Root Cause Analysis Webinar

Phone: (702) 824-9512
Access code 204-987-863

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Ops A La Carte

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INTRODUCTION

- Thank you for joining us this morning (or afternoon)
- In April of this year, we held our annual Reliability Symposium in Santa Clara, California, featuring 7 of our reliability seminars, and Root Cause Analysis (RCA) was one of these seminar.
- Based on the response of that seminar, we decided to highlight RCA as our featured service in our newsletter last quarter http://www.opsalacarte.com/Newsletters/2008summer_news.htm and decided to hold a webinar to provide further information.
- We invited two of our solutions partners – DfR Solutions and SigmaQuest – to participate in this webinar because their complementary offerings really help to portray a more complete view on RCA.

INTRODUCTION

There are over **700** people registered for this webinar so we obviously hit on a very hot topic.

FORMAT

- Four different experts will give presentations
- At the beginning and end of each presentation, we will be asking “polling” questions to get a better idea on the make-up of the audience and your level of interest/experience. We will make these statistics available to the audience after the webinar is over.
- During the discussion, feel free to ask any questions you’d like by typing into the question area on the right.

FORMAT

- At the end of each presentation, we will review all the questions that came in during that portion of the presentation and then will respond to as many as we have time for in the remaining portion of that section.
- After the end of the webinar, there will be a short set of prepared survey questions.

FORMAT

- For any questions not answered in that time, we will respond to each person individually after the webinar is over.
- If you think of a question after the end of the webinar, feel free to email it to me at mikes@opsalacarte.com and I will make sure to get the question to the correct panelist.

FORMAT

- At the end of the presentation, we will send you a follow-up email, thanking you for attending.
- For those of you interested, we can also send a copy of the slides.
- We will also provide you with a way to contact us if you need further information.

PRESENTATIONS

0) 9:00-9:15am: Introductions

1) 9:00-11:00am: Understanding the Motivation and Basics of Root-Cause Analysis in Electronics.
By: Jim McLeish, CRE, Senior Technical Staff, DfR Solutions

2) 11:00-11:45am: Understanding Techniques to Address Mechanical Components in the Evaluation of System Reliability.
By: Cliff Lange, Ph.D., PE, Ops A La Carte

3) 11:45am-12:30pm: A Mechanical RCA Case Study.
By: Kim Parnell, Ph.D., PE, Ops A La Carte

4) 12:30pm-1:00pm: Data Collection: An Important Aspect of RCA Investigation.
By: Al Alaverdi, VP Technology, SigmaQuest

PRESENTERS

Presentation 1: Understanding the Motivation and Basics of Root-Cause Analysis in Electronics.

Summary: Before successful Root-Cause Analysis can even start, organizations and individuals must understand the need to have basic problem solving skills, tools and knowledge of how problems occur and how they can be fixed. This portion of the webinar will discuss the fundamentals of RCA and cover some of the best practices in the electronics industry from the Physics of Failure point of view.

Author: Jim McLeish, CRE, Senior Technical Staff, DfR Solutions

Jim has 30 years of automotive Electrical/Electronics (E/E) experience. He has worked in systems engineering, design, development, production, validation, reliability and quality assurance of both components and vehicle systems. He holds three patents, is the author or co-author of three GM E/E validation and test standards and is credited with the introduction of Physics-of-Failure engineering techniques to GM.

PRESENTERS

Presentation 2: Understanding Techniques to Address Mechanical Components in the Evaluation of System Reliability

Summary: In this portion of the webinar, we will first review the standard design guidelines for robust mechanical design. This is followed by a brief review of the critical elements of mechanical systems and the corresponding failure mechanisms. Then, we will go through a detailed review of RCA for a high temperature power plant creep failure and the analysis of fatigue of wind turbine blades.

Author: Cliff Lange, Ph.D., PE, Ops A La Carte

Cliff has 30 years of industry experience in both reliability engineering and root cause failure analysis. Most recently Dr. Lange spent 12 years developing reliability programs for the Semiconductor Equipment Manufacturing industry. He worked at General Electric Company and Exponent Failure Analysis where he gained extensive experience in finite element modeling and root cause analysis of structural, mechanical and electrical failures.

PRESENTERS

Presentation 3: A Mechanical RCA Case Study

Summary: This portion of the webinar will provide an overview of a particularly spectacular process plant accident in Nevada. This incident became visible as a small fire which spread rapidly and ultimately ended with two devastating explosions. Through this case study, we will show how to develop a scenario and an initial sequence of events, modify scenarios based on new evidence, and identify the Root Cause of this accident and the sequence of events leading to the ultimate catastrophe.

Author: Kim Parnell, Ph.D., PE, Ops A La Carte

Kim specializes in failure analysis and reliability of mechanical systems. He is an expert in mechanical engineering design and behavior of systems ranging from biomedical devices, to electronic and miniature components, to power generation, automotive, and aerospace applications. Kim is an independent consultant and was previously a Senior Manager with Exponent where he analyzed and investigated accidents and failures in a variety of industries. Kim has MS and PhD degrees in Mechanical Engineering from Stanford.

PRESENTERS

Presentation 4: Data Collection: An Important Aspect of RCA Investigation

Summary: A company needs a good data collection system that quickly and easily identifies and corrects the root cause for failures which result in warranty returns - to uncover emerging trends and patterns before they become issues. This, in turn, will provide a number of benefits which we will address in this portion of the webinar.

Author: Al Alaverdi, VP Technology, SigmaQuest
Al has over 20 years of experience in testing and manufacturing software development. Al is an expert at process engineering and in the development of tools to enhance product performance and manufacturing efficiencies.

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Ops A La Carte is a Professional Consulting Firm focused on Reliability Engineering Services, Reliability Management, and Reliability Education to assist you in developing and executing any and all elements of Reliability throughout your Organization and your Product's Life Cycle. We work in the area of Electronics, Mechanical Systems, and Software.

In the area of RCA, Ops A La Carte has performed countless root-cause analyses in the area of electronics, mechanics, and software.

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DfR Solutions has world-renowned expertise in applying the science of Reliability Physics to electrical and electronics technologies, and the company is a leading provider of quality, reliability, and durability (QRD) research and consulting for the electronics industry. DfR's integrated use of Physics-of-Failure (PoF) and Best Practices provides crucial insights and solutions early in product design and development, and throughout the product life cycle.

In the area of RCA, DfR Solutions has their own failure analysis lab in Maryland and has performed over 250 root-cause investigations in the past 4 years

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SigmaQuest provides an on-demand suite of solutions that help companies build better products using business intelligence techniques for product design, manufacturing, supplier quality, repair and returns. Benefits are reduced warranty costs; improved product quality, lower costs of goods sold, and increased revenue and profits.

In the area of RCA, SigmaQuest is well positioned because its solutions can be used for collecting failure data for use in the critical step of analyzing and gathering data/evidence.

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reliability designed, reliability delivered

Understanding the Motivation and Basics of Root-Cause Analysis in Electronics

Abstract: Before successful Root-Cause Analysis can begin, organizations and individuals must understand the need to have basic problem solving skills, tools and knowledge of how problems occur and how they can be fixed.

This portion of the webinar will discuss the fundamentals of RCA and cover some of the best practices in the electronics industry from the Physics of Failure point of view.

James McLeish, CRE

Background: Jim McLeish

- Education:
  - Dual EE/ME MS in Electronics Control Systems
  - ASQ-CRE (American Society of Quality - Certified Reliability Engineer)
- 32 years of Automotive, Military and Industrial Electrical/Electronics (E/E)
  - Part 1: Product Design, Development, Systems Engineering & Production
    - 3 Patents Electronic Control Systems
    - EE System Engineering and Architecture Planning
    - Product Engineering Management
  - Part 2: Validation, Reliability, Quality Assurance, Warranty Problem Solving & Test Technology Development
    - Variety of Management & Technical Leadership Positions:
  - Part 3: Senior Technical Staff/Consulting Associate - Design for Reliability Solutions.
    - Principle Investigator for E/E Failure Analysis and Root Cause Problem Solving.
    - E/E Manufacturing Process Optimization, Yield Improvement.
    - Reliability Demonstration, Product Validation and Accelerated Testing.
    - Field Return/ Warranty Analysis
    - Design Reviews for Proactive Problem Prevention
    - Society of Automotive Engineering (SAE) - Reliability Committee
    - DOD MIL-HDBK-217 Update & Enhancement Tea

Background: DfR Solutions

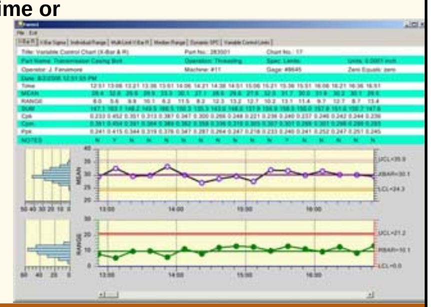
- DfR Solutions is an Engineering- Laboratory Services and Consulting firm experienced in Physics of Failure based Quality, Reliability and Durability (QRD) research, consulting and applied science for electrical and electronics products and technologies.
- The DfR staff provide knowledge and science based solutions that maximize product integrity and accelerate product assurance activities.
- DfR captures the broad range of reliability and quality issues in electronics through the expansive expertise of our multi-discipline staff.
  - Physicists, Material Scientists, Chemists and Electronic Engineers from Various Industry Segment.
  - Over 500 failure analysis and root-cause investigations in the past 4 years,
  - A world leader in failure analysis in electronics.
  - Strong partnerships with the leading companies in the field of electronics,
- DfR strives to make our clients life easier by providing knowledge based solutions for electronic quality, reliability and durability issues.
  - From component specifications and computer modeling based lifetime predictions.
  - From robust design of products and process to accelerated product qualification.
  - From technology insertion to RCA and failure analysis.

1) Motivation for Root Cause Analysis

- The 1st rule of business is now:
  - “The competitor who Consistently, Reliably and Profitably provides the greatest value to customers FIRST wins.”
- 2nd rule is:
  - "There are NO OTHER RULES".
- In other words it’s Survival of the Fittest and the Best.
- **Continuously Improvement** is Essential to Becoming and Staying the Best or At Least Remaining Competitive.

1) Motivation For Root Cause Analysis
- Continuous Improvement (C.I.)

- **Continuously Improvement** is the ongoing effort to improve products, services or processes, in order to advance the goals of an organization, business or society.
  - A never ending effort to discover and eliminate:
    - **Inefficient process road block and bottle necks,**
    - **Non value added activities,**
    - **Problems,**
    - **Either "incremental" improvement over time or "breakthrough" improvement all at once.**
    - **Japanese Version Kaizen - "Change for the Better".**
- Examples of C.I. Tools
  - Statistical Process Control
  - 6 Sigma Quality
  - Best Practices / Leasons Learned
  - Process Optimization
  - Problem Solving



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2) Introduction to Root Cause Analysis
- Problem Solving

- **Problem Solving** is an integral part of cognitive thinking & decision making. It is essential to many aspect of daily live, it involves:
  - Using tools to obtain relevant data, information and knowledge,
  - Creating mental models of situations and how the world works,
  - Make logical connections that lead to the formation of potential solution concepts,
  - Evaluate the potential solutions against goals, constrains and desires.
- Problem solving method examples:
  - Trial-and-error
  - Brainstorming
  - Root Cause Analysis
- Problem Solving uses similar skills as:
  - Solving a puzzle
  - Detective work.

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2) Problem Solving, Failure Analysis & Continuous Improvement Has Been the Basis of Engineering Since Humans First Make Tools & Structures

Lessons Learned for Problem Solving
During the Construction of the Early
Step & Bent Pyramid Enabled the Ancient Egyptians
To Later Build Bigger & Better Pyramids

3) Introduction to Root Cause Analysis (RCA)

- **Root Cause Analysis** - is a category or problem solving methods that focus on identifying the ultimate underlying reason of why an event occurred.
  - **Based on the belief that problems are more effectively solved by correcting or eliminating the root causes, rather than merely addressing the obvious symptoms.**
  - **The root cause is the trigger point in a causal chain of events, which may be natural or man-made, active or passive, initiating or permitting, obvious or hidden.**
  - **Efforts to prevent or mitigate the trigger event are expected to prevent the outcome or at least reduce the potential for problem recurrence.**
  - **RCA is a full-blown analysis that identifies the chain of physical and human related root cause(s) behind an undesirable event .**
  - **This differs from basic troubleshooting and problem-solving processes that typically seek solutions to specific, relatively simple difficulties.**
  - **The undesired event may be a product durability failure, a safety incident, a customer complaint, a quality defects, human error . . . etc.**
  - **It helps focus CA/PA (Corrective Action / Preventive Action) efforts at the points of most leverage it is essential for pointing change management efforts in the right direction.**

3) Introduction to Root Cause Analysis - Failure Analysis (FA)

- **Failure Analysis** is a subcategory of RCA techniques
  - **Systematic examination of “Failed Devices” to determine the root cause of failure.**
  - **Use knowledge gained to improve technology, quality and reliability.**
  - **Primarily associated with the physics and material science of mechanical, structural and E/E (Electrical /Electronic) devices and materials (i.e. hardware).**
  - **Software FA is a growing subcategory involving computer science & programming.**
  - **Forensic Engineering a subcategory that uses science and technology to investigate materials, structures, products or components that fail or malfunctions to establish facts for criminal or civil legal actions.**

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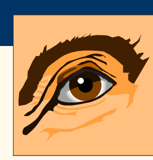
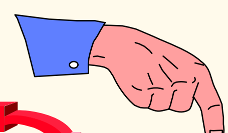
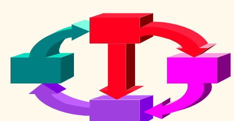
3) Introduction to Root Cause Analysis - Failure Analysis (FA)



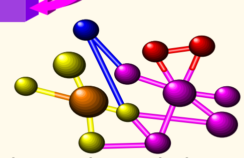
- **Failure analysis** is designed to:
  - **Identify the *failure modes* (the way the product failed),**



  - **Identify the *failure site* (where in the product failure occurred),**



  - **Identify the *failure mechanism* (the physical phenomena involved in the failure),**



  - **Determine the *root cause* (the design, defect, or loads which led to failure) and recommend failure prevention methods**
- **FA** begins with non-destructive techniques, then proceeds to destructive techniques.

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3) Introduction to Root Cause Analysis - Section Summary

- **The Hierarchary:**
  - **Continously Improvemet**
    - Essential to being competidive and advancing objectives.
  - **Problem Solving**
    - An important method for continuous Improvement.
  - **Root Cause Analysis**
    - One type or problem solving approach that works to identify not only what and how an undesired event occurred, but also why it happened so as to prevent reoccurance.
  - **Failure Analysis**
    - A broad subcategory of Root Cause Anaylsis techniques that can be used when failed or malfunctioning devices are available for examination.
    - FA has many sub categories and specialists realated to the type of technologies and materials that failured.

4) RCA Approaches, Management & Reporting Methods

- **Root cause analysis is a generic term for diligent structured problem solving.**
- **Over the years various RCA techniques and management methods have been developed**
- **5 of the most popular RCA approaches are:**
  - **The" 5 Whys" Technique**
  - **The 8D (Eight Disciplines) Problem Solving Process**
  - **Shainin Red "X" Statistical Problem Solving**
  - **Six Sigma**
  - **Physics of Failure / Reliability Physics**

4.1) The 5 Why Approach

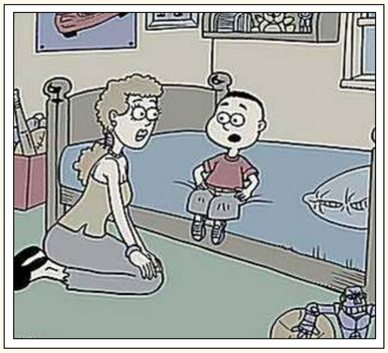
1) WHY?

2) WHY?

3) WHY?

4) WHY?

5) WHY?



Mom, Why is the Sky Blue?
Why Can't we see God?
Why is water wet?
Why . . .

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4.1) The 5 Why Approach

- The 5 Why's is a simple problem-solving technique developed by Toyota* to quickly get to the root of a problem.
- The 5 Why strategy involves looking at any problem and asking: "Why"? and "What caused this problem"?
  - The answer to the first "why" must prompt another "why" and the answer to the second "why" must prompt another and so on.
  - The rule of thumb is that the "Why" question must be asked & resolved at least 5 times in order to identify the true underlining root cause of the problem.
  - **Toyota's Philosophy:**
    - **A Rush to action that addresses only symptoms or a problem only produces temporary relief.**
    - **Only after the "True" Root Cause has been identified can an "EFFECTIVE STRATEGY TO PERMANENTLY RESOLVE" the issue be developed**.

* Ref. "The Toyota Way, by Jeffrey K. Liker, McGraw-Hill 2004

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4.1) The 5 Why Approach
Example:

	ISSUE	OBVIOUS RESPONSE
	There is an oil spill on the floor	This is a safety hazard, Clean it up
WHY	A machine is leaking oil	Fix the oil leak
WHY	A gasket has failed	Replace the gasket
WHY	The gasket is made out of paper which breaks down quickly	Find a better gasket
WHY	Low cost paper gaskets were purchased instead of durable graphic or silicon gaskets	Developed detailed specifications to provide better direction to purchasing
WHY	Purchasing bonuses are based on up front cost savings not long term performance	Change purchasing incentive policy to promote total value over short term savings

Toyota is known of not stopping at the technical issues. They continue until the root causes of organization, cultural & people motivation issues are also understood & addressed.

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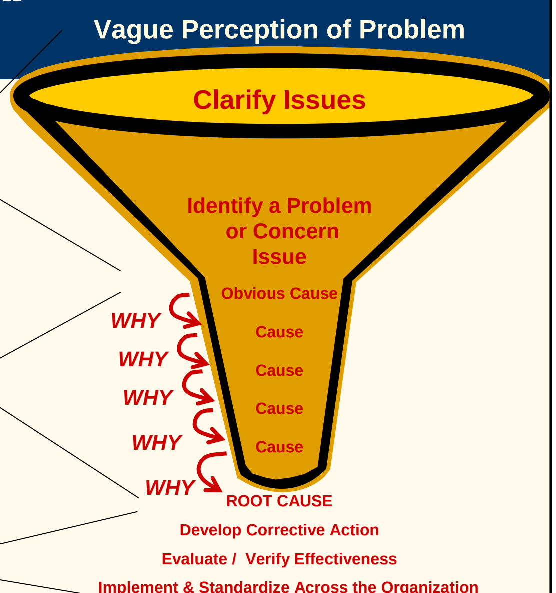
4.1) The 5 Why Approach

The "Funnel Model"

Phase 1) Identify the Issue

Phase 2) Issue Investigation

Phase 3) Corrective Action



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4.1) The 5 Why Approach - Summation

- Benefits
  - Easy to remember, Simple to apply,
  - Gets deeper into "Root Cause" than many other problem solving techniques, so better in the long run.
  - Informal, flexible, open structure, little bureaucracy
    - Organizations/users adapts to their own needs.
- Potential Issues / Concerns.
  - More time consuming investigate than quick fix approaches.
  - Sorting out issues with MORE THAN 1 CAUSE.
  - Mistakes in developing/answering a "Why" question can mislead the investigation.
  - Requires some Subject Matter Expertise
    - Hardest part of 5-Whys is asking the right "Why" questions.
    - Every organization does not have access to experts in every area.
    - Depends on some knowledge of cause & effect.
      - To ask the right questions,
      - Know how to follow them up in order to reach the right conclusions.
      - Novices can follow the wrong path.
  - Informal, flexible, open structure, little bureaucracy = Little guidance.
  - Repeatedly ask why can appear threatening to involved people.
    - Fear of an inquisition and assigning blame.
    - Self preservation instincts can lead to lack of cooperation or hiding information.

