Introduction

Applied Experimental Design

Getting Started

- Instructor Introduction
- Participant Introductions
  - Name
  - Knowledge and Experiences in ED
  - Expectations
  - Concerns
- Topic Introduction
- Agenda

Notes:

What is Experimental Design?

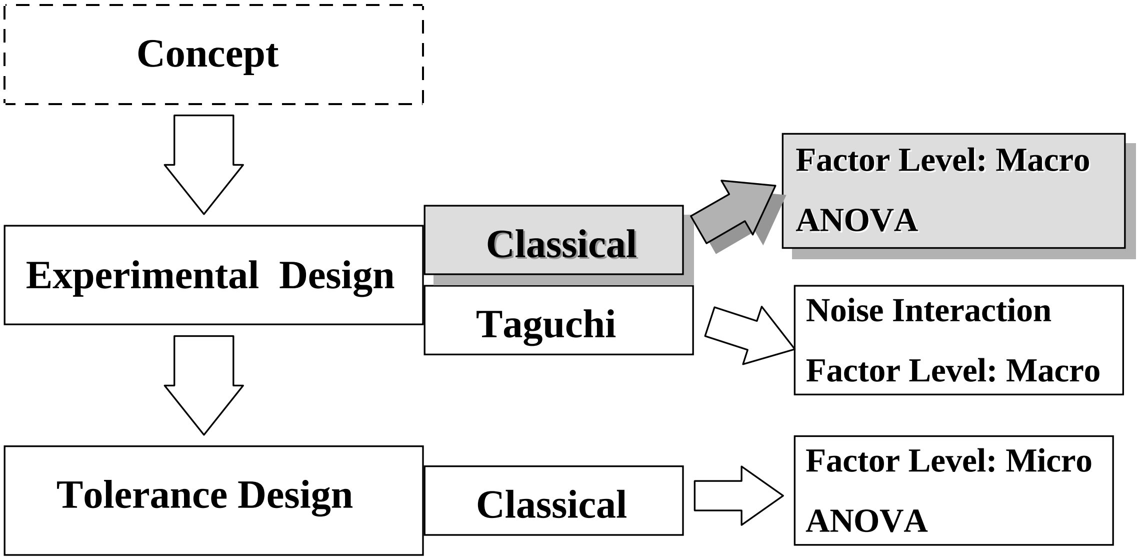
A statistically based, value-added technique for the identification and quantification of multiple parameters simultaneously, for either product or process, through structured experimentation, with the purpose of developing predictive models.

Experimental Design (ED) is a structured approach to evaluating multiple variables simultaneously, thus allowing maximum output with minimum resources. The use of ED methodology avoids the inefficiencies of the one-factor-at-a-time (OFAAT) method. Experimental Design methodology is based on statistical principles which are readily available in many textbooks. However, one need only have a conceptual understanding of these basic principles in order to effectively use the ED methods.

When used as an iterative process, the data retrieved through ED methods provides the ability to build predictive system models, and ultimately functional products and efficient processes.

Notes:

Experimental Methods Overview



Any product or process design begins with a concept. Classical Design of Experiments (DOE) provides a methodology for establishing functional designs from the concept design phase. Once that concept is defined, the engineer must select and evaluate variables that influence functionality in order to provide high quality and useful products for the customer. Two basic experimental methodologies that share many common traits have evolved: DOE and Taguchi Methods.

Classical DOE originated in England in the 1920's, when Dr. Ronald Fisher studied variables influencing crop yields. During the 1950's and 60's, Dr. Genichi Taguchi developed an experimental methodology that is based upon many of these same statistical principles. This methodology is called the Taguchi Method or Parameter Design. Parameter Design focuses on the evaluation of control factors against influential noise factors, and guides the engineer in the selection of control variables that are robust against noise.

The classical methodology is also useful in identification of factors that induce real effects at small deviations from nominal product specification values. This application provides engineers with a methodology to evaluate product tolerancing requirements.

