Introduction to Reliability

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Reliability vs. Quality (Glesner, Kececioglu, et al.)

Reliability Assurance

is the ability of a system or component to perform its required functions under stated conditions, for a specified period of time.

Quality Assurance

is a set of activities whose purpose is to demonstrate that a product meets all quality requirements.

Reliability vs. Quality (Glesner, Kececioglu, et al.)

Reliability

"…is concerned with the performance of a product over its entire lifetime"

"…assures that components, equipment and systems function without failure for desired periods during their whole design life, from conception (birth) to junking (death)"

Quality

"…is concerned with the performance of a product at one point in time"

"…usually during the manufacturing process"

"…assures conformance to specifications"

"…checks that the incoming parts and components meet specifications"

"…assures products are inspected and tested correctly"

"…is a single, albeit vital, link in the total reliability process"

Reliability vs. Quality (Burrows)

I hope this isn't true or stops being true…

Quality in many organizations has devolved into being inspection after the fact instead of designing for what is needed to assure customer satisfaction.

Reliability is Quality and Quality is Reliability

Reliability is Quality Over Time

Quality and Reliability Must be Designed For!

If you are not involved in the product and process design, you will be playing catch up and clean up your entire career.

If you are not teaching and coaching others, you are not helping as much as you can.

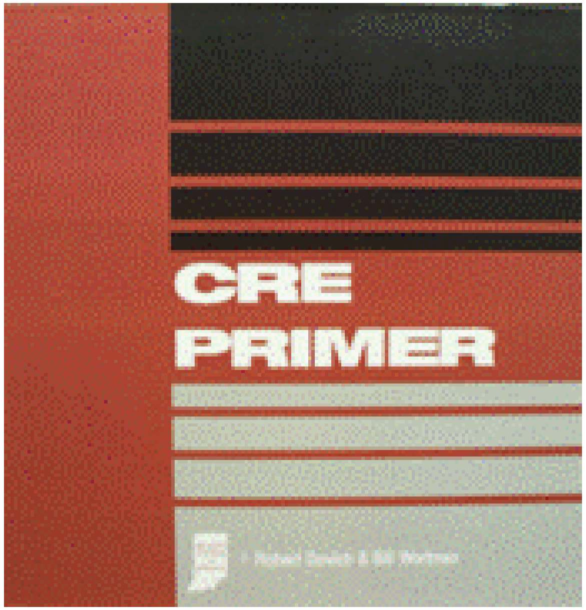
Agenda

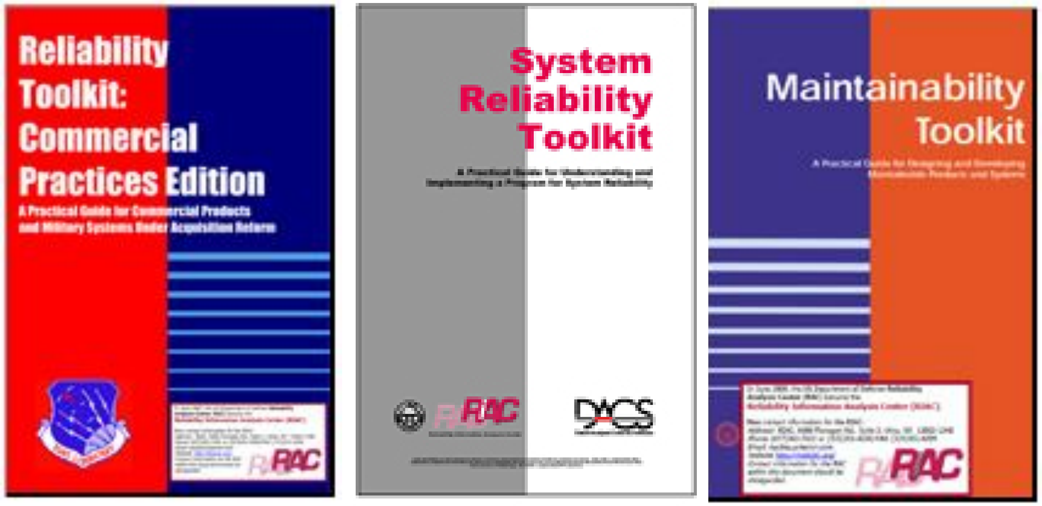
- **Facilitator**
  - Dan Burrows, ASQ Reliability Division Regional Councilor
  - E-mail: d1c1b1@hotmail.com
  - Phone: 708-532-1800 ext. 81894
- **Agenda**
  - Reliability Approach
  - Reliability Roles
  - Reliability Tools
  - Discussion
- **Questions/Comments Encouraged**
  - We may “Parking Lot” some questions

It’s All About Excellence!

Recommended References / Training Guides

www.qualitycouncil.com **www.quanterion.com** **www.theriac.org**





Reliability Approach

This Is Where We Want To Go

- **Reliability is an integral part of how your company develops products and production systems**
  - ***Plan for it - Design for it - Do it (and verify) - Learn from it (and get even better)***
- **Customer focus**
  - ***External customers*** **stay and new customers come to your company based on reliability**
  - ***Internal customers*** **get better designs and more effective production systems to succeed with**
- **Business performance improves**
  - **Better and Possibly Faster Product and Production System Launch**
  - **Increased Customer Satisfaction**
  - **Increased Overall Equipment Effectiveness**

Scope of Efforts

- **Some companies choose to scope their efforts...**
  - **Complex Products -** Products that have several layers of complexity and active electrical and mechanical elements
  - **Critical Applications -** Products that are used in critical applications with stringent government or industry requirements
  - **Production Systems -** Production Systems that are critical to internal performance even if the product made is not a risk

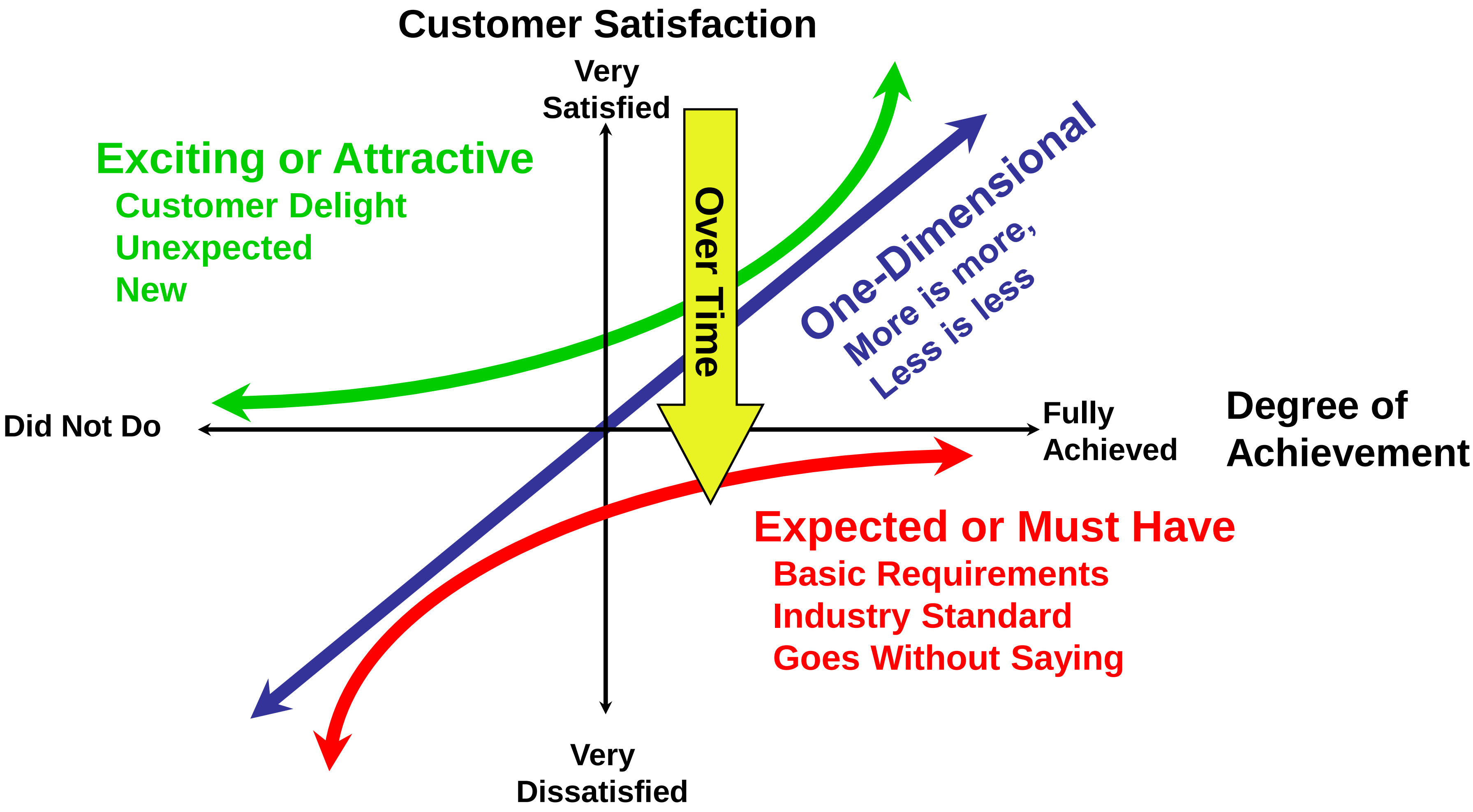
Reliability Definition vs. the "Real World"

- **Reliability** is the probability that an item can perform its intended function for a specified interval under stated conditions following prescribed procedures.

- ***There are "Real World" conflicts with this textbook definition that we need to keep in mind…***
  - **Probability** – Customers expect a probability of 1, "It Works"
  - **Intended Function** – The product may be used in unintended ways and still be expected to work
  - **Under Stated Conditions** – The product may be operated outside of the stated conditions and still be expected to work
  - **Prescribed Procedures** – Customers may not have the required tools or skill level and may not follow procedures and still expect the product to work

➔ ***Customers are looking for Quality over Time***

Kano Model – Where Is Reliability?



How Can Reliability Help?

- **Reliability Tools**
  - Focused Efforts on Critical Areas
  - Efficient and Effective implementation
  - Supports Product Development (e.g.. Stage Gate)
- **Life Cycle Perspective**
  - Customer expectation of reliability does not stop when the product ships or the warranty period is over
  - We must know how the product performs over the intended life and feed that knowledge back for Continuous Improvement
  - Total Cost of Ownership versus Lowest Sticker Price
  - Higher Overall Equipment Effectiveness leads to Lowest Production Cost
- **Quality System**
  - Reliability efforts support ISO 9001
    - Clause 7 Product Realization
    - Clause 8 Measurement Analysis and Improvement

The Right Tool at the Right Time

Product Development Stages					
Forward Project Planning	Project Planning & Conceptual Design	Detail Design & Costing	Prototype Build & Test	Pilot Build & Final Documentation	Production & Operation
•Field Data Collection & Analysis •QFD •LCC	•QFD •FMEA •R&M Analysis •DOE •LCC	•FMEA •R&M Analysis •DOE •LCC	•FMEA •R&M Analysis •Reliability Test •DOE •LCC	•FMEA •R&M Analysis •Reliability Test •DOE •LCC	•Field Data Collection & Analysis •CAPA •FMEA •DOE •LCC

