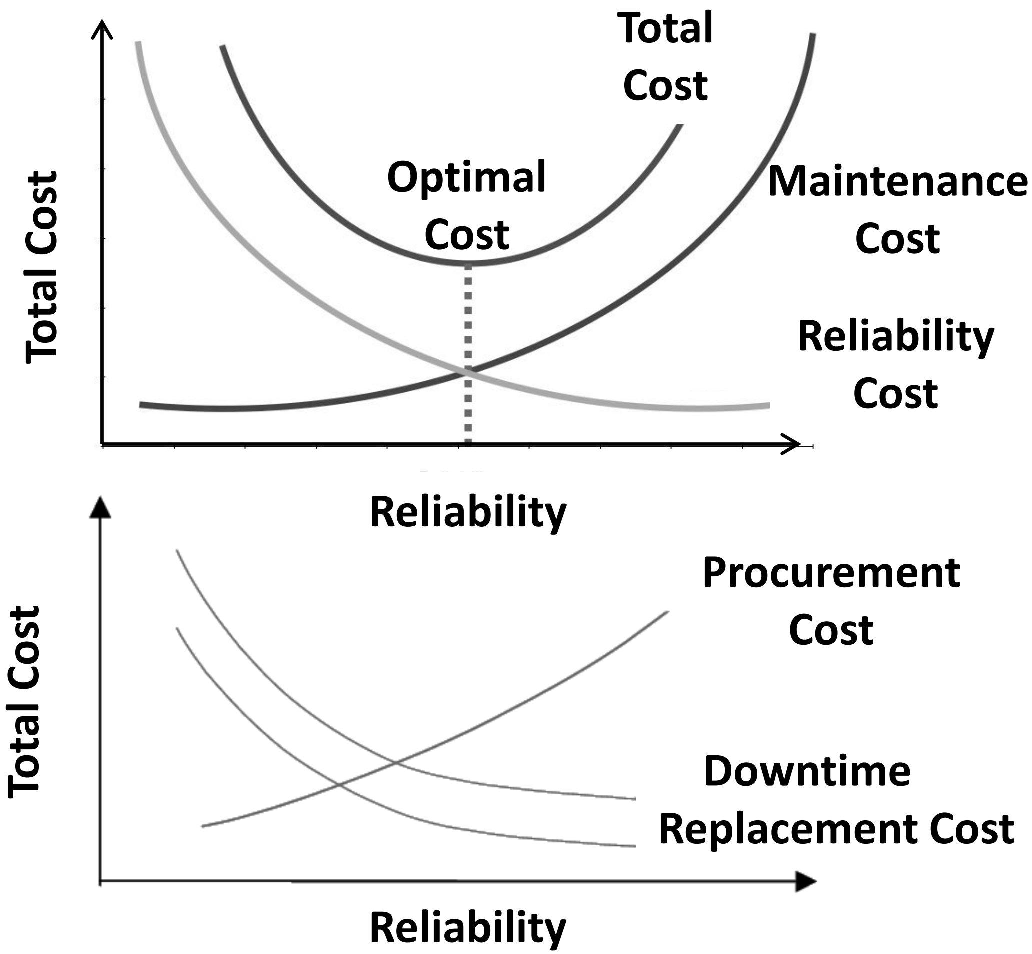




Motivation

From the customer perspective

- Balance maintenance and reliability cost
- Balance procurement cost with downtime and replacement cost



Source: https://www.researchgate.net/figure/258121389_fig1_Figure-1-The-costs-of-TCO-versus-product-reliability
https://www.fiixsoftware.com/blog/focus-availability-cost-reduction/

Motivation

Key drivers

Reliability goals and plans drive:

Design prioritizations:

- Avoid under-reliability and customer dissatisfaction costs
- Avoid over-reliability costs without increase to market demand (i.e., reliability that is higher than the customer is willing to pay for)

Schedule predictability:

