Connecting FMEA and DOE

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Connecting FMEA and DOE

- **Objective**
  - **Understand what DOE is**
  - **Review what FMEA is**
  - **Solving issue**
    - **Not just explain it or rationalize it**

Premise

- FMEAs can have strong impact on design
- Potential is limited for a variety of reasons
  - Narrow view or inexperienced group
  - Limited depth
  - Need facilitated by third party from a systems perspective
  - Performed too late in a project
  - Viewed as THE deliverable

DOE is...

- Design of Experiments
  - An efficient technique to collect an adequate amount of usable data with the least amount of effort
  - Can be used with hardware or computer simulations
    - Product or process development

Who has previous exposure to DOE?

DOE Definition

- **DOE organizes the collection of development test data to determine the most statistically confident relationship between inputs and outputs.**
  - **Complexity of the relationship is chosen by the user.**

Provides understanding
- equation
- priority
- area of interest

Tools

- **Factorial Designs**
  - **Full (2^k form)**
  - **Fractional (2^{k-p} form)**
- **Advanced Designs (Response Surface Methods)**
  - **3 level (<u>not</u> a 3^k form)**
  - **5 level (composite with factorial as a basis)**

Organizing the collection of data to determine the most statistically confident relationship

Tool Comparison / Typical Equations

OFAT typical output (main effects)

$y = z + a*A + b*B + c*C$

Factorial typical output (main and interactions)

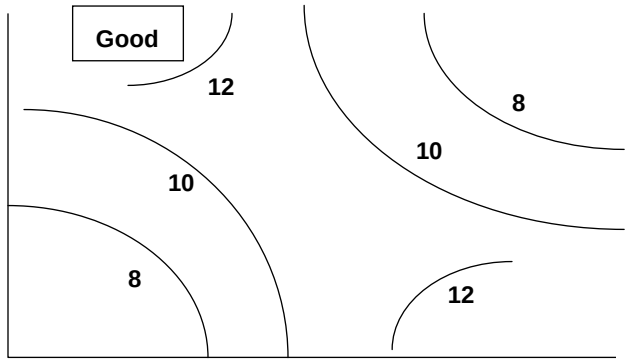
$y = z + a*A + b*B + c*C + d*A*B + e*A*C + f*B*C + g*A*B*C$

Response Surface typical output (main, interactions, quadratic)

$y = z + a*A + b*B + c*C + d[A]^2 + e[B]^2 + f[C]^2 + g[AB] + h[AC] + i[BC] + j[ABC] + p[A]^3 + q[B]^3 + r[C]^3 + s[A^2B] + t[AB^2] + u[A^2C] + v[AC^2] + w[B^2C] + x[BC^2]$

More information (fine tuning) is achieved as progress to more rigorous tools

Response Surface Method, Postage Stamp



FMEA

- **What is it**
  - **A method to identify potential failure modes and the potential impact on performance. Ultimately can yield a numerical value for relative risk.**
- **Why use it**
  - **Prioritize development effort, understand root causes**
  - **Design out failures from products and processes**
  - **Influence decisions**
  - **Test considerations, quality inspection points, preventative maintenance, operational constraints, useful life**

FMEA

- **FMEAs are intended to**
  - **Identify potential failure modes and rate severity of effects**
  - **Identify critical and significant characteristics**
  - **Help engineers prioritize and focus on eliminating product and process concerns and help prevent problems from occurring**

FMEA

- Three Types (can be at concept level as well)
  - Design
    - Can flow from the design concept WBS
      - Questions to ask: what if we cannot design the product to meet the customer requirements (not if there are manufacturing defects – stay out of that at this level)
  - Process
    - Manufacturing
      - Per the potential development manufacturing/ assembly process steps
      - Updated through the production life of the product?
    - Business
      - Using the established procedures
      - As a way to evaluate a change to a process, form, etc.

Issue Resolution

- The issues discovered during the process need to be addressed.
- A few popular areas are discussed to get the sense of what to do after the matrix is generated.