Reliability Training

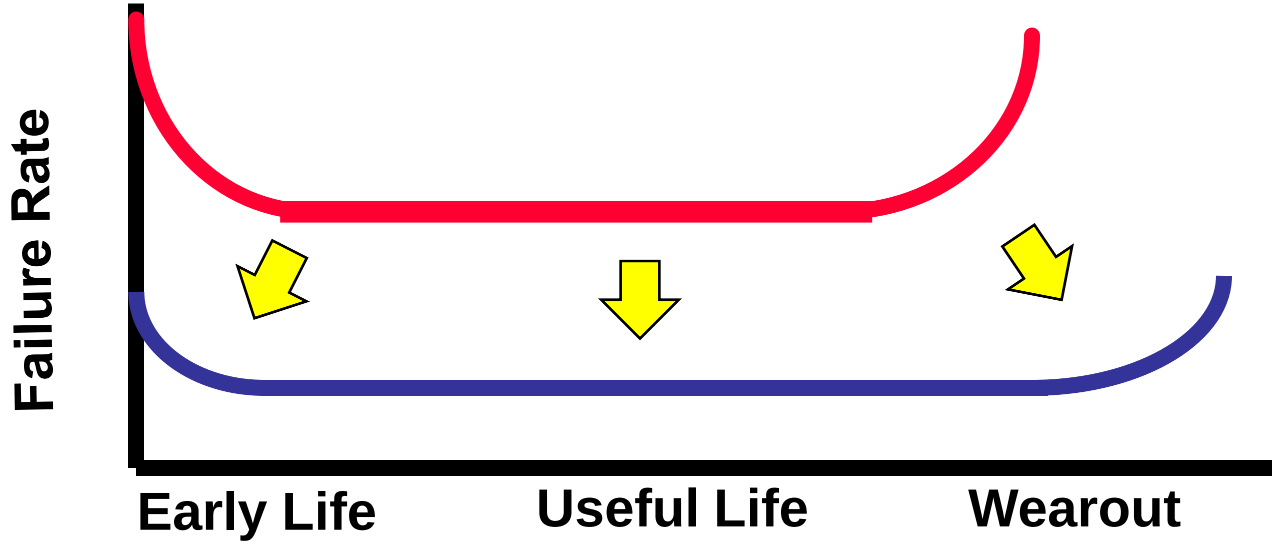
Body Of Knowledge	HRS	Senior Mgmt	Marketing Finance	New Prod Develop	Sourcing Matl Plan	Mfg Mfg Eng Tech Service	Support & Training	Quality
Overview	1	A (All)	A (All)	A (All)	A (All)	A (All)	A (All)	A (All)
Quality Function Deployment	D-8	D (All)	D (Key)	D (Key)				D (Key)
	A-1		A (Other)	A (Other)			A (Key)	A (Other)
Failure Mode and Effects Analysis	D-8			D (Key)		D (Key)		D (Key)
	A-1	A (All)	A (All)	A (Other)	A (Key)	A (Other)	A (Key)	A (Other)
Reliability & Maintainability Analysis	D-8			D (Key)		D (Key)	D (Key)	D (Key)
	A-1	A (All)	A (All)	A (Other)	A (Key)	A (Other)		A (Other)
Field Data Collection and Analysis	D-4		D (Key)	D (Key)			D (Key)	D (Key)
	A-1	A (All)	A (Other)	A (Other)	A (Key)		A (Other)	A (Other)
Corrective and Preventive Action	D-4	D (All)	D (Key)	D (Key)	D (Key)	D (Key)	D (Key)	D (All)
	A-1		A (Other)	A (Other)	A (Other)	A (Other)	A (Other)	
Design of Experiments	D-16			D (Key)		D (Key)		D (Key)
	A-1	A (All)		A (Other)		A (Other)		A (Other)
Life Cycle Cost	D-4	D (All)	D (Key)	D (Key)	D (Key)	D (Key)	D (Key)	D (Key)
	A-1		A (Other)	A (Other)	A (Other)	A (Other)		A (Other)
Reliability Testing	D-4			D (Key)		D (Key)	D (Key)	D (Key)
	A-1	A (All)	A (All)	A (Other)	A (Key)	A (Other)		A (Other)
D – Detailed		Off(12,22h)	Key(8,24h)	Key(11,57h)	Key(8,13h)	Key(11,45h)	Key(8,27h)	Key(4,57h)
A - Awareness			Oth(28,8h)	Oth(65,9h)	Oth(55,3h)	Oth(50,7h)	Oth(93,3h)	Oth(16,12h)
Total = 3921	**Hrs**	264	416	1212	269	845	495	420

Managing Reliability

- **Reliability Engineering**

  A systems approach to planning for, designing in, verifying, and tracking the reliability of products throughout their life to achieve reliability goals.

"Bathtub Curve"



In Unison

"Drain the bathtub."

Reliability Roles

Management Role

- **Management must *visibly and vocally* support Reliability efforts**
  - Incorporate reliability requirements into business system "gates"
  - Incorporate reliability goals into personnel development and evaluations
- **Reliability Tools**
  - Quality Function Deployment
  - Life Cycle Cost
  - Corrective and Preventive Action
  - Awareness of Reliability Prediction, Maintainability Analysis, FMEA, DOE, Reliability Testing, Field Data Collection and Analysis

➢ ***Note that I recommend that management is at least aware of and conversant in all that is needed since reliability is a way of doing business***

Sales & Marketing Role

- **Sales & Marketing gathers and interprets the Voice of the Customer**
- **Reliability Tools**
  - Quality Function Deployment
  - Field Data Collection and Analysis
  - Life Cycle Cost
  - Corrective and Preventive Action
  - Awareness of Reliability Prediction, FMEA, Reliability Testing
- ***Coordinated effort with Engineering - Realism vs. Wish List***
- ***Coordinated effort with Service - Targeted Responsiveness vs. Fire Drills***
- ***Use Reliability efforts to your advantage***
- ***Be careful of "overselling" – you must do what you say you do***

Engineering Role

- **Engineering designs in reliability for the product life cycle**
- **Reliability Tools (all of them)**
    - Quality Function Deployment
    - Reliability Prediction
    - Maintainability Analysis
    - Failure Mode and Effects Analysis
    - Design of Experiments (Product Development/Optimization)
    - Reliability Testing
    - Field Data Collection and Analysis
    - Life Cycle Cost
    - Corrective and Preventive Action
- ***Using the tools to focus efforts on the critical items***
- ***Standardize on what is proven to work***
- ***Life Cycle viewpoint in an environment of cost and schedule pressures***

Purchasing Role

- **Purchasing helps make sure supplied items are reliable and suppliers are partners in this journey**
  - Supplier Designs – Suppliers have full life cycle responsibility
  - Commodities – Your responsibility to ensure proper application
  - Standardize on what is proven to work
- **Reliability Tools**
  - Life Cycle Cost
  - Corrective and Preventive Action
  - Awareness of Reliability Prediction, Maintainability Analysis, FMEA, DOE, Reliability Testing, Field Data Collection and Analysis
- ***Include Reliability requirements in procurement process (supplier selection, requirements, data, testing)***
- ***Lead suppliers by example***

Manufacturing Role

- **Manufacturing preserves the designed in reliability and can be a source of improvement**
  - Well organized work flow with a “5S” shop and trained personnel using clear procedures eliminates errors that can become failures
  - Coordinate with engineering to simplify manufacture and standardize content to improve reliability and maintainability
  - ***Overall Equipment Effectiveness is plant floor reliability***
- **Reliability Tools**
  - Maintainability Analysis
  - Failure Mode and Effects Analysis
  - Design of Experiments (Process Optimization)
  - Reliability Testing
  - Corrective and Preventive Action
  - Awareness of Life Cycle Cost

Customer Service Role

- **Service helps understand the product life cycle**
  - Entire life cycle
  - Usage environment
- **Reliability Tools**
  - Maintainability Analysis
  - Field Data Collection and Analysis
  - Life Cycle Cost
  - Corrective and Preventive Action
  - Awareness of QFD, Reliability Prediction, FMEA
- ***Feeding back needed information to the rest of the organization***
- ***Full knowledge beyond Out-of-the-Box and Warranty – expected usage life is often much longer than these!***

What If Folks Don't Play Their Roles?

Reliability Tools

Basic Reliability Terms

- **Reliability - The probability that an item can perform continuously, without failure, for a specified interval of time when operating under stated conditions.**

- **Failure - A failure is an event when an item is not available to perform its function at specified conditions when scheduled or is not capable of performing functions to specification.**

- **Failure Rate - The number of failures per unit of gross operating period in terms of time, events, cycles.**

- **MTBF - Mean Time Between Failures - The average time between failure occurrences. The number of items and their operating time divided by the total number of failures.** ***For Repairable Items***

- **MTTF - Mean Time To Failure - The average time to failure occurrence. The number of items and their operating time divided by the total number of failures.** ***For Non-repairable Items***

Basic Reliability Terms

- **Maintainability - A characteristic of design, installation and operation, usually expressed as the probability that an item can be retained in, or restored to, specified operable condition within a specified interval of time when maintenance is performed in accordance with prescribed procedures.**

- **MTTR - Mean Time To Repair - The average time to restore the item to specified conditions.**

- **Maintenance Load - The repair time per operating time for an item.**

Basic Reliability Terms

- **Overall Equipment Effectiveness - A measure of a production system's ability to meet requirements for availability, efficiency, and yield. This represents the system's ability to operate, at specified production rate, to specified quality standards, when needed.**
- **Availability - A measure of the time that a system is actually operating versus the time that the system was planned to operate.**
- **Efficiency - A measure of the actual production rate that a system produces product versus the specified production rate of the system.**
- **Yield - A measure of the portion of product that meets defined product quality specifications versus the total amount of product produced.**

Reliability Plan

Planning – A Solid Start

- **Planning Is Critical**
  - "If you fail to plan, plan to fail"
- **Integral to Product Development Process**
  - Product Development Process is the roadmap for projects
  - We do not want Reliability to stand alone or apart from the process
- **Reliability Planning is Flexible Too**
  - Certain "Must Haves"
  - Options based on the nature of the project
- **Planning is the responsibility of the Project Manager**
  - Project Manager is the leader
  - Some elements can be delegated

Basic Elements of a Reliability Plan

- **General Information**
  - Who's and What's
- **Environmental and Usage Factors**
  - These factors must be known in order to properly design
- **Reliability Performance Targets**
  - Select targets based on specific customer or industry requirements
  - Select targets based on meeting project-specific requirements
- **Reliability Tasks**
  - Some tasks are driven by the project's reliability performance expectation
  - Other tasks may be performed based on project-specific requirements
  - Due Dates and Completion Dates keep the project and tasks on track
  - Resource Needs - identify who does what

Reliability Analysis

Similarity Analysis

- **Compare the Proposed Design to Previous / Similar Designs**
  - Test Data
  - Customer Complaints
  - Warranty
  - Anything Else
- **Consider any Differences with the New Design**
  - Application, Environment, Customer Requirements, Industry Requirements, Materials, Software, Firmware, Supplier, Etc…
- **Are Previous / Similar Designs Adequate?**
  - Document your findings
- **Are Previous / Similar Designs Not Adequate?**
  - Document your findings
  - Determine actions necessary to address the inadequacies

Design Analysis

- **Design Analysis is performed to ensure that the stress applied to a part is below its specified rating**

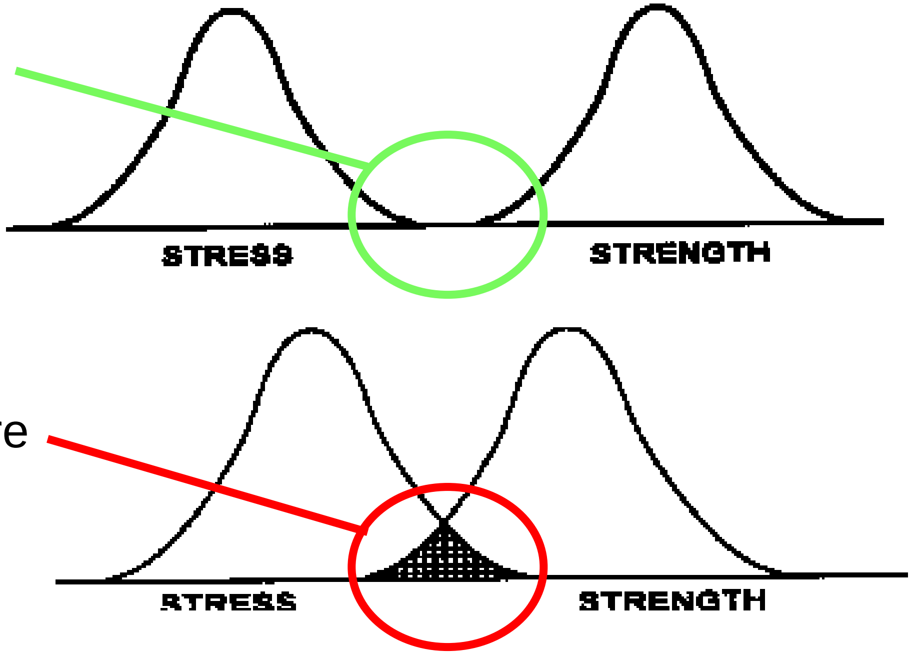
- **Design Analysis is used to**
  - Design parts properly
  - Make proper part selection
  - Screen out the use of marginal parts
  - Provide for design uncertainties
  - Reduce the effects of part variation, parameter drift and transient stresses

