Robustness Thinking in Design for Reliability

A Best Practice in Design for Reliability

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HAYLION Technologies
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https://attendee.gotowebinar.com/register/2625796907172545805
Popcorn Story

Who Never Tasted Popcorn before?
Not simply a REHASH of the lessons learned

Microwaves popcorn-making is not simply a REHASH of the lessons learned in conventional way of popcorn-making, but a fundamentally different and proactive methodology.

DO THINGS RIGHT (DMAIC Mind-Set)
Conventional Way of Popcorn-making, fixing existing process, following conventional experience and procedures and … However, quality of popcorn is still heavily based on experience and …

DO RIGHT THINGS (Design Thinking Mind-Set)
Microwaves Way of Popcorn-making
Right and Robust Technology,
Good Quality of popcorn is not based (insensitive to) on experience
Better, Faster and Cheaper
Begin With the End in Mind
(Covey - 7 Habits of Highly Effective People)

• Will your customer always use your product under best conditions?
• Will your product always be manufactured under best conditions?

No!

Variation Happens!!
Objectives

- Define robustness
- Explain product development using Robust Engineering versus traditional product development
- Explain Robust Design for Reliability
- Define Objective Function, Basic Function, and Ideal Function
- Explain how Ideal Function and Two-step Optimization lead to robust technology development and achieve "Better, Cheaper, Faster" product development
- Explain how to conduct a preliminary robustness assessment
- Explain the value of robustness assessment
- Case study in robust autonomous driving technology development
Story in 1970 – SONY TV

Made in Japan

Made in USA

0.3% Defects

Customer satisfaction decreased when colour density deviated from target

100% Compliance

But American families liked the TV made in Japan better

Target X

Decreased Satisfaction

When it is NOT on Target
Story in 2018– Self-Driving Vehicle Accident

Reliability vs. Robustness Story
Dr. Matthew Hu Introduction

“Robust Engineering” & “Robust Design” feature, case studies and a deep dive, respectively.

Axiomatic Design - first symposium case studies and a deep dive

Enhancing Robust Design with the Aid of TRIZ and Axiomatic Design (Matthew Hu, Kai Yang, and Shin Taguchi).
Un-Reliability

### Failure Rate

- **Infant Mortality** (Early failure period)
  - Manufacturing variation
- **Best period**
  - Usage variation
- **Wear-out period**
  - Inner variation & deterioration

- **Constant failure rate**

### Time

- **Production Processes Under Statistical Control?** Not Usually!!
- **Usage Environment Under Statistical Control?**
Controls

- Selection of *Low Defect rate Parts, Joints, Fasteners, Interconnects, etc.*
- Selection of *Low Defect Rate Processes*
- Designing *Within Process Capability*
- Robust Design

**Conformance**

**Tools**
- Robust Design
- DOE
- Critical Parameter Management
- DFMEA/PFMEA/DFA/DFM
- Statistical Tolerancing
- Design and Process Capability (Cp, Cpk)
- Mistake-Proofing, SPC, Control Plans
- HALT and HASS

Useful Life

**Design Controls**
- Selecting high reliability Parts, Joints, Interconnects, Fasteners, etc.
- Designing with the minimum number of Processes, Parts, Joints, Fasteners, Interconnects, etc.
- Designing with low stress levels on Parts, Joints, Fasteners, Interconnects, etc.

**Tools**
- DFA – Part count reduction
- Reliability Data and Statistical Models
- Physics of Failures – Failure Mechanisms
- DOE
- Deterministic design
- Prediction
- Test to Failure
- HALT/ALT

Wear Out Life

**Controls**
- Selecting appropriate internal stress levels and materials to meet expected time to failure or replacement

**Tools**
- Reliability Data and Statistical Models
- Physics of Failures – Failure Mechanisms
- DOE
- Prediction
- Test to Failure/ALT

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**ASQ Reliability and Risk Division series webinar 3/11/2021**

Dr. Matthew Hu, mhu@rstiglobals.com; Phone: 281-299-4230
The Challenge of Reliability Theory Assumptions

Probability models under the assumption:

• Processes under statistical control?
  – Probably not!!