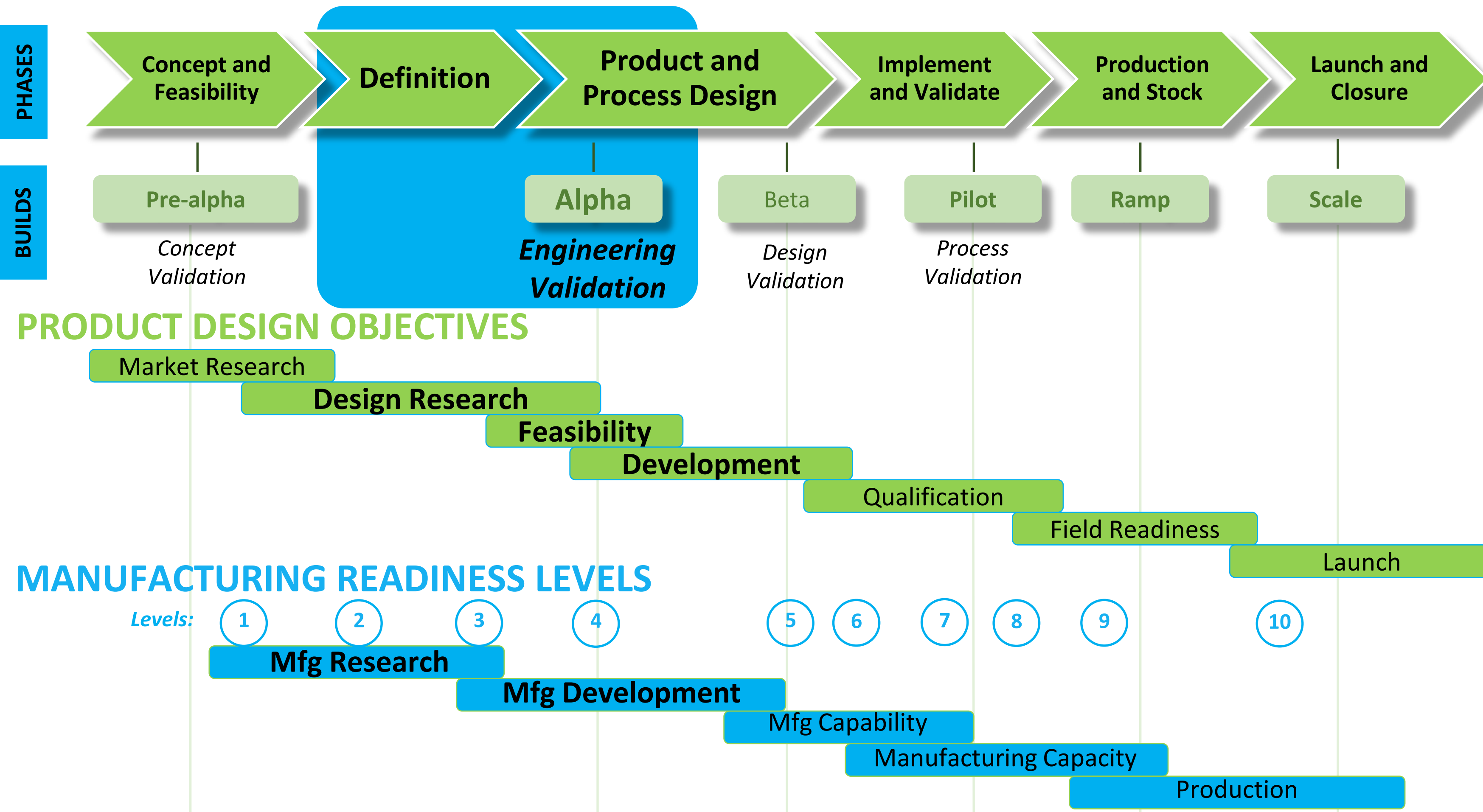
- Avoid time-to-market delays and cost implications

Failure-rate predictability:

- Warranty burden and service costs

Design For Reliability

Where does this fit into the development cycle?



Module Outline

- Learning objectives
- Reliability process overview
- Establishing reliability goals
- Reliability driven product design
- Available tools and partners
- Links to other relevant modules

Learning Objectives

- LO1. Understand importance of reliability goals and how to set them
- LO2. Understand strategies for managing reliability goals throughout product lifecycle
- LO3. Understand available tools and partners to assist "Design for reliability"

Reliability Process Overview

Key drivers and lifecycle review

PHASES	Concept and Feasibility	Definition	Product & Process Design	Implement and Validate	Production and Stock	Launch & Closure
RELIABILITY	Establish Preliminary Reliability Plans	Set the Reliability Goals for the Product(s)	Design and Implement the Reliability Case for the Product(s) to Support	Verify the Product Reliability from Initial Product Builds. Refine the Reliability Case	Validate Product Reliability from Initial Production	Validate Product Reliability from Production and Customer Feedback

- Converting market/customer requirements into consistent (i.e., reliable) product realization
- Reliability involves activities throughout the product lifecycle

Reliability Process Overview

Objectives

Reliability testing objectives by build version:

- **Pre-alpha testing**: establish reliability goals
- **Alpha testing**: test and refinement of the product design
- **Beta testing**: test and refinement of manufacturing processes
- **Pilot**: validate design and manufacturing before production
- **Production ramp**: validate warranty and service impacts

Tip: Product reliability and warranty burden implications are realized after launch, but proper design for reliability enables accurate predictions to be made and corrective actions to be implemented much earlier in the production process