Design Analysis -
Stress-Strength Probability Analysis

It is more useful to understand the variability of stresses and strengths to prevent overlap of the stress distribution onto the strength distribution in order to improve the reliability of a design

Little Chance of Failure

Greater Chance of Failure



Reliability Prediction

- **Predict product reliability based on the content of the design and its stresses**

- **Several Reliability Prediction Models**
  - Telcordia/Bellcore SR-332 (Electrical for Telecommunications)
  - MIL-HDBK-217F (Electrical for Military, some Automotive)
  - NSWC-98/LE1 (Mechanical)

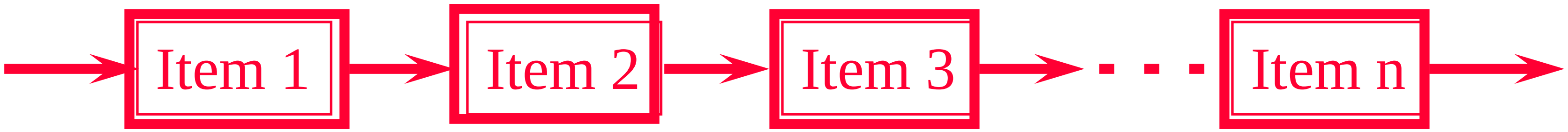
Reliability Prediction Example

Using Telcordia/Bellcore SR-332 prediction techniques…

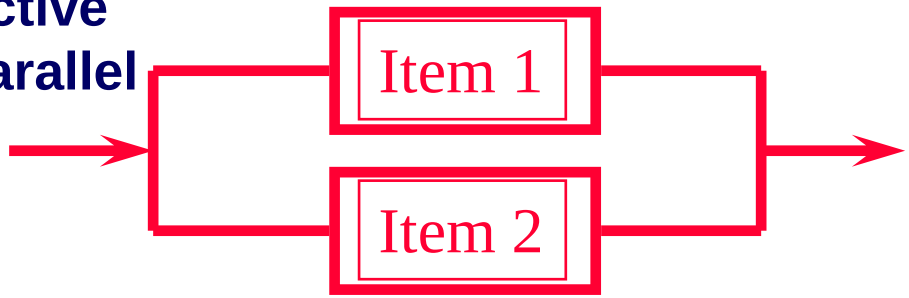
Part	Qty	Base Failure Rate Per 10^9 hours	Qual Factor	Env Factor	Temp Factor	Elec Stress Factor	Total Device Failure Rate Per 10^9 hours
IC, Bipolar	17	26	1.0	1.0	1.0		442
IC, NMOS	14	58	1.0	1.0	1.0		812
Transistor	5	6	1.0	1.0	1.0	1.0	30
Capacitor	5	2	2.5	1.0	1.0	1.0	25
LED	1	4	3.0	1.0	1.0		12
Total Design							**1321**

Reliability Modeling / Redundancy

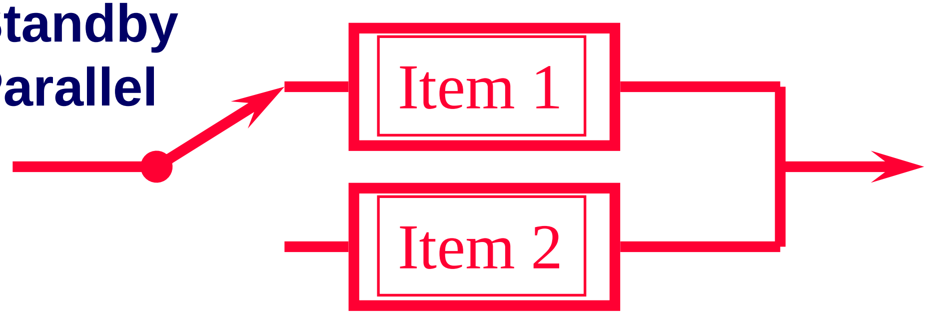
Series



Active Parallel



Standby Parallel



Redundancy can get you more reliability but usually at a cost, size, or weight penalty

Maintainability Analysis

- **Maintainability Analysis enables you to design for maintenance so that crisis maintenance is handled quickly and scheduled/preventive maintenance is performed with ease and economy**
- **Maintainability Assessment Matrix**
  - Accessibility, Diagnosis, Skill Level, Tools, Alignment
- **Fault Detection and Isolation**
  - Troubleshooting Charts
  - On-Board Diagnostics
- ***Maintainability & Design for Manufacture***
  - *DFM is very supportive of Maintainability needs*
- ***Total Productive Maintenance***
  - *Improving Overall Equipment Effectiveness*
  - *Applies to your operations and your product in the customer's hands*

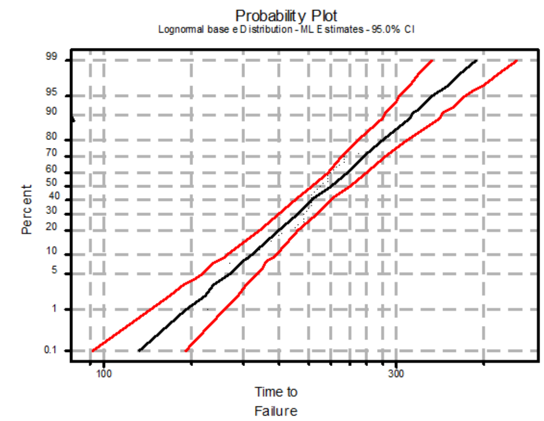
Maintainability Assessment Matrix

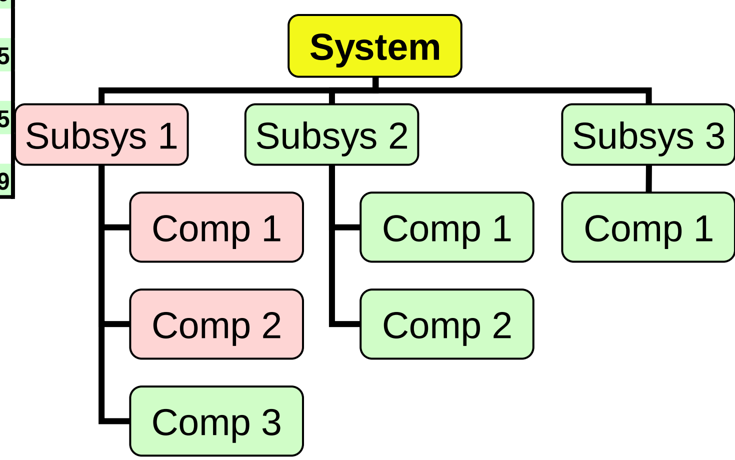
RATING	ACCESSIBILITY	DIAGNOSIS	SKILL LEVEL	TOOLS REQUIRED	ALLIGNMENT
1	Clear View and Accessible	Highly Detectable (indicates problem)	No Training	No Tools	Self
3	Clear View but Inaccessible	Reasonably Detectable	General Skill Level	Basic Mechanic's Tools	Single Point No Tools Required
5	Unclear View and Inaccessible (special tools)	Moderately Detectable (fault light)	Skilled Trades	Trade Specific Tools (micrometer, multimeter, etc.)	Single Point With Tools
7	Unclear View and Inaccessible (awkward body motions)	Difficult to Detect (shows up in product/parts)	Special Training	Specialty Tools (tool room)	Multiple Points With Tools
9	Unclear View and Inaccessible (additional people and/or equipment required)	Not Detectable	Unique Technology Training	OEM Patented Tools and/or Sophisticated Test Equipment	Multiple Points by Making Parts

Reliability & Maintainability Analysis Example

Item	Qty	Single Item MTBF Hr/Fail	Single Item Failure Rate Fail/Hr (1 / MTBF)	Total Item Failure Rate Fail/Hr (Qty x FR)	Single Item MTTR RepairHr/Fail	Maintenance Load RepairHr/OpHr (Qty X FR X TTR)
Conveyor	1	1000	0.0010	0.0010	2.0000	0.0020
Part Loader	2	2500	0.0004	0.0008	0.5000	0.0004
Robot Welder	1	500	0.0020	0.0020	4.0000	0.0080
Controller	1	5000	0.0002	0.0002	0.2500	0.0001

R&M SUMMARY		
Failure Rate (Fail/Hr)	= SUM (Qty X FR)	**0.0040**
Mean Time Between Failure (Hr/Fail)	= 1 / Failure Rate	**250.00**
Maintenance Load (Maint Hr / Op Hr)	= SUM (Qty X FR X TTR)	**0.0105**
Mean Time To Repair (Hr/Fail)	= Maintenance Load / Failure Rate	**2.6125**
Availability	= MTBF / (MTBF + MTTR)	**0.99**





Failure Mode and Effects Analysis

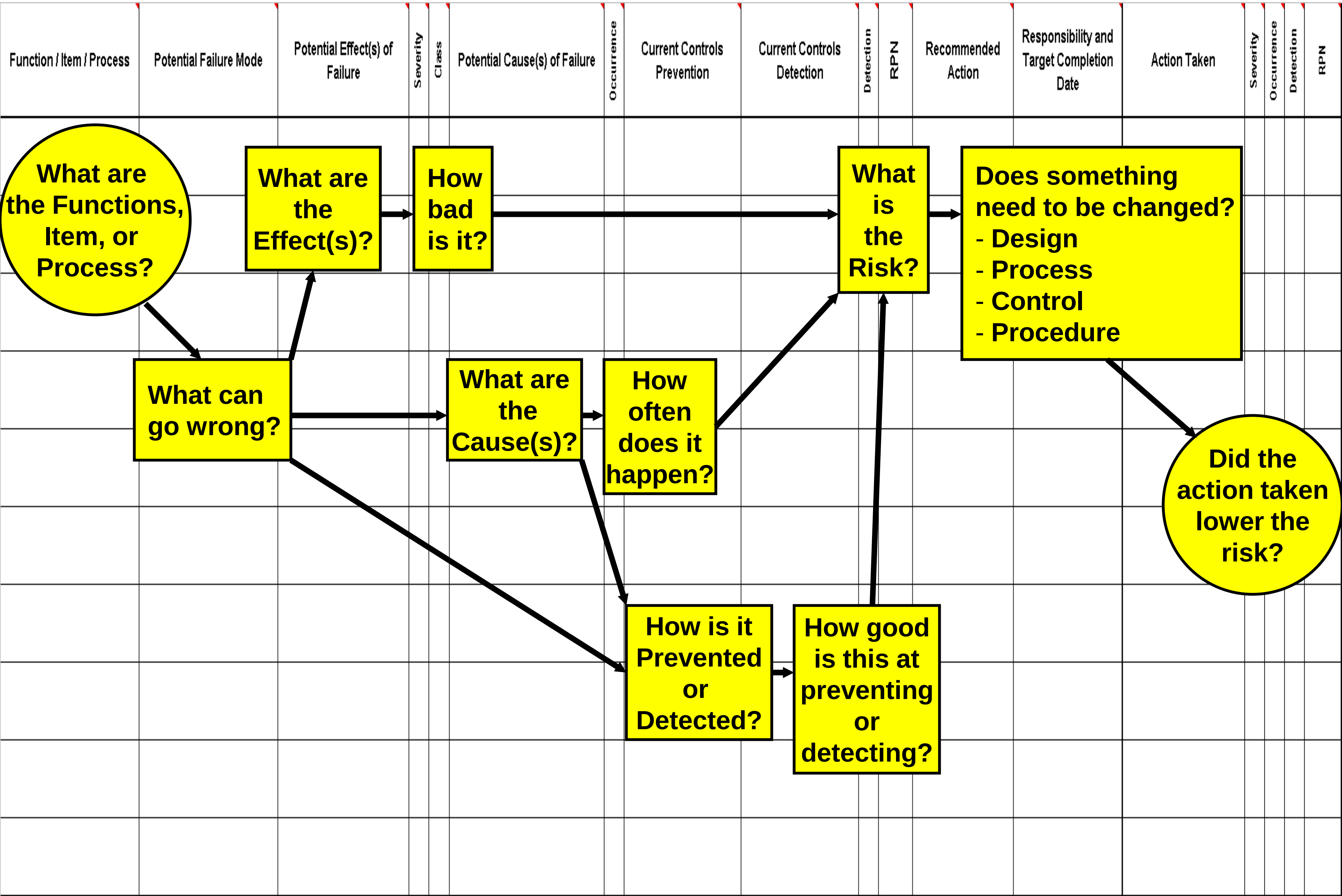
Failure Mode and Effects Analysis

FMEA is a team approach to identifying and addressing potential failure modes and their effects on product or process performance *before* they occur

Used to

- Identify and address failure modes or potential failure modes early on
- Initiate and track Actions
- Provide a “Living Document” for the current project and as lessons learned for future projects

FMEA Flow


Function / Item / Process
Potential Failure Mode
Potential Effect(s) of Failure
Severity
Class
Potential Cause(s) of Failure
Occurrence
Current Controls Prevention
Current Controls Detection
Detection
RPN
Recommended Action
Responsibility and Target Completion Date
Action Taken
Severity
Occurrence
Detection
RPN
What are the Functions, Item, or Process?
What are the Effect(s)?
How bad is it?
What is the Risk?
Does something need to be changed?
- Design
- Process
- Control
- Procedure
What can go wrong?
What are the Cause(s)?
How often does it happen?
Did the action taken lower the risk?
How is it Prevented or Detected?
How good is this at preventing or detecting?