• Lagging indictors of reliability performance
  – The design is created before testing
  – Usage feedback is even much later
Reliability and Robustness (An Engineering Measure of Reliability)

Reliability: probability of a product performing its intended function for a specified life under the operating conditions encountered.

Computing probability of success requires knowledge of \( m, s, f(.) \)

Robustness: ability of a product to perform its intended function consistently in the presence of uncontrollable user environment (noise) during its intended life. In other words, the product is insensitive to noise.

Assessing robustness requires knowledge of \( m, s \)

Q: How do you know the \( f(.) \) when a design is new?
Back to Basic

- Work with the failure mechanisms
- And their relations to Variation!
Reliability in a World Full of Variation

Without Variation
No World!
Life is Variation!

Variation Creates Problems:
- Deviations
- Disturbances
- Noise
What is Robustness?

Webster’s dictionary defines robustness as:
• being powerfully built, sturdy
• boisterous, rough
• marked by richness and fullness

Dr. Taguchi defines robustness as:
• the state where the technology, product, or process performance is minimally sensitive to factors causing variability (either in the manufacturing or user’s environment) at the lowest cost.
A Simple Connector Reliability Design
Typical DfR Process Used by Companies

DFR Stages & Activities

1. **CONCEPT PHASE**
   - **DEFINE** Reliability Objectives
   - **IDENTIFY** Key Reliability Risks
     - **ASSESS** Proposed Design Reliability

2. **DESIGN PHASE**
   - **QUANTIFY** Analyze & Improve Reliability

3. **DEVELOPMENT PHASE**
   - **ASSURE** Reliability

4. **MANUFACTURING PHASE**

5. **SUPPORT PHASE**
   - **SUSTAIN** Monitor & Control Reliability
Typical DfR Process Used by Companies

DFR Stages & Activities

<table>
<thead>
<tr>
<th>DFR STAGE</th>
<th>CONCEPT PHASE</th>
<th>DESIGN PHASE</th>
<th>DEVELOPMENT PHASE</th>
<th>MANUFACTURING PHASE</th>
<th>SUPPORT PHASE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEFINE</td>
<td>Requirements &amp; Goals</td>
<td>Identify Key Reliability Risks</td>
<td>Assess Proposed Design Reliability</td>
<td>Quantify Analyze &amp; Improve Reliability</td>
<td>Assure Reliability</td>
</tr>
<tr>
<td>IDENTIFY</td>
<td>Environment &amp; Usage</td>
<td>Change Point Analysis</td>
<td>Robust Design</td>
<td>Life Data Analysis</td>
<td>Demonstration Testing</td>
</tr>
<tr>
<td>ASSESS</td>
<td>Critical-to-Reliability (CTR)</td>
<td>FMEA</td>
<td>System Reliability</td>
<td>Accelerated Testing</td>
<td>Risk Assessment</td>
</tr>
<tr>
<td>PROPOSED</td>
<td>Baseline Reliability</td>
<td>Reliability Model</td>
<td>Simulation</td>
<td>Degradation Analysis</td>
<td>Supplier Control</td>
</tr>
<tr>
<td>DESIGN</td>
<td>PFMEA</td>
<td>Critical Design Parameters Management</td>
<td>Failure Analysis</td>
<td>PFMEA</td>
<td>PFMEA</td>
</tr>
<tr>
<td>ACTIVITIES</td>
<td>Critical Design Parameters Management</td>
<td>Prognostic Health Management</td>
<td>Manufacturing Capability</td>
<td>Burn-in</td>
<td>Burn-in</td>
</tr>
<tr>
<td>RELIABILITY</td>
<td>Reliability Allocation</td>
<td>Life Data Analysis</td>
<td>Accelerated Testing</td>
<td>Failure Analysis</td>
<td>Failure Analysis</td>
</tr>
<tr>
<td>MODEL</td>
<td>Physics of Failure</td>
<td>System Reliability</td>
<td>Simulation</td>
<td>Failure Analysis</td>
<td>Failure Analysis</td>
</tr>
</tbody>
</table>

DFR STAGE Charts Prepared by: Matthew Hu

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Charts Prepared by: Matthew Hu
The Challenge of Reliability Design at The Lowest Cost