Reliability Process Overview

Accountability

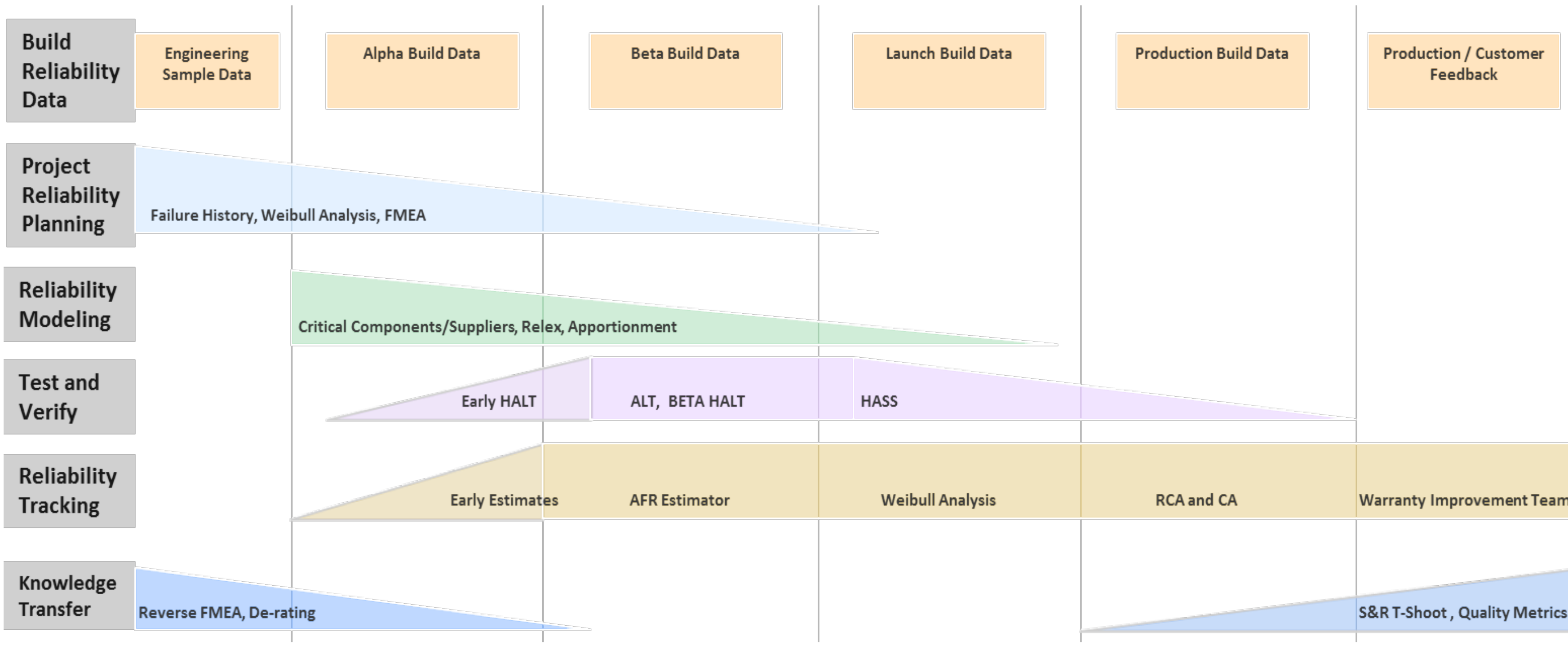
Broad engineering roles/teams/responsibilities:

- **Design (Research and development [R&D])**: functionality, usability, reliability, performance, serviceability, and manufacturability
- **Manufacturing**: design specification conformance at production capacity
- **New product introduction (NPI) process**: translate design into processes for production ramp (can be owned by design team, manufacturing team, or some combination of teams)
- **Other teams**: marketing, quality, technical publications, service and repair, finance, etc.

Tip: For proper accountability, the design team needs to remain involved after NPI handoff in order to prove that reliability goals are being met

Reliability Program Plan

Example – A good plan



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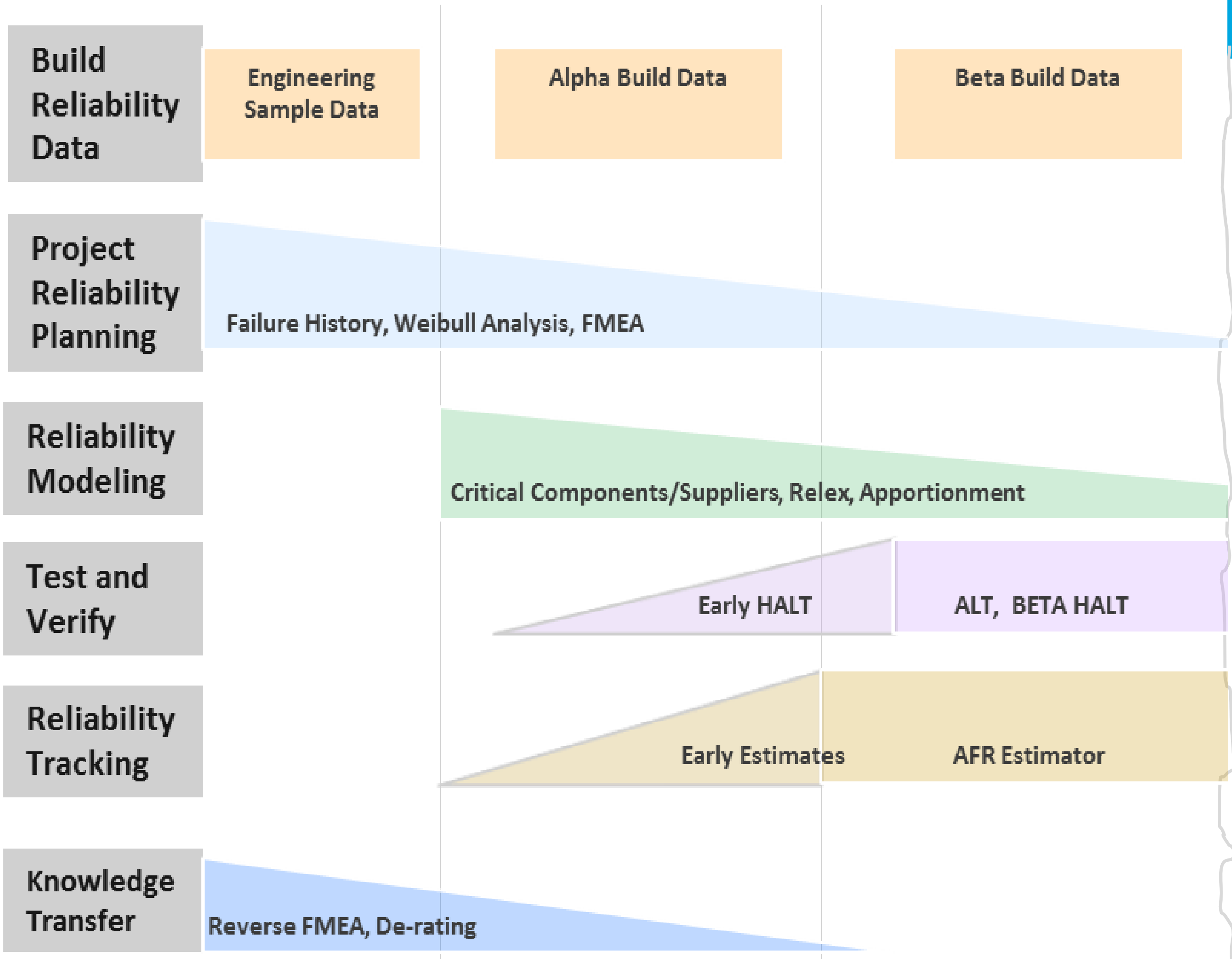
Reliability Program Plan