Notes:

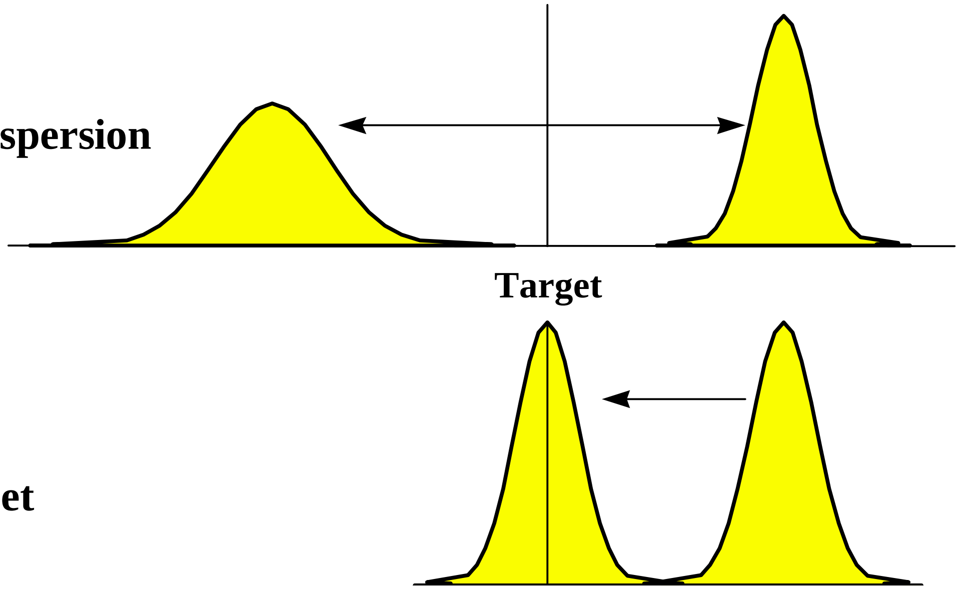
Experimental Designs

Classical Design	**Parameter Design**
Control Factor Effects	**Control Factor Effects**
F → F Interaction	**Noise → F Interaction**
Functional Response	**Signal → Response**
Yield Data Response	

The classical approach quantifies the effect of independent variables that control the function of the component or system under investigation. This approach also quantifies the degree of factor-factor interaction that cannot be measured using the one-factor-at-a-time (OFAAT) approach. The parameter design or Taguchi method quantifies a factor effect in the presence of system noise, such that the experimenter may select the control factor level that is most **robust** against that specific noise factor.

Notes:

Two-Step Optimization



Step 1

Minimize dispersion

Step 2

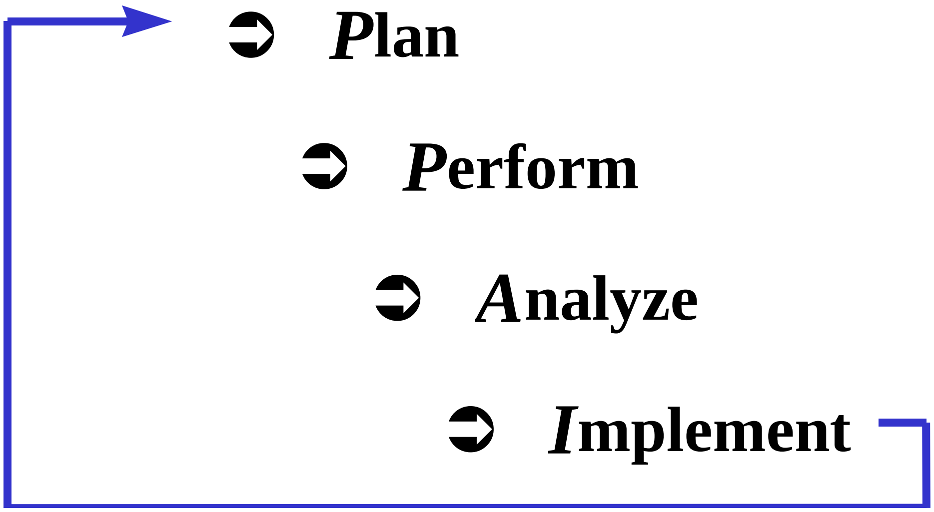
Shift to target

The Two-Step Optimization process promotes a two-element philosophy for achieving a functional and quality product or process. The first step is to reduce variability and the second step focuses on shifting the output mean to a functional target.