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4.2) 8D (Eight Disciplines) Team Problem Solving Process

- 8D is a problem-solving methodology that emphasize team synergy.
- Originated in 1974's as part of MIL-STD-1520
  - "Corrective Action & Disposition System for Nonconforming Material"
- Ford introduced and popularized the process within the Auto Industry in 1987.
  - First known as TOPS - "Team Oriented Problem Solving".
  - Evolved into today's widely used 8D process.
- Philosophy - When a problem cannot be solved quickly by an individual, a team approach is the most effect way to resolve the situation.
  - Team are more effective than the sum efforts of individuals working separately.
  - Essential to assign the right members to each a team and support them.
    - Team members need to have the inclination and skills needed for each problem
    - Team members need to be provided with the time and resourced need to solve the problem.

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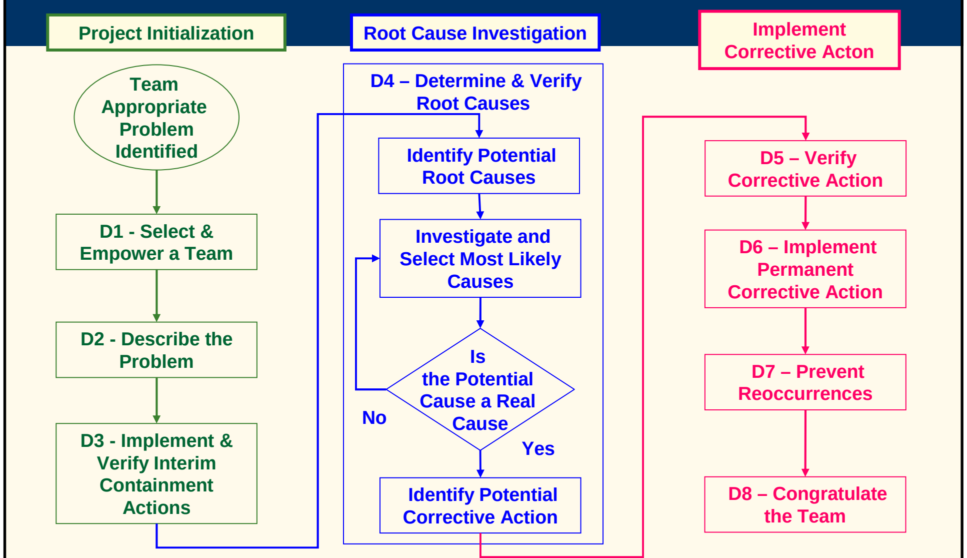
4.2) 8D Problem Solving Process (PSP)



4.2) 8D PSP - Phase 1 Project Initialization

- **Starting Point - An Appropriate Problem is Identified.**
  - 8D Method does not define how problem awareness is developed.
  - Always use the right tool for the job:
    - Ensure problem warrant the resources of team PSP effort.
    - Avoid one size fits all tool and processes.
    - Avoid management dictates i.e. "all departments MUST deploy at least five 8D PSP per year".
- **D1 - Use Team Approach**
  - Establish a small group of people with the collective knowledge, time, authority and skills to solve the problem, develop and implement corrective actions.
    - Provide each team with an executive champion to report to and clear roadblocks.
    - Each team requires a team leader to pace the process, lead meetings, coordinate team efforts.
    - Intermix skills: problem solvers, technical knowledge, manuf. process, test, analysis . . . etc.
    - Ensure team members have the inclination to work towards a common goal.
- **D2 - Describe the Problem**
  - You can not fix a problem you don't know what's broke.
    - Clearly describe the problem in measurable, specific terms.
    - Clarify what, when, where and how much, impact to customers.
    - Info will be needed later to measure corrective action effectiveness.
- **D3 - Implement and Verify Short-Term Containment Actions**
  - Stop or limit the bleeding as quickly as possible.
    - Define and implement screens, extra Q.C procedures, Rework . . . other appropriate actions.
    - To protect the customer & limit losses from the problem until a permanent C.A. is implemented.
    - Verify effectiveness with data and enhance if necessary.

4.2) 8D PSP - Phase 2 - Root Cause Investigation

- **4. Determine and Verify Root Causes -**
  - Phase where team conducts the actual root cause Investigation.
  - Team applied experience and brain storm of preliminary information to identify potential causes.
  - Team collects data, follows leads, performs analysis, authorizes test, apply statistics . . . etc.
    - Specific procedures or tools not defined by the 8D process.
    - Team empowered to follow the facts, apply their expertise and available resources to determine the best investigation approach.
    - Identification of "true" root cause(s) must be verified, proven and documented by data not opinion) to proceed to corrective action activities.
  - Concludes with team proposal for potential corrective action(s).

4.2) 8D PSP - Phase 3 - Corrective Action

- **5. Verify Corrective Actions -**
  - Select the best case or optimal corrective action.
  - Perform test builds, process runs & evaluations to verify effectiveness & feasibility.
  - Confirm that the selected CA effectively resolves the problem without side effects.
  - Develop Corrective Action business case and obtain management approval.

- **6. Implement Permanent Corrective Actions -**
  - Revise the product and/or process to implement the permanent fix
  - Establish monitoring to make sure it's working.
  - If issues reoccurs implement additional controls or go back a few steps & try again.

- **7. Prevent Recurrence -**
  - Improve practices & procedures to prevent recurrence of this & similar problems.
  - Modify specifications, update training, document lessons learned, review work flow.

- **8. Congratulate Your Team -**
  - Recognize the collective efforts of your team.
  - Publicize accomplishments, share knowledge & learning across the organization
  - Going public with success spreads knowledge and learning.
  - Letters of thanks, certificates of recognition.

4.2) 8D Sample Reports & Worksheets

- Many 8D report templates exist.
  - Simple: “just the facts” & results documentation reports (Ref. Example right).
  - Complex: “document every step” formats that include pages of worksheets for preferred tools (Ref. Following Example).
  - No Universal Format
    - **Many format variations possible.**
    - **Use what works for your products, organization & customers.**

Problem No	Source		Product Family	Product code
(Unique Tracking number) Such as Kimball Supplier CAR or FA Number	(Source of the Defect)			
	Customer reference	Quantity reported	Receive date	Quantity returned

D1 Team members (Initials/name)			Serial Numbers			
Name of the Team Members						

	Assigned to	Effective Date
D2 Description of problem		
The problem description needs to be a concise answer to the question of who, what, where, when, and the magnitude of the nonconformity.		
Customer notified		
D3 Interim Containment actions		
Containment is action taken to isolate a KEG manufacturing site from nonconforming material. Containment actions need to not create unwanted effects and should be immediate.		
Customer notified		
D4 Define the root cause		
Root cause is to include escape root cause and root cause of the nonconformity. The root cause description is to identify all causes and explain why the nonconformity occurred, and why the nonconformity was not identified and contained within the manufacturing process (reason for escape). The root cause shall be verified by testing each cause against the nonconformity description and test data.		
Customer notified		
D5 Choose and verify permanent corrective actions		
The permanent Corrective Action(s) will resolve the problem for the KEG manufacturing site and not create any unwanted side effects.		
Customer notified		
D6 Validate permanent corrective actions		
Factual data shall be used to prove that the permanent Corrective Action has eliminated the nonconformity. The data shall be provided with the Corrective Action document.		
Customer notified		
D7 Prevent reoccurrence of the problem		
Systems, practices, and procedures need to be modified to prevent recurrence of this and all similar problems.		
Customer notified		
D8 Congratulate the Team		

	Initials	Date	Update	N / Y / NA
SMCR Needed/Submitted			DFMEA/PFMEA	
SMCR Approved			Control plan(s)	
PPAP Required			Process Flow	
PPAP Approved			Inspection Criteria	
Concern closed. Customer			Work instruction(s)	
Concern closed. Internal			Procedure(s)	

4.2) 8D PSP Variation - The 5 Phase PSP

- **Simplified Version of the 8D.**
  - **Used to resolve & document less complex / everyday issues.**
  - **That don’t require the resources or expertise of a team approach.**
- **Many Common Features:**
  - **1) Problem Description.**
  - **2) Immediate Actions.**
  - **2) Root Cause Conclusions.**
    - **RCA Investigation Plan Optional.**
    - **A Lesson Learned Opportunity?**
  - **4) Corrective Acton Plan (CAP)**
    - **Part / Process &**
    - **The System.**
  - **5) Verification/Validation of CAP.**
- **No Universal Format**
  - **Many format variations possible.**
  - **Use what works for your products, organization & customers.**

5 PHASE PROBLEM SOLVING REPORT

INITIATOR:	DEPARTMENT(S)	CHAMPION:
INITIATING REPORT:	P/N OR PROCESS	ISSUE DATE:
INITIATING REPORT #:	PART NAME:	
VEHICLE NUMBER:	PLATFORM:	REQUIRED ANSWER DATE:
ATTACHMENTS TO FILE:	DEFECT CODE:	QUALITY CONTACT :
ASSEMBLY PLANT:	DEFECT NAME:	PHONE #:
		SWITCH BUILD DATE:

I. PROBLEM DESCRIPTION (S) OR QUANTIFICATION:

II. IMMEDIATE ACTION (S)

PERSON RESPONSIBLE: PHONE NUMBER: N/A DATE IDENTIFIED:

III. ROOT CAUSE DETERMINATION(S) :

PERSON RESPONSIBLE: PHONE NUMBER: DATE IDENTIFIED:

IV. CORRECTIVE ACTION PLAN. (CAP):

Product:

System:

PERSON RESPONSIBLE: PHONE NUMBER: DATE IDENTIFIED:

V. VERIFICATION/VALIDATION OF CAP(S):

Product:

System

PERSON RESPONSIBLE: PHONE NUMBER: DATE IDENTIFIED:

CANDIDATE FOR A LESSON LEARNED ACTIVITY: ___ YES ___ NO

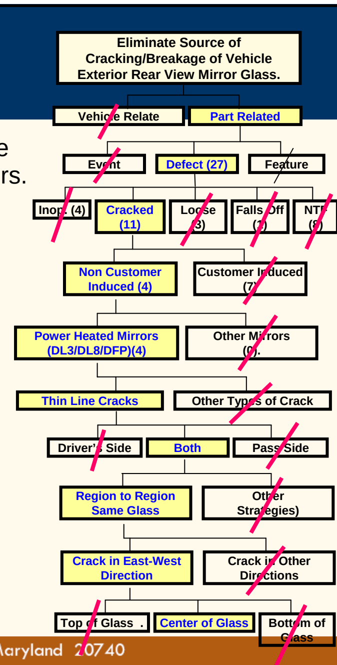
SUPERINTENDENT'S APPROVAL

PRINT NAME DATE SIGNATURE OTHER POTENTIAL PROCESSES

4.2) 8D/5 Phase Problem Solving Processes - Summation

- **Benefits - Address a Number of 5 Why Concerns,**
  - **Early initial problem containment counter balance time need for thorough RCA**
  - **Drawing on team experience reduces potential for RCA errors.**
  - **Team format expands potential to tap available subject mater expertise.**
  - **Opportunity for novices to learn from more experienced personnel.**
  - **Provides a formal PSP structure without dictating methods and tools.**
    - **Team retain freedom to select tools and follows leads.**
    - **Team members feel empowered, respected and appreciate trust.**
  - **Easily converted into an 8D problem solving/ RCA report**
    Example 8D worksheet/ report template (on following pages) provides:
    - **Sections for documenting outcome of all 8 steps.**
    - **RCA Worksheet for 5 Why and Fishbone Cause & Effect diagrams.**
    - **Status documentation**
- **Potential Issues / Concerns.**
  - **8D structure provides susceptibility to excessive bureaucracy & micro-management.**
    - **Excessive status report updates detract from problem solving efforts.**
    - **Process management personnel represent non-value added overhead.**
    - **Management "throughput / efficiency" improvement efforts that degrade RCA effectiveness (teams will avoid time consuming hard problems to avoid poor performance ratings in systems that emphasize quantity over quality)**
  - **Management with lackluster team recognition / congratulations**

4.3) Shainin Red "X" - Diagnostic Journey

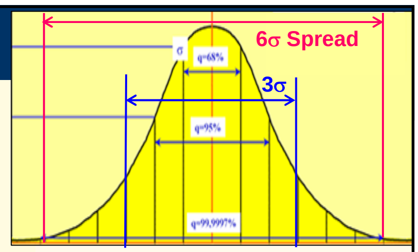


- A Red X Statistical "Journeyman" or "Master" start the process by organizing a team of problem stake holders.
- The team creates a problem definition tree diagram (similar to a fault tree minus the logic symbols).
  - Create a visual map of the issue or sequence of events that relate to or resulted in a failure.
  - Included relevant issues & realistic contributing factors.
- Use the diagram as a guide for evaluating the impact of each factor.
  - Use progressive search questioning strategy a series of (yes/no) questions concerning degree contribution to reduce the field of suspects.
  - Cross off the factors that are minor contributors to the outcome to eliminate them from serious consideration.
- The remaining factor in each category line are considered to be the factors worthy of detailed statistically evaluations.

4.4) Six Sigma (6σ)

- A methodology for **"Improving Business Performance".**
- Pioneered by Motorola Q.A. manager Bill Smith (mid 80's) who proved that:
  - Manuf. lines with high in-process defects rates requiring Rework/Repairs (R/R) had higher field failure rates & warranty costs than lines with low repair rates.
  - Low repair rate (build right on the first attempt) lines also had improved customer satisfaction that resulted in better sales.
    - **Root Causes:**
      - **Defect escapes from quality control systems.**
      - **Inadvertent, hidden damage during addition handling, rework & retest.**
  - Lines with "better/tighter process capability" resulted in:
    - **"Higher First Pass Quality" making them "More Efficient & Cheaper to Operate", even if the better equipment had higher up front costs, due to:**
      - **Less Effort & Costs for the "Hidden Factory" (Q.A, R/R & Root Cause).**
      - **Improved efficiency from higher throughput.**
- "Quality Pays" Even Better than Phil Crosby's "Quality if Free" Philosophy.
- Enabled QRD professional to communicate in the native language of executive management: "Time and "$" Money"

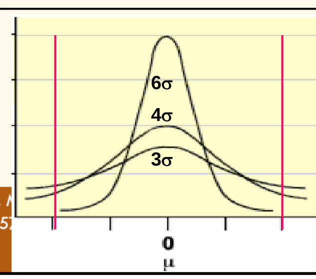
4.4) Six Sigma (6σ)



- **Sigma σ is the symbol for Statistical Standard Deviation of the normal distribution (bell curve).**
- **The "σ" measurement scale define how much of process's normal distribution is capable of being contained within required tolerance limit *"ON THE FIRST PROCESS PASS"*.**
- **Out of spec "defects" are measured in terms of Defects Per Million Opportunities (DPMO).**
- **Processes that operate at a "6σ" quality capability level produce < 3.4 DPMO "for each operation".**
- **DPMO is related to process operations not the number of parts produced, Example:**
  - **A circuit board requires 100 component placement operations so 1,000,000 placements ~ 10,000 boards.**
  - **The same board requires 500 solder joints so 1,000,000 soldering operations ~ 2,000 boards.**
  - **10,000 6σ boards would require no more than 3.4 placement repairs & 17 solder repairs.**
  - **Wave soldering typ. run at 100-500 DPMO (4.78-5.19σ),**
  - **Reflow soldering is typ, 25-100 DPMO (5.55-4.78σ).**
- **The goal is more capable processes that produce a tighter variation spread within the spec limits**

σ (Std Dev) Conversion Table

σ	In Spec Yield	DPMO (Outliers)
1	30.85%	691,462
2	69.14%	308,534
3	93.32%	66,807
4	99.38%	6,210
5	99.9767%	233
6	99.99966%	3.4



4.4) Six Sigma (6σ) Improvement Processes

- DMAIC - Define, Measure, Analyze, Improve & Control
  - The 6σ improvement system for:
    - **Existing" processes related problems**
    - **Sub-optimized process that fall below specification & yield expectations.**
- DMADV - Define, Measure, Analyze, Design & Verify
  - The 6σ improvement system for:
    - **Developing new processes or products or**
    - **Resolving design related problems.**
  - Also used in Design For Six Sigma (DFSS) a methodology for new produce development.
- Obvious similarities with the previously discussed 8D and 5 Phase PSP's
  - Different definitions and terms.
  - Some differences in statistically tools.

4.5) Physics of Failure - Definitions

- **Physics of Failure (PoF also known as Reliability Physics).**
  - A Proactive, Science Based Engineering Philosophy.
  - Development & Applied Science of ***Product Assurance Technology*** base on:
    - A Formalized and Structured approach to Failure Analysis/Forensics Engineering that focuses on total learning and not only fixing a current problem.
    - Material Science, Physics & Chemistry.
    - Variation Theory & Probabilistic Mechanics.
    - Up Front Understanding of Failure Mechanisms and Variation Effects.
      - Knowing how & why things fail is equally important to understand how & why things work.
      - Knowledge of how thing fail and the root causes of failures, enables engineers to identify and design out potential failure mechanisms in new products and solve problems faster.
      - Provides scientific basis for evaluating usage life and hazard risks of new materials, structures, and technologies, under actual operating conditions.
    - Applicable to the entire product life cycle
      - Design, Development, Validation, Manufacturing, Usage, Service.

4.5) PoF Grew Out of the Limitations of Statistics Based Reliability Prediction

- ***Fundamental Limitations***
  - ***Statistical probability should be used only when we lack knowledge of the situation and cannot obtain it at a reasonable cost.***
  - ***"Statistics are applicable only when:***
    1. You are unavoidably ignorant about a given issue,
    2. Some action is necessary and cannot be delayed."

    Leonard Peikoff
    In Book & Lectures on The Art of Thinking
  - ***In other words, if you're trying to determine a course of action:***
    - Your best bet is to acquire knowledge and not to blindly use statistics to play the odds.