Example – A good plan (cont.)



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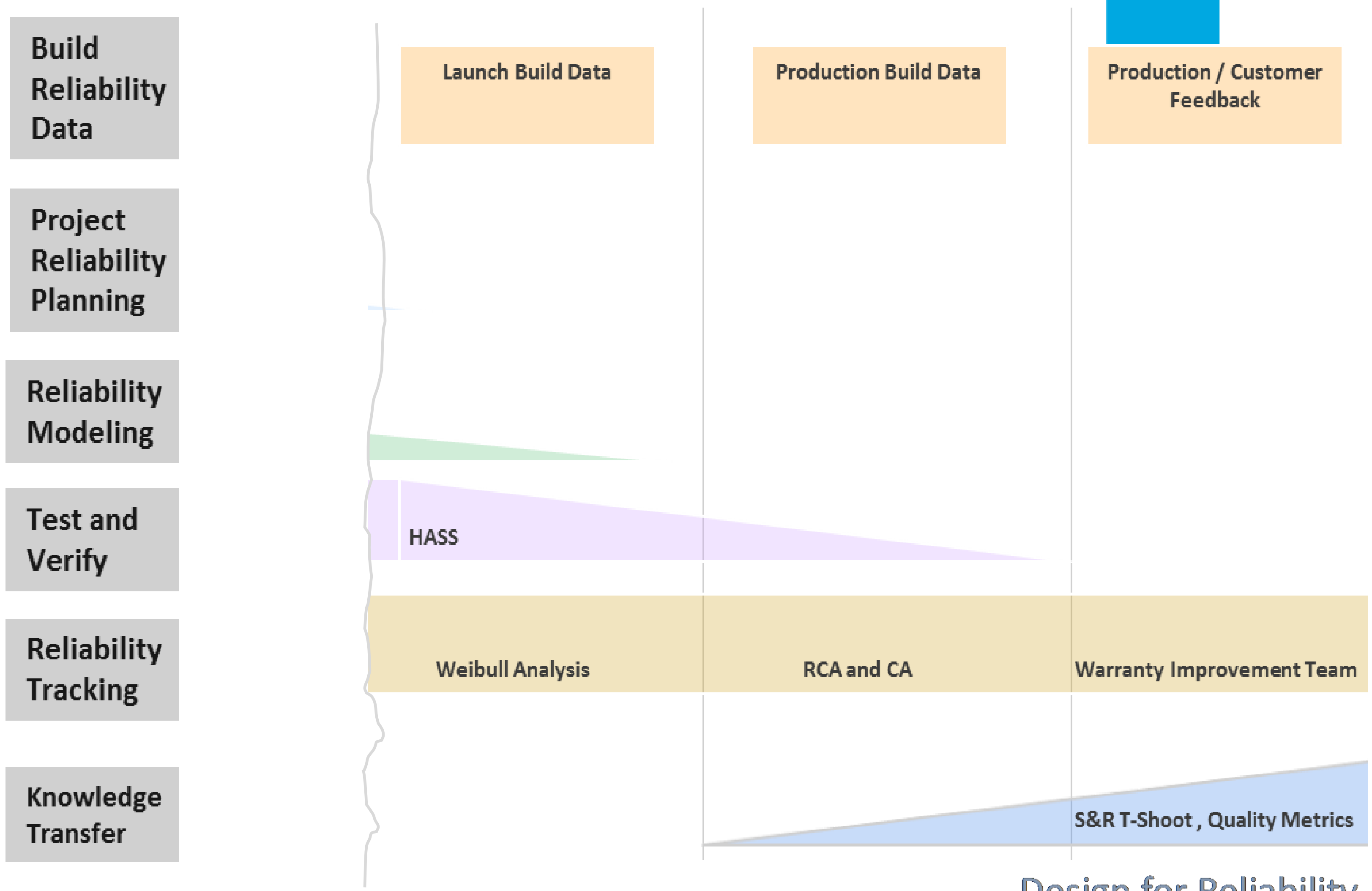
Reliability Program Plan

Example – A good plan (cont.)