Reliability Efforts included

- d/pFMEA
- HALT
- Design of Experiments
- 8D
- Weibull analysis conducted
- SOP developed
- SPC implemented
- Operator trained

Results

- Connectors were still disconnected as unexpected
- One of the main reasons for an automotive safety recall
Conventional Approach

- Design-Test-Fix
- Test parts under severe conditions
- Ignore deterioration, wear & degradation
- Low knowledge gain
- Reliability checking by life test (reactive)
- Determine failure modes
- Predict operational lives

- No cost integration
- Lack of leading indicator
- Identify causes
- Minimize failures
- May lead to controlling some factors
- Unstructured
- Warranty claim and fire fighting
- Eliminate the symptoms downstream
- 1 symptom--1 problem--1 solution
- High uncertainty
- Trade off unknown
- Lack of engineering confidence
- Does not encourage technologies development

![Image of life cycle with Mean value of mass-produced design A and Mean value of mass-produced design B.](image)
Design Domains

Performance Target

Critical Characteristics

\[ y = f(x_1, x_2, x_3) \]

\( x_1 \) = Signal factors (special control factors e.g., current/voltage in motor design)
\( x_2 \) = Control factors
\( x_3 \) = Uncontrollable factors (e.g., temperature)

Minimize variation (sigma) by process capability improvement

\[ \sigma_y = \left[ \left( \frac{\partial y}{\partial x_1} \right)^2 \sigma_{x_1}^2 + \left( \frac{\partial y}{\partial x_2} \right)^2 \sigma_{x_2}^2 + \ldots \right]^{1/2} \]

Minimize sensitivity to variation by choosing good nominal values for \( x_s \)
The Challenge of Reliability Design at The Lowest Cost

Voids & Bubbles

Cross Section for Energy Variation

Quality Support Group

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Advantage of Robust Product Development

Conventional Approach
- Build-Test-Fix
  - Symptoms Focused
- Fire Fighting
  - Too many iterative loop
  - Concept, Functionality Optimization

New Approach: Predictive Design- in Quality
- Design-Optimization-Verify-Launch
- New Paradigm
  - Product, process optimization cost reduction

From
- Evolving design requirements
- Extensive design rework
- Product performance assessed by “build and test”
- Performance and producibility problems fixed after product in use
- Functionally serial product development
- Quality “tested in”

To
- Disciplined CTQ flowdown
- Controlled design parameters
- Product performance modeled and simulated
- Designed for robust performance and producibility
- Functionally integrated product development
- Quality “designed in”
Control Factors & Noise Factors

Availability of Control Factors

Existence of Noise Factors

Fire Prevention by Robust Optimization

A Typical company spends 70% of Engineers' Time to firefight.


Upstream Downstream

A slide from ASI
Robustness Solves the Problem

Robustness

low variation of ideal performance around the target value IN SPITE OF the effects of Noise Factors (uncontrollable user environment)
Deterministic Design

Under a simple stress-strength framework, design nominal are chosen to provide “strength” that exceeds the “stress” the product will experience.

It is known that stresses and strengths may vary, so safety margins are selected to minimize risk of failure, based on

- Rules of Thumb
- Past Experience

Without some probabilistic analysis, understanding of the nature of the variability and how it combines to affect performance is limited.

Consider two designs from a solely deterministic perspective. Which is less likely to fail?
Probabilistic Design

How can design be insensitive to noise…?

- Probabilistic analysis helps one understand the shape and dispersion of variability caused by noise.

- The interference region between stress and strength defines the probability of failure—this determines reliability.

- A design with a larger safety factor may have lower reliability depending upon stress and strength variability.