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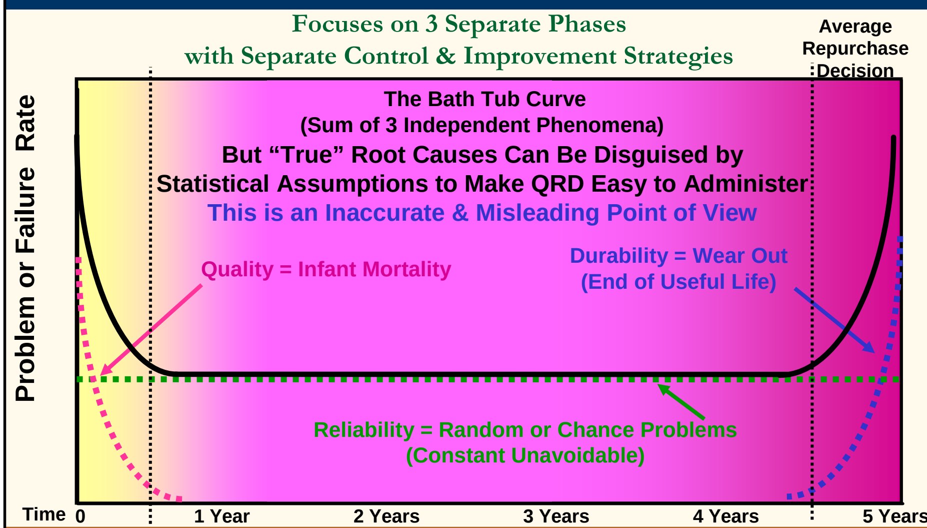
4.5) A View of Quality, Reliability & Durability (QRD) Via The Traditional Product Life Cycle Failure Rate "Bath Tub" Curve

Focuses on 3 Separate Phases
with Separate Control & Improvement Strategies



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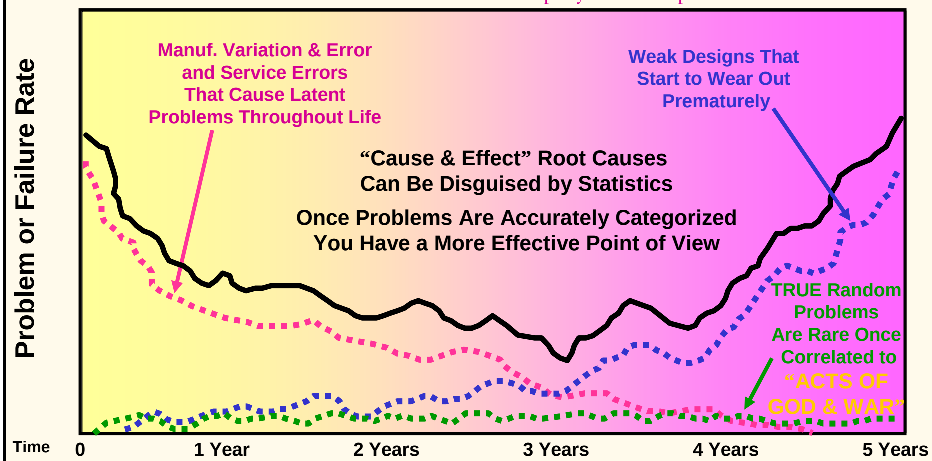
4.5) A "PoF FAILURE MECHANISM" Based "REALISTIC" View Reveals the True Interactive Relationships Between Q, R & D

- Real failure rate curves are irregular, dynamic and full of valuable information, not clean smooth curves to simplify the data plots.



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4.5) Root Cause Implications of the Physics of Failure Point of view

- The focus of "Traditional Reliability Methods" on "Random/Chance Failures" conveys a perception that problems and failure are inevitable & unavoidable.
  - "Resistance is Futile"
- The Physics of Failure approach emphasizes:
  - An ordered understandable, predictable universe of cause & effect relationships.
  - The role of root cause analysis problem solving for discovering, understanding and mastering these cause and effect relationships.
  - Using RCA to build a "Compendium of Formalized, Institutionalized Knowledge" for Future Problem Prevention as well as for solving today's problems.

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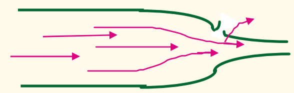
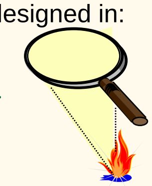
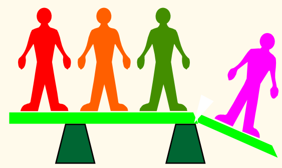
4.5) Key PoF Terms and Definitions

- **Failure Site :**
  - The location of potential failures, typically the site of a designed in:
    - *stress concentrator* ,

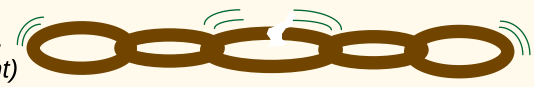




    - *design weakness* or *(designed in)*



    - *material variation or defect*. *(process related or Inherent)*



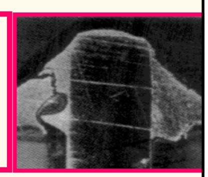
  - Knowledge Used to Identify and Prioritized Potential Failure Sites and Risks in New Designs During PoF Design Reviews.

4.5) 3 Generic PoF Failure Categories and Detection Methods

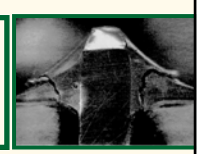
GENERIC FAILURE CATEGORY | **TYP. FAILURE DETECTION**

- **Errors - Incorrect Operations & Variation Defects/Weaknesses.**
  - Missing parts, incorrect assembly or process.
  - Process control errors (Torque, Heat treat).
  - Design errors
    - Missing functions,
    - Inadequate performance.
    - Inadequate strength.
- **Overstress.**
  - Overheating.
  - Voltage/Current
  - Electro static discharge.
  - Immediate yield, buckling, crack.
- **Wearout/Changes, via Damage Accumulation.**
  - Friction wear.
  - Fatigue.
  - Corrosion.
  - Performance changes/parameter drift

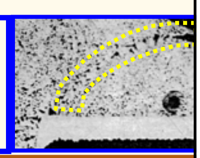
Quality Assurance Immediate or *Latent defects*



Performance Capability Assessments

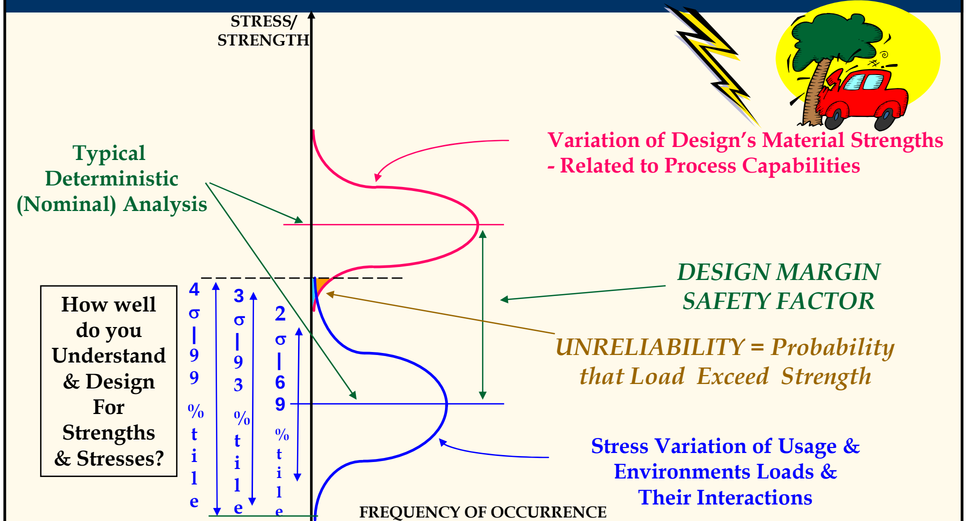


Stress-Life Durability Assessments



4.5) Generic PoF Failure Categories

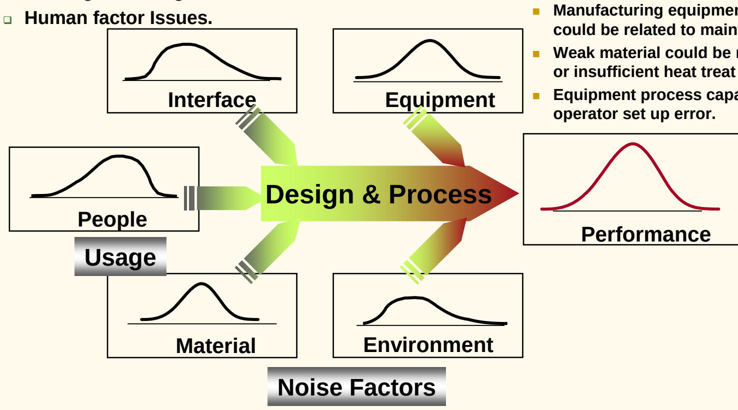
1) Overstress - When Loading Stress Exceed Material Strength

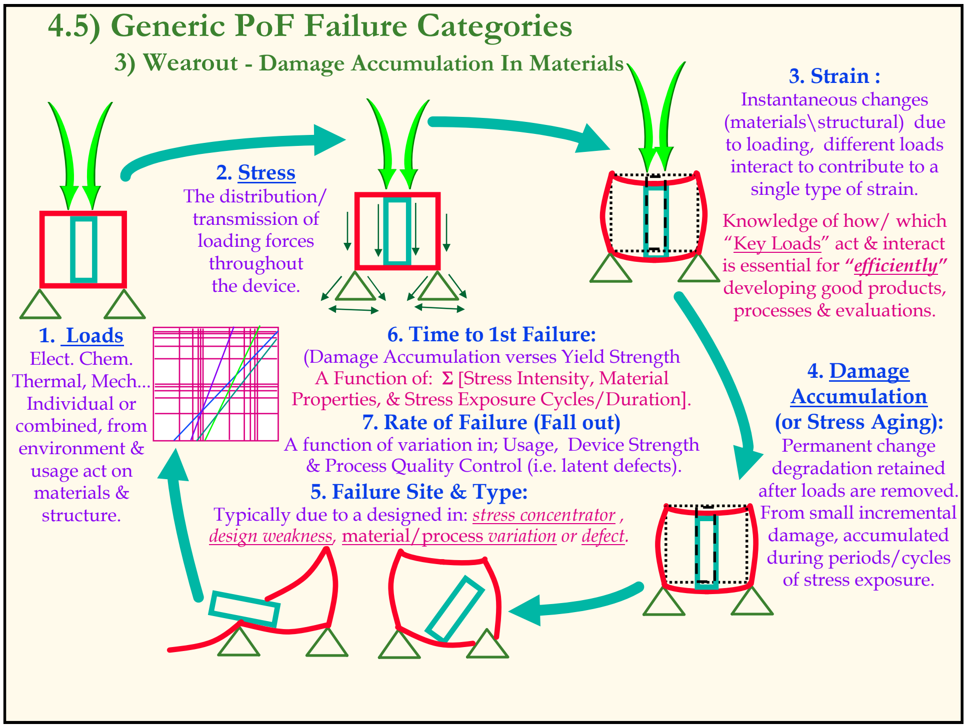


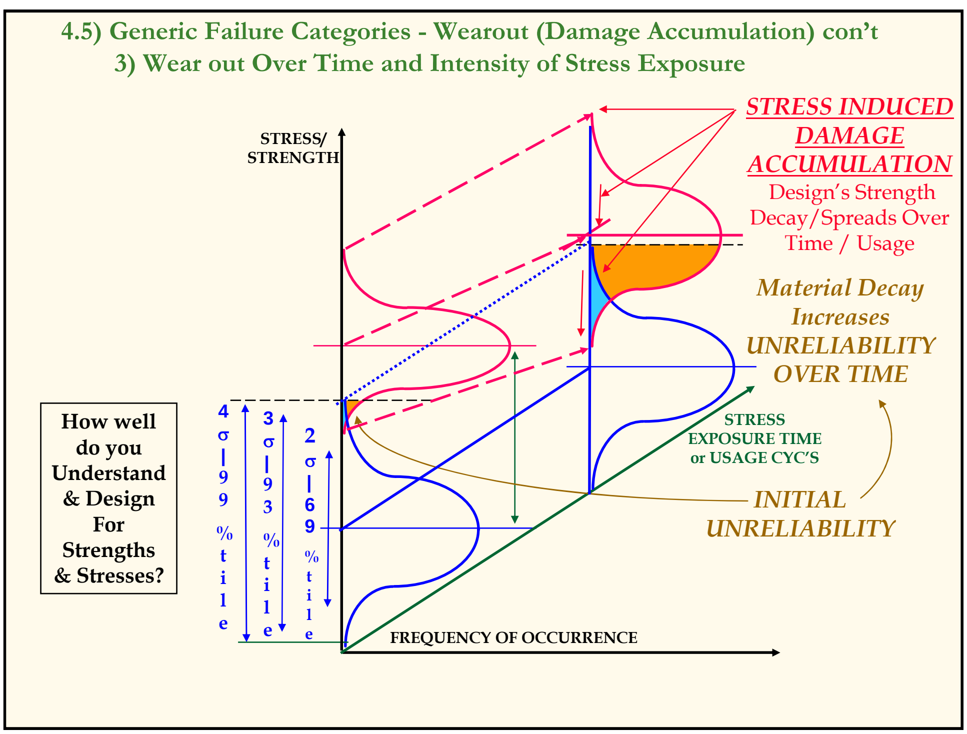
4.5) Generic PoF Failure Categories

2) Errors and Variation Issues (They Are Everywhere)

- Errors Broadest Category
  - Errors in Design, Manufacturing, Usage & Service.
  - Missing knowledge
  - Human factor Issues.
- Variation
  - Fine line between excessive variation & out right errors.
  - Both related to various quality issues.
    - Manufacturing equipment wear out & failure could be related to maintenance errors.
    - Weak material could be raw material variation or insufficient heat treat processing errors.
    - Equipment process capabilities limitation or operator set up error.




4.5) Generic PoF Failure Categories
3) Wearout - Damage Accumulation In Materials
1. Loads
Elect. Chem. Thermal, Mech... Individual or combined, from environment & usage act on materials & structure.
2. Stress
The distribution/ transmission of loading forces throughout the device.
3. Strain :
Instantaneous changes (materials\structural) due to loading, different loads interact to contribute to a single type of strain.
Knowledge of how/ which "Key Loads" act & interact is essential for "efficiently" developing good products, processes & evaluations.
4. Damage Accumulation (or Stress Aging):
Permanent change degradation retained after loads are removed. From small incremental damage, accumulated during periods/cycles of stress exposure.
5. Failure Site & Type:
Typically due to a designed in: stress concentrator , design weakness, material/process variation or defect.
6. Time to 1st Failure:
(Damage Accumulation verses Yield Strength A Function of: Σ [Stress Intensity, Material Properties, & Stress Exposure Cycles/Duration].
7. Rate of Failure (Fall out)
A function of variation in; Usage, Device Strength & Process Quality Control (i.e. latent defects).


4.5) Generic Failure Categories - Wearout (Damage Accumulation) con't
3) Wear out Over Time and Intensity of Stress Exposure
STRESS/ STRENGTH
FREQUENCY OF OCCURRENCE
STRESS INDUCED DAMAGE ACCUMULATION
Design's Strength Decay/Spreads Over Time / Usage
Material Decay Increases UNRELIABILITY OVER TIME
STRESS EXPOSURE TIME or USAGE CYC'S
INITIAL UNRELIABILITY
How well do you Understand & Design For Strengths & Stresses?
4 σ | 99 %tile
3 σ | 93 %tile
2 σ | 69 %tile

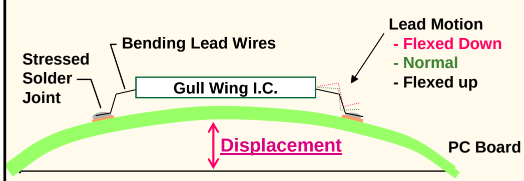
4.5) Generic Failure Categories

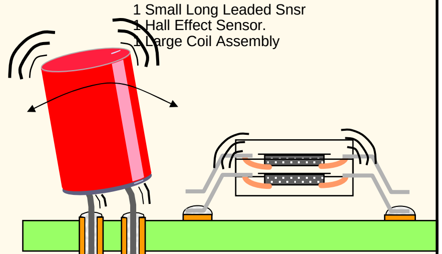
Overstress - Examples of Wear Out Failure Mechanism

- Mechanical
  - Fatigue
  - Creep
  - Wear
- Electrical
  - Electro-Migration Driven Molecular Diffusion & Inter Diffusion
  - Thermal Degradation
- Chemical / Contaminate
  - Moisture Penetration
  - Electro-Chemical-Migration Driven Dendritic Growth.
  - Conductive Filament Format (CFF)
  - Corrosion
  - Radiation Damage
- When Over Stress Issue are Detected.
  - Verify supplier's are meeting material strength specs & purity expectation.
  - Re-evaluate field loading / stress expectation used to design the part.
  - Sort out stresses,
    - **Combined stress issues are often involved.**
  - Re-evaluate effectiveness of product durability testing

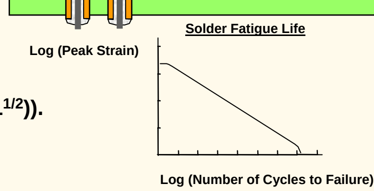
4.6) Physics of Failure Examples - Circuit Board Related Vibration Durability Issues

- Board in Resonance
  - Components. Shaken Off/Fatigued by Board Motion.
    - By Flexing Attachment Features
- Components In Resonance.
  - Components Shake/Fatigue themselves apart or off the Board.
  - Especially Large, Tall Cantilever Devices
    3 Med. Sized Alum CAPS
    1 Small Long Leaded Snsr
    1 Hall Effect Sensor.
    1 Large Coil Assembly





- Time to Failure Determine by Intensity/Frequency of Stress Verses Strength of Material



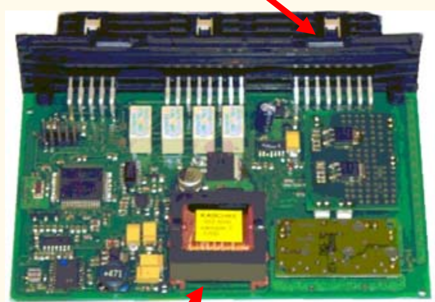
Steinberg's Criterion:

For a 10 million cycle life, $Z < 0.0008995 \cdot B/(C \cdot h \cdot r\,(L^{1/2}))$.