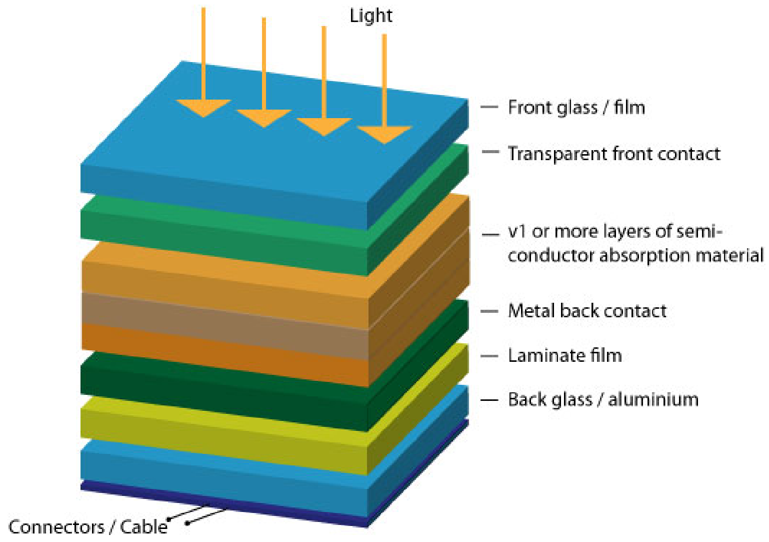


Reliability Planning

Example – A poor plan

Background:

- Jane Doe Solar Panel company did not understand market requirements for long-term usability versus the less important need for consistent energy conversion over life. In addition, they had no strategy in place to manage their design for reliability (including early reliability testing).

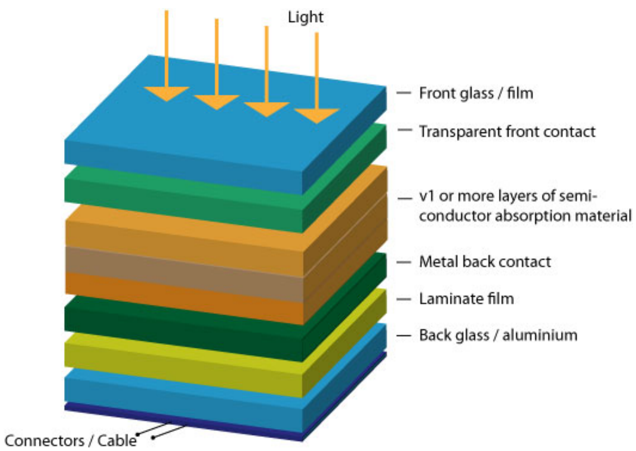


Reliability Planning

Example – A poor plan (cont.)

Result:

- They over-invested time and money in coatings and materials development to maximize energy conversion stability. The resulting schedule slips motivated them to under-invest in reliability and deliver products that often failed after a few years. A design correction was possible, but the problem was not identified until well after many products had been in service.



Establishing Reliability Goals

Primary considerations

- **Market differentiation:** will customers pay for higher reliability, and how will the marketing/sales group define "higher reliability" to customers?
- **Total cost (TC):** what are the cost implications of higher or lower reliability?

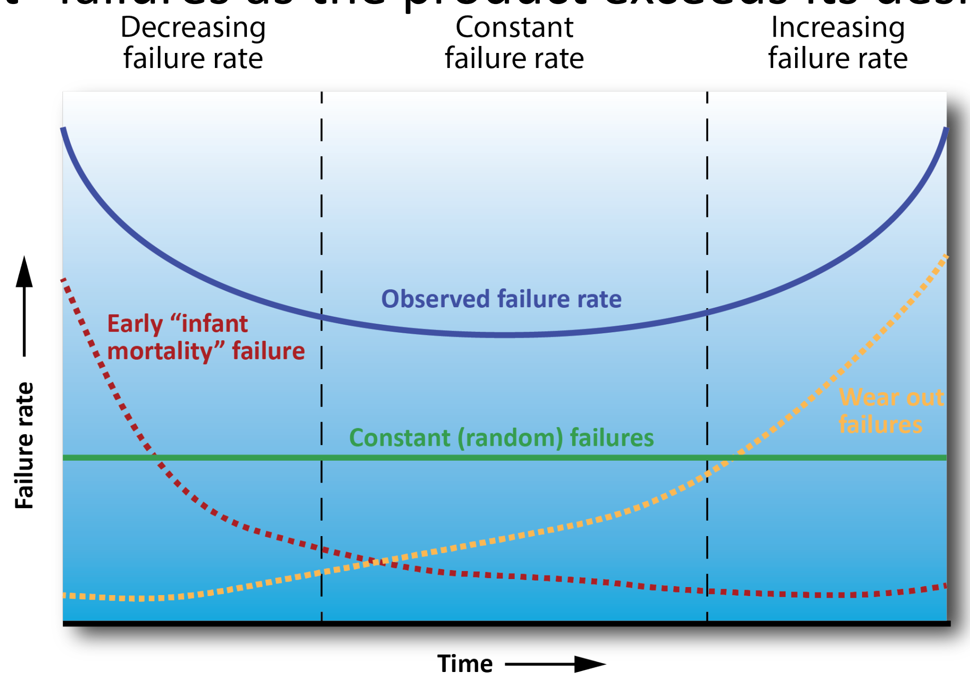
- **Brand power:** what are the positive and negative effects on overall product brand?
- **Consequence of failure:** are there safety or other property damage concerns to consider?

Tip: Start with preliminary reliability goals up front and gather information throughout product development to refine the goals appropriately. Use reliability knowledge from past products to improve future products.