DESIGN 1
- Smaller safety margin, higher reliability

DESIGN 2
- Larger safety margin, lower reliability

Safety Margin

Mean Stress

Mean Strength

Interference region
# The 5 types of Noise factors

The 5 types of Noise factors that disturb ideal function

<table>
<thead>
<tr>
<th>Noise Factor</th>
<th>Caused by</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inner Noise (Capacity)</strong></td>
<td></td>
</tr>
<tr>
<td>1. Piece-to-piece variation</td>
<td>Production rate</td>
</tr>
<tr>
<td>of part properties (such as</td>
<td></td>
</tr>
<tr>
<td>dimensions)</td>
<td></td>
</tr>
<tr>
<td>2. Changes over time in</td>
<td>Exposure to repetitive demand</td>
</tr>
<tr>
<td>dimensions or strength</td>
<td></td>
</tr>
<tr>
<td>(such as wear out, fatigue,</td>
<td></td>
</tr>
<tr>
<td>deterioration, chemical,</td>
<td></td>
</tr>
<tr>
<td>degradation)</td>
<td></td>
</tr>
<tr>
<td><strong>Outer Noise (Demand)</strong></td>
<td></td>
</tr>
<tr>
<td>3. Customer usage and duty</td>
<td>Conditions of use</td>
</tr>
<tr>
<td>cycle</td>
<td></td>
</tr>
<tr>
<td>4. External operating</td>
<td>Climatic and application conditions</td>
</tr>
<tr>
<td>environment</td>
<td></td>
</tr>
<tr>
<td>5. Internal operating</td>
<td>Component &amp; system interactions and interfaces</td>
</tr>
<tr>
<td>environment (error states</td>
<td></td>
</tr>
<tr>
<td>from on component being</td>
<td></td>
</tr>
<tr>
<td>received as a noise factor</td>
<td></td>
</tr>
<tr>
<td>by another)</td>
<td></td>
</tr>
</tbody>
</table>
**Noise Impact in Bathtub-Curve**

**Strength Noises**
1. Piece to piece/comp.-comp. variation
2. Aging/Wear out/ strength over time / cycles

**Stress Noise**

**Conditions of Use**
3. Customers usage and duty cycle or usage profile

**Operating environment**
4. External (climate/location)
5. Internal subsystems /components interactions / interfaces

---

**Stress**
Affected by Outer Noises

**Strength**
Affected by Inner Noises

**Failures Occur**

**DFR**

- a. infant mortality
- Noise #1

**CFR**

- b. useful life
- Noises #3/4/5

**IFR**

- c. wear out
- Noise #2

Affected by Mfg. Variation

Affected by Customer Usage Variation

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Robust Design

Make design insensitive to the uncontrollable user environment (noise).

- Concentrates on:
  - identifying the “ideal function(s)” for a specific technology or product/process based on its energy transformation, then selectively choosing the best levels of design parameters that optimize performance reliably (even in the presence of factors causing variability) at lowest cost.
  - application of two-step optimization.
Robustness – An Approach to Make Money

• Robustness reduces performance variations and achieves Six Sigma quality
• Avoids failure modes
• Achieves customer satisfaction
• Also shortens development time to market – reduces build/test/fix cycles
Robust Design for Reliability

**Minimize Sensitivity to Noise**
- Concept / System Design
- Robust Parameter Design

**Reduce Rate** of change of product parameters
- Tolerance Design

Redundancy
(Cost of failures vs. cost of providing redundant components)

Capable Manufacturing Process

Input Energy → Output Response

Ideal Function

Robust Design for Reliability

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System Thinking & Robustness

The achievement of higher reliability can also be viewed as an improvement to Robustness.

Design Space Optimal Points Searching
Create Robust Design

The principle of parameter design is a powerful methodology to increase the distance from the failure mode.

Exploiting Non-Linearity

X2 results in less variation in Y
Robust Engineering

Robust Engineering Emphasizes CI* on Three Main Design Stages

• System Design
• Parameter Design
• Tolerance Design

Robust Design Principles

1. Identify and Select Proper System Output Response (s)
2. Measure Functions using S/N** Ratio or Equivalent
3. Take Advantage of Interactions between Control & Noise Factors
4. Use Orthogonal Arrays
5. Apply Two-step Optimization

Note: *CI: Continuous Improvement, S/N=Signal-to-Ratio
Model for Robustness Thinking

Ideally 100% of input energy (the signal) should convert into 100% ideal function.
Results of Robust Design Effort (Shrink and Shift)

Step 1
Reduce Variability
Take advantage of control factors affecting variability

Adjusted Mean
Select factors to ship mean with minimum impact veracity

- Reduced variation
- Improved targeted performance
- Improved reliability
- Improved customer satisfaction

Assess the limitation of a given design
Example of Mechanical Crimped Connector

New Approach - Intent: To transfer energy from input energy to form a proper shape.