Combined Approach to FMEA

- ***Combined Approach***
  - *Combining Design and Process elements on one form helps to eliminate things being overlooked or not communicated*
  - *Product Development teams are an excellent vehicle for accomplishing combined approach FMEA*

- ***Other Methods***
  - *Interfaces and Interactions*
  - *Boundary Diagrams*

Reliability Testing

Reliability Testing

- **Reliability Testing is used to find failure modes, demonstrate reliability, and screen out defects.**
  - Finding failure modes can be accelerated and performed on a limited number of units ahead of production go ahead or product release
  - Reliability demonstration often requires multiple units and regimented procedures. Often done on commodity type items where it is more affordable.
  - Screening is often done on items that have a “burn-in” period
- ***May be possible to “bootstrap” off of existing testing***
- ***It is better to find potential reliability problems early than to prove unreliability late in the process***
- ***Never dismiss a failure without proper investigation***

Types of Reliability Tests

- **What is appropriate for your project?**
  - Qualification Test
  - Stress Test
  - Life Test
  - Demonstration Test
  - Run-In / Burn-In Test
  - *… there are more*

Qualification Test

- **All products shall successfully pass product qualification tests as defined by the product specification.**
- **Qualification test should include:**
  - Operating Stresses – include operating load and environmental extremes and rates of change.
  - Storage Environments – include storage extremes and rates of change.
  - Shipping Environments – include shipping extremes and rates of change.
  - Assess pre and post test performance, looking for outright Failures *and* Performance Degradation

Step Stress Test (aka HALT)

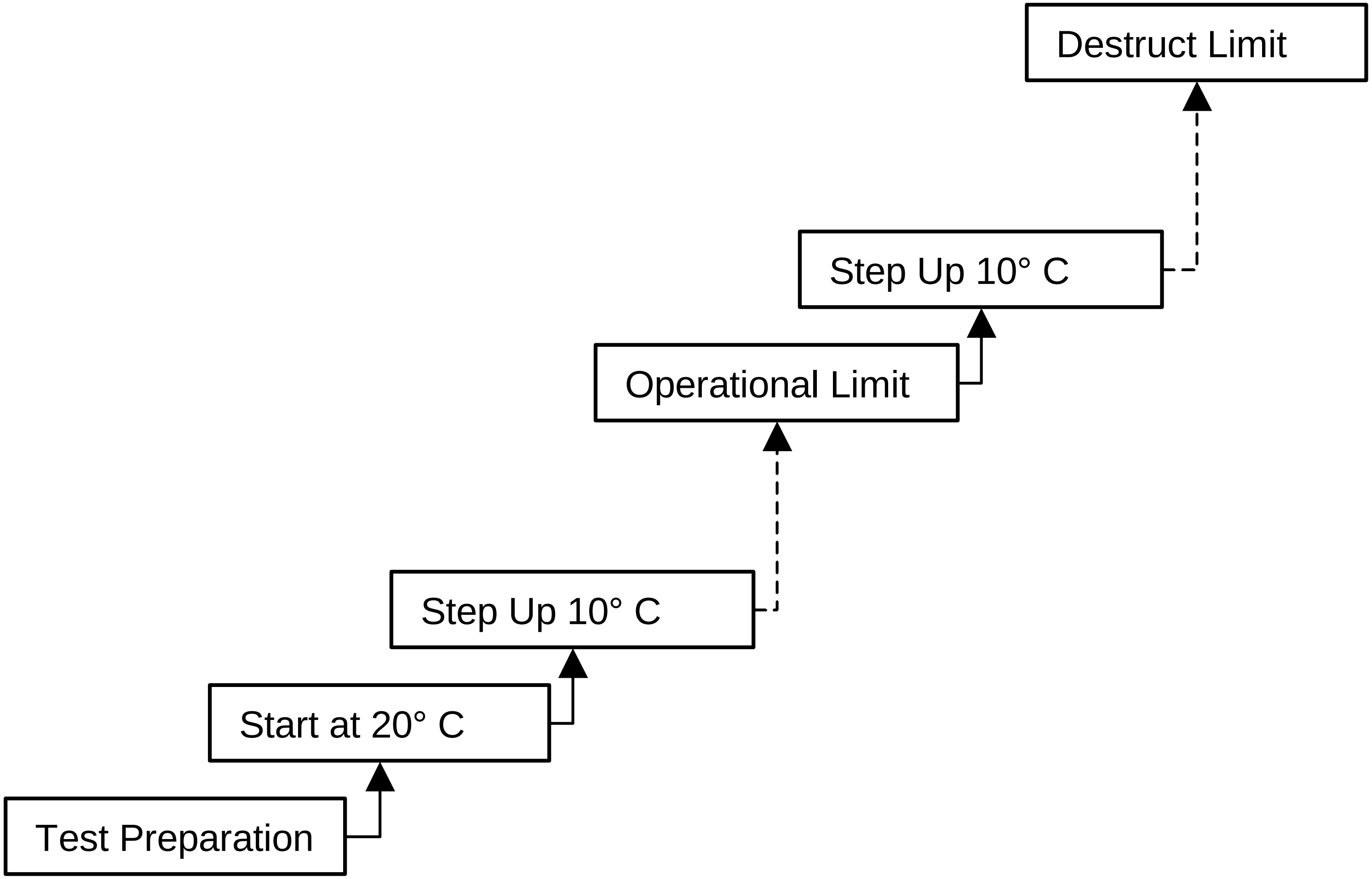
PURPOSE

Step stress testing is intended to identify weaknesses in product design to improve product performance and identify overdesign to reduce product cost. In some cases, product reliability may be estimated from step stress test results.

SCOPE

- Step stress testing should be performed on new or significantly changed products as early in the product design phase as possible with functionally representative test units in order to identify needed design changes as early as possible.
- Step stress testing typically includes temperature step stress, rapid temperature change, and vibration step stress.
- Step stress testing might also include other stresses as appropriate for the product being developed.
- Step stress testing is intended to be a test to failure test in order to learn as much as possible about the product.

Step Stress Test Example – High Temperature



Accelerated Life Test (aka AGREE Test)

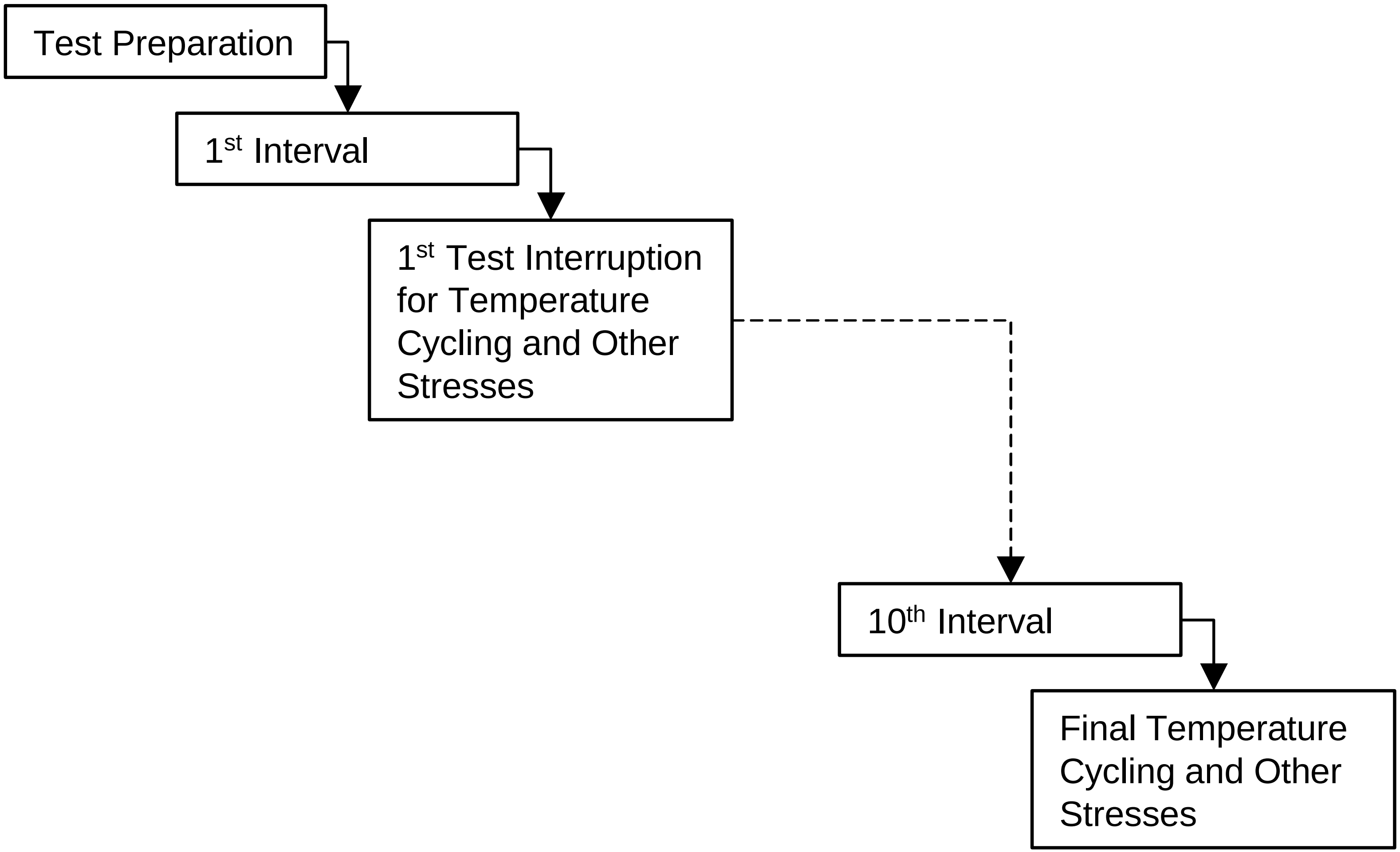
PURPOSE

Accelerated life test is intended to accelerate the accumulation of life stresses on a product to simulate usage life in a rapid manner to verify product usage life or identify weaknesses in the product design. Product reliability may be estimated from accelerated life test results.

SCOPE

- Accelerated life test should be performed on new or significantly changed products as early in the product implementation phase as possible with production representative test units in order to identify product life issues as early as possible.
- Accelerated life test typically includes the simultaneous application of temperature stress, humidity stress, and vibration stress.
- Accelerated life test might also include other stresses as appropriate for the product.