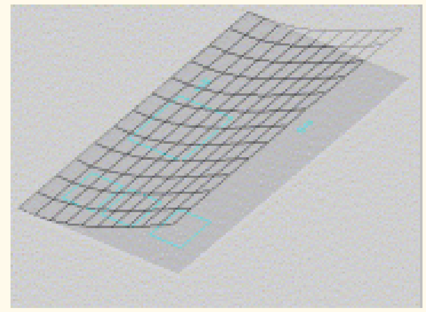
Ref: Vibration Analysis for Electronic Equipment, by David S. Steinberg

4.6) PoF Example
– E/E Module Vibration Analysis

Connector Provides Primary PCB Support



CAE Modal Simulation of Circuit Board Flexure



Transformer
A Large Mass, will drive a Large Vibration Modal Response

	Original	CAE Guided Redesign Adds Back Edge Support
Board Displacement (mils)	13.95	1.15
Natural Frequency (Hz)	89	489
Vib. Durability Calculation	25 Days	**> 50 Years**

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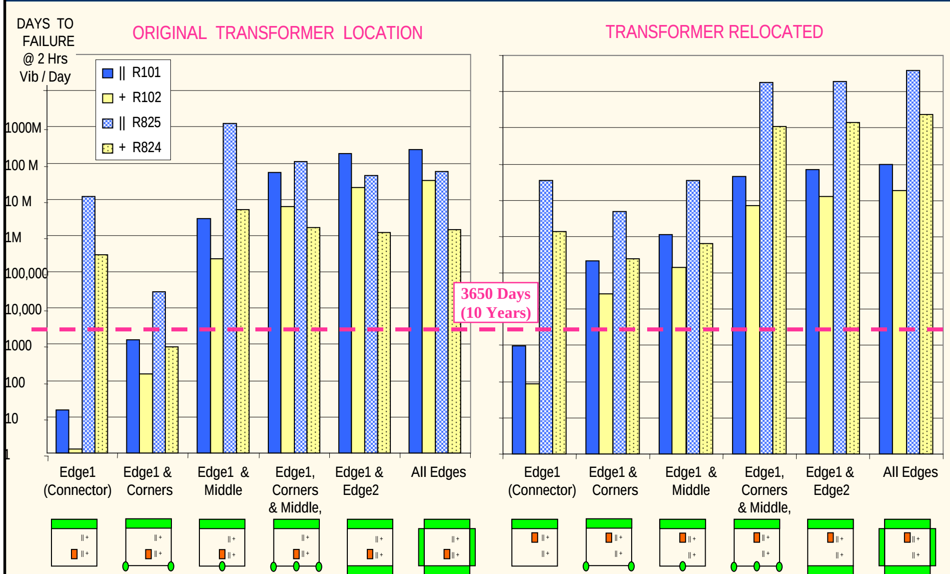
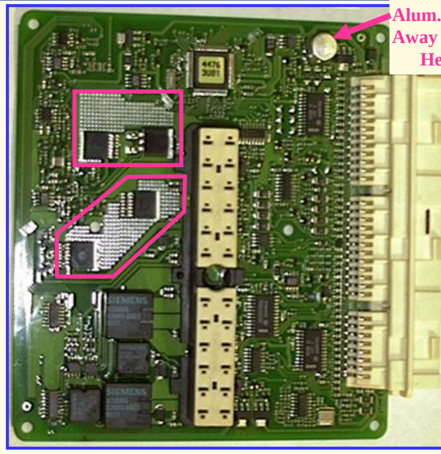
4.6) PoF Example Vibration Durability Calculations
- For Alternative PCBA Support & Mass Locations



4.6) PoF Example

- Thermal Stress Balance/Distribution & Stress Avoidance

Infrared Thermal Imaging Reveals Hot Spots From Concentration of High Power Component Surrounding Heat Sensitive Alum. Electrolytic Cap.



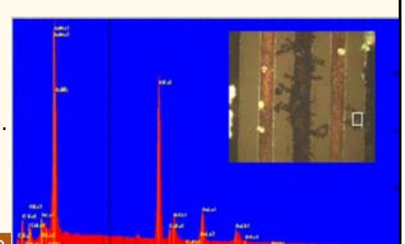
Another Design Uses an Array of Thermal Vias as a Heat Spreader to Lower Peak Temperatures. Alum. Caps Located Away From High Power Areas

4.6) PoF Example - Moisture/Contaminate Failures

- Electro-Chemical Metal Migration Shorts - a.k.a. Dendritic Growth

- Excessive Ionic Residue Contaminates on Circuit Board can interact with atmospheric humidity to form an electrolyte.
- When a voltage differential is present across a small distance copper ions can be excited to migrate from the anode to the cathode of the circuit (+ to -).
- A copper trail will be deposited along the way that will eventually support current leakage short circuits.
- 4 factors are required:
  - 1) Excessive Ionic Residues
  - 2) Humidity (typ.>65% R.H. varies with Temp.
  - 3) Exposed Copper.
  - 4) Voltage difference bias over a short distance

Ionic Chromatograph.
Identifies Electro-Chemical Contaminates From Manuf. Processes



4.6) PoF Example - Moisture/Contaminate Failures - Detrimental Contaminates

- **Chloride Residues**
  - One of the more detrimental residues found on PCB
  - Typically related to flux residues.
  - Chlorides will initiate and propagate electrochemical failure mechanisms, such as dendrite growth metal migration and electrolytic corrosion, when combined with water vapor and an electrical potential.
  - Levels > 2 mg./sq. in. typically can not be tolerated.
- **Bromide residues**
  - Generally related to bromide fire retardant in epoxy-glass laminates.
  - Can also come from solder masks, marking inks, or fluxes with bromide activators
  - Fire retardant, bromide is not typically degrading to long-term reliability of PCBs.
  - Bromide from a flux residue, can be very corrosive
  - Epoxy-glass laminate bromide levels typical range of 0 - 7 mg/sq. in.
  - Bromide levels >12 mg./sq. in. can be detrimental on organic PCB
    - **Levels between 12-20 mg./sq. in. are borderline risks**
    - **Levels above 20 mg/sq. in. are a significant risk especially if from flux residues.**

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4.6) PoF Example - Moisture/Contaminate Failures - Detrimental Contaminates

- **Sulfate Residue**
  - Sulfates can come from many sources, contact with sulfur-bearing paper or plastics, acid processes in fabrication, or from water used for rinsing & cleaning.
    - **Minimal Risk: 0.0 – 1.0 mg./sq. in.**
    - **Marginal Risk: 1.0 – 3.0 mg./sq. in.**
    - **High Risk: > 3.0 mg./sq. in.**
  - Sulfate levels above 3.0 mg./sq. in. are corrosive & detrimental to circuit reliability.
  - With sulfate levels above 3.0 mg/ sq in, look for a sulfate-bearing chemical used in processing especially sodium/ammonium per-sulfate and sulfuric acid.
- **Nitrate Residue**
  - Nitrate has approximately the same electronegative corrosivetivity as sulfate.
  - The mg./sq. in residue concentration risk levels for sulfate also apply to nitrate.

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4.6) PoF Example - Moisture/Contaminate Failures - Detrimental Contaminates

- **Wear Organic Acids (WOA)**
  - WOAs like adipic or succinic acid, are activators in many solder fuxes
  - Residue levels vary greatly with the flux delivery system (foam, spray, paste) and the heating profile the determines the rate of consumption during soldering.
    - **Low solids solder paste: 0-20 mg./sq.in.**
    - **Spray-applied, low-solids flux: 20-120 mg./sq.in.**
    - **Foam-applied flux process: 120-150 mg./sq.in.**
    - **Water soluble flux w/good cleaning: 0-15 mg./sq.in.**
  - Water-soluble fluxes generally have a much lower WOA content than low-solids (no-clean) fluxes.
  - WOA levels are under 150 mg./sq. in. are generally not a risk.
  - Excessive WOA amounts (>150 mg/in2) present a significant PCB reliability risk.
  - Un-reacted WOA flux residues will readily absorb atmospheric moisture then support corrosion and the formation for current leakage dendritic growth failures.

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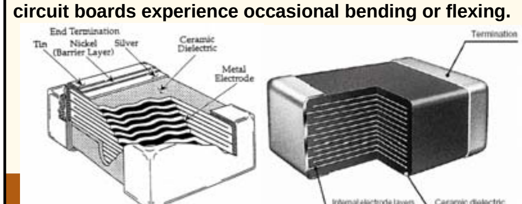
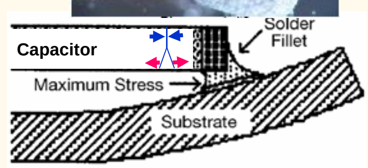
4.6) PoF Example - Capacitor Flex Cracking Examples

Capacitor are fundamental, passive electric devices for energy/electron/charge storage.
A cap is formed by two parallel conducting plates (electrodes) separated by a dielectric material.
- Dielectrics are insulators, poor conductor of electricity that support electrostatic fields. Rather than passing an electric current, dielectrics absorb electronics into an electro-static field.

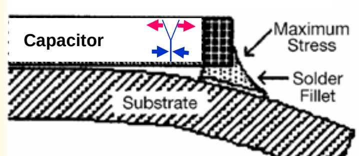
For solid dielectrics such as Barium Titanate ($BaTiO_3$) a hard, brittle ceramic, many small plates/dielectric sections are stacked in parallel to create a large capacitance in a very small package.

The brittle fragile nature of the thin dielectric ceramics can result in fracture cracks in the capacitors if their circuit boards experience occasional bending or flexing.





Ends Bend Up
Tensile Stress (Crack Site) on Bottom



Ends Bend Down
Tensile Stress (Crack Site) on Top

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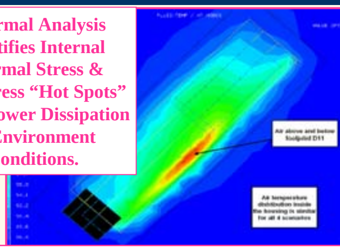
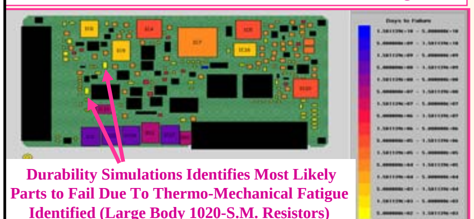
4.6) PoF Example
- Thermal Stress & Thermal-Mech. Durability

Thermal Analysis Identifies Internal Thermal Stress & Overstress "Hot Spots" From Power Dissipation & Environment Conditions.

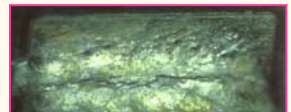


Infrared Thermal Imaging Of Thermal Stress & Overstress "Hot Spots"

Thermal-Mechanic Durability Modeling to Identify Potential Intermittent Circuits Due to Themo-Mechanical Fatigue



Durability Simulations Identifies Most Likely Parts to Fail Due To Thermo-Mechanical Fatigue Identified (Large Body 1020-S.M. Resistors)



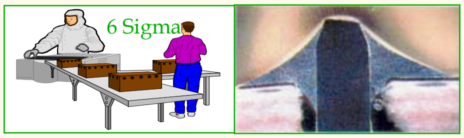
1020 Resistor Fatigue Confirmed In Accelerated Life Test

5) Manufacturing Issues
Highly Reliable Products Need To Be Built Right As Well As Designed Right.

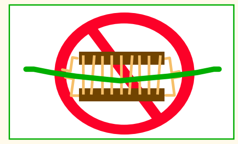
- A Robust Well Balanced Design Can Be Rendered Un-Reliable by Fabrication and Assembly Errors or Excessive Variation Issues.
- A Consistent and Capable Manufacturing Process and Supply Chain is also Required

5) Manufacturing Issues
The 5 Most Common E/E Device Manufacturing Issues

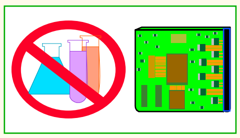
- Most Root Cause techniques are only call upon after a failure has happen to determine what when wrong.
- But the many of same methods can also be used to determine if new products are being built right



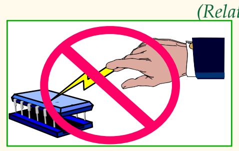
ASSEMBLY & SOLDERING PROCESS
(Related to up to 60% of E/E Assembly Issues)



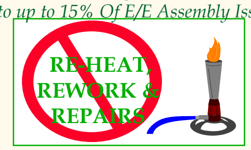
In Process Board Flexure
Cracked & Missing Components.
(Related to up to 15% Of E/E Assembly Issues).



Ionic Contaminate
(Circuit Board Cleanliness to Prevent Humidity Related Short Circuit Growths)
(Related to up to 20% Of E/E Assembly Issues).



Electro Static Discharge (ESD)
(Component Damage)
(% Varies Often Related To Spills)



Rework & Repair
Latent Rework & Handling Damage *(% Varies)*

6) Identifying What the Problem Is
- Root Causes Failure Analysis Techniques

- Return parts Root Cause Failure Analysis always starts with Non-Destructive Evaluation (NDE).
  - Designed to obtain maximum information with minimal risk of damaging or destroying physical evidence

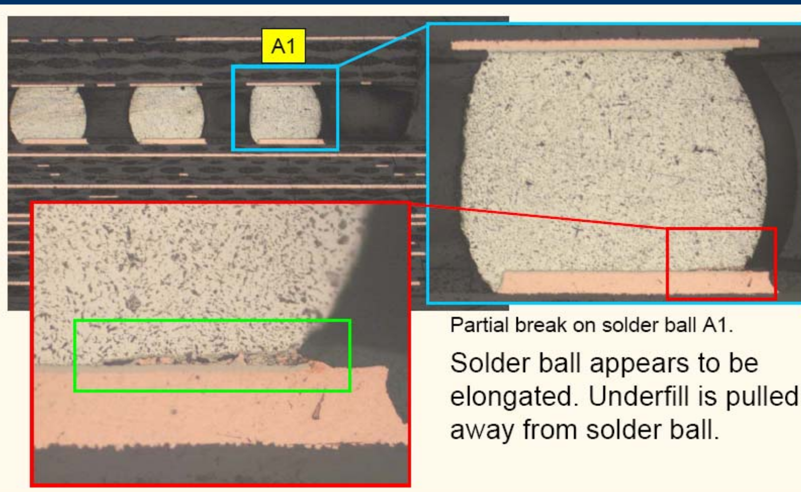
- Non Destructive Evaluation Methods
  - Visual Inspection
  - Electrical Characterization
  - Optical Microscopy
  - Scanning Electron Microscopy
  - Acoustic Microscopy
  - Xray Microscopy
  - Infrared Thermal Imaging
  - SQUID Microscopy
  - Spectral Material Analysis (Elemental Composition)
  - Ion Chromatography-Chemical Analysis

- Destructive Evaluation Methods
  - Decapsulation
  - Microsectioning
  - Metallographic Metallurgical Analysis
  - Focused Ion Beam Milling
  - Electrical Transient Probe Testing
  - Material Property Characterization
    - Thermo Mechanical Analysis (TMA)
    - Differential Scanning Calorimetry (DSC) Polymer Thermal-Mechanical Properties

6.1 Visually Aided Inspection - Microscopy Optical & SEM

- Enables the visualization, inspection and evaluation of tiny objects and details.
  - Light based optical Microscopes provides magnifications up to 1500x, resolution down the 0.2 micrometer.
  - Electron beam based Scanning Electron Microscopes provides magnifications up to 2,000,000x.
- Modern professional grade microscopes are equipped with digital imaging capture for documentation and comparison purposes.

6.1) Microscopic Failure Analysis of Solder Separation in BGAs - Root Cause: Excessive Underfill Thermal Expansion

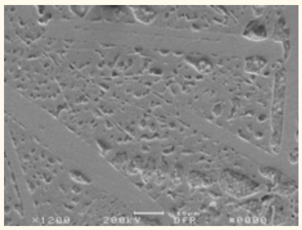


Partial break on solder ball A1.

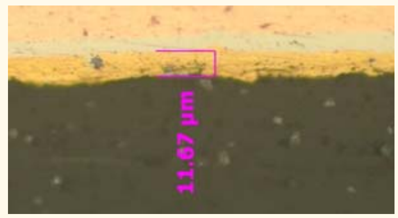
Solder ball appears to be elongated. Underfill is pulled away from solder ball.

6.1) Microscopic Failure Analysis of Solder Joint Fracture - Root Cause: Failure Due to Gold Embitterment

- Cross section of failed solder joint revealed excessive Gold-Tin ($AuSn_{4)}$ intermetallics.
- SEM Energy Dispersive X-ray Spectroscopy (EDS) found solder's gold content >8%.
- Embrittlement will occur if gold content exceeds 3.5% by weight.
- Excessive component gold plating allowed large amount gold to diffuse into the solder .
  - Controlling Factors: Excessive Gold, Soldering Temperature and Time Above Liquidus



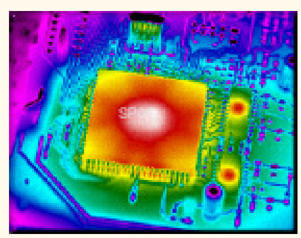
1200x SEM image reveals needle-like structures of $AuSn_4$ intermetallics in the solder joint

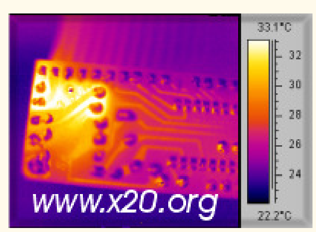


Cross section of component with thickness of gold plating layer.

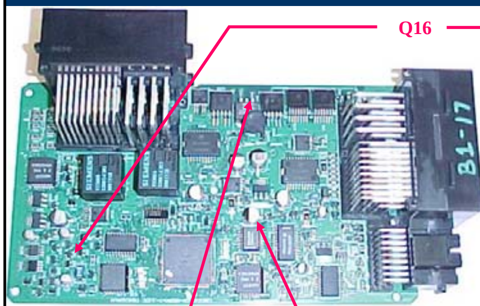
6.2) Thermal Imaging Microscope

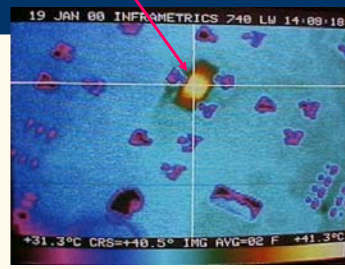
- Thermography is the use of an infrared imaging and measurement camera to "see" and "measure " thermal energy emitted from an object.
  - Provides precise non-contact temperature measurement capabilities.
  - Spectral range can be broken into one of four ranges, near IR: 0.75-3 microns, middle IR: 3-6 microns, far IR: 6-15 microns and extreme IR: 15-30 microns.
- Important parameters include measurement temperature range, spectral range, accuracy, resolution and steady state vs. real-time
  - Resolution, PCBA: 15 microns
  - Resolution, on-die: 1 micron
- Use points
  - Find Electrical shorts
  - Power Components
  - Identify Temperatures,
  - Find Hot Spots
  - Trace Heat Flow Paths

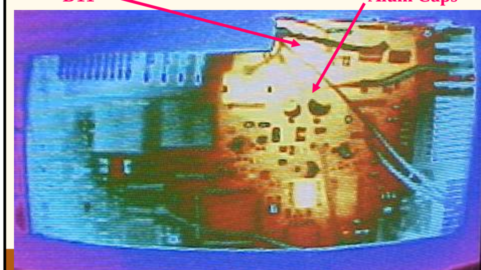




6.2) Infrared Thermal Imaging







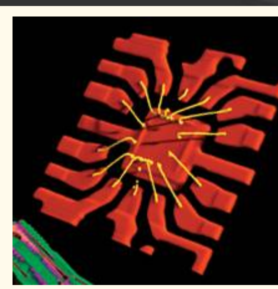
Thermal Anomalies Detected

- **Q16 producing heat when is it suppose to be in an off state - Sneak circuit detected.**
- **D11 detected a hot spot that exceeded thermal bogies.**

Resulting in over heating near by Alum Caps

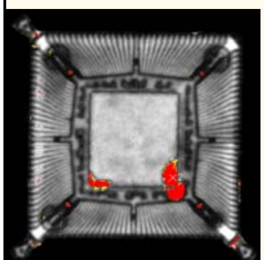
6.3) X-ray Microscope

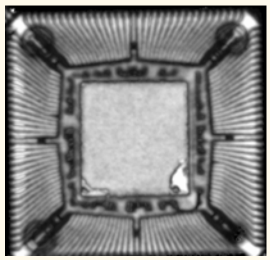
- Enables internal inspection through the use of X-ray energy
- Latest innovations
  - Digital Detector
  - Laminography ('virtual' cross-sectioning)
    - 3D reconstruction
  - Nanofocus resolution
  - Oblique viewing

