Using the Power of Statistical Thinking

Stat-Ease 2nd Annual DOE Conference
Dinner Presentation
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Objectives

- Obtain a common understanding of Statistical Thinking, its definition, and its application
- Clarify the distinction between Statistical Thinking and statistical methods
- Demonstrate the power of Statistical Thinking in concert with DOE planning and analysis.
What is Statistical Thinking?
Statistical Thinking is a philosophy of learning and action based on the following fundamental principles:

- All work occurs in a system of interconnected processes,
- Variation exists in all processes, and
- Understanding and reducing variation are keys to success.

*Glossary of Statistical Terms - Quality Press, 1996*
Systems and Processes

Statistical Thinking is a philosophy of learning and action based on the following fundamental principles:

- All work occurs in a system of interconnected processes

Glossary of Statistical Terms - Quality Press, 1996
A series of activities that converts inputs into outputs
Without a process context, practitioners often apply inappropriate statistical methods (such as performing ANOVA on unstable processes), which at best minimize their impact on improvement, and at worst, lead to mistrust of statistics.
Statistical Thinking is a philosophy of learning and action based on the following fundamental principles:

- All work occurs in a system of interconnected processes,
- *Variation exists in all processes*

*Glossary of Statistical Terms - Quality Press, 1996*
Variation and Targets

Variation can be thought of as:
1. Deviations around the overall average, or
2. A deviation of the overall average from a desired target
Specifications vs. Targets

Worst - Worse - Good - Best - Good - Worse - Worst

Bad
Good
Bad

Lower Spec
Upper Spec

Target

A
B
C
Align the Voices

Voice of the Process

Voice of the Customer

Target
Understand and Reduce Variation

Statistical Thinking is a philosophy of learning and action based on the following fundamental principles:

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Glossary of Statistical Terms - Quality Press, 1996
Types of Variation

- Common Cause
- Special Cause
- Structural Cause
Definitions

- **Common Cause**
  - Variation a process would exhibit if behaving at its best

- **Special Cause**
  - Variation from intervention of sources external to the process

- **Structural Cause**
  - Inherent process variation (like common cause) that looks like special cause
    - Has a predictable onset
Common Causes

- Numerous
- Repetitive
- Originate from many sources
- Common to all the data
- Predictable in terms of a band of variation
Special Causes

- Sporadic in occurrence
- Onset often not predictable
- Originate from few sources
- Increase total variation over and above existing common causes
  - Can be one time upsets, or
  - Permanent changes to the process
- May enter or exit a process via process inputs (outside sources) or through conversion activities
Improvement for Common Causes

- All the data are relevant
  - Not just the “bad” or out of spec points
- A fundamental change is required
- Three improvement strategies:
  - Stratify
  - Disaggregate
  - Designed experimentation
- Management should initiate and lead the change effort
Improvement for Special Causes

- Work to get very timely data
- Immediately search for cause when control chart gives a signal
- No fundamental process changes
- Seek ways to change some higher level process
  - Maintain good special causes
  - Prevent recurrence of undesirable special causes
Questions to Help Distinguish Between Special and Common Causes

- Did this happen because we got caught and were unlucky, or did something or someone specifically cause it?
  - Unlucky = Common Cause
  - Specific event = Special Cause

- Could it have elsewhere, at another time, to someone else, with different materials?
  - Yes = Common Cause
  - No = Special Cause

- Was it specific to a person, material, condition or time?
  - Yes = Special Cause
  - No = Common Cause

From Heero Hacquebord
Structural Causes of Variability

- Variation that is part of the system but looks like a special cause
- **Consistent difference (across space)**
  - Among injection molder cavities
  - Across a coated or extruded roll
  - Around a part
- **Structure over time**
  - Machine wear
  - Consistent cyclic data
    - Coating roll patterns
Dealing With Structural Variation

- Remove structure if possible
  - Requires change to the process
- Use 3-Chart method
  - Structure only affects the Range chart
- Model structure and remove effect
  - Requires data analysis
  - Does not reduce process variability
  - Allows better assessment of other sources of variation
Robustness - An Underused Concept

- Key aspect of Statistical Thinking
- Reduce the effects of uncontrollable variation in:
  - Product design
  - Process design
  - Management practices
- Anticipate variation and reduce its effects
Robustness of Product and Process Design

- Another way to reduce variation
- Anticipate variation
  - Design the process or product to be insensitive to variation
- A robust process or product is more likely to perform as expected
- 100% inspection cannot provide robustness
Robust Design in Anticipation of Customer Use or Abuse

- Washing machine tops
- User-friendly computers and software
- Low-maintenance automobiles
- 5 mph bumpers
- Medical instruments for home use
Process Robustness Analysis

- Identify uncontrollable factors that affect process performance
  - Weather
  - Customer use of products
  - Employee knowledge, skills, experience, work habits
  - Age of equipment

- Design process to be insensitive to factors’ uncontrollable variation
Three Ways to Reduce Variation and Improve Quality

- **Control the Process:** Eliminate Special Cause Variation
- **Improve the System:** Reduce Common Cause Variation
- **Anticipate Variation:** Design Robust Processes and Products
Statistical Thinking and Statistical Methods

- Statistical thinking provides a philosophical framework for use of statistical methods.