Notes:

Stages of Process Execution

Structure provides *control and focus*



➲ ***P*lan**

➲ ***P*erform**

➲ ***A*nalyze**

➲ ***I*mplement**

These four steps parallel the classical Quality Improvement Cycle: Plan-Do-Study-Act. A structured project provides **focus** and **control** over the various procedures that formulate a project. Proper utilization of these four key elements will substantially increase the likelihood of successfully achieving useful and meaningful results.

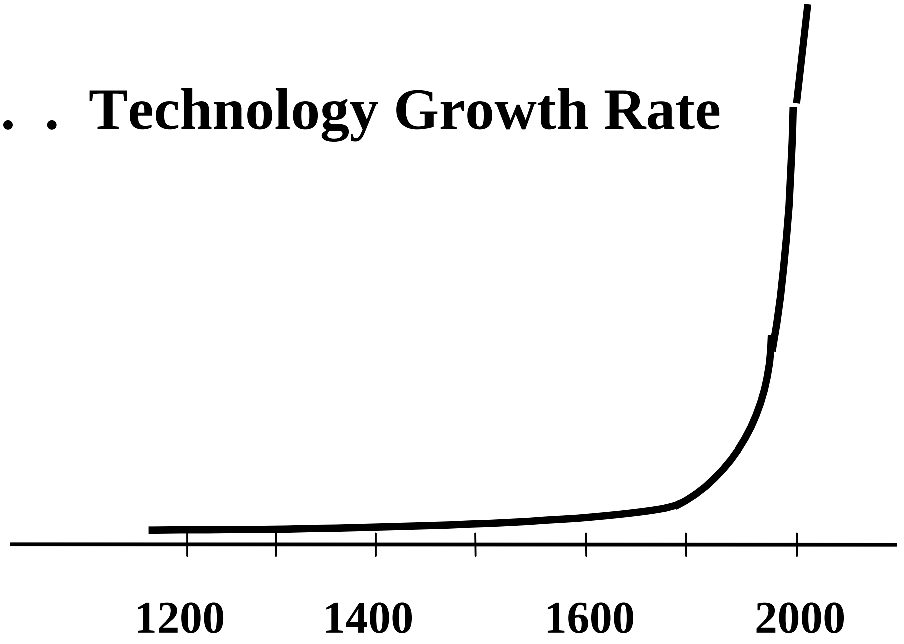
The key to any experiment is a good plan, executed with care and proper scientific technique, analyzed with scientifically proven methods, and implemented with as much enthusiasm as created the desire to solve the original problem. The implementation phase is often the most underestimated and under-resourced stage of execution. Management and experimenter can easily underestimate the resources needed to implement the results of an effective experiment. It is often assumed that the results will be properly implemented, just because the solution has been uncovered. Not so!

Effective implementation requires planning prior to action, follow-up analysis, and maintenance.

Notes:

Why Experimental Design?

. . . . Technology Growth Rate



As technology expands, the amount of available information becomes unmanageable. In order to remain competitive, a company must find ways to identify and evaluate the parameters that control processes and products without adding costs. This workshop is designed to blend the use of statistical techniques into an engineering environment.

- In 1998, information doubled every 5 years (President Clinton's State-of-the-Union address).
- Computing power doubled every 18 months (Strategies for Fast Changing Times by Nate Booth).
- A 1995 Chevrolet had more computing power than the Apollo 13 spacecraft months (Strategies for Fast Changing Times).
- Between 1980 and 1995, the top 100 companies in U.S. reduced their workforce by 25% months (Strategies for Fast Changing Times).

Notes:

Old Habits are Hard to Break

If you always do what you always did;
you'll always get what you always got.

- *wise but unknown philosopher*

As technologies progress, companies who intend to remain competitive must review and select applicable methods that assist in achieving their product goals and quality philosophies. A competitor is probably evaluating these same tools and techniques.

Notes:

Benefits of Experimental Design?