Motor Design - Consequence

- In use, a motor has the opportunity to stall. This would increase the current draw and over-heat the motor.
- This could be caused by ice build up. Ice build up is a very likely reality.
- The motor design could over-heat to the point of burning up the internal parts. This would requirement replacement of the motor.
- Because the occurrence of ice is high, the consequence is "bad" and we cannot detect the high temp, this is an unacceptable situation.
- The design was modified to include a temperature sensitive "fuse". It has the ability to reset when temperatures fall back to normal levels (providing time for ice removal). The fuse temp was used at the material design limit.
- This did not eliminate the failure mode – lack of motor performance – but it did eliminate the consequence of removal and replacement.

Motor Cooling DOE - Consequence

- Goal: Find a simple solution so the fuse does not trip during normal operation.
- Response: Maximum temperature and time to achieve it.
- Approach: Using a bench test, use a common motor to understand various manufacturing and design parameters impacting motor heating.
- Result: Changes allowed new design to pass performance test and avoid the negative thermal consequence.

Weld Strength - Occurrence

- A system requires a strong and light design. Titanium appears to be capable of meeting the requirements.
- Fatigue life is a critical requirement – and is highly dependant on weld strength. Weld quality is highly variable with titanium.
- If the design fails, major damage could be generated.
- Because the occurrence of weak welds is possible, the consequence is "bad" and we cannot detect impending fatigue failure, this is an unacceptable situation.
- The weld design parameters need to be understood to improve likelihood for meeting the fatigue requirements.

Titanium Weld Fatigue Strength - Occurrence

- Goal: Predict and design a high reliability titanium product
- Response: Fatigue strength, reliability
- Approach: Determine technical holes or uncertainty in calculation of fatigue strength. Use DOE to derive empirical equations to fill the gaps. Reliability will be determined through Monte Carlo analysis.
- Result: Requirements and expectations were created and shared with the customer. A confident solution was now available to achieve challenging requirements.

Fixture Visual Inspection - Detection

- As a part of a process, a critical alignment of parts in manufacturing is needed
  - This could be "completeness" of information for an application or ECO in a business setting
- This adds pain and rework if not done right. The occurrence is high and the impact is high, so we need to improve detection. An expert operator/ worker is introduced as an inspection step.
- Did this fix anything? It delays the process. It puts your best operator on a task that does not add value. And it probably is not an effective inspection. Best thing?

Fixture Design DOE – Fixed thru Occurrence

- Goal: Manufacturing fixture to be set so anyone can do it right – instead of requiring a special operator
- Response: Process outputs, dimensions
- Approach: Using key factors, use a DOE to find robust settings.
- Result: A blend of settings found that allows less sensitive performance to avoid cause (without a detection solution). During test, the structure allowed the designer of the fixture ability to see other techniques for a better fixture.

Consequence Techniques

- Redesign for "fail safe"*
- Add a redundant function
- Add a back up function, with limited functionality – allows basic critical operation
- Address liability issues (warnings)
  - Keep in mind, extra "sensors" just adds to the potential items that can cause down time. Must balance with other requirements. Maintenance and reliability for example.
  - Also need to consider – can someone over ride my system?

* Area where DOE can help

Occurrence Techniques

- Further/ deeper factor analysis*
- Understand tolerance sensitivity*
- Redesign*
- Provide safety margins
- Redundancy
- New approach

* Area where DOE can help

Detectability Techniques

- Test development*
- Develop new measurement techniques*
- Understand periodic maintenance expectations*
- Include imbedded sensors and/ or software to provide early warning signals*
  - Temperature, vibration, etc.
- Redesign to allow inspection
- Training to improve identification capability

* Area where DOE can help

FMEA and DOE Working Together

- Perform FMEA early on new development
  - Work on the right things/ focus resources
  - Obtain understanding (empirical equations) from DOE
  - Resolve issues/ perform optimization of products and processes
- Assemble the right team
  - Experienced group
  - Appropriate depth
  - Facilitated by third party from a systems perspective
- View FMEA as a step in the process to better design

Connecting FMEA and DOE

- **Summary**
  - **Need to make these living documents that influence design and track resolution**
  - **At times, resolution needs to acquire additional information. This can be achieved by DOE**
  - **If you are interested in a copy of this presentation, leave you card or email address and I will get it to you.**