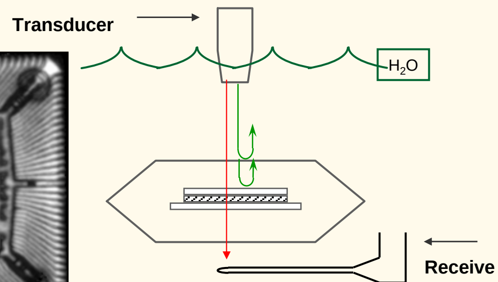


6.4 Acoustic Microscopy

- Non destructive method for inspecting internal structures.
  - By mapping the echo pattern of high frequency (>20 kHz) sound waves.
  - Sonic energy excites loose or moveable structures.
- Requires immersion in water (acoustic signals reflected by air)
  - Enable non-destructive detection/location of: structures, cracks, voids and delamination

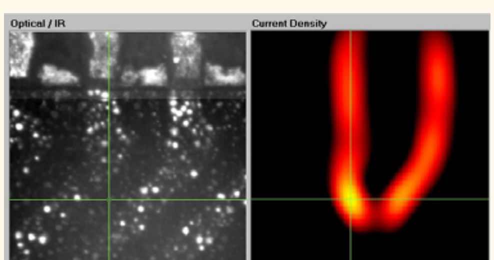


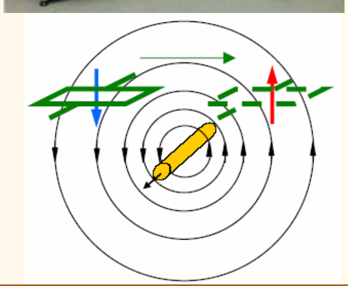




6.5) SQUID Microscopy
Superconducting QUantum Interference Device

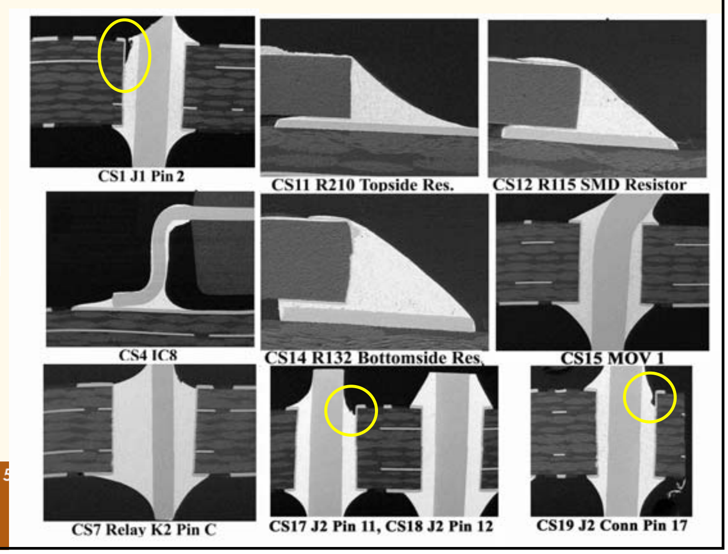
- Current flow in devices produce a magnetic field
  - SQUID uses a highly sensitive magnetic detector (superconductor) to resolve these fields
  - Magnetic field image is converted to a current density image, allowing for fault location
- Resolution down to 300 nm
- Critical technology for detecting the current path of electrical shorts through a package or material.





6.6) Micro Cross Sections - a Destructive Analysis technique for the internal evaluations of component's good for detecting manuf. defects

- **Metallographic Analysis** involves X-Sections of metals (i.e. Leads & Solders) for material quality evaluations.



This Webinar is a based on a 2 day Short Course: "Understanding Failure & Root-Cause Analysis in Electronics"

- ***1) Introduction and Objectives***
  - The Need for Root Cause Analysis
  - Difference Between Problem Solving, Failure Analysis & RCA Of Field Failures
- ***2) Root Cause Approaches, Management & Reporting Methods***
  - The" 5 Whys" Technique
  - The Eight Disciplines (8D) Technique
  - Shainin Red "X" Statistical Problem Solving
  - Six Sigma
  - Physics of Failure/ Reliability Physics
- **Break**
- ***3) Generic Failure Categories***
  - Design Quality & Errors
  - Manufacturing Quality & Errors
  - Environmental & Usage Considerations - Their Role in Over Stress & Accelerated Wear Out Failures
  - Environment & Self Heat Temperature Issues
  - Vibration, Shock & Drop
  - Humidity
  - Contaminates
- ***4) Finding Failure Modes – Where Problems Are & How They Manifest Themselves.***
  - The Need for Data
  - Collecting & Analyzing Data for Problem Solving
  - Trending analysis results (plotting a timeline
  - Pareto Analysis
  - Other Data Sources
    - Test Reports
    - Warranty Data
    - Fleet Maintenance Logs/Reports
    - Customer Surveys
    - Investigation Interviews
- **Lunch**

This Webinar is a based on a 2 day Short Course: "Understanding Failure & Root-Cause Analysis in Electronics"

- ***5) Fault/Failure Investigation - Identifying What the Problems Is - Part I) Developing a Hypothesis***
  - Customer & Service Technician Feedback & Interviews,
  - Reference Product & Technology History/Lessons Learned
  - Identifying Contributing Events
  - Ishikawa (fishbone) diagrams
  - Fault Tree Analysis
  - Dealing with Multiple Problems – Event/Issue Charting
- ***6) Identifying What the Problem Is - Part II) Return Parts Analysis***
  - Managing a Return Part Program
  - Initial Issue Confirmation Functional Checks
  - Electrical Fault Isolation
- **Break**
- ***7) Identifying What the Problem Is - Part III) Root Causes Failure Analysis***
  - Physical Component Failure Analysis Laboratory Methods
  - Cross-Sectioning / Metallographic Analysis
  - IC Decapsulation
  - Optical Microscopy
  - Electron Microscopy
  - Ion Chromatography
  - Surface Analysis (FTIR, EDS, XRF, etc.)
  - Material Analysis (DSC, TMA, TGA, etc.)
  - Mechanical Analysis Techniques (Micro-tester, Bend Testing, Pull Testing, etc.)
- **End of Day One**

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- ***8) Typical EE Failure Modes, Mechanism & Signatures***
  - Printed Circuit Board Substrate Issues
    - Manufacturing Defects
    - Plated Through-Hole Via Issues
    - Conductive Anodic Filaments
    - Electrochemical Migration (Dendritic Growth)
  - Integrated Circuit Packaging & Die Issues
    - Wire Bond Failures
    - IC Pop Corning
    - Integrated Circuit Die Issues
    - ESD/EOS
  - Fluid Penetration Issues (new)
  - Thermal Issues (new)
- ***Break***
  - Capacitors (Ceramic, Aluminum, Tantalum)
  - Passive Components
  - Electro-Mechanical Devices.
  - Terminals and Contacts
  - Wire Failures
  - Relay
  - Speakers & Audio Alarms PCB Assembly
  - Solder Quality Issues
- *Lunch*
- ***9)Using CAE Simulation in RCA***
  - Vibration & Shock
  - Thermal Simulations
- ***10) Developing/Implementing a Permanent Corrective Action Plan***
  - Developing the Corrective Action Plan
  - Stakeholder Teamwork & Buy In.
    Fixing the Problem Rather Than Assigning Blame
  - Fixing the Design, the Supply Chain or Assembly Process
  - Building a Business Case/Getting Approval for the Plan
  - Internal Failure Rev. Board/Management Rpts & Approval
  - Customer Reports and Approval
  - Regulatory Agency Review & Approval
- **Break**
  - Validating the Fix
  - Implementation Verification
  - *Learning From Failure - Corrective Action to Prevention*
    - Documenting the Issues
    - Document and Reusing Lessons Learned
    - Implementing the Fix
      - Engineering and Validation Issues
      - Assembly Processes, Maunf. & Quality Issues
      - Suppliers and Supplier Quality Issues
- ***Wrap-Up*** **& Adjourn**

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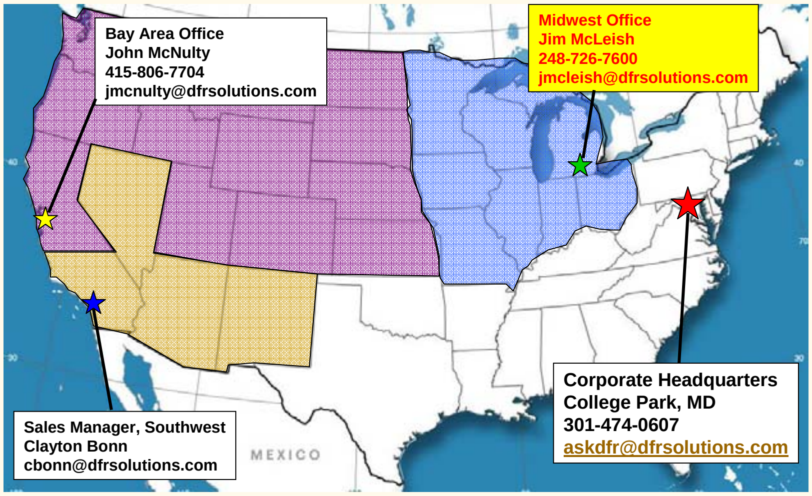

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Root Cause Analysis

Mechanical Components and Systems

by Clifford Lange, PhD, PE, Ops A La Carte

Root Cause Analysis – Mechanical Components
Polling Questions

- **Are you familiar with creep related problems or have direct experience with solving a creep issue?**
  - **Don’t know what creep is**
  - **Some familiarity with creep**
  - **Direct experience with creep behavior**
- **Do you understand the application of structural reliability methods (e.g. FORM/SORM) for the understanding of failure mechanisms**
  - **Don’t know what structural reliability methods are**
  - **Some familiarity with structural reliability methods**
  - **Direct experience with structural reliability methods**

Design for Reliability – Mechanical Components

- **Conform to accepted industry design standards (ASTM, SAE, ANSI, etc.)**
  - **Avoid the need to use high tolerances (e.g. < 0.010”) and be cognizant of tolerance stack up issues**
  - **Ensure compliance with all recommended rating guidelines**
  - **Anticipate unusual environmental effects**
- **Incorporate contract manufacturers early in the design process (they are the experts)**
- **Perform reliability assessment on primary wearout mechanisms**

Critical elements of mechanical systems

- **Transmitting elements**
  - **Shafts, belt drives & flexible couplings**
  - **Springs & gears**
  - **Actuators, accumulators & reservoirs**
  - **Brakes & clutches**
  - **Motors, pumps & valves**
- **Constraining, confining, & containing elements**
  - **Seals & gaskets**
  - **Bearings & Shaft sealing devices**
- **Fixing elements**
  - **Bolted connections or threaded fasteners**
  - **Weldments**
- **Elements supporting machinery functions**
  - **Lubrication systems**

Typical failure mechanisms of mechanical systems

- **Stress rupture or fracture**
  - **Insufficient design**
  - **Changes in load history or component application**
- **Fatigue**
  - **Poor material characterization or load history**
- **Creep**
- **Wear and/or fretting**
- **Environmental effects**
  - **Corrosion**
  - **IGSCC**
  - **Hydrogen embrittlement**

Reliability prediction for mechanical systems

- Bloch, H.P. and Geitner, F.K.; "An Introduction to Machinery Reliability Assessment;" Van Nostrand Reinhold, 1990.

- "Handbook of Reliability Prediction: Procedures for Mechanical Equipment;" Naval Surface Warfare Center – Carderock Division; CARDEROCKDIV, NSWC-94/L07, March 1994.

Example: Creep Failure

- **High temperature aluminum heater weldments**
- **Pre-stressed concrete (water) pipe failures**
- **Power plant steam pipe creep rupture**
  - **Steam pipe ruptures lead to in depth inspections at all aging facilities**
  - **Main steam piping at TVA Gallatin Units 3 & 4 showed excessive deformation (~ 10% radial strain – wall thinning)**
  - **Average diametral strain is 5.3% (swelling)**
  - **Initial "thin-wall" creep calculations indicated evidence of bending moments but results were inconsistent with data**
  - **Thick wall "finite element" calculations improved predictions**
  - **Results indicated that the ASTM creep rate law predicts approximately 2x service heater data**

8.6 Example: Creep Failure of Steam Piping

FE ANALYSIS

- SECONDARY CREEP RATE LAWS FOR 2¼CR-1MO AT 1050°F (σ in ksi, $\dot{\epsilon}$ in hr^{-1})

$$\dot{\epsilon} = 1.5886 \times 10^{-15} \sigma^{10.075}$$

$$\dot{\epsilon} = 8.476 \times 10^{-12} \sigma^{5.05}$$

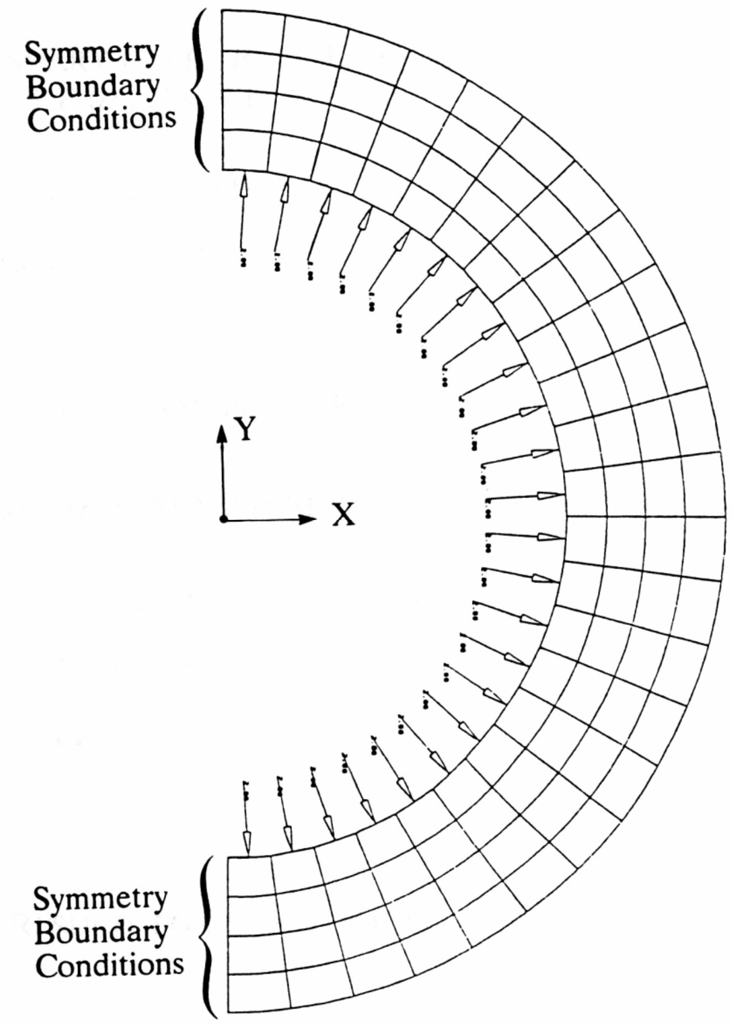
- 2000 PSI INTERNAL PRESSURE

- NORMALIZED APPLIED BENDING MOMENTS

$$\bar{M} = \frac{\sigma_{axial}\text{ (moment)}}{\sigma_{axial}\text{ (pressure)}} = \frac{MR/I}{pR/2t}$$

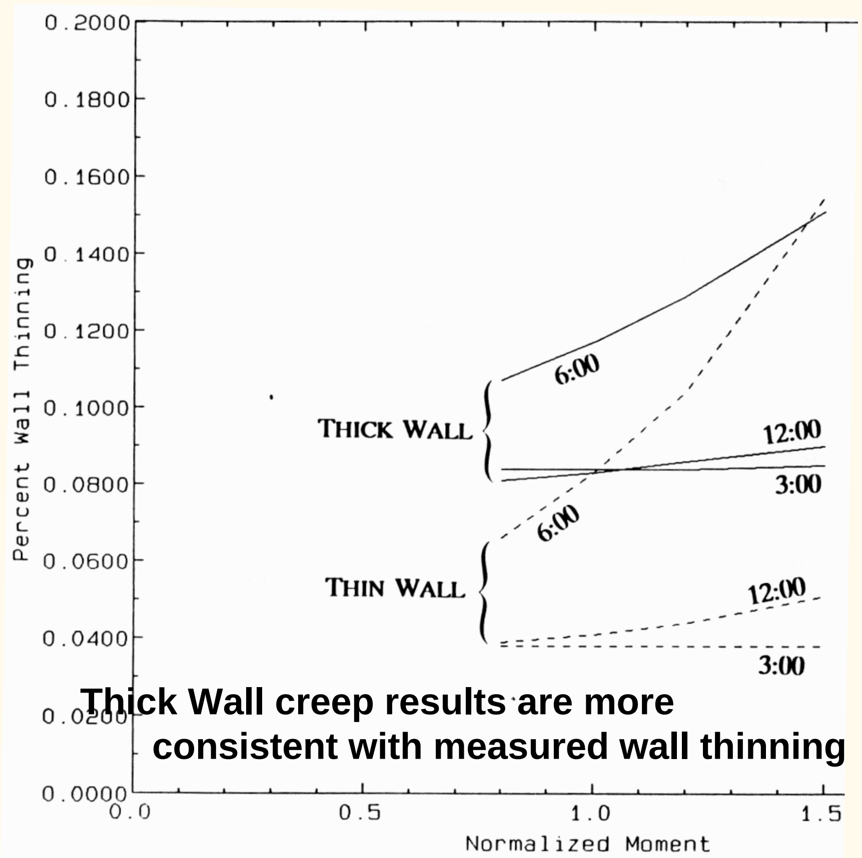
$$0.8 \leq \bar{M} \leq 1.5$$

- ALL RESULTS FOR 50,000 HOURS



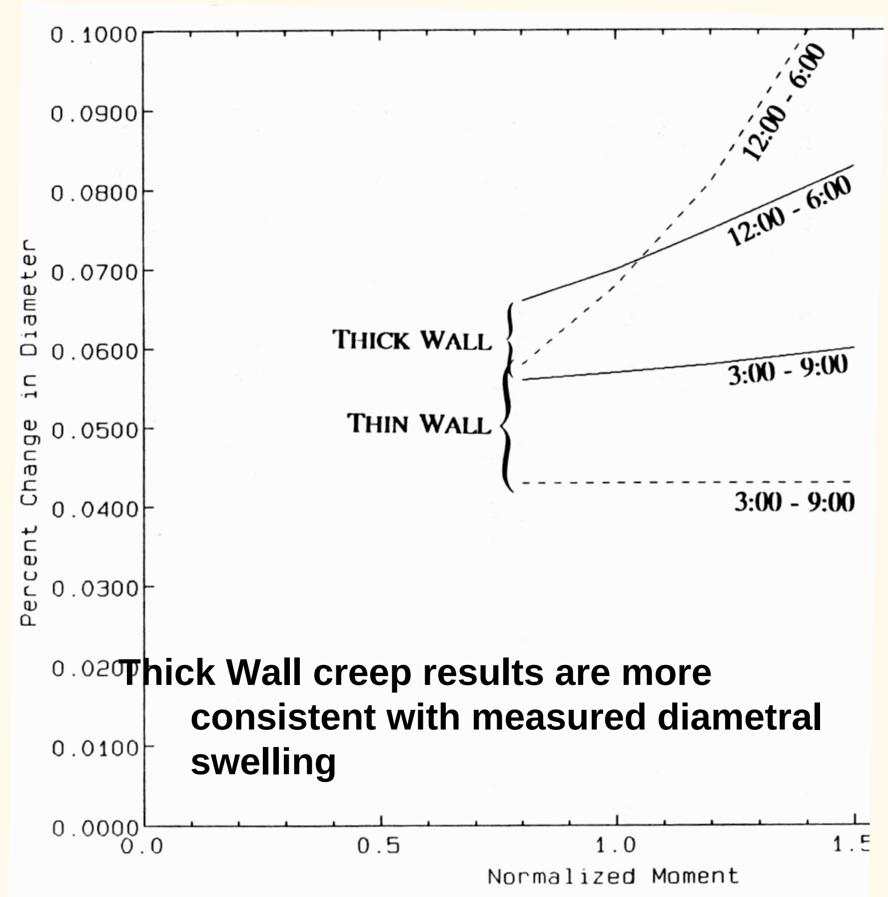
8.6 Example: Creep Failure of Steam Piping