Reliability Bathtub Curves

Overview

- The bathtub curve is generated by mapping (1) the rate of early “infant mortality" failures when first introduced, (2) the constant rate of “random” failures during its useful life, and (3) the rate of “wear out" failures as the product exceeds its design lifetime



See Module 4C and 7C for more bathtub curves

Source: https://en.wikipedia.org/wiki/Bathtub_curve

Quality Goals

Establish these prior to product design

- ☐ **Early failure rate (infant mortality)**: typically caused by manufacturing, assembly, shipping issues

Example: less than one percent in first 90 days

- ☐ **Design reliability goal (constant rate failures)**: typically drives the component selection and design strategy

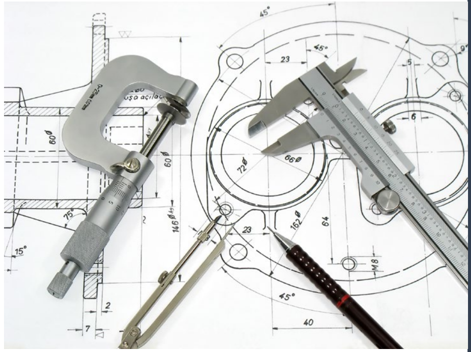
Example: 90 percent system survivability at year five at 25°C (or other environment/use parameters)

- ☐ **Design life goal (wear out)**: this is the point where the components selected will start to wear out

Example: seven years at 25°C (or other environment/use parameters)

Reliability-Driven Design

Decision tradeoffs



- Reliability-driven design facilitates intelligent design-tradeoff decisions
- Cost/benefit analysis used for selecting best approach

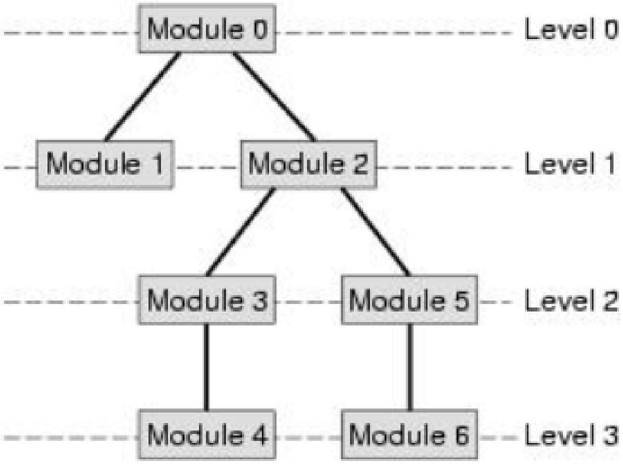
Example design and decision alternatives:

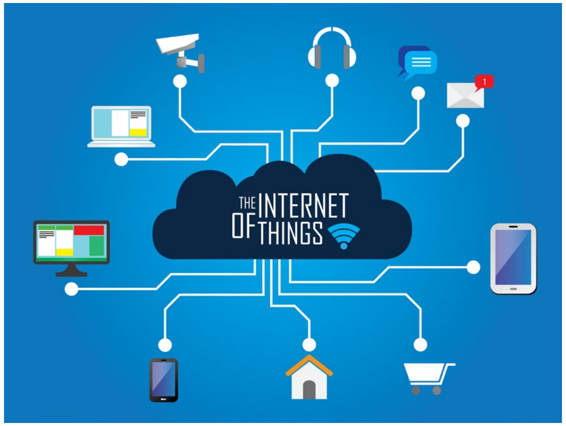
- Overdesign versus replacement or repair strategy for unreliable component/subsystem
- High factor of safety conservative design versus plan for 100% inspection on critical components
- Computer simulation of performance versus functional physical testing
- Product screening tests with high rejection rates versus higher quality manufacturing or design without screening test

Design Considerations

Reliability, test, inspection, and repair

- **System complexity**: number of subsystems, interdependence between subsystems
- **Modular design**: easier to troubleshoot and repair
- **"Smart" design**: embedded sensors or firmware/software indicators to reveal when and where failures occur (consider whether this can be part of an "Internet of Things (IoT)" strategy for pre-emptive failure intervention)

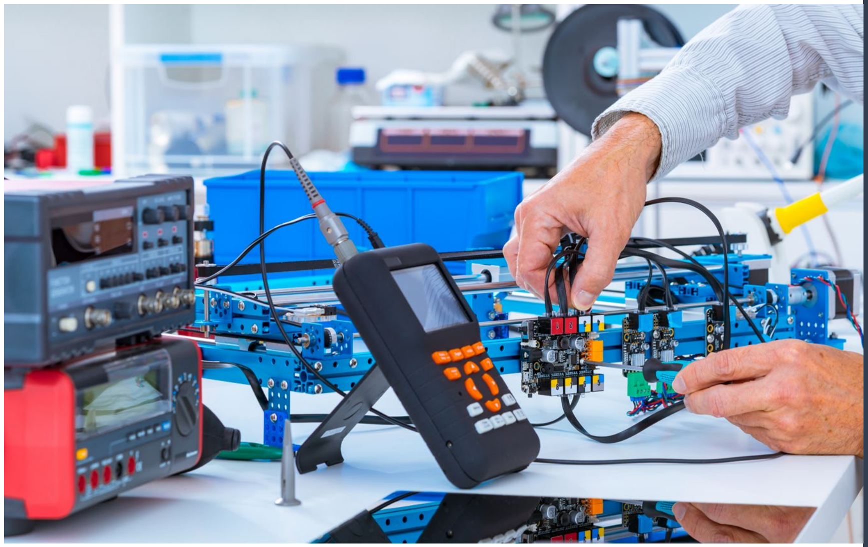




Design Considerations

Reliability, test, inspection, and repair (cont.)