What to measure to understand performance?

Quality Problems:

- Poor electrical conduction
- Poor tensile strength
- Poor vibration resistance
- High voltage drop
- Degraded electrical & mechanical integrity
- ... etc

Results:

- Pull strength increased
- Voltage drop reduced
- Improved process capability

S/N = \frac{\text{Desired Output}}{\text{Harmful Output}}

Focus what you want. Don’t focus what you don’t want!
The Challenge of Reliability Design at The Lowest Cost

Voids & Bubbles

Pull Strength and Voltage Drop

Wire Crimp Height

Bellmouth

Front

Rear

N/mV

CH1

CH2

Compression Rate

Pull Strength

Voltage Drop
Example of Mechanical Crimped Connector

New Approach - Intent: To transfer energy from input energy to form a proper shape.

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- ... etc

Results:
- Pull strength increased
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\[ S/N = \frac{\text{Desired Output}}{\text{Harmful Output}} \]

Focusing on basic function, minimizes the difficulty in improving this problem

Focus what you want. Don’t focus what you don’t want!
Example of Reliability Improvement in Robust Design (cont’d)

Optimized design in presence of uncontrollable usage environment.

### Control Factors

<table>
<thead>
<tr>
<th>#</th>
<th>Material Type</th>
<th>Material Thickness</th>
<th>Crimp leg length</th>
<th>CH/CW ratio</th>
<th>Strok length</th>
<th>Res. Of Press</th>
<th>P.W. terminal</th>
<th>Angle of punch</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>#1</td>
<td>#2</td>
<td>#3</td>
<td>#4</td>
<td>#5</td>
<td>#6</td>
<td>#7</td>
<td>#8</td>
</tr>
<tr>
<td>2</td>
<td>#9</td>
<td>#10</td>
<td>#11</td>
<td>#12</td>
<td>#13</td>
<td>#14</td>
<td>#15</td>
<td>#16</td>
</tr>
</tbody>
</table>

### Noise Factors

<table>
<thead>
<tr>
<th>Noise Factors</th>
<th>M1=0.2</th>
<th>M1=0.2</th>
<th>M1=0.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSA Wire</td>
<td>K1=-5%</td>
<td>K2=-7.5%</td>
<td>K1=-5%</td>
</tr>
<tr>
<td>Aging</td>
<td>Before</td>
<td>After</td>
<td>Before</td>
</tr>
</tbody>
</table>
| Stressor levels for Discovery Based Testing | ![Stressor levels](image)

### The Designs

- **Inner Array**: L18
- **Strength**: 
  - **Output Response**: Ideal Function
  - **Input Energy**: 
    - **Output Response**: Ideal Function
    - **Failure Modes**: 
      - **Output Response**: Ideal Function
      - **Input Energy**: 
        - **Output Response**: Ideal Function

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Dr. Matthew Hu, mhu@rstiglobals.com; Phone: 281-299-4230
Example of DfR Basic Tools Application (cont’d)

**Crimped Connector Reliability Demonstration Plan & Report**

<table>
<thead>
<tr>
<th>RDM Candidates</th>
<th>RELIABILITY/ROBUSTNESS IMPLEMENTATION</th>
<th>VALIDATION EVIDENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise Factors Present in the Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Impact Noise Factors</td>
<td>Metric</td>
<td>Range</td>
</tr>
<tr>
<td>N1. P-to-P variation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N2. Wear-out / Aging</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N3. Customer Duty Cycle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N4. External Environment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N5. System Interactions</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Key Function /Technology**

<table>
<thead>
<tr>
<th>Noise Factor</th>
<th>Validation Test from RCL</th>
<th>Critical Metric</th>
<th>Test Target</th>
<th>Metric</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Impact Failure Modes (Soft / Hard)</td>
<td>Related Component Subsystem / System</td>
<td>Pull strength Life Test</td>
<td>N</td>
<td>150</td>
<td>N1. Different Wire Size</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mm</td>
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<td></td>
<td>Y/N</td>
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<td></td>
<td>CSA%</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y/N</td>
</tr>
</tbody>
</table>

**Example:**

- **Withstand Force (Pull Strength)**
- **Wires Disconnected**
- **Terminal and Wire strands**
- **Pull strength Life Test**
- **N**
- **N1. Different Wire Size**
- **N2. Aging**
- **Validated Metric**
- **Range**
- **Completion Date**

**Probability Plot for Optimal AA, B2, AA**

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Dr. Matthew Hu, mhu@rstiglobals.com; Phone: 281-299-4230
Why Robust Design?