- **Comparison of Wall Thinning**



Thick Wall creep results are more consistent with measured wall thinning

- **Comparison of Diametral Swelling**



Thick Wall creep results are more consistent with measured diametral swelling

Results reflect ASTM Creep Rate Law

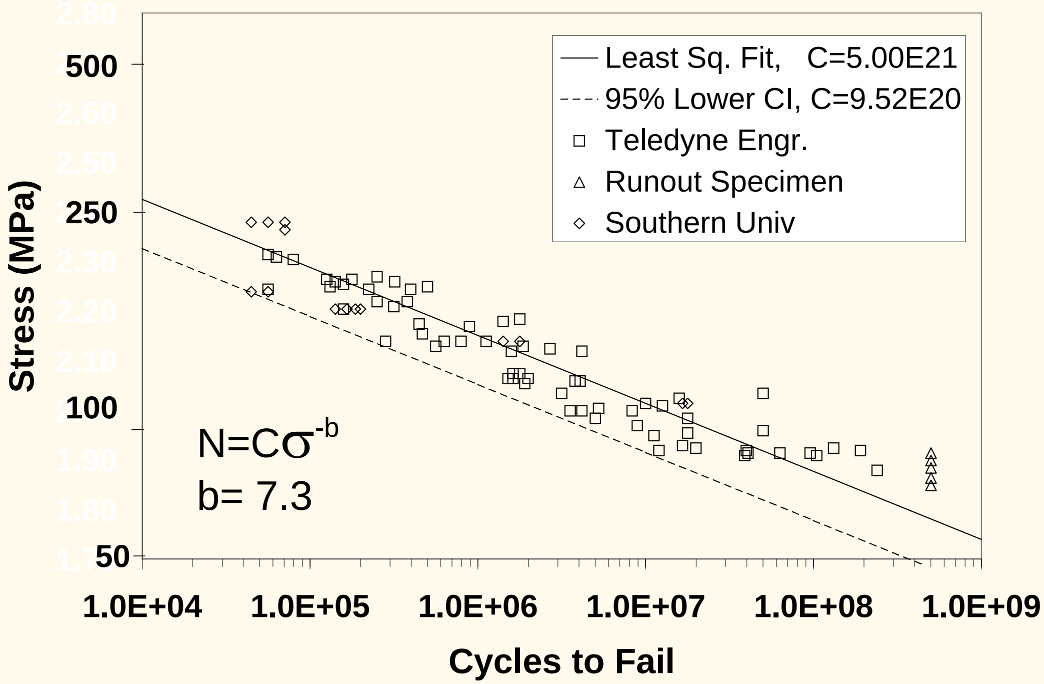
8.6 Example: Structural Reliability as a RCA Tool

- **Wind Turbine design provides a good example of an ongoing RCA program**
  - **Traditional fatigue analysis often focus on uncertainty with the material properties and/or the load (e.g. stress) spectrum**
- **New technology (e.g. Structural Reliability Methods) employed to improve the RCA**
  - **In many cases uncertainty in the underlying load environment, the stress response and the computational techniques employed can be significant contributors to fatigue failures**
  - **Problems involving many different sources of uncertainty are effectively addressed using Structural Reliability Techniques**

8.7 Example: Fatigue – Traditional Analysis

- **Wind turbine blade application**
- **Typical S-N data for aluminum used for design**
- **Stress spectrum assumed to be determined experimentally – Monte Carlo simulation used to generate sample stress distribution**
- **Fatigue analysis considers both best fit and 95% CI on S-N properties as well as the measured stress histogram and a bounding load spectrum**
- **Results compared across all assumed input variables**

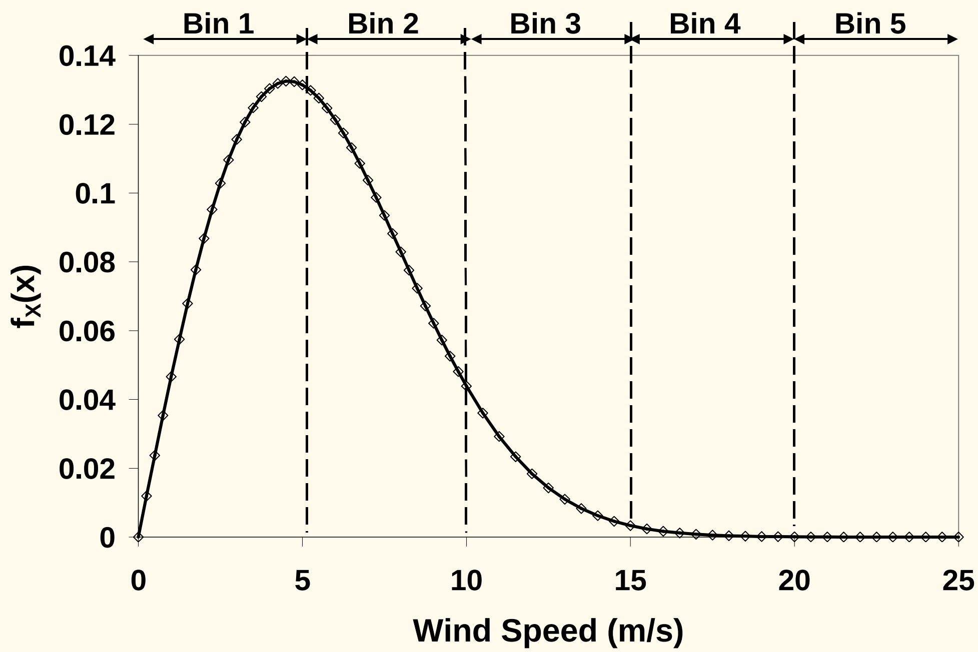
8.7 Example: Fatigue – Material Behavior



- Fatigue data is for 6063 Extruded Aluminum
- Both a least squares best fit and a 95% confidence level used in fatigue analysis
- Miner's Rule used to sum fatigue contributions over different stress amplitudes

$$\Delta = \frac{n_1}{N_1} + \frac{n_2}{N_2} + \cdots + \frac{n_i}{N_j} = 1$$

8.7 Example: Fatigue – Applied Stresses

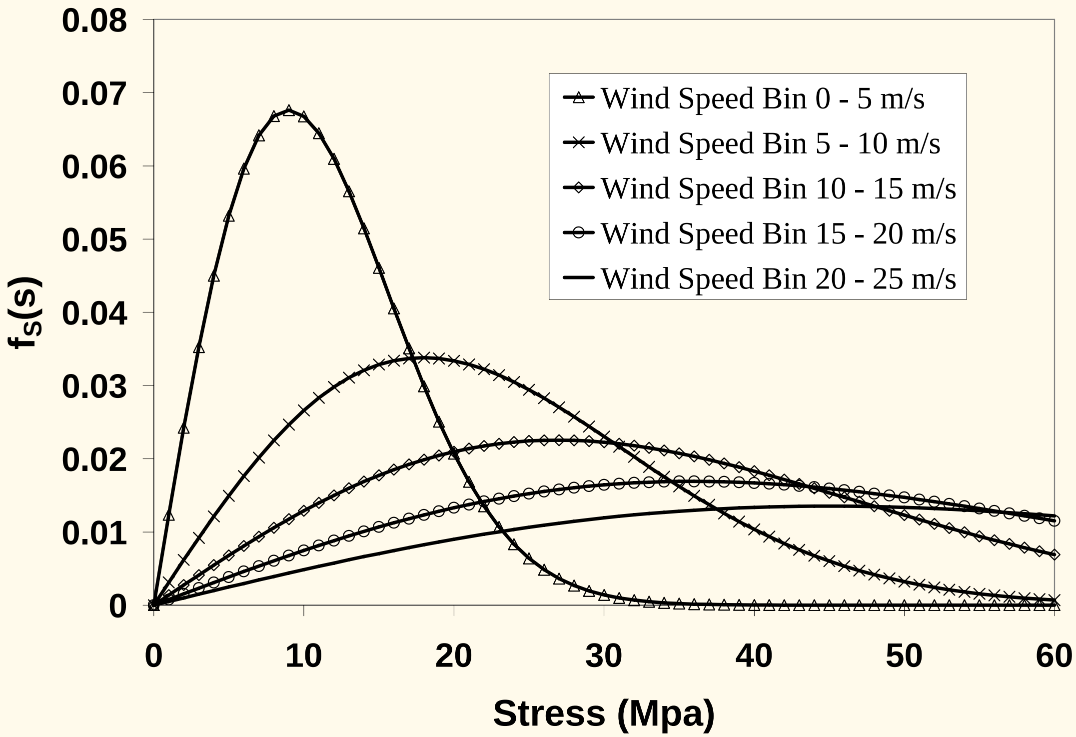


$$P[X \leq x] = 1 - e^{-\left[x / \beta_X \right]^{\alpha_X}}$$

$$\beta_X = \frac{\overline{X}}{(1/\alpha)!}$$

- **Applied stresses for wind turbine blade vary with wind speed**
- **A typical wind speed distribution representative of mid-west USA is assumed**
- **Distribution is Weibull with α = 2.0 & μ = 6.3 m/s**
- **5 different stress amplitude distributions are assumed for 5 corresponding wind speed bins between 0 and 25 m/s.**

8.7 Example: Fatigue – Applied Stresses

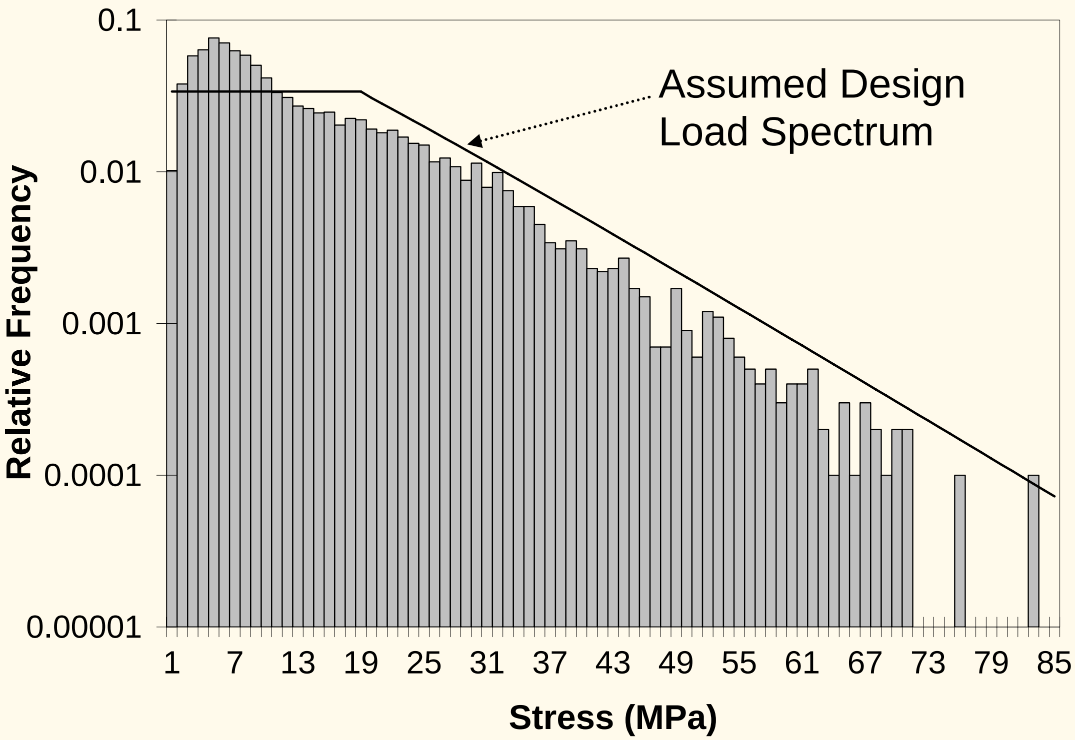


$$P[S \mid X \leq s \mid x] = 1 - e^{-\left[s|x / \beta_S \right]^{\alpha_S}}$$

$$\beta_S = 1.2 \cdot x$$

- **Distribution of stress amplitudes stresses in each wind speed bin also assumed Weibull**
- **Assume α_s = 2 with shape factor β_s linearly dependent on wind speed, X**
- **Contribution potential for high stress amplitudes is evident**

8.7 Example: Fatigue – load Spectrum



- **Monte Carlo simulation used to produce 10K stress amplitudes**
- **Assumed design load spectrum used to model anticipated long term loading conditions**
- **Both histogram and load spectrum used in analyses**

8.7 Example: Fatigue – Risk Level?

S-N Material	Loading	Lifetime: years	Damage Δ
C_{ave}	Histogram Data	1232	.0162
C_{ave}	Design Spectrum	426	.0470
$C_{.95}$	Histogram Data	216	.0925
$C_{.95}$	Design Spectrum	81	.2465

- **All 4 combinations of C and Loading used to evaluate relative influence of each parameter & uncertainty level**
- **Both fatigue lifetime and damage results presented**
- **Results show satisfactory design against fatigue failure**

8.7 Example: Fatigue – Structural Reliability

- **Used to evaluate designs probabilistically considering both the mean and standard deviation of design inputs**
- **Results are probabilities of failure and the relative importance of each input (random variable)**
- **For fatigue – rather than ask;**

“What is the actual fatigue life of the component**?”**

the more appropriate question;

“With what confidence will the component meet it’s target lifetime**?”**

can now be answered.

- **For RCA we can identify the leading contributors to failure**

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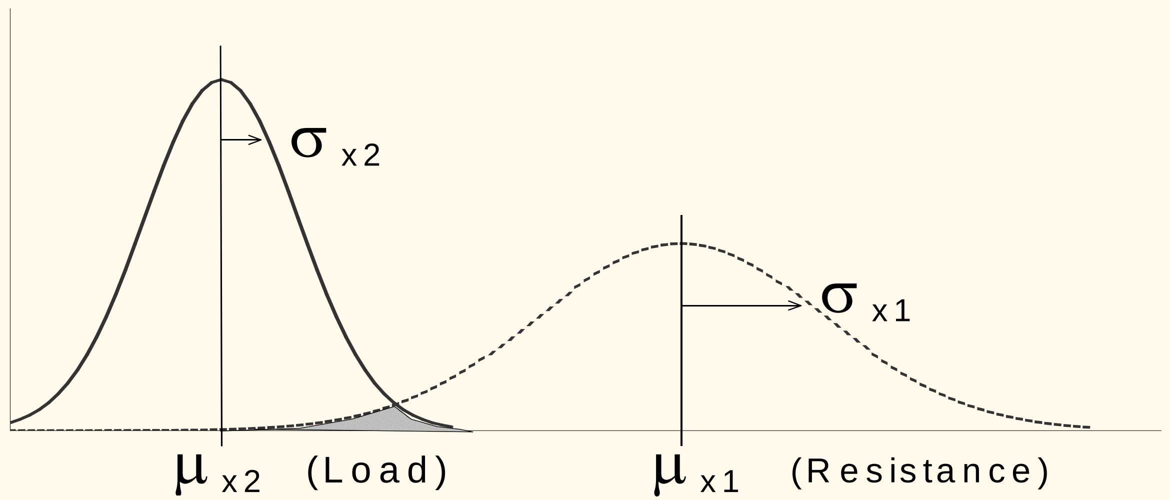
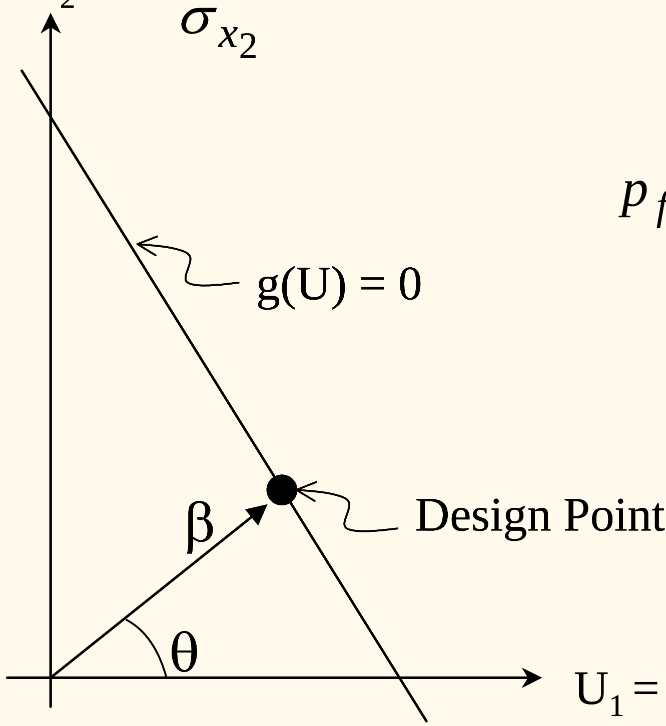
8.7 Example: Fatigue – Structural Reliability



- **Intuitively the risk or probability of failure can be inferred from the overlap of the region of the load and resistance random variables**
- **Both the relative values of the mean and variance of each random variable affect the failure probability**