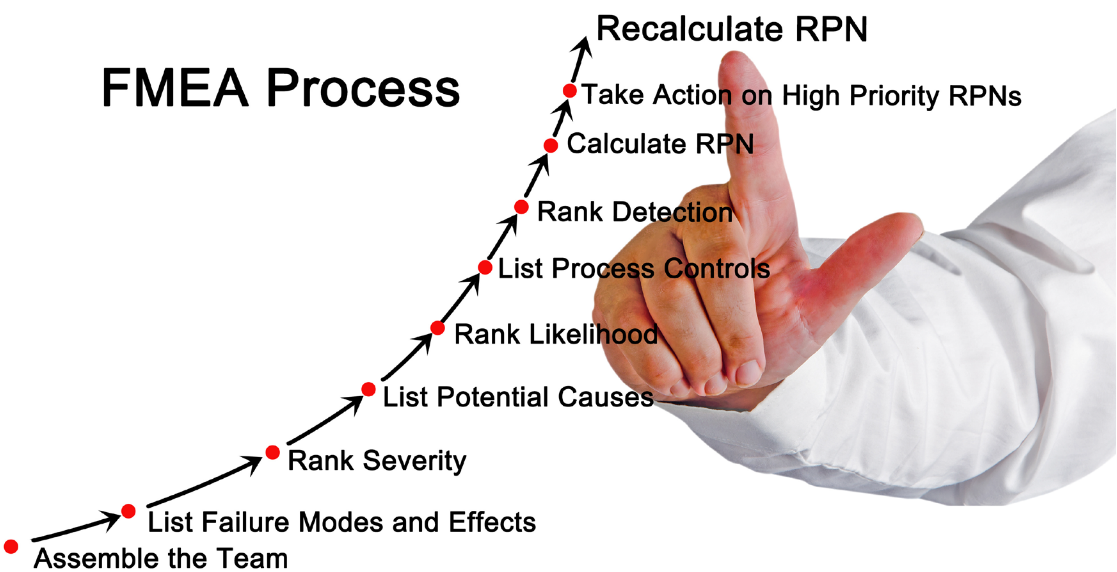
- **Packaging and shipping**: ease of packaging, durability through shipping, durability through unpacking and set-up
- Design for self-diagnosis and repair
- Design for part replacement
- Design for redundancy or overdesign



Reliability Tools

Risk analysis, priorities, and initial predictions

- **Failure Mode Effect Analysis**: Predicting potential failures and comparing overall impacts for prioritizing risks and mitigation options
- Historical data (i.e., service, repair, field failure rates, warranty data) useful starting point for reliability predictions and decisions



See Module 2C and 4A for more on FMEA

Reliability Tools

Data collection

- Reliability databases (i.e., in Relex software)
- Online and catalog information (i.e., component specifications can provide lifetime and use case data)

Specifications

Component	Parameter	Design Specification
Battery	Charge time	6 hours
Battery	Discharge time	2 hours
Mobile wireless link	Minimum range	3 meters
GPS receiver	Accuracy	10 meters
Compass	Accuracy	One cardinal direction
Speed	Accuracy	2 miles per hour
GPS (Android)	Accuracy	30 feet
GPS (Android)	Update time	5 seconds

Reliability Tools

Software and statistics

- Weibull analysis and life probability statistics for warranty forecasting and test planning
- Commercial off-the-shelf reliability software (i.e., Reliasoft, Relex, Windchill)
- Closed loop software link between computer-aided engineering (CAE) tools and reliability data/calculations
  - Easier design changes and optimization
  - Automatic updates to documentation, process, design package, etc.

Computer modeling and simulation of performance:

- **Mechanical loads**: structural, fluid flow, thermal, etc.
- **Environment loads**: temperature, pressure, and humidity
- **Cyclic fatigue analysis**: electrical, thermal, and mechanical

Reliability Tools

Assessment methods and examples

Destructive evaluation method:

- Accelerated and highly accelerated life tests (HALT)
- "Tear-down" and "Break-open" product or components

Non-destructive evaluation methods:

- Highly Accelerated Stress Screen (HASS) or proof testing
- Burn-in or stabilization testing
- Out of box audit (OBA)
- On-going reliability testing (ORT)
- X-ray, ultrasound, or thermal imaging
- Manual or automated versions for testing

See Modules 4C and 7B for more details

Reliability Partners

Potential partner demographics

- Reliability organizations and consultants
- Test & inspection development and service professionals
- Software/hardware vendors

Reliability Partners

Examples

- Reliability organizations and consultants
  - https://accendoreliability.com/
  - http://www.sre.org/
  - http://rs.ieee.org/
  - https://asq.org/
  - https://accendoreliability.com/
- Test and inspection development and service professionals
  - https://ewi.org/
  - http://reliantlabs.com/
  - http://www.intertek.com/
  - https://www.nts.com/
  - http://www.sgs.com/

Reliability Partners

Examples (cont.)