Efficiency And Effectiveness
Robustness "Rules of Engagement"

1. Concentrate on **Ideal Function**, and establish a way to measure it; do not use symptoms of poor quality.
2. Identify sources of the **five types of noise** and expected magnitudes.
3. Introduce product noise **early**. Drive the performance away from ideal situation.
4. Concentrate on the **effects** of the noise, rather than the noise themselves.
5. Understand how error states and noise factors cross system interfaces and boundaries.
6. Develop a noise factor management strategy.
7. Work out how to include remaining Noise Factors in tests.
8. Plan a robustness assessment of current design to compare against ideal performance.
9. Where robustness improvement strategy is obvious from knowledge of physics, **DO IT!**
10. Where robustness improvement is not obvious from current knowledge of the physics, plan parameter design studies (using DoE if necessary) to discover the improvement.
11. Management needs to design this into the Product Design Process and check that it is done to an appropriate degree.
Case Study: Robustness Thinking In Innovative Problem Solving


IDENTIFY

1. Hydraulic Lash Adjuster Project Scope
   -raise Failure/Working Schedule
   -Lash Adjuster
   -Lash Adjuser System Overview
   -Before Optimization (Design Hull Factor Movement)
     (see Before Adjuster Hull Movement)
   -Before Performance Measures

DEFINE

2. Hydraulic Lash Adjuster
   -Lash Adjuser
   -Lash Adjuser Design
   -Lash Adjuser System Overview

3. Before Optimization
   -Design Hull Factor Movement
   -Before Performance Measures

CONCEPT ROBUSTNESS: FUNCTION DECOUPLING

4. Concept Robustness Assessment
   -Valve Closing Velocity Box Plot
   -Validation of Concept
     -Validated Benefits:
     • Improved high time reliability
     • Generated $689,000 hard savings & more than $1.8
       millions soft savings.
     • Resolved the hydraulic lash adjuster issues with
decoupled concept design (inherent robustness).
     • Increased Cpk from 1.34 to 2.89

5. Robust Parameter Optimization
   -Optimize
   -Optimization
   -Optimization

6. Concept Robustness Assessment
   -Valve Closing Velocity Box Plot
   -Validation of Concept

7. Pugh Concept Selection
   -Table: Selection Criteria
   -Table: Pugh Matrix
   -Table: Pugh Matrix

8. Concept Robustness Assessment
   -Valve Closing Velocity Box Plot
   -Validation of Concept

Dr. Matthew Hu, Phone: 281-299-4230,
System Robustness and Redundancy

An important result of our Comprehensive Risk Management and Deep Integration process is systems diversity, robustness and redundancy, which are key drivers of the safety of the Alphaba Bus.

Integrated Vehicle Health Monitor

**System Robustness**

- Steering and Braking
- Electrical Power
- Vehicle Localization
- Signal Communications
- Redundant Collision Detection

**System Robustness**

All critical systems have been designed, optimized in the presence of user conditions, tested and validated through intrusive testing, test track durability testing and extensive on-road mileage accumulation.

Signal Communications between computers, sensors and actuators have an alternate path if the primary fails.

Redundant Collision

Redundant Collision Detection our vehicle includes a crash-imminent braking system calibrated to work as a backup to the self-driving system that can apply the brakes to stop the car if necessary.
Important Takeaway

- Robust design is essential to achieve competitive advantage
- Make design insensitive to uncontrollable user environment (Noise)
- Early development of robustness is key to proactive quality and reliability Improvement
  - Capture, front load noise and manage noise
  - Gain control of your product performance
  - Optimize robustness – avoid all failure modes
- Apply Robust design principles at early stages of product design to “forecast” problems and take preventive action.
Questions?
Thank You!

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