8.7 Example: Fatigue – Structural Reliability

$$U_2 = \frac{x_2 - \mu_{x_2}}{\sigma_{x_2}}$$



$$U_1 = \frac{x_1 - \mu_{x1}}{\sigma_{x1}}$$

$$\beta = \frac{\mu_{x_1} - \mu_{x_2}}{\sqrt{\sigma_{x_1}^2 - \sigma_{x_2}^2}}$$

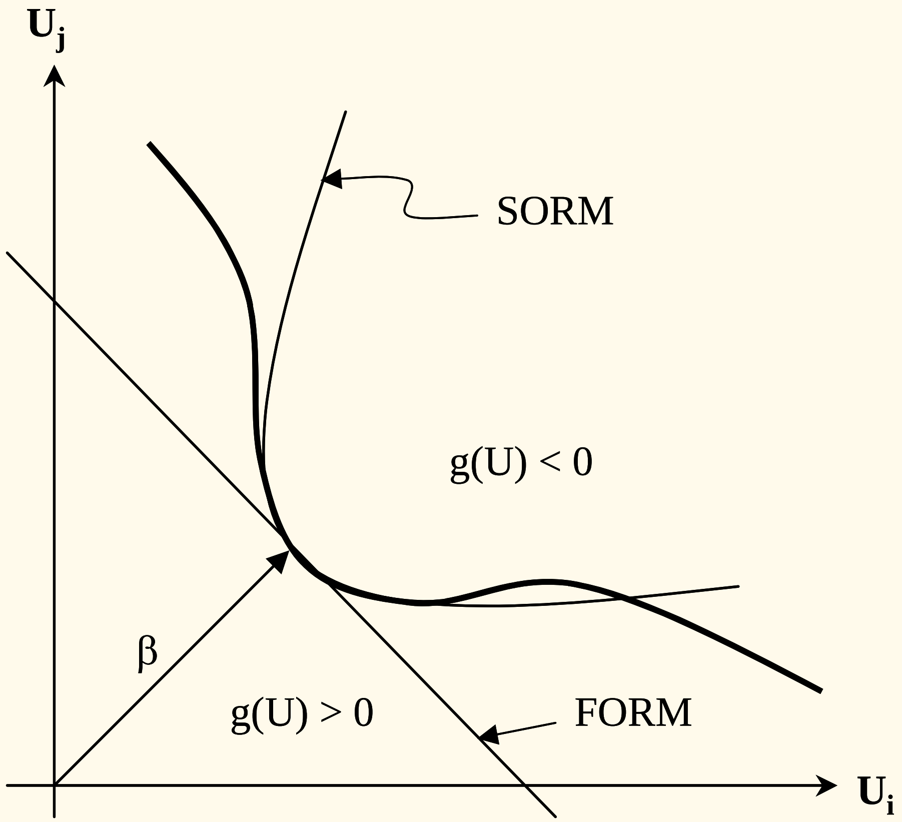
$$p_f = \Phi^{-1}(\beta)$$

- **Limit state equation, G(X), defines the fail and non-fail conditions**

$$G(X) = X_1 - X_2$$

- **Failure probability determined by the μ and σ^2 of X_1 and X_2**
- **Calculations performed in standard "U-space" where the design point determines both the p_f and the relative importance of X_1 & X_2**

8.7 Example: Fatigue – Structural Reliability



- **In the general formulation the limit state equation is not linear and the random variables are not Normal**
- **Linear (FORM) and parabolic (SORM) approximations are used at the design point to calculate failure probabilities and importance factors**

8.7 Example: Fatigue – Structural Reliability

- **Limit State Equation defines failure conditions**

$$G(X) = T_f - T_t$$

- **Time to failure determined using Miners rule with an average damage per cycle**

$$T_f = \frac{\Delta}{f_0 \overline{D}}$$

- **Average damage rate determined considers all possible stress amplitudes and their incremental damage**

$$\overline{D} = \int_{x=0}^{\infty} \int_{s=0}^{\infty} \frac{f_{S|X}(s \mid x) f_X(x)}{N_f(s)} dsdx$$

8.7 Example: Fatigue – Structural Reliability

- **Both the underlying environmental variable, X, and the stress amplitude, S, given the load environment, are Weibull distributions**

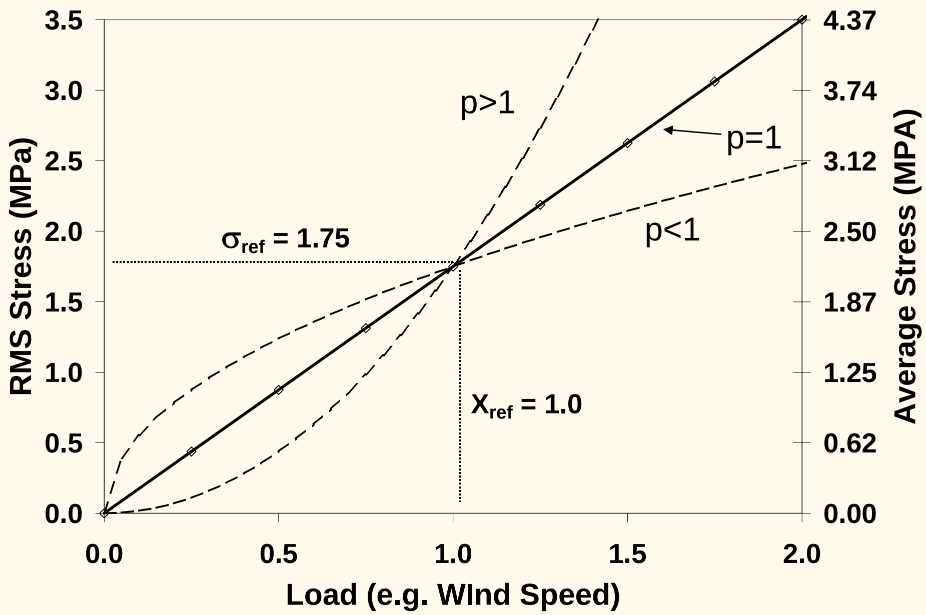
$$P[X \le x] = 1 - e^{-\left[x/\beta_X\right]^{\alpha_X}}$$

$$P[S \mid X \le s \mid x] = 1 - e^{-\left[s|x/\beta_S\right]^{\alpha_S}}$$

- **With the shape factor, b_X, of the environment determined from the average, X, and the average of the stress response dependent upon the environment**

$$\beta_X = \frac{\overline{X}}{(1/\alpha)!}$$

8.7 Example: Fatigue – Structural Reliability



$$\sigma(x) = K\sigma_{ref}\left(\frac{x}{x_{ref}}\right)^{p}$$

$$\beta_s = \sigma(x)[2/(2/\alpha_s)!]^{1/2}$$

- **The RMS of the stress process is a function of the underlying environment variable, X**
- **Random vibration theory is used to define the shape factor, β_s, as a function of the RMS stress and shape factor, a_s**
- **The RMS exponent, p, used to identify increasing/decreasing stress processes**

8.7 Example: Fatigue – Generalized Formulation

- **Resulting expression for fatigue life a function of 12 random variables**

$$T_f = \frac{C\Delta}{f_0}\left[\left(\frac{\sqrt{2}\sigma_{ref}K}{\sqrt{(2/\sigma_s)!(1-KS_m/S_u)}}\right)^b \left(\frac{\overline{X}}{x_{ref}(1/\alpha_x)!}\right)^{bp} \left(\frac{b}{\alpha_s}\right)! \left(\frac{bp}{\alpha_x}\right)!\right]$$

- **Stress parameters K and σ_{ref} are raised to the power, b, as a result of the S-N relationship**
- **Environmental parameters, X, are raised to the composite power, bp, reflecting the combined nonlinear effect of the RMS stress on the environmental variable, X**

8.7 Example: Fatigue – Traditional Approach

Var	Definition	Dist Type	Mean	COV
X	Mean Wind Speed	Constant	6.3	-
α_x	Wind Shape Factor	Constant	2.0	-
x_{ref}	Ref Wind Speed	Constant	1.0	-
σ_{ref}	Reference Stress	Constant	1.75	-
p	RMS exponent	Constant	1.0	-
K	Stress Conc Factor	Constant	1.0	-
α_s	Stress Shape Factor	Normal	2.0	.15
C	S-N Coefficient	Weibull	5E21	.613
b	S-N Exponent	Constant	7.3	-
f_o	Cycle Rate	Constant	1.2	-
Δ	Miner's Damage	Constant	1.0	-

Mean Lifetime:	467 years
Failure Probability	FORM .61 % SORM .94 %
Importance Factors:	Stress Shape Factor: 24.9 % S-N Coefficient, C: 75.1 %

- **CYCLES computer program used to perform calculations**
- **Input values reproduce those used in the traditional fatigue analysis**
- **Results confirm previous results that fatigue design is not likely to fail**
- **Most significant input is the S-N coefficient**

8.7 Example: Fatigue – Generalized Approach

Var	Definition	Dist Type	Mean	COV
X	Mean Wind Speed	Normal	6.3	.075
α_x	Wind Shape Factor	Normal	2.0	.15
x_{ref}	Ref Wind Speed	Constant	1.0	-
σ_{ref}	Reference Stress	Normal	1.75	.075
p	RMS exponent	Normal	1.0	.05
K	Stress Conc Factor	Normal	1.0	.1
α_s	Stress Shape Factor	Normal	2.0	.15
C	S-N Coefficient	Weibull	5E21	.613
b	S-N Exponent	Constant	7.3	-
f_o	Cycle Rate	Normal	1.2	.2
Δ	Miner's Damage	Normal	1.0	.15

- **There exists uncertainty in design inputs other than the S-N law and loading spectrum in fatigue design**
- **X, a_x, s_{ref}, p and K are all considered to be uncertain in the wind turbine example**
- **Uncertainty in Miners rule and the fluctuating cycle rate are also considered**

8.7 Example: Fatigue – Results

Mean Lifetime:	467 years
Failure Probability	FORM 5.67 % SORM 7.38 %
Importance Factors:	Mean Wind Speed, $\overline{X}$: 6.7 % Wind Shape Factor, α_x: 25.2 % Reference Stress, σ_{ref}: 6.2 % RMS exponent, p: 24.0 % Stress Conc Factor, K: 10.6 % Stress Shape Factor, α_s: 9.3 % S-N Coefficient, C 16.6 % Cycle Rate, f_o: 0.8 % Miner's Damage, Δ 0.5 %

- **Considering uncertainty contributions from all potential sources changes the conclusions from the original analysis**
- **Failure probabilities have increased to unacceptable levels (5-10%) while the mean lifetime remains unchanged**
- **Most significant inputs are mean wind speed and the RMS exponent, p**

8.7 Example: Fatigue – Structural Reliability

- **Structural Reliability methods provide risk levels (e.g. pf) as well as the relative importance of the design inputs (e.g. random variables)**
- **All 3 aspects of the fatigue problem; the loading environment, structural response and the local failure criterion may include uncertainty and can be included in the fatigue evaluation**
- **The methodology can employed through alternative limit state equations or extended to other fatigue problems (e.g. crack growth).**
- **The most critical design inputs are identified**

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RCA Case Study

The PEPCON Incident

A Process Plant Accident &
Guidelines for General Investigations

T. Kim Parnell, PhD,PE

Root Cause Analysis Webinar

July 23, 2008

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Why Review a Plant Accident?

- Interesting and well-studied event
- Provides general guidelines for RCA team organization
- Insights for investigation and documentation
- Contrast investigation of "unique" event like this with RCA of high-volume products

The PEPCON Incident

- Fire and massive explosions at the PEPCON plant in Henderson, NV on May 4, 1988.
- PEPCON produced Ammonium Perchlorate (AP) – an oxidizer
- Combination of events:
  - Human error – cigarette likely started initial fire
  - Large quantity of AP on site due to Challenger disaster
  - 16” natural gas line running under the plant (with leaking stitch welds)

PEPCON Explosions

- Two large explosions equivalent to 200 Tons and 500 Tons of TNT (3.0 and 3.5 on the Richter scale)
- Over $70M property damage; windows broken up to 30 miles away
- 16” Natural Gas Pipeline
  - Ruptured 40 foot section
  - Crushed more than 260 feet
  - Long-term leakage prior to blast from poor stitch welds

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PEPCON Incident Investigation

- Organization of Teams
- Site documentation and evidence collection; develop timeline
- Metallurgical analysis; Fracture mechanics
- Fire cause & origin
- Gas migration through soil
- Blast effects & damage
- Conditions for AP deflagration/detonation

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Fire & Brimstone

- Rapid spread of fire; catastrophic explosion
- Most of event captured on video

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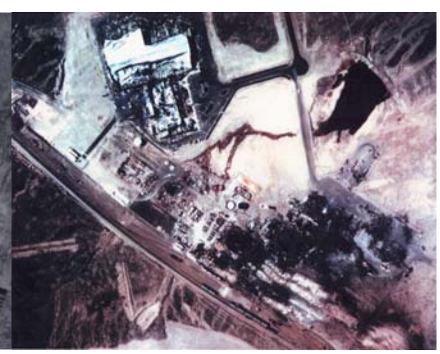
Massive Explosion & Shockwave

- Stills from video shot from Black Mountain – over 10 miles away

Aerial View - Before & After

Before

After



Near Ground Zero…

- Rail cars overturned
- Autos overturned

At the Plant

Plant Buildings

Production Equipment

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Ruptured Gas Pipe – Initial View

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Pipe After Some Digging

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Pipe After Complete Excavation

Ruptured & Crushed Pipe Sections

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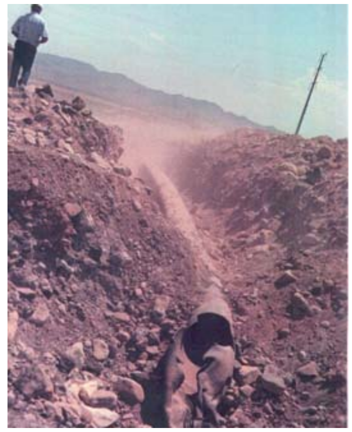
Pipe Sections



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16" Natural Gas Pipeline

- Ruptured 40 foot section
- Crushed more than 260 feet
- Long-term leakage prior to blast from poor stitch welds

- Big Question: Did the pipe rupture occur before or after the explosions??

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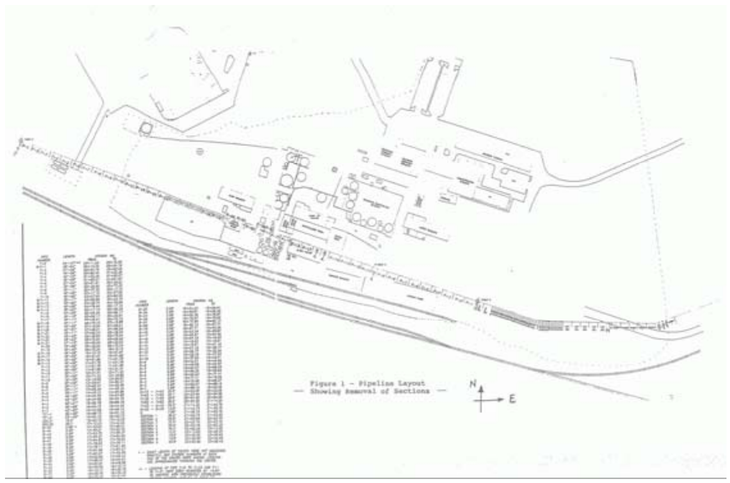
Pipeline Section Identification



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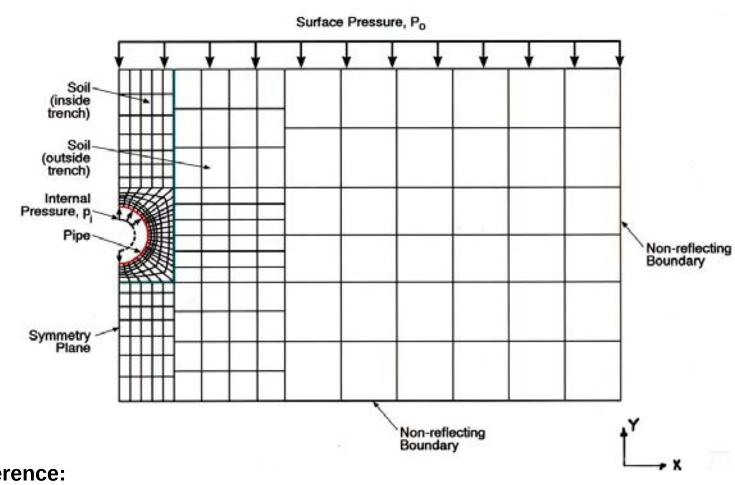
Pipe/Soil Finite Element Model



Reference:
Parnell, T.K. and Caligiuri, R.D., "Analysis of the Dynamic Response of a Buried Pipeline due to a Surface Explosion," *Computational Aspects of Impact and Penetration*, L. E. Schwer and R. F. Kulak, eds., Elme Press International, 1991.

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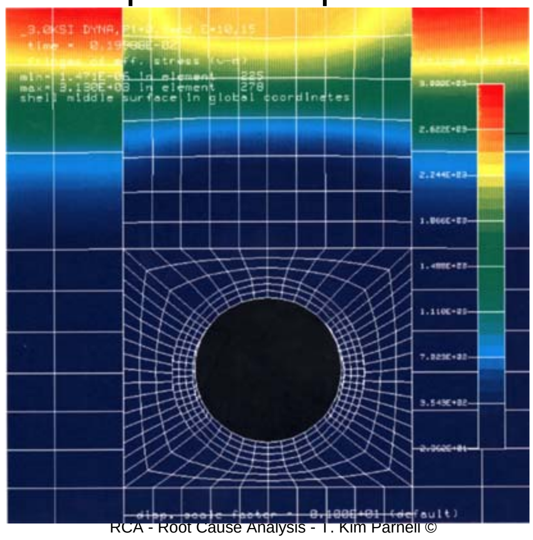
Pipe Crushing Due to Blast

Response Sequence #1



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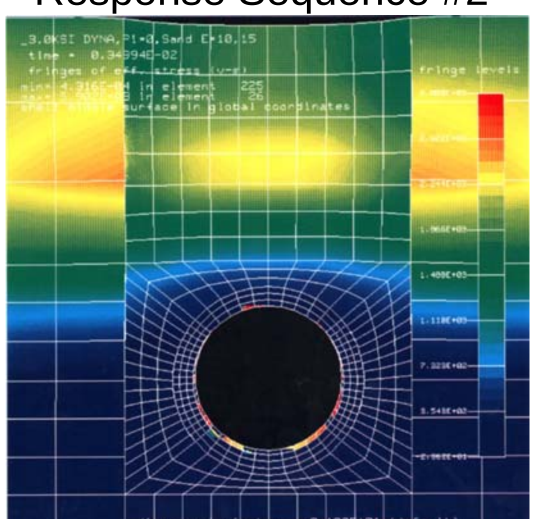
Pipe Crushing Due to Blast

Response Sequence #2



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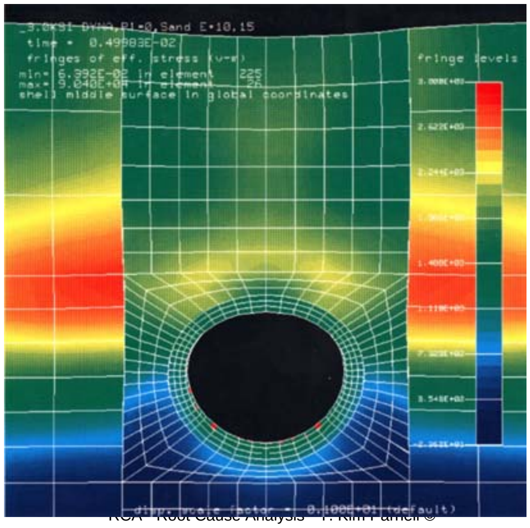
Pipe Crushing Due to Blast

Response Sequence #3



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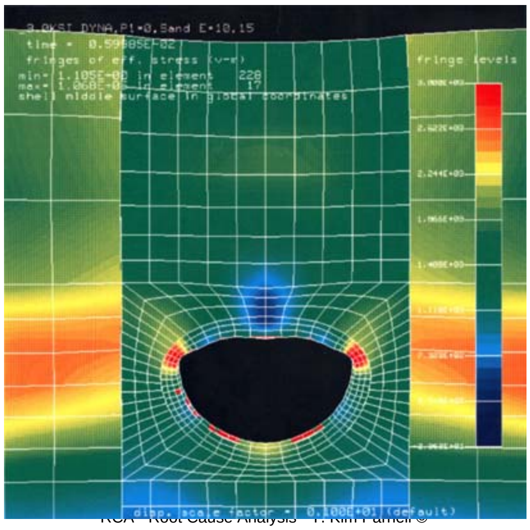
Pipe Crushing Due to Blast

Response Sequence #4



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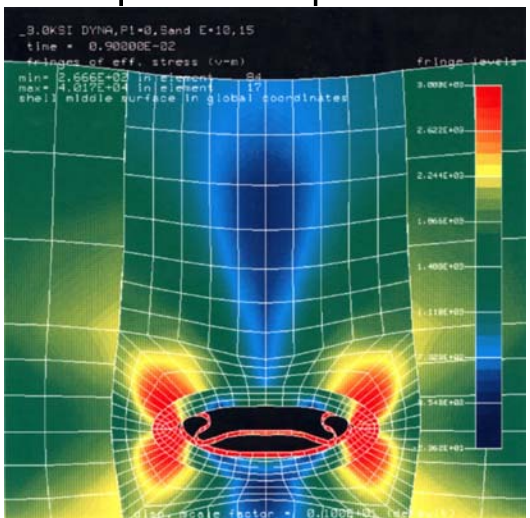
Pipe Crushing Due to Blast

Response Sequence #5



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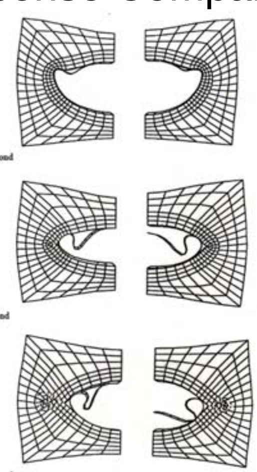
Pipe Crushing Due to Blast

Response Comparison

Pressurized

Depressurized



a) $t = 0.0075$ second

b) $t = 0.010$ second

c) $t = 0.0125$ second

Figure 6: Deformation of pipe and adjacent soil is shown in sequence for pressurized pipe on the left and unpressurized pipe on the right. The pressurized pipe is modelled as $p_i = 300$ psi and $P_b = 3000$ psi, while the unpressurized pipe is modelled as $p_i = 0$ and $P_b = 2500$ psi.

