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DOE Applied to Secondary Operations for Plastic Parts

Perry K. Parendo
651-230-3861
Perry@PerrysSolutions.com

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Practical Application of DOE for the Development Process

- Develop faster and better with Design of Experiments (DOE)
  - Do you need it
  - When should you want to use it

Agenda

- DOE definition
- DOE compared to traditional methods
- Case studies
- Do I need it?
- Project examples
- How to use DOE tools

DOE Definition

- DOE is a tool to assist in the process of understanding a system

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Tools

- **Factorial Designs**
  - Full (2^k form)
  - Fractional (2^{k-p} form)
  - Taguchi - maximum assumptions
- **Advanced Designs (Response Surface Methods)**
  - 3 level (not a 3^k form)
  - 5 level (composite with factorial as a basis)
  - Optimization
- **Related Statistical Tools**
  - Probabilistic Failure Assessment (Monte Carlo analysis)
  - Statistical Process Control (SPC)
  - Measurement System Analysis (Gage R&R)

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

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Typical Equations (for 3 variables)

One Factor At a Time (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)

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

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DOE vs. Traditional Methods

- Traditional Methods come in two forms:
- The first approach
  - Fix all variables and only changes one of them to understand its effect.
  - Then they fix it at the "best" level, and change another variable. This is continued until all variables are completed or funding expires.
  - Each step occurs one at a time - thus this is also called One Factor At a Time (OFAT) testing.

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DOE vs. Traditional Methods (cont.)

- Second approach
  - Change many things at the same time. If the problem gets fixed, it is hard to tell which variable did it. Thus all are considered important. Not an organized or systematic approach.
  - Other words for these traditional approaches are: by guess / by golly, hit and miss, seat of the pants, shot gun approach, or more nicely "Exploratory Testing" or the Scientific Method.

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Ultrasonic Welding

- Background - New product was being shipped but found some were leaking
- Tried tweaking within vendor recommendation but could not achieve requirement
- Customer frustrated it was taking so long

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Ultrasonic Welding (cont.)

- Goal: Predicting where to operate would be great! Need to rebuild trust with customer.
- Response: leakage and appearance
- Approach: Executed first DOE at vendor recommended ranges
- Result: Found “bad” and “ok” areas; could predict better area!

* Predicted operation area

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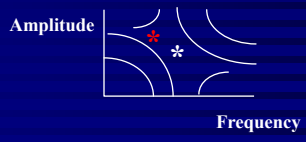
Ultrasonic Welding (cont.)

- Phase Two DOE Approach: We proved operation in new area with confidence by centering new test at predicted point.
- Result: While original estimate was ok, a better point of operation was determined.



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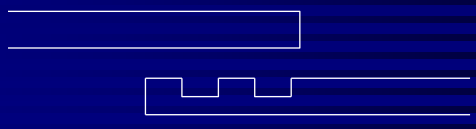
Bonding

- Goal: Improve joint retention
- Response: Retention force with static loading



Bonding (cont.)

- Approach: Explore different adhesive materials, surface finishes and joint designs.
- Result: Found the window of operation on the bench. Could dial in exact desired strength

Plasma Treatment

- Goal: Improve joint retention for challenging plastic material – polyethylene for example
- Response: Surface energy and Retention force

Plasma (cont.)

- Approach: Evaluate impact of plasma treatment on adhesive bonding
  - Consider applied voltage, duration of exposure, and time after exposure
  - Also include environmental conditions for storage (summer versus winter)
- Result: With understanding of standard process, could also understand target time to finish the bonding process without degrading eventual joint strength

Why do you test?

- Depends on Experience
  - Testing is performed to gain knowledge
    - More knowledge reduces project risk
  - Other people's experience is leveraged through "physics" or other sciences

Can test on product hardware, process or computer models

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If I test, do I have to use DOE? Why do I need it?

- **Depends on Experiment**
  - If your situation asks the questions "what if" and "what else", you do not have the required understanding and will most likely need DOE
  - If the Experiment is "proving" you know something, DOE does not make sense
    - For example, if high confidence you are applying well known technical principles – simple confirmation testing is all that would be required

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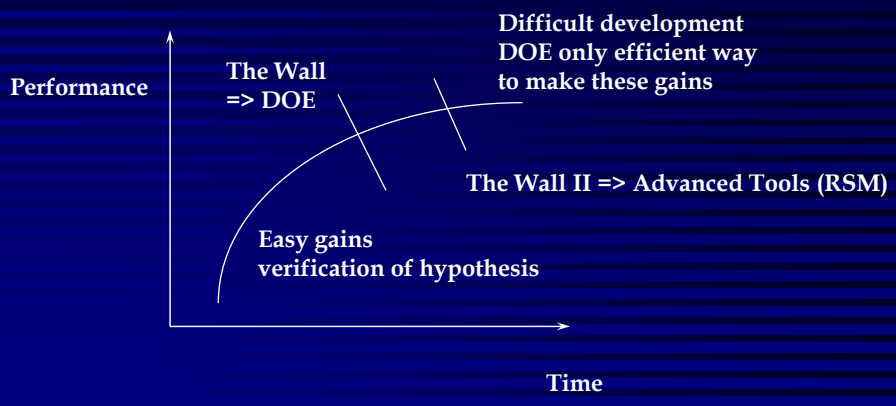
Design Stages



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Project Examples

- Welding, web processes, heat treat, stamping
- Molding plastic and rubber, foaming (gaskets, diaphragms and piece parts)
- Adhesive in assembly, epoxy curative reaction, powder coating colorization, adhesive delivery
- Plating, vapor deposition, cleaning, soldering, polishing
- Laser cutting, drilling and surface grinding equip.
- Medical fluid sampling equipment
- Electronics, composites, food, resin, product comparison, control systems
- Seal repeatability, product durability/ reliability
- Office process flow, process waste, mfg sim.
- Analysis of hydraulic, thermal & molding

223 of these projects saved an estimated $9,193,400.

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How do I use it?

DOE with Secondary Operations
Perry K. Parendo
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DOE Process

- Define goal - need
- Define response(s) to measure progress to goal
- List all variables and down select to "key" variables using engineering judgment
- Select appropriate design matrix - approach *
- Select safe/consistent test levels for variables
- Address tradeoffs between responses
- Perform test
- Analyze results *
- Discuss next step

* Where DOE software helps

Perry's Solutions, LLC

- Consulting and Training services from DOE and SPC to project planning and management

- Phone: 651-230-3861
- Email: Perry@PerrysSolutions.com
- Website: www.PerrysSolutions.com