Accelerated Life Test



Combined Acceleration Factor

Combined Acceleration Factor

- The combined acceleration factor of multiple stresses applied simultaneously can be calculated by multiplying together the individual stress acceleration factors according to the Eyring Model:

$$Acceleration_{Total} = Acceleration_{Temperatue} \text{ x } Acceleration_{Humidity} \text{ x } Acceleration_{Vibration}$$

Example: A product with a temperature acceleration of 9.66, a humidity acceleration of 5.15, and a vibration acceleration of 11.39 will have a total acceleration of 566.64 if all stresses are applied simultaneously.

Reliability Demonstration Test

- **Reliability Demonstration Test involves demonstrating a certain level of reliability performance with a certain level of confidence to a specified test condition.**
- **Testing may be failure-free or may involve failures.**

Reliability Demonstration – MTTF or Failure Rate

MTTF and Failure Rate Demonstration

Failure Free

						MTTF	Failure Rate
Time per Unit	100	*Enter*	**Point Estimate**			*5000*	*0.000200000*
Number of Units	50	*Enter*	***Confidence Intervals***				
Confidence Level Desired	0.90	*Enter*		One-Sided	Lower	*2171*	*0.000460517*
				Two-Sided	Lower	*1669*	*0.000599146*
				Two-Sided	Upper	*97479*	*0.000010259*
MTTF Desired to be Demonstrated	2000	*Enter*	**Required Time per Unit**	*92*			
Number of Units	50	*Enter*					
Confidence Level Desired	0.90	*Enter*					
MTTF Desired to be Demonstrated	2000	*Enter*	**Required Number of Units**	*46*			
Time per Unit	100	*Enter*					
Confidence Level Desired	0.90	*Enter*					

Failures Occur

						MTTF	Failure Rate
Total Time on All Units	5000	*Enter*	**Point Estimate**			*1250*	*0.000800000*
Total Number of Failures	4	*Enter*	***Confidence Intervals***				
Confidence Level Desired	0.90	*Enter*	**Stop after Predetermined # of Failures**				
				One-Sided	Lower	*748*	*0.001336156*
				Two-Sided	Lower	*645*	*0.001550731*
				Two-Sided	Upper	*3659*	*0.000273263*
			Stop after a Predetermined Time				
				One-Sided	Lower	*626*	*0.001598717*
				Two-Sided	Lower	*546*	*0.001830703*
				Two-Sided	Upper	*3659*	*0.000273263*

Overall Equipment Effectiveness

- **Overall Equipment Effectiveness is a measurement of a production system's ability to meet requirements for availability, throughput, and quality. It is a percentage calculation that represents the portion of the time that the system is operating, at specified production rate, to specified quality standards versus the time that the system was planned to operate.**

OEE = Availability x Efficiency x Yield

Overall Equipment Effectiveness

OEE = Availability x Efficiency x Yield

Availability = Uptime / (Uptime + Downtime)

Efficiency = Design Cycle Time / Actual Cycle Time

Yield = Good Parts / Total Parts

- ***How is the Production System performing?***
- ***Is it running?***
- ***At design rate?***
- ***Are the parts good?***

What Would You Try To Improve?

OEE	Availability	Efficiency	Yield
85% =	90%	95%	98%
70% =	75%	95%	98%
66% =	90%	75%	98%
64% =	90%	95%	75%

Field Data Collection and Analysis

Data Collection

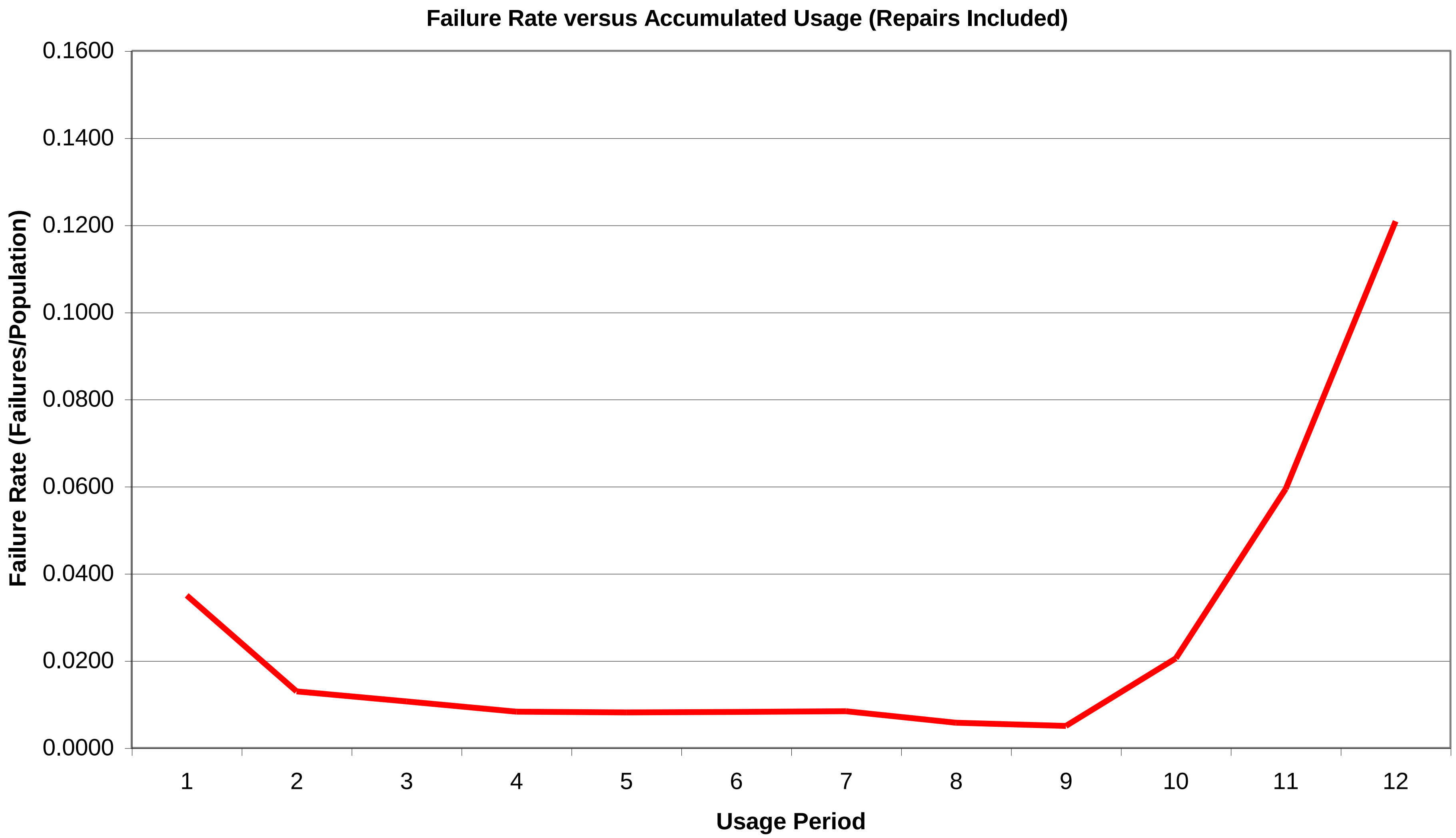
- **Minimum Data Needs for each item**
  - Design Configuration
  - When Produced
  - How Many Produced
    - Total Population
    - Or Sample Population being studied
  - When Entered Service
  - When Failed
  - How Many Failed
- **Additional Data Needed to better identify Failure Modes and Corrective/Preventive Action**
  - Usage Application and Environment
  - How Failed – Failure Mode
  - Immediate Action Taken to Repair or Replace
  - Time to Repair or Replace
  - Root Cause of Failure

Usage Time and Calendar Time Analysis

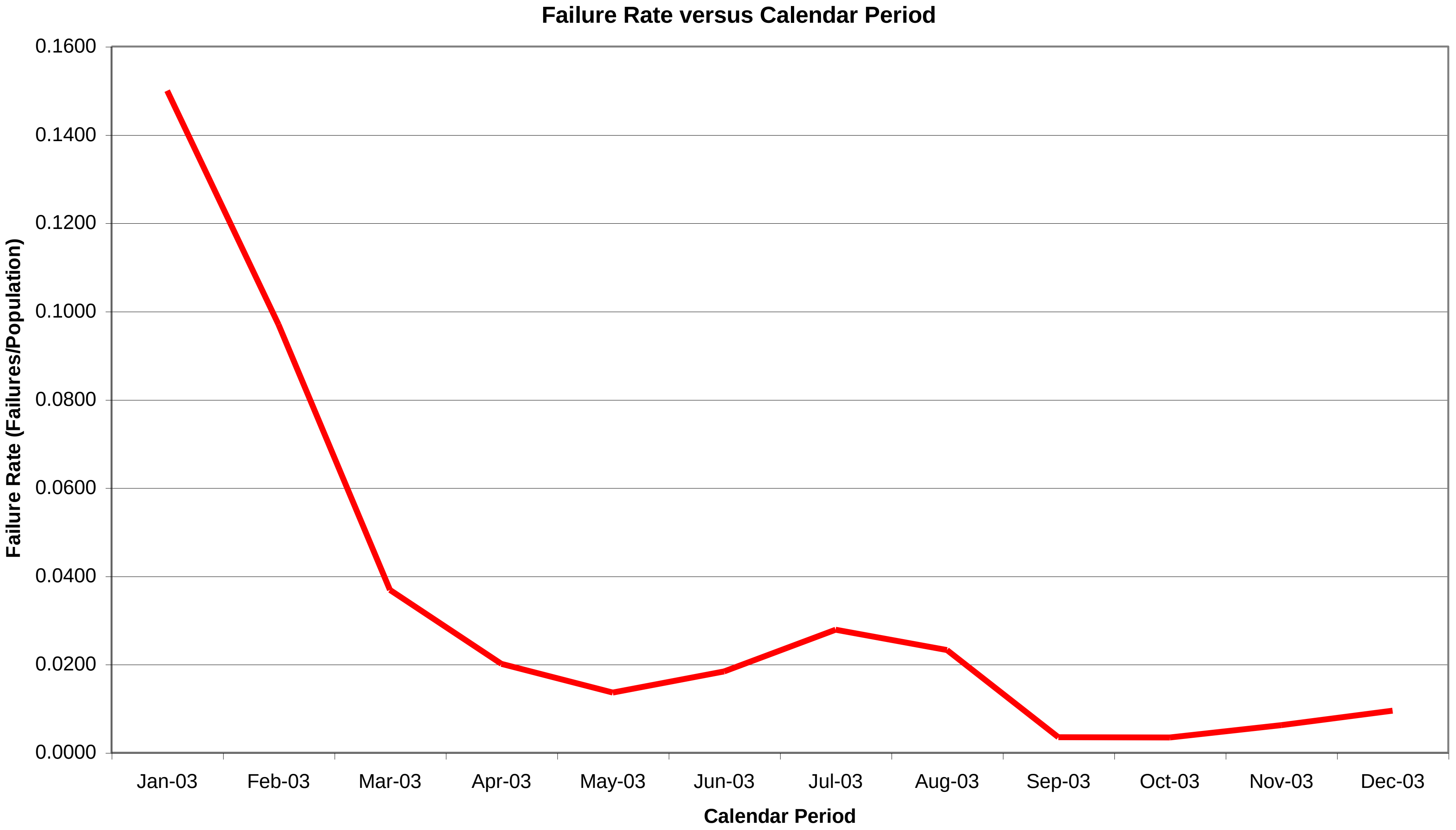
- **Usage Time Pattern?**
- **Calendar Time Pattern?**

		Total Quantity Failed or Recalled During Period											
Ship Period	**Ship Qty**	**Jan-03**	**Feb-03**	**Mar-03**	**Apr-03**	**May-03**	**Jun-03**	**Jul-03**	**Aug-03**	**Sep-03**	**Oct-03**	**Nov-03**	**Dec-03**
Jan-03	**500**	75	20	10		5	10	30	25	10	15	30	55
Feb-03	**1000**		125	25	10		10	25	30		5	30	55
Mar-03	**1500**			75	20		25	50	45			5	15
Apr-03	**2000**				70	15	30	45	30		10	5	5
May-03	**2000**					75	25	55	35			5	10
Jun-03	**2000**						65	45	50		5	5	
Jul-03	**2000**							55	45	5			5
Aug-03	**2000**								40	10	5	10	5
Sep-03	**1500**									25	5		5
Oct-03	**1500**										10	5	5
Nov-03	**1000**											10	5
Dec-03	**1000**												5