- The framework focuses on processes, recognizing variation, and using data to understand the nature of the variation.

- Statistical methods, when used in the context of statistical thinking, can produce analyses that lead to action and resulting improvement.
Statistics and Improvement

Statistical Thinking  Statistical Methods

Process → Variation → Data → Improvement

Philosophy → Analysis → Action
## Comparison of Statistical Thinking and Statistical Methods

<table>
<thead>
<tr>
<th></th>
<th>Statistical Thinking</th>
<th>Statistical Methods</th>
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<tbody>
<tr>
<td><strong>Overall Approach</strong></td>
<td>Conceptual</td>
<td>Technical</td>
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<tr>
<td><strong>Desired Application</strong></td>
<td>Universal</td>
<td>Targeted</td>
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<td><strong>Primary Requirement</strong></td>
<td>Knowledge</td>
<td>Data</td>
</tr>
<tr>
<td><strong>Logical Sequence</strong></td>
<td>Leads</td>
<td>Reinforces</td>
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Without a Process View

- People don’t understand the problem and their role in its solution
- It is difficult to define the scope of the problem
- It is difficult to get to root causes
- People get blamed when the process is the problem (85/15 Rule)

*You can’t improve a process that you don’t understand*
Statistical Thinking -
ex.: subgrouping

Within batch

Between batch
Without Data

- Everyone is an expert: discussions produce more heat than light
- Historical memory is poor
- Difficult to get agreement on:
  - Definition of the problem
  - Definition of success
  - Degree of progress
Without Understanding Variation

- Management is by the last datapoint
- Fire-fighting dominates
  - Special cause methods are used to “solve” common cause problems
- Tampering and micromanaging abound
- Efforts to attain goals fail
- Process understanding is hindered
  - Learning is slowed
Without Statistical Thinking

- Process management is ineffective
- Improvement is slowed

“Early on, we failed to focus adequately on core work processes and statistics.”

David Kearns and David Nelder, Xerox Corporation
**Steps**

1. Describe the process
2. Collect Data on Key Process and Output Measures
3. Assess Process Stability
4. Address Special Cause Variation
5. Evaluate Process Capability
6. Analyze Common Cause Variation
7. Study Cause-and-Effect Relationships
8. Plan and Implement Changes

**Tools**

- Flowchart
- Checksheet
- Data Sheet
- Surveys
- Time Plot / Run Chart
- Control Chart
- See Problem Solving Strategy
- Frequency Plot / Histogram
- Standards
- Pareto Chart
- Statistical Inference
- Stratification
- Disaggregation
- Cause & Effect Diagram
- Experimental Design
- Scatter Plots
- Interrelationship Digraph
- Model Building
**Problem Solving Strategy**

**Steps**
- Document the Problem
- Identify Potential root Causes
- Choose Best Solutions
- Implement / Test Solutions
- Measure Results

**Sample Tools**
- Checksheet
- Pareto Chart
- Control Chart / Time Plot / Run Chart
- “Is/Is Not” Analysis
- “5 Whys”
- Cause & Effect Diagram
- Brainstorming
- Scatter Plot
- Stratification
- Interrelationship Digraph
- Multivoting
- Affinity Diagram
- Design of Experiments
- Checksheet
- Pareto Chart
- Control Chart / Time Plot / Run Chart
- Flowchart
- Procedures
- Training

**Problem Solved?**
- Yes
- No

**Standardize**
The Iterative Nature of Experimentation
Benefits of DOE

- More Information from fewer Experiments
- Evaluation of Plausible Relationships
- Prediction of Future Results
- Optimization of Responses
- Control of Processes
**Historical Data or DOE?**

**Historical Data**
- take what you can get
- limited range
- taken over time
- correlation

**Designed Experiments**
- controlled conditions
- defined range
- focused time frame
- causation

What is your objective?
Adequate Design

- Has stated objective with hypothesis statement
- Considers
  - Replication
  - Blocking
  - Ranges
  - Form (split plot, randomization, etc.)
- DOE Journal and Summary
Considerations for Planned Experiments

- **Scope of validity**
  - factors
  - ranges
  - responses
  - NOTE: adequate measurements needed for both factors and responses

- Replication
- Randomization
- Blocking
Value of Replication
Value of Replication

Cure

Tension
Replication

- Need “yardstick” for comparison so you know effects rise above system noise (common cause variability)
- Make sure replicates are different (e.g. Not repeat measures on same sample)
- Typically, replicates are spread throughout a series of experiments
Randomization/Blocking

- Techniques to ensure that effects are not due to outside influences
Evaluating the Results

- Are the results significant?
  - Statistically
  - Practically

How do you know?

Be sure of significance before looking at plots!
Is Result Significant?

Something Important

<table>
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<th>Last Period</th>
<th>This Period</th>
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It Depends!

Common Cause

Special Cause
Your DOEs

- Do you have adequate test methods?
- Is the process stable?
- Is the design appropriate to the objective? (by the way, what is that objective?)
- Is the model significant? (low p)
- Does the model explain a large portion of the variability in the data? (high $R^2$)
- Does the model make sense?
- Have confirmatory runs been made?
- What next steps are suggested?