- Software/hardware vendors
  - http://www.reliasoft.com/index.html
  - https://www.ptc.com/en/product-lifecycle-managementwindchill/quality
  - https://www.isograph.com/
  - http://keysight.com/

List Of Terms

In glossary

- **Design for Reliability** and availability models use block diagrams and Fault Tree Analysis to provide a graphical means of evaluating the relationships between different parts of the system.
- **Engineering Validation** measures and analyzes the process, audits and calibrates equipment and creates a document trail that shows the process leads to a consistent result to ensure the highest quality products are produced. (Repeat from 2C)
- **Design Research** was originally constituted as primarily research into the process of design, developing from work in design methods, but the concept has been expanded to include research embedded within the process of design, including work concerned with the context of designing and research-based design practice.
- **Feasibility** is the process in product life cycle which first translatesfeasible ideas into technically feasible and economically competitive product concepts, and then produces product concept through concept generation and selection. Two commonly used techniques to decide the best design candidate are design-to-cost and life-cycle-cost analyses. (Repeat from 2B)
- **Development** The systematic use of scientific and technical knowledge to meet specific objectives or requirements.
- **Manufacturing Research** is the lowest level of manufacturing readiness. The focus is to address manufacturing shortfalls and opportunities needed to achieve program objectives. Basic research (i.e., funded by budget activity) begins in the form of studies.
- **Manufacturing Development** or Engineering & Manufacturing and Development (EMD)phase is where a system is developed and designed before going into production. (Repeat from 2B)
- **Pre-alpha Testing** Refers to testing associated with conceptvalidation. This validation could be customer discovery based of could require documented evidence that establishes a high degree of certainty that a particular product or process will consistently meet established criteria for concept success and reliability goals.

List Of Terms

In glossary (cont.)

- **Alpha Testing** is in-house testing of a pre-production model or version, to locate or estimate design flaws or deficiencies.
- **Beta Testing** is second level, external pilot-test of a product (usually a software) before commercial quantity production. At the beta test stage, the product has already passed through the first-level, internal pilot-test (alpha test) and glaring defects have been removed.
- **Pilot** is a small-scale campaign, survey, or test-plant commissioned or initiated to check the conditions and operational details before full scale launch.
- **Production Ramp-Up** is the start or increase in *production* ahead of anticipated increases in product demand and also in an effort to confirm all production assumptions.
- **Research and Development (R&D)** refers to innovative activities undertaken by corporations or governments in developing new services or products, or improving existing services or products.
- **Market Differentiation** is a promotional method employed by a business to create an especially strong presence in a particular market. When using market differentiation, a manufacturer might produce several variations on a basic product to be marketed under the same brand in order to give itself a greater range of coverage and hence promote a sense of dominance within that market.
- **Total Cost (TC)** describes the total economic cost of production and is made up of variable costs, which vary according to the quantity of a good produced and include inputs such as labor and raw materials, plus fixed costs.
- **Brand Power** is the trust satisfaction and loyalty assumed by your customer when they s4ee your name on a product. This can be affected dramatically by your reliability goals.
- **Consequence of Failure** is the effect of failure that may go beyond the loss of the product that fails. If a power unit running a pump that keeps a city from flooding where to fail the consequence of failure far outweighs the cost to replace the pump.

List Of Terms

In glossary (cont.)

- Infant Mortality **Failures or Early Failure Rate** is caused by defects designed into or built into a product and are completely unacceptable to the customer. To avoid infant mortalities appropriate specifications, adequate design tolerance and sufficient component derating can help, and should always be used, but even the best design intent can fail to cover all possible interactions of components in operation. In addition to the best design approaches, stress testing should be started at the earliest development phases and used to evaluate design weaknesses and uncover specific assembly and materials problems.
- **Random Failures** is a defect or failure whose occurrence is unpredictable in absolute sense, but is predictable in a probabilistic or statistical sense.
- **Wear Out Failures** are identified when failure is no longer random and greater than specified acceptability usually caused by stress exceeding strength. Wear Out Failures are characterized by an increasing failure rate with failures that are caused by the "wear and tear" on the product over time.
- **System Complexity** is the number of subsystems, interdependence between subsystems. Complexity is not to your advantage. Review all components within an assembly to determine whether components can be eliminated, combined with another component or the function can be performed in a simpler way. Designing for fewer part components can reduce costs related to purchasing, stocking and general infrastructure. Labor and assembly have a compounding effect on the metal fabrication process. The number of components increases, the total cost of fabricating and assembly increases. When you can simplify assembly steps within your part or product design, lead times are reduced.
- **Modular Design** or "modularity in design," is a design approach that subdivides a system into smaller parts called modules or skids that can be independently created and then used in different systems.
- **Smart Design** involves embedded sensors or firmware/software indicators to reveal when and where failures occur. (Consider whether this can be part of an "Internet of Things (IoT)" strategy for pre-emptive failure intervention.)

List Of Terms

In glossary (cont.)

- **Failure Mode Effect Analysis (FMEA)** - An FMEA is often the first step of a system reliability study. It involves reviewing as many components, assemblies, and subsystems as possible to identify failure modes, and their causes and effects.
- **Mechanical Loads** is the external mechanical resistance against which a machine, such as a motor or engine, or a material that cause stresses, deformations, and displacements in structures. Excess load or overloading may cause structural failure, and hence such possibility should be either considered in the design or strictly controlled.
- **Cyclic Fatigue Analysis** evaluates material fatigue caused when subjected to a cyclic load. This type of structural damage occurs even when the experienced stress range is far below the static material strength. Loads tested include electrical, thermal, and mechanical.

Other Relevant Modules

Further details

- Module 2B Product Lifecycle Management Tools
- Module 2C and 4A – PFMEA and DFMEA details
- Module 4C Beta Prototype and Test Plan: Simulating Product Use Conditions
- Module 7B – Sustaining Quality and Warranty: Pilot and Scaling for the Production Ramp
- Module 7C – Sustaining Quality and Warranty: Field Product Quality, Service, and Repair