Usage Time Analysis



Calendar Time Analysis



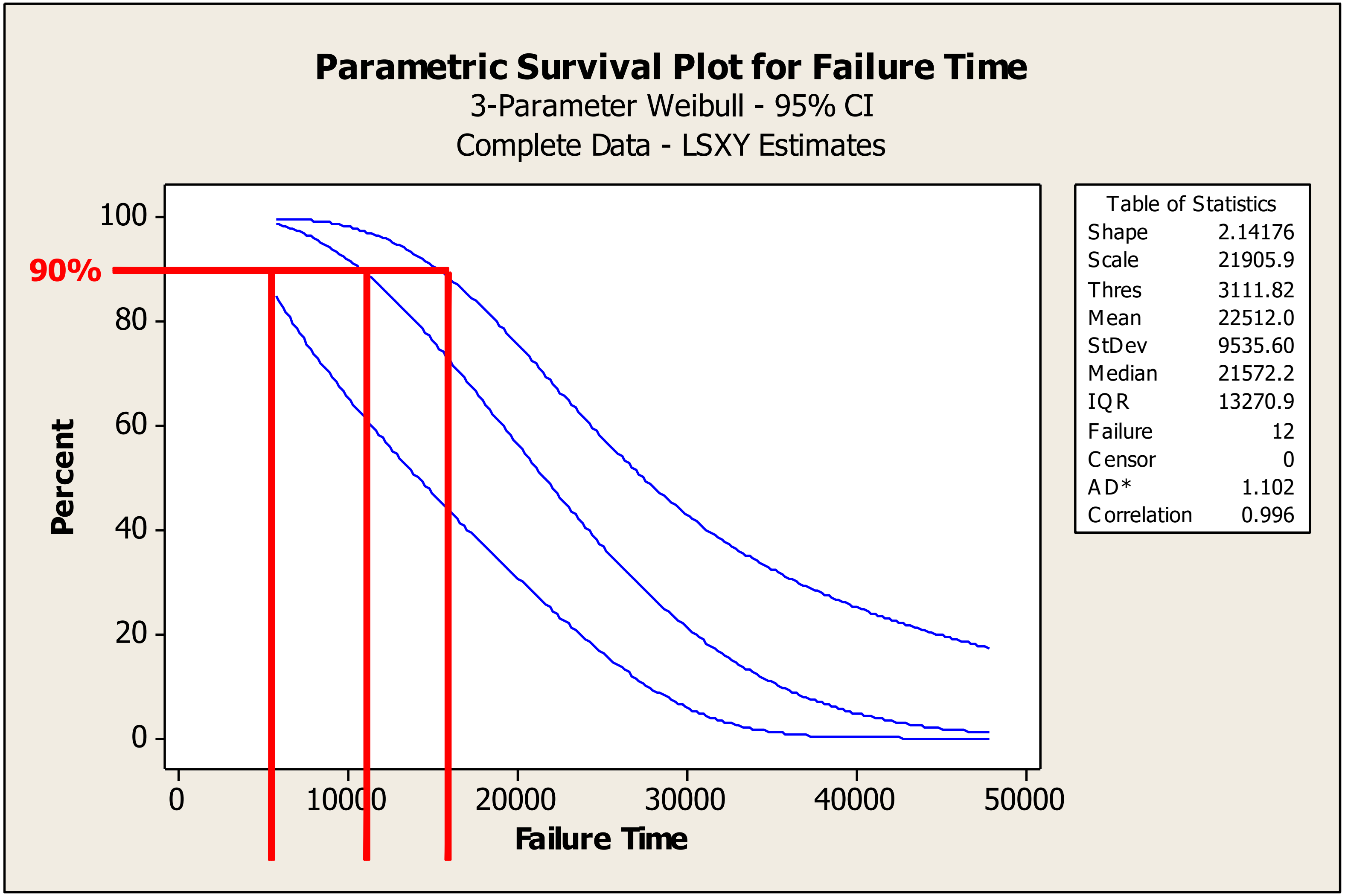
Distribution Analysis

- **Distribution Analysis involves identifying the statistical distribution that the field data follows and estimates of reliability and confidence intervals based on the identified distribution**

  - The most basic types of Distribution Analysis involve having a complete set of data for the population or sample population and knowing all failure times (uncensored) or failure times and times at which the field study was ended (censored).

  - Minitab or other specialized software can be used to perform this analysis.

Survival Plot

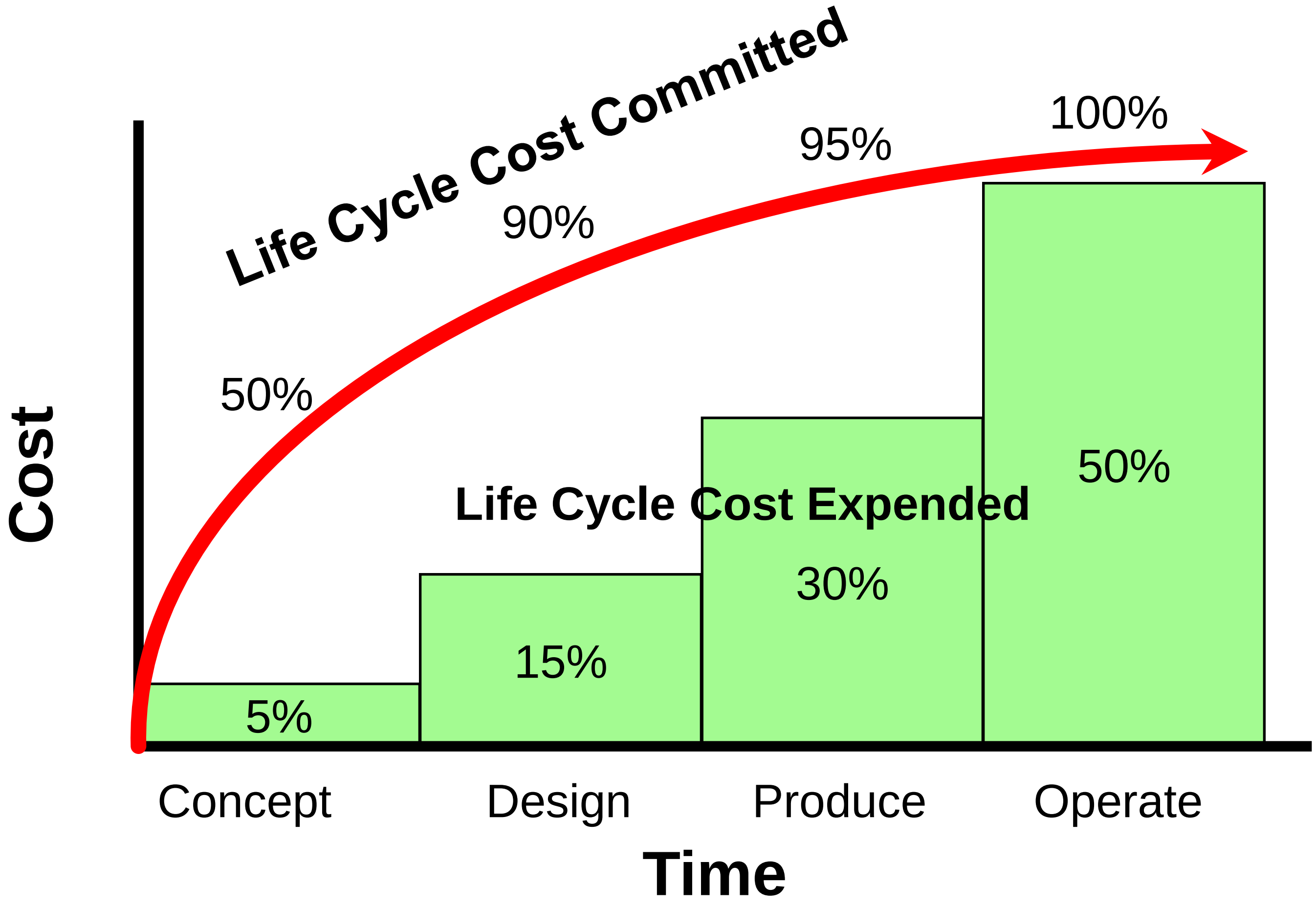


Life Cycle Cost Analysis

Life Cycle Cost

- **Life Cycle Cost looks at the complete picture of all of the costs involved with a product to identify the most cost effective solution for a specific application**
  - Marketing Viewpoint: Introduction-Growth-Maturity-Decline
  - Operations Viewpoint: Research-Design-Develop-Produce-Sell-Ship-Warranty
  - Customer Viewpoint: Purchase-Operate-Maintain-Dispose
- ***It is difficult to break the fixation on the Price Tag***
  - *Lower LCC often requires a higher initial investment*
- ***LCC encourages design decisions based on the life of the product***
- ***LCC encourages customers to service and maintain the product***
- ***Manage the product life cycle to maximize profits***

Up Front Efforts Drive Life Cycle Cost



LCC Example

COST IDENTIFICATION	VEHICLE	
	NEW Ford Windstar	USED Dodge Caravan
Acquisition Cost (A)	$ 25,000	$ 11,000
Operating Cost (O)	$ 4,500	$ 4,350
Maintenance Cost (M)	$ 1,500	$ 4,000
Conversion Cost (C)	$ (6,000)	$ (3,000)
Life Cycle Cost (LCC)	$ 25,000	$ 16,350
Final Vehicle Choice		USED Dodge Caravan

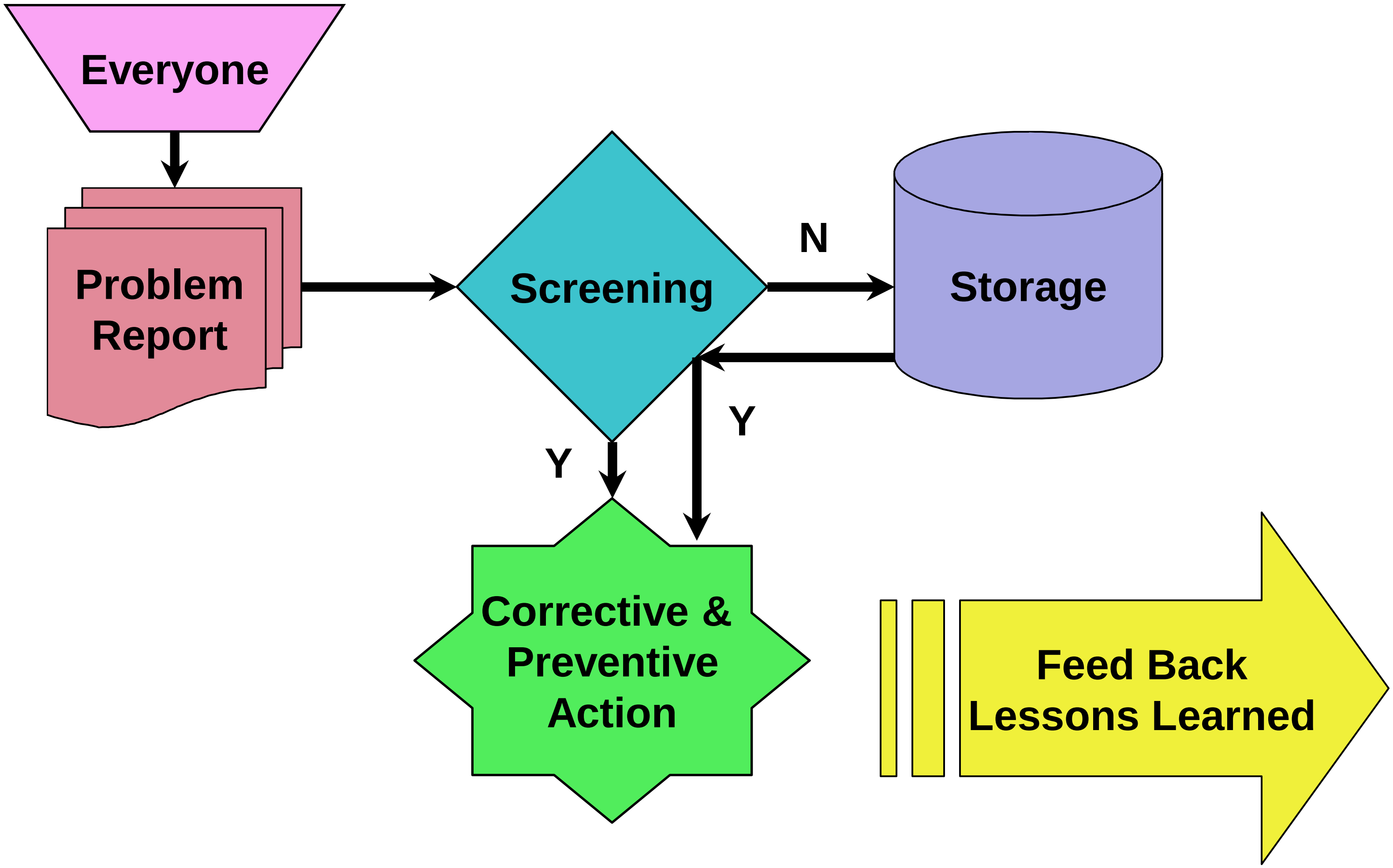
COST IDENTIFICATION	PAINT SYSTEM	
	Brush Right, Inc.	Coatings Plus, Inc.
Acquisition Cost (A)	$ 2,750,000	$ 3,500,000
Operating Cost (O)	$ 8,600,000	$ 8,000,000
Maintenance Cost (M)	$ 10,000,000	$ 6,500,000
Conversion Cost (C)	$ -	$ -
Life Cycle Cost (LCC)	$ 21,350,000	$ 18,000,000
Most Viable LCC		Coatings Plus, Inc.