Summary

- Document in detail
  - Inspection
  - Measurements
- Get the right expertise on the team; update as needed
- Develop the scenario
- Test the hypotheses

PEPCON Explosion - References

- Video links
  - History Channel, 8:00 minutes
    http://video.aol.com/video-detail/pepcon-explosion-may-1988/1249549102
  - Exponent – 2:00 minutes
    http://www.youtube.com/watch?v=HJVOUgCm5Jk
  - Z-Axis
    http://podcasts.zaxis.com/pac/pepcon-explosion
  - Summary article
    http://www.interfire.org/res_file/pdf/Tr-021.pdf
    http://www.reviewjournal.com/news/pepcon/

Data Driven RCA

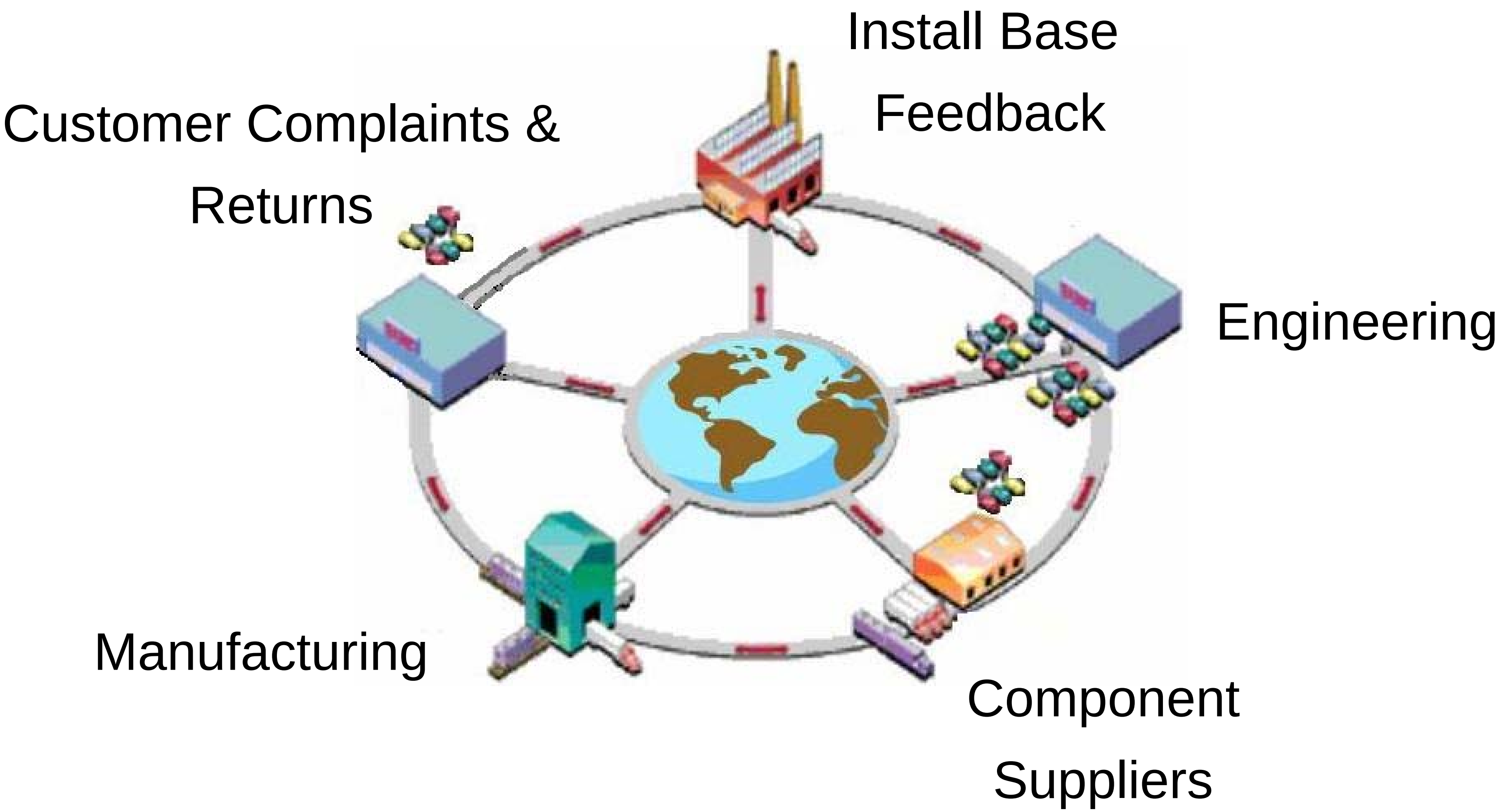
Al Alaverdi
SigmaQuest

SigmaQuest

SigmaQuest

- Solutions for Data Driven Quality Management & RCA
- Focus on High Tech, Telecom, Consumer Electronics, Medical Devices
- Good Data = Shortest path to RCA

RCA – A 360° Perspective



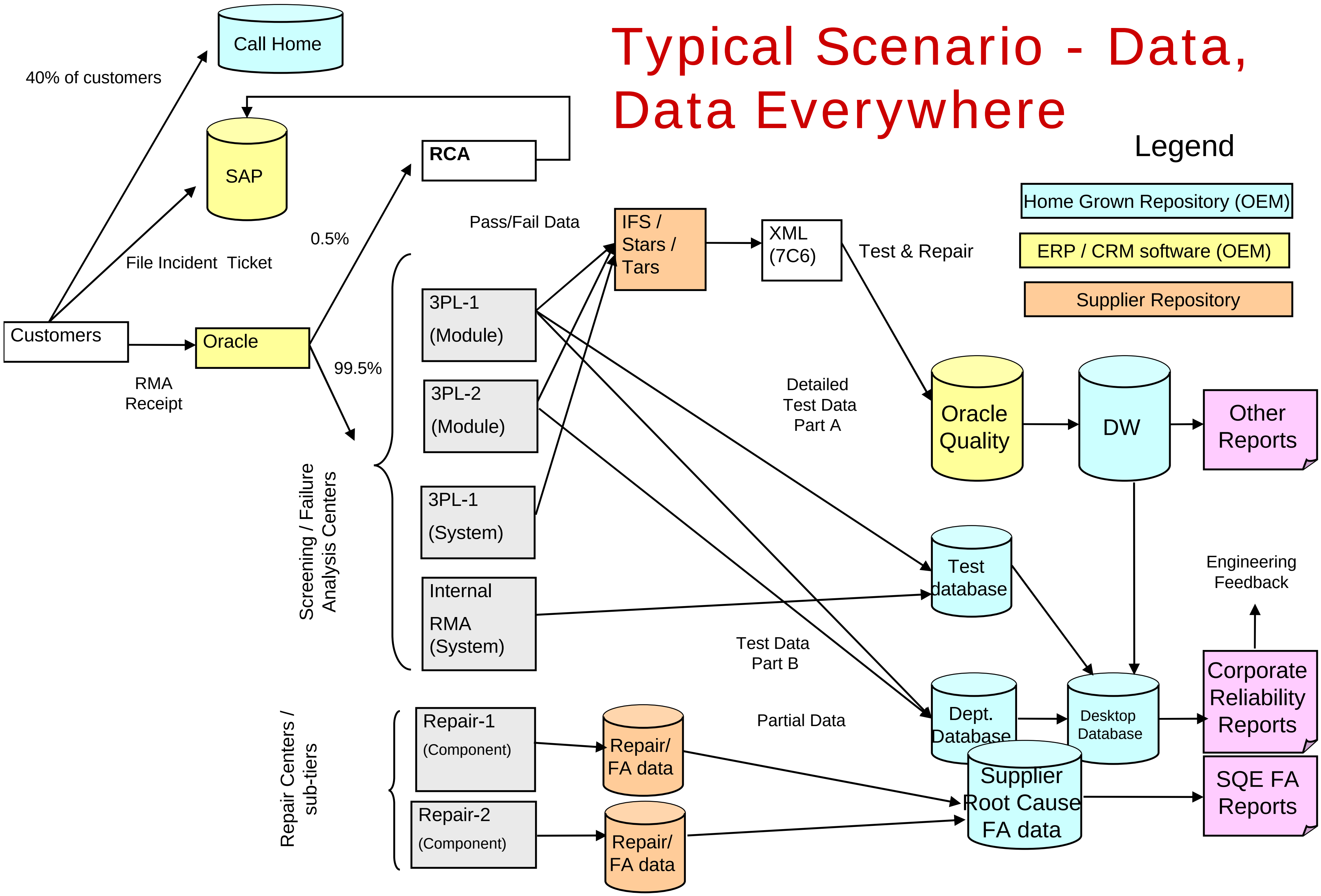
Eliminate Data Fragmentation

“Single View of Truth”

Data Acquisition Challenges

- Political
  - Engineering, Ops, Service, Quality
  - Component Suppliers, CMs, Repair Centers
- Data Quality
  - Are you collecting the right data ?
  - Accuracy, Granularity, Latency
  - Consistency (Part #, Serial #, Version, Revision)
- IT
  - Data Storage, Analytics , Large volumes of data

Typical Scenario - Data, Data Everywhere



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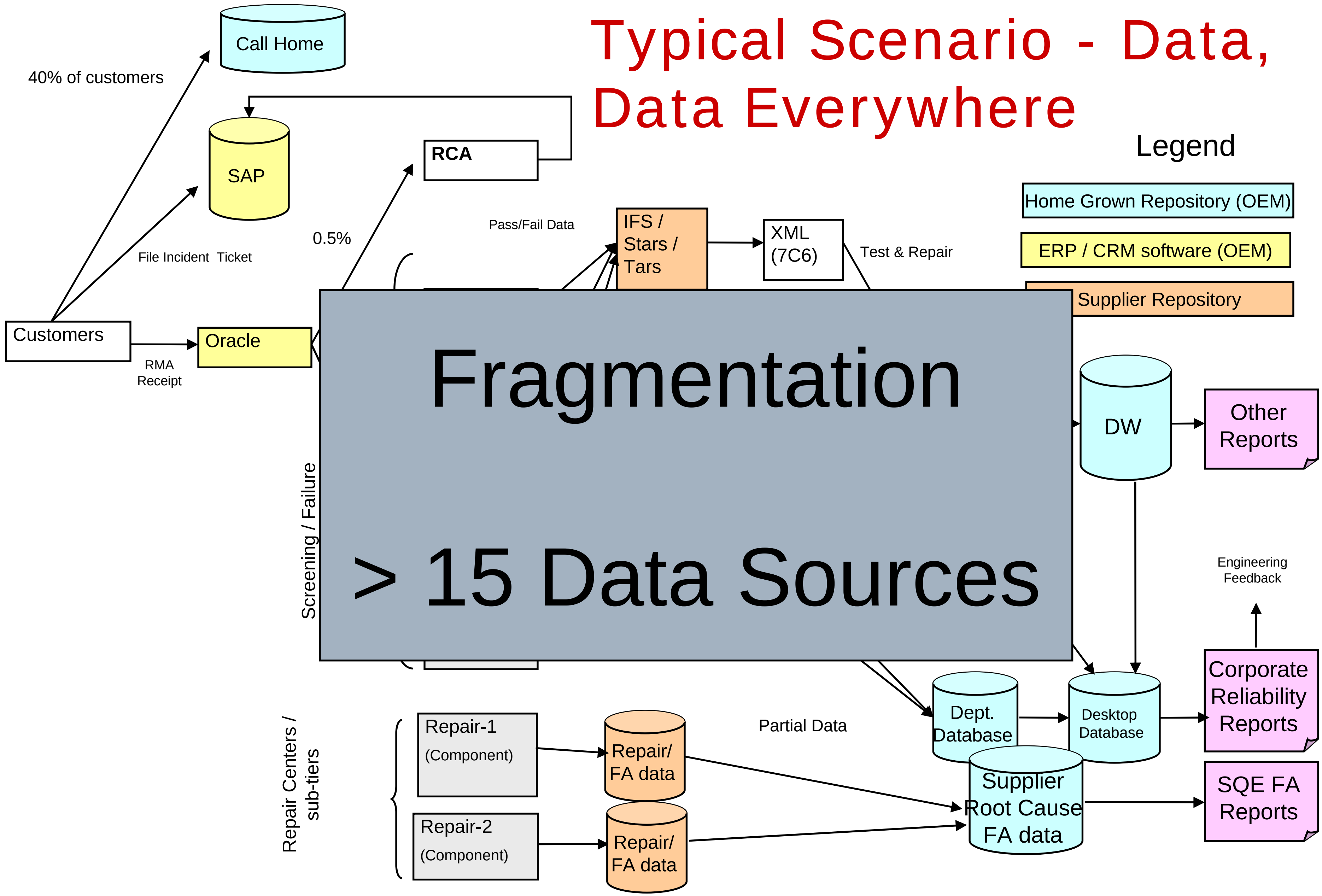
Typical Scenario - Data, Data Everywhere

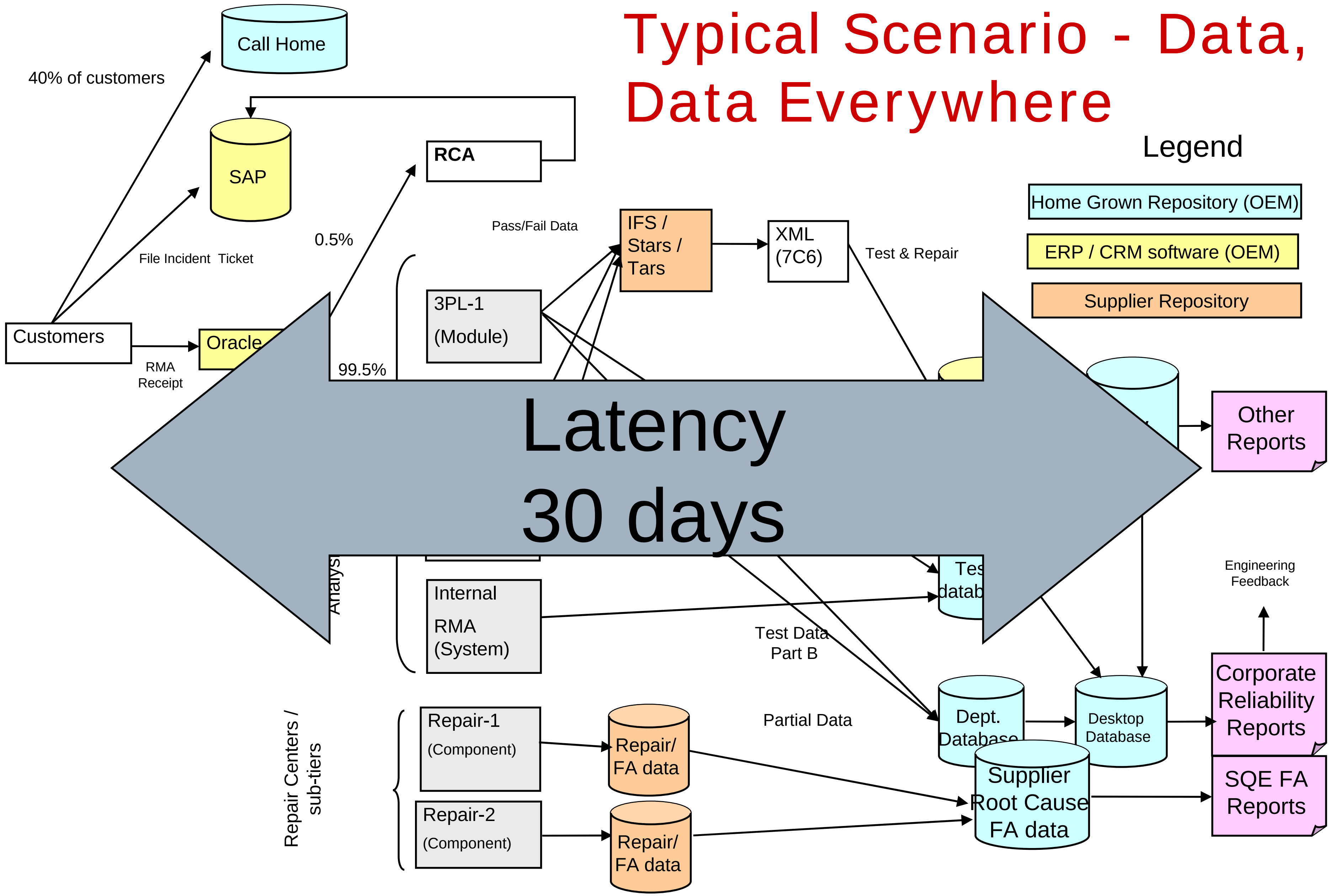


Fragmentation

> 15 Data Sources

SigmaQuest

Typical Scenario - Data, Data Everywhere



Building an Early Warning System To Expedite RCA

Leading Risk Indicators

- What happened ?

- Why ?
  - What is the root cause
  - Is it a Design, Process or Supplier Issue?
  - How do I prevent it from happening again

SigmaQuest

Demo

Using Data To Accelerate RCA

- Cultivate holistic data strategy
- Invest in Early Warning to accelerate RCA
- **Empower intellectual resources to make better decisions, sooner**

Contact Information

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Question & Answer

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