Provides capability to:

- ➲ **analyze multiple variables simultaneously**
- ➲ **identify high impact variables**
- ➲ **identify variable interactions**
- ➲ **improve process & product function**
- ➲ **improve employee morale**
- ➲ **achieve a quality philosophy**

Effective experimental designs:

- provide the ability to evaluate many variables simultaneously, therefore minimizing experimentation time and maximizing resource usage.
- provide the ability to identify high impact variables, allowing resources for process and product upgrades to be spent on variables which improve product function and process efficiency most appreciatively.
- provide a method of identifying and quantifying factor interactions which may effect product performance and process efficiency.
- provide quantifiable information on process and product function which can be directed toward greater customer satisfaction.
- motivate employees since their efficiency increases, resulting in greater job satisfaction and provides opportunity to focus on their primary work function.
- provide a structured methodology which allows the experimenter to maximize their corporate quality philosophy.

DOE Supports Many Philosophies

- ☑ **Robustness (On-Target Engineering)**
- ☑ **Six Sigma (Cp = 2 or 3.4 ppm defect rate)**
- ☑ **Traditional Process Specifications**
  Cp = 1 (2700 ppm defect rate)

Quality philosophies range from:

- supporting robust products and processes which allows for the manufacture of highly functional, low cost, durable products to minimize the Quality Loss Function and ultimately provide product flexibility.

- supporting six sigma status to provide minimal product variance and maximize process efficiency. A process demonstrating product variability that is half the specification range of the design parameter with an on target mean reflects a process capability index of 2, or about 3.4 ppm defect rate.

- depending on fire-fighting and sorting methods to maintain quality product which meet customers specifications and implementing technology on an ‘as needed’ basis to satisfy a customer’s **insistence** for improved product variance. A traditional quality philosophy may focus on maintaining a product variability that is equal to the specification range of the design parameter. With an on target mean, this reflects a process capability index of 1, or about 2700 ppm defect rate.

Notes:

Identify the Real Problem

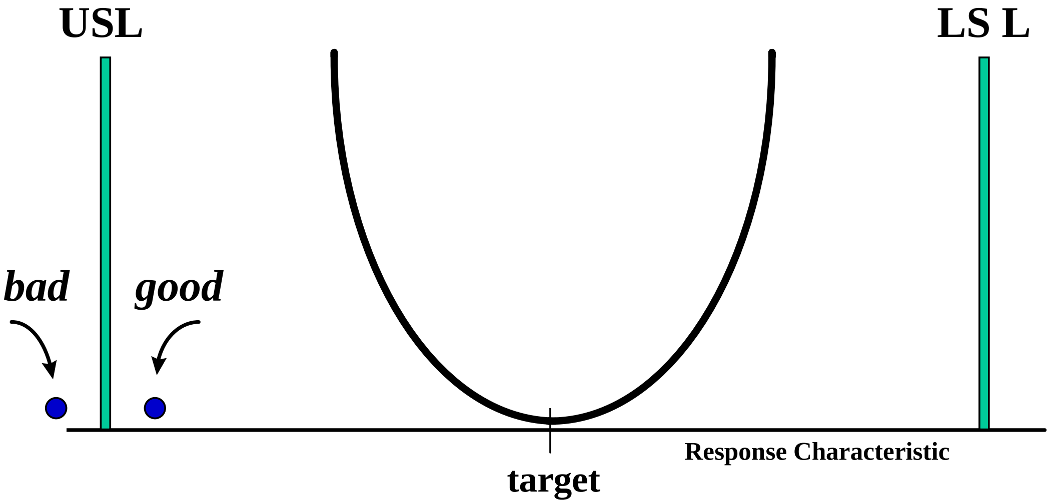
> **Many of the problems existing in industry today are not caused by people within the organization, but result from the systems within which people must work.**
>
> ***Author Darryl Landvater***

It is very easy to criticize the work force for the problems that exist in the workplace. Author Darryl Landvater has a different spin on this philosophy. In his book *World Class Production and Inventory Management*, the author discusses the use of obsolete and inefficient Manufacturing Resource Planning (MRP) strategies that cultivate poor and inefficient work habits.