Corrective and Preventive Action

Corrective and Preventive Action

- **What if things do fail?**
- **Corrective and Preventive Action is a systematic and documented approach to solve problems and feed the information back into the system for continuous improvement**
- ***Use techniques that close the loop***
  - *8-Discipline: Problem-Containment Action-Team-Root Cause-Verify Corrective Action-Implement Corrective Action-Prevent Recurrence-Congratulate Team*
  - *Six Sigma: Define-Measure-Analyze-Improve-Control*
- ***Screening** to determine which items get worked, which items get stored, and the priority need to be established otherwise the organization can get swamped*
- ***Everyone can and should be involved – you, customers, and suppliers***

Corrective and Preventive Action System



Total Productive Manufacturing / Predictive Maintenance / Reliability Centered Maintenance

Evolution of “PM”

- **Preventive Maintenance**
  - Actions taken to prevent failures from arising, like oil changes
- **Predictive Maintenance**
  - Monitoring techniques such as Vibration, Thermal, Infrared Photography, or Electrical Load to identify the precursors to failure
- **Planned Maintenance**
  - Term to avoid implied legal guarantees of failure free operation if PM is adhered to
- **Productive Maintenance**
  - Term to relate improved productivity to applying good maintenance techniques
- **Productive Manufacturing**
  - Term to relate improved business operations performance to applying good maintenance techniques.
- **Percussive Maintenance**
  - When all else fails, whack it with a hammer!

What is TPM?

My Opinion

- I prefer the term "***Total Productive Maintenance***" because it acknowledges the link between maintenance and productivity.
- I use the term "Maintenance" broadly to cover whatever tools or techniques an organization uses to keep their production systems in good shape and running at peak performance.

Overall Equipment Effectiveness is the goal you need to reach

"If it helps, use it and do it." - Burrows

Nakajima (Father of TPM)

TPM Is Profitable

- With zero breakdowns and zero defects, how much more profitable would you be?

Challenge Limits

- Do not stagnate at Breakdown Maintenance by the maintenance department – move forward to Preventive, Productive, and eventually TPM focusing the broader organization on maximizing equipment effectiveness and attaining economic life cycle cost

Maximizing Equipment Effectiveness

- Measure it, with accurate data, to understand

  Overall Equipment Effectiveness = Availability X Efficiency X Yield

- Successful Implementation:
  - Eliminate the six big losses
  - Autonomous Maintenance Program
  - Scheduled Maintenance Program for the Maintenance Department
  - Increased Skills of Operations and Maintenance Personnel
  - Initial Equipment Management Program

Nakajima continued…

Organizing For Implementation

- ***Must be Led and Championed by Top Management***
- Preparation
  - Announce > Educate > Create Teams and Organizations > Create Policies and Goals > Formulate Master Plan

Implementation And Stabilization

- Preliminary Implementation
  - TPM Kickoff > Targeted Area
- TPM Implementation
  - Improve Effectiveness of Each Piece of Equipment > Develop Autonomous Maintenance for Workers ***(5 S)*** > Develop Scheduled Maintenance for Maintenance Department > Conduct Training to Improve Operation and Maintenance Skills > Develop Early Equipment Plan
- Stabilization
  - Implement TPM Fully and Set Higher Goals

Small Group Activities

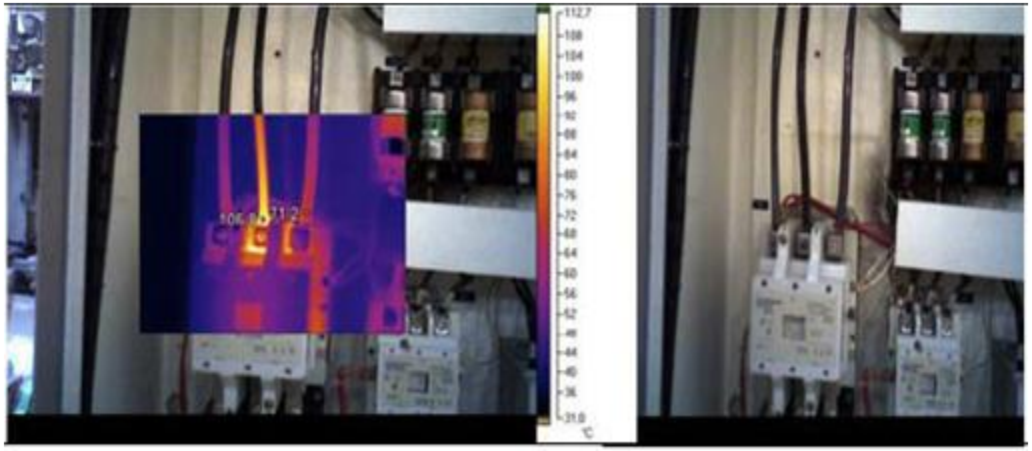
- Empowered and Autonomous Teams whose ***Goals Coincide with Company Goals***

OEE vs. 7 Big Losses

Overall Equipment Effectiveness = Availability X Efficiency X Yield

Availability	Efficiency	Yield
Breakdowns	Reduced Speed	Quality Defects
Setup and Adjustment	Idling/Minor Stoppage	Start-Up Losses
		Tooling Losses

Machine Signature / Predictive Analysis



Machine signature analysis, predictive maintenance, and condition monitoring are all terms used to describe the application of techniques to detect the signs of problems on equipment before they become failures.

And detecting the signs of problems and addressing concerns before they become failures can save you time and money.

Some of the techniques involved include…

Machine Signature / Predictive Analysis

Thermal Analysis - This is typically thermography pictures to identify hot spots in control panels, electrical boxes, electrical connections, and motors before you notice a problem. This is especially useful for finding hot spots that are causing strange or intermittent operation that can be very frustrating to trace.

Vibration Analysis - This is done on moving elements to identify damage, degradation, and misalignment that reveal themselves in unusual vibration frequencies and energies. This is very useful in identifying the signals of problems before they become hard failures.

Noise Analysis - This is typically ultrasonic noise detection. Air leaks, bearing whine, pump cavitation, and even electrical arcing give off ultrasonic noise that the human ear can't detect.

Tribology/Oil Analysis - This detects the condition of and contaminants in lubrication and fluid power (hydraulics) and, depending on what is found, points towards problems that can become failures.

Electrical Load Analysis - This detects instabilities in electrical load or supply that can point to problems that can become failures.

Electro Magnetic Interference - This detects EMI fields and interference that can affect equipment operation.

A Possible TPM Roadmap

- **The Way I See It…**
  - **Measure and Monitor System Effectiveness**
    - Automated Data Collection, Paper Logs/ Spreadsheets, Field Studies
    - Define – ***Measure*** – Analyze – Improve - Control
  - **Data-Driven Improvement Efforts**
    - Knock Down High Drivers for Maximum Effort/Benefit Leverage
  - **Autonomous Maintenance by Operators**
    - Treat it like you paid for it and own it / 5 S
  - **Planned & Predictive Maintenance by Maintenance Experts**
    - Learn and acquire more predictive techniques
  - **Equipment Acquisition Requirements with Teeth**
    - Overall Equipment Effectiveness
    - Life Cycle Cost
    - Supplier Support

➢ ***If management really commits to allowing this and workers commit to really doing their best, the barriers go away… but it will take time***

Some call it Reliability Centered Maintenance

The Way I See It…

Fundamental Design for Reliability and Maintainability of production systems

plus

Total Productive Maintenance

equals

Reliability Centered Maintenance

Since you are intentionally driving reliability and maintainability into the design, using what you learn to drive best practices on the shop floor, and measuring, monitoring, and refining what you are doing for continuous improvement.

What If Folks Don't Use The Tools?

Some Other Useful Tools

Quality Function Deployment

- **Quality Function Deployment helps to ensure that the "Voice of the Customer" drives product development**
  - Up front activity
  - Team approach to determine the Whats and Hows
  - "House of Quality" approach allows you to add rooms to show relationships, correlations, how much, and competitive assessments
  - Weighted matrix scoring focuses scarce resources on the most important issues
- ***Also used for Competitive Analysis***
- ***Also used for internal customers (process redesign)***

QFD - House of Quality Example

Importance To Customer

Recommend using a
1 to 10 scale to provide
better separation of values

Relationship Matrix

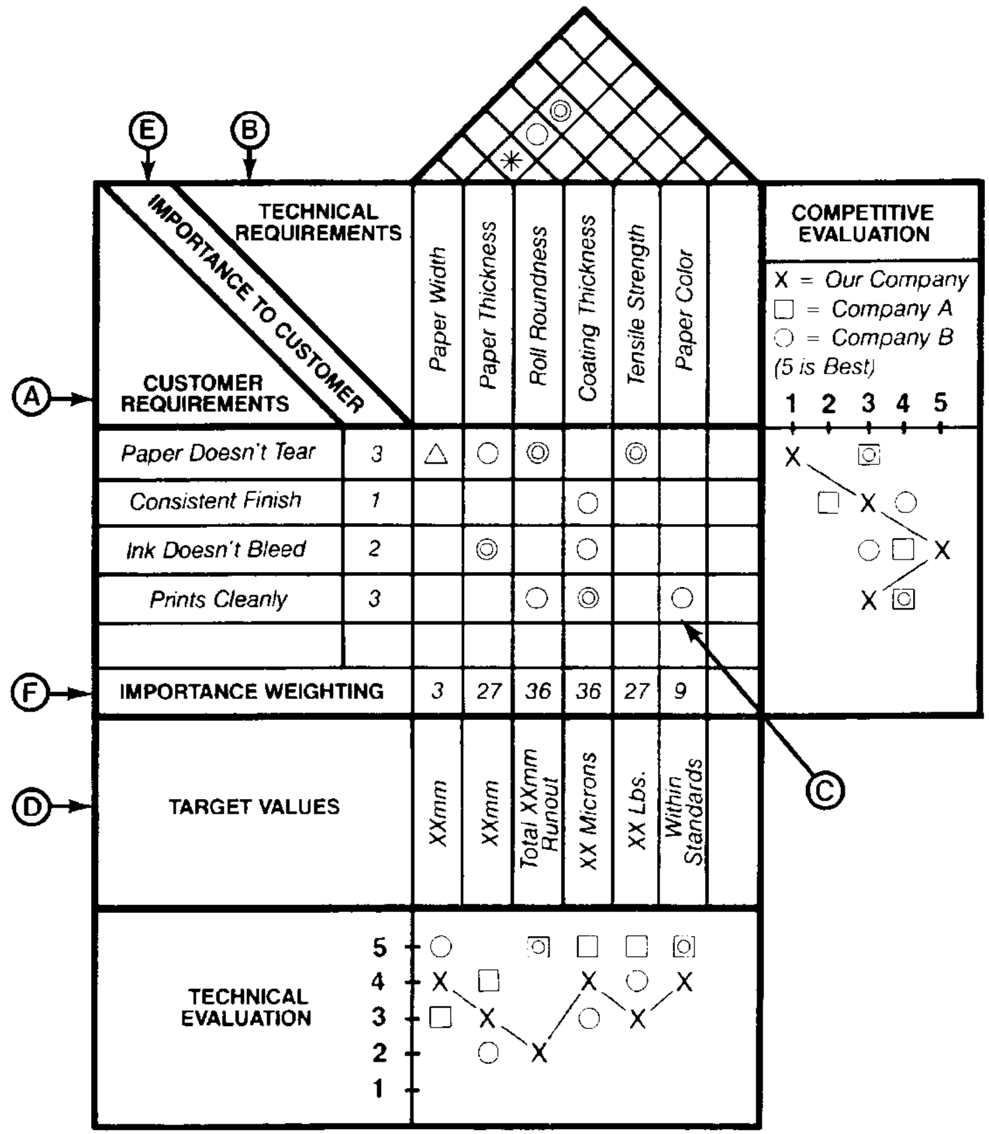
◎ Strong Relationship = 9

○ Moderate Relationship = 3

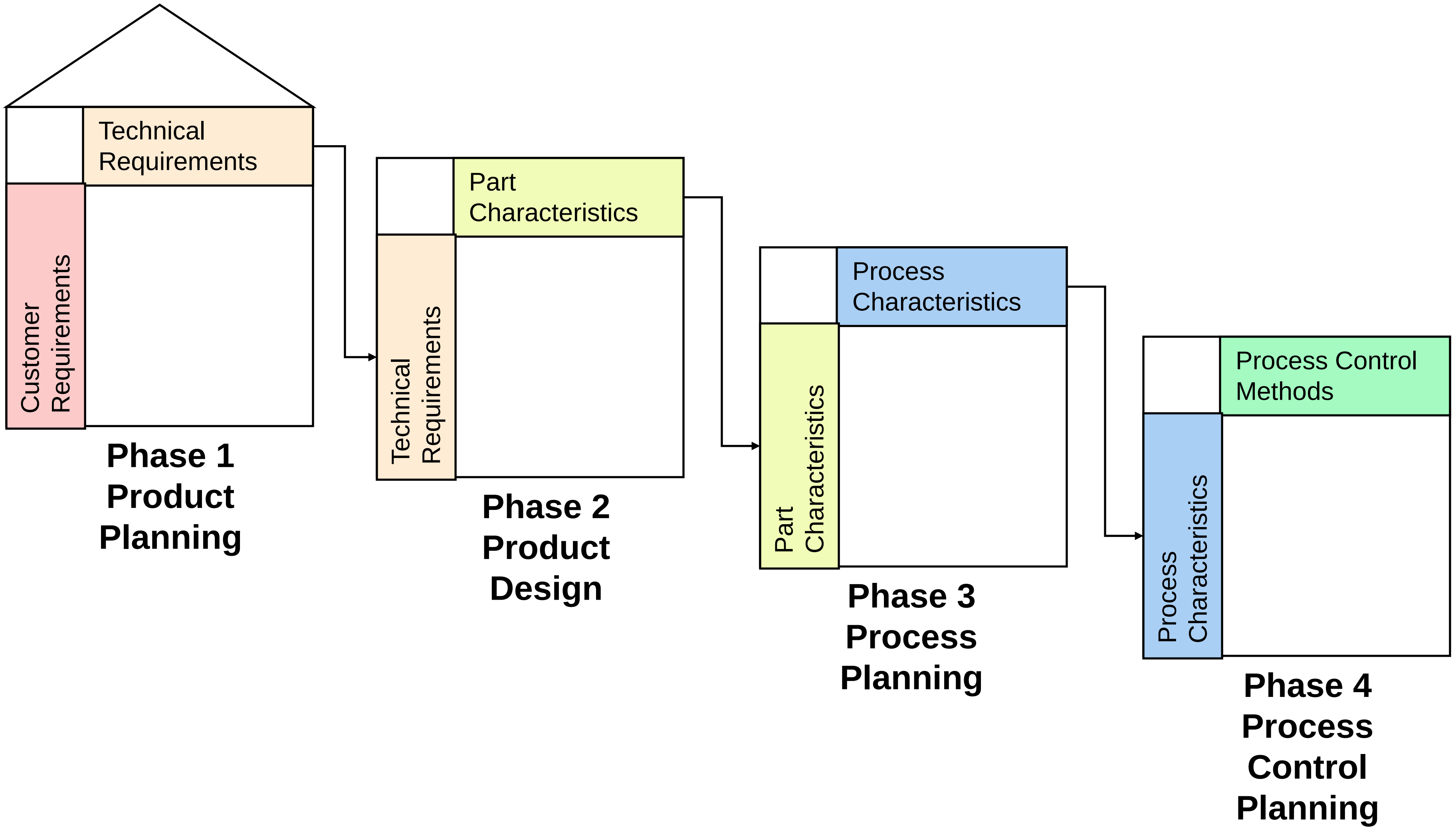
△ Weak Relationship = 1

Correlation Matrix

◎ Strong Positive Correlation
○ Positive Correlation
× Negative Correlation
✳ Strong Negative Correlation



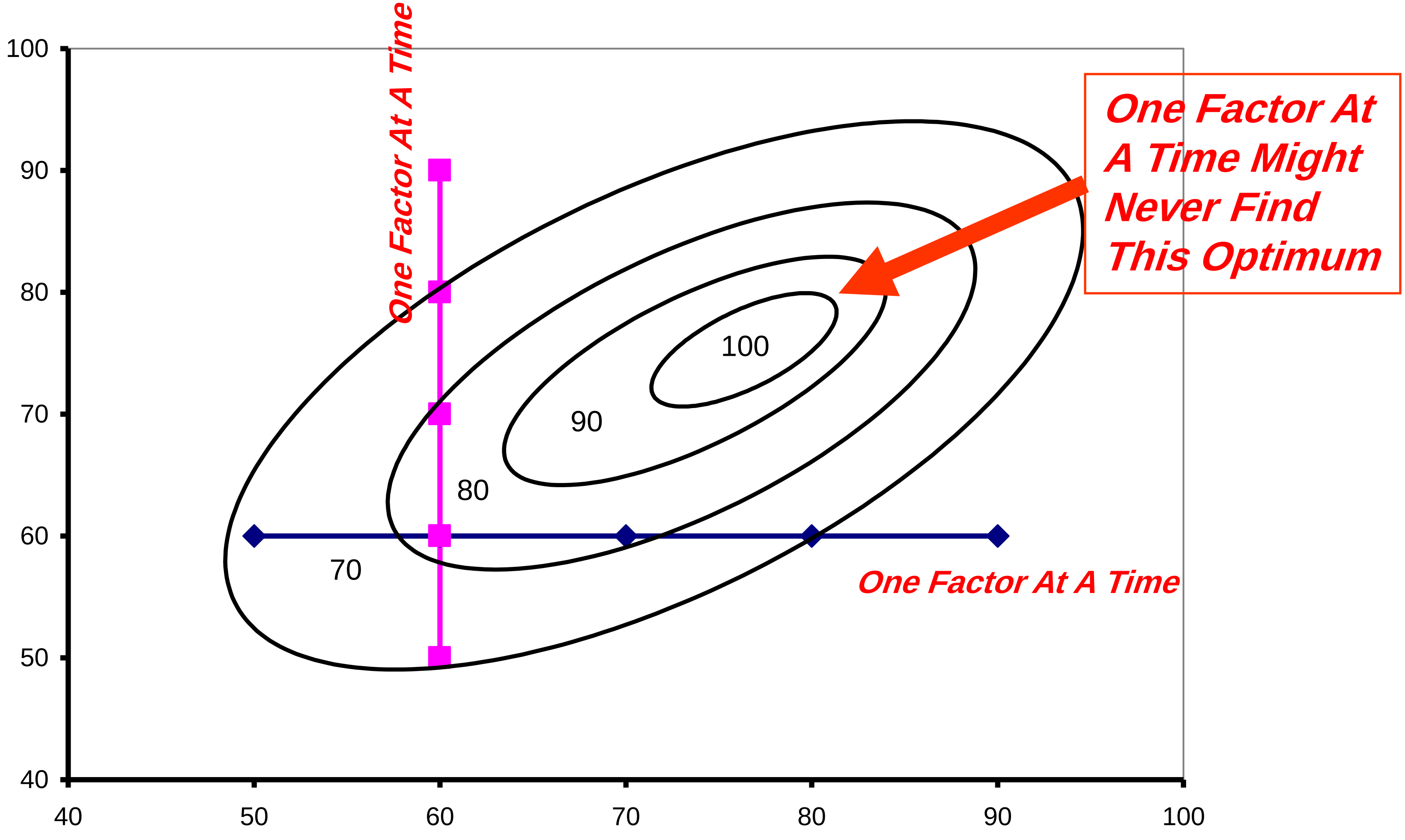
4 Phase Approach to QFD



Design of Experiments

- **Design of Experiments is a very powerful tool for determining which factors drive desired responses**
  - Show interactions between factors and higher order effects
  - Optimize performance and cost
  - More efficient than varying one factor at a time
- ***Design***
  - *Can it be done?*
  - *Optimize performance*
- ***Production***
  - *Optimize yield and cost*
- ***Can be used for "Data Mining"***

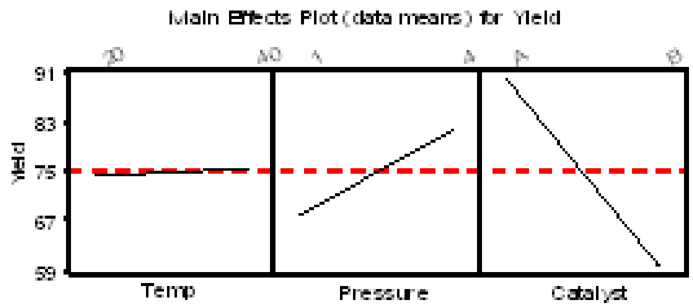
One Factor At A Time Testing Doesn’t Work

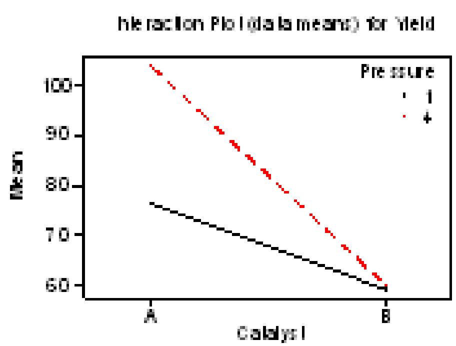


DOE Example

Temp	Pressure	Catalyst	Yield
20	1	A	65
40	1	A	66
20	4	A	98
40	4	A	102
20	1	B	55
40	1	B	53
20	4	B	68
40	4	B	66
20	1	A	85
40	1	A	89
20	4	A	107
40	4	A	108
20	1	B	63
40	1	B	66
20	4	B	52
40	4	B	54

Term	Effect	Coef	SE Coef	T	P
Constant		74.81	2.561	29.21	0.000
Temp	1.38	0.69	2.561	0.27	0.795
Pressure	14.12	7.06	2.561	2.76	0.025
Catalyst	-30.38	-15.19	2.561	-5.93	0.000
Temp*Pressure	-0.13	-0.06	2.561	-0.02	0.981
Temp*Catalyst	-1.13	-0.56	2.561	-0.22	0.832
Pressure*Catalyst	-13.37	-6.69	2.561	-2.61	0.031
Temp*Pressure*Catalyst	-0.13	-0.06	2.561	-0.02	0.981





Estimated Coefficients for Yield using data in uncoded units

Term	Coef
Constant	63.0417
Pressure	4.70833
Catalyst	-4.04167
Pressure*Catalyst	-4.45833

Yield = 63.0 + 4.7(Press) – 4.0(Cat) – 4.5(Press)(Cat)

What If Folks Do Reliability Right?

One Last Time… In Unison

“Drain the bathtub.”

Wrap-Up

- **Questions / Comments**

- **Thanks**