These same philosophies are true in the engineering workplace. The one-factor-at-a-time experimental technique dominates in many industries because our technical staff has not been sufficiently educated or has not been provided the enablers or the incentives to use these more efficient techniques.

Notes:

On-Target Engineering vs. Traditional Specification Philosophy

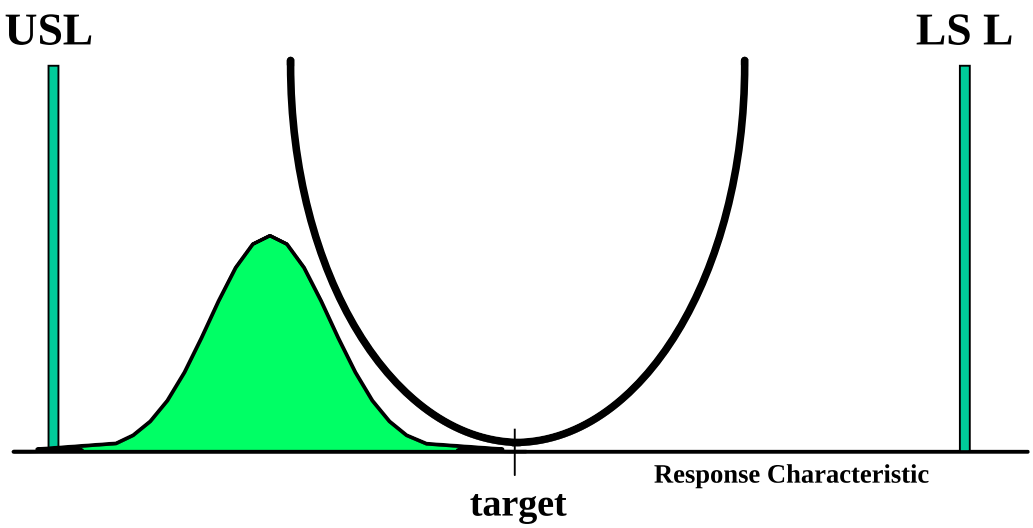


On-Target Engineering, a philosophy promoted by Dr. Genechi Taguchi, focuses on product and process quality relative to the perception of the customer. This philosophy of manufacturing each product on a specified target is graphically compared to the traditional philosophy of upper and lower product specifications. The traditional approach treats all products between the upper specification limit (USL) and the lower specification limit (LSL) as equal in quality. In contrast, the Taguchi quality loss model measures product deviation from the proposed target and applies a monetary loss to manufacturers and customer related costs.

Design of Experiments supports continuous improvement philosophies including Six Sigma and On-Target Engineering.

Notes:

On-Target Engineering vs.
Continuous Improvement Process

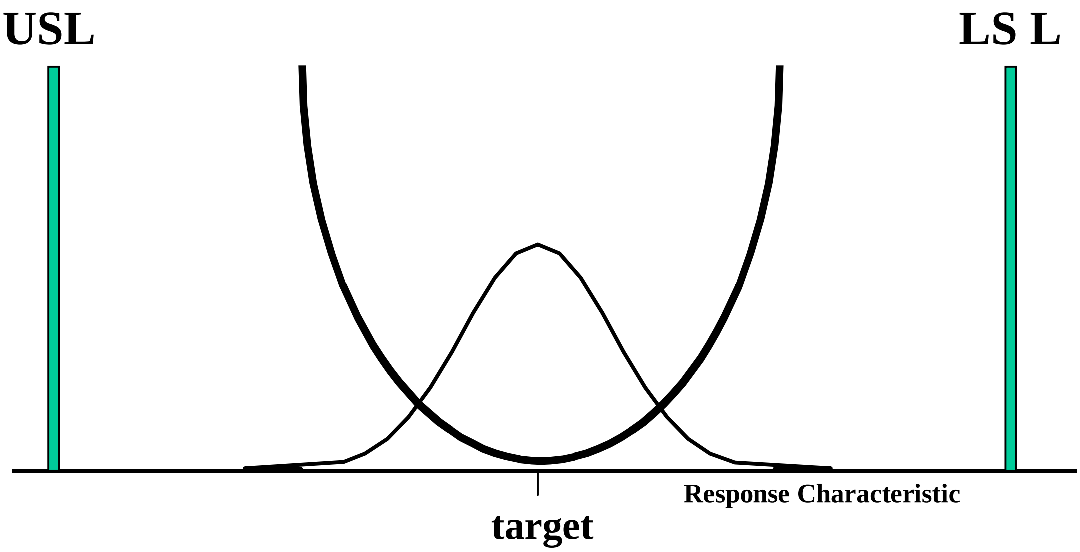


The Quality Loss Function (QLF) philosophy supports a quadratic loss rate as product performance deviates from the specified target value.

The QLF is composed of two components:
- variation around the product mean (σ^2)
- deviation of the product mean (μ or y-bar) from a specified response target (t).

Notes:

Quality Loss Function (QLF)



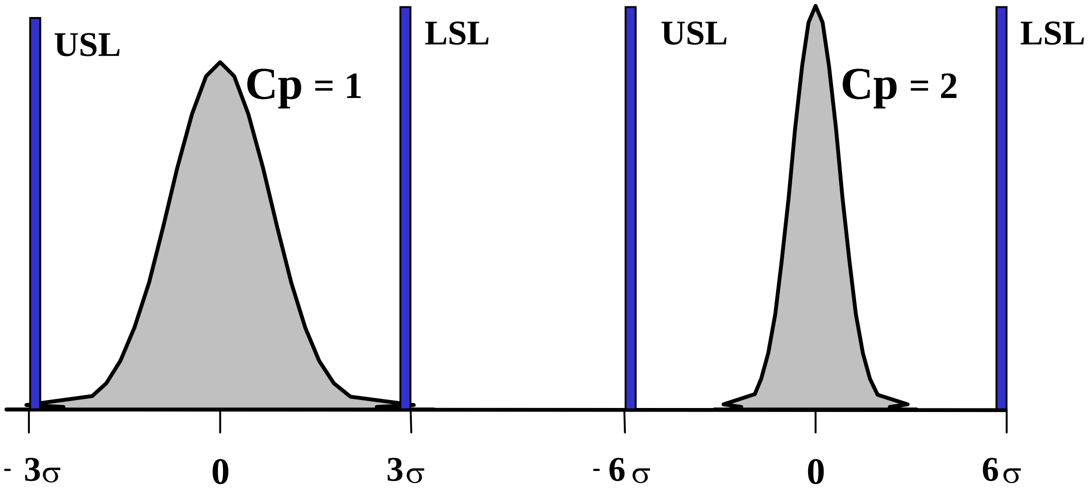
The Experimental Design method promotes quantifying system component contributions to function prior to manufacturing, such that a product functional level can be selected prior to manufacturing.

DOE supports a reduced QLF.

Notes:

Six Sigma vs. Traditional Philosophy:

. . . . on specifications



The traditional specification limits and the six-sigma philosophies are described in terms of the manufacturing process capability index or C_p. C_p is the ratio of the range of specification limits (USL - LSL upper and lower specification limits) as the numerator and the process variability of 6σ as the denominator.

If a manufacturer maintains a 3σ variability or a $C_p = 1$ for a product, one would expect approximately 2700 ppm of product would fall outside the specification limits. A six-sigma variability or a $C_p = 2$ is expected to yield only 3.4 ppm of product outside the specification limits.

Notes:

Workshop Agenda

Day 1

- **Full Factorial Experimentation**
- **‘Effects’ Interpretation**
- **Prepare an Experimental Plan**
- **Analyzing Experimental Data**

Day 2

- **Analysis of Variance (ANOVA)**
- **Fractional Experimentation**
- **DOE Software**
- **Polymer Thread Case Study**

Notes:

Workshop Agenda

Day 3

- **Fractional Experimentation**
- **Polymer Thread Case Study**
- **Team Presentation: Experimental Data**

Day 4

- **Multiple Level Experimentation**
- **Evolutionary Operations (EVOP)**
- **Composite Designs**
- **Team Presentation: Project Results**

Notes: