Understanding Variation

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Session Objectives

• Describe Shewhart’s theory of variation
• Identify data reports that should incorporate the use of Shewhart charts
• Implement Shewhart’s method of control charts to promote learning and effective decision-making from data and reports

We hope to extend the application of Shewhart’s methods presented in to data sets across a range of publically available sources used by the US federal government and health care organization to assess conditions and make decisions based on them. The scale of these data sets makes the failure to understand and apply Shewhart’s theory even more important than data from individual organizations.
Understanding Variation is a cornerstone to the Science of Improvement.
Walter Shewhart, 1931, *Economic Control of Quality of Manufactured Product*

Theory of Common and Special Causes of Variation

Application of Control Charts to Manufacturing

“We are sold on the idea of applying scientific principles. However, a change is coming about in the principles themselves and this change gives us a new concept of control.”
W. E. Deming, *Out of the Crisis*, 1986 (and other publications)

“Another half-century may pass before the full spectrum of Dr. Shewhart’s contributions has been revealed in liberal education, science, and industry”.

**CHAPTER 11: Common Causes and Special Causes of Improvement. Stable System.**

The central problem in management and in leadership, in the words of my colleague Lloyd S. Nelson, is failure to understand the information in variation. (p. 309)

Only information from a stable system tells us about the process.

94% of variation belongs to the system (management's responsibility). 6% is special or unique to individuals.

No amount of care or skill in workmanship can overcome fundamental faults in the system. (p. 315)

Adjustments based on variations within a stable system augment the problems.
Examined how Walter Shewhart’s theory of variation could be used in decision making by individuals and organizations in non-manufacturing situations. The paper included examples of the economic and psychological losses associated with inappropriate reaction to variation in data.
We want to extend the application of Shewhart’s methods presented in our 1990 article to data sets across a range of publicly available sources—sources that are used by and the basis for the U.S. government and other organizations to assess conditions and make decisions.
In the U.S. Health Care System we see:

- Massive increases in publicly available data and data repositories
- Focus on using data to make good decisions and identify trends
- Intense need to know if interventions and policies have intended impact (return on investment)
Case #1: Assistant Secretary for Planning & Evaluation: Health System Measurement Project

• Publically available (Open Source)
• Tracks gov’t data on critical U.S. health system indicators
• Presents national trend data in different formats
• 10 main categories

HHS’s Office of the Assistant Secretary for Planning and Evaluation has developed the Health System Measurement Project to ensure a robust monitoring system through which people inside and outside government can assess how the system is doing and identify areas that need improvement.
Quality Category

**Measure:** Percentage of NH residents experiencing one or more falls with major injury in the past 30 days – *CMS Minimum Data Set*

“When taking this scale of scored values into account…it is easy to see that they are not changing very much from quarter to quarter.” *Final Analytic Report as summarized for CMS*
Shewhart I chart - with shift detected

data points below and above limits, ≥ 8 points below and above center line

Process is not stable and has fundamentally changed in a negative direction.
We can now separate pre and post shift phase.
I Chart with Phase Separation

What we learn with Shewhart Chart:
- Shift beginning 2007 Q4
- New predictable range (14.9 to 15.4%)
- National increase 0.5% (3.4% relative increase)
- 9 additional annual deaths in Phase 2

What might explain this shift, what can we learn?
Case #2: Centers for Disease Control and Prevention: Infant Mortality

• Publically available (Open Source)
• Tracks infant mortality in U.S. over time
• Presents national trend data in different formats
• Includes annual breakdown by state
Figure 1. Infant mortality rates, by race and Hispanic origin of mother: United States, 2000–2013
Shewhart Charts for Infant Mortality

**Aggregate Infant Mortality 2003-2012 (U' Chart)**

- UCL: 6.87
- LCL: 6.17

**Quarterly Infant Mortality 2009-2013 (U' Chart)**

- UCL: 6.9
- LCL: 5.4
Which states demonstrate non-random variation? Which states can we learn the most from?
Bar chart increases risk of tampering – acting on data based on the belief that common cause variation is a special cause.

The Effects include:

1. Compromised learning
2. Increased variation
3. Demoralized workforce
4 Challenges with “Big Data” and “More Data”

1. Focus becomes volume of information
2. It’s costly (negative economic impact)
   - Information overload cost the US economy at least $997 billion per year in reduced productivity and innovation as of 2010 (Spira, 2011)

3. Hard for humans to process
   - The average human can hold 7 “chunks” of information (plus or minus 2 chunks) in working memory (Miller, 1956)

4. It’s a-theoretical (stability/cause system)
   - “Most comparative effectiveness studies are conducted in unstable systems, where there are multiple sources of outcomes variation. It is impossible to interpret the results of these studies appropriately without knowing the sources of those variations and their effects on outcomes.” (Brook, 2012)
Confusion vs. Information

At some point as you increase the amount of information you actually begin to increase the level of confusion again.

There is a point at which increasing information reduces confusion.

At some point as you increase the amount of information you actually begin to increase the level of confusion again.
The Path Forward

“We are sold on the idea of applying scientific principles [to management]. However, a change is coming about in the principles themselves and this change gives us a new concept of control.”

<table>
<thead>
<tr>
<th>Current Principles</th>
<th>Future Principles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Data</td>
<td>Useful Data</td>
</tr>
<tr>
<td>Warehouse/research bias</td>
<td>Practical/applied bias</td>
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<tr>
<td>Description</td>
<td>Prediction</td>
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<tr>
<td>Static</td>
<td>Temporal</td>
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<tr>
<td>Variation from targets</td>
<td>Stability of processes</td>
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</table>
Shewhart’s Theory of Variation

**Common Causes**—those causes inherent in the system over time, affect everyone working in the system, and affect all outcomes of the system

- Common cause of variation
- Chance cause
- Stable process
- Process in statistical control

**Special Causes**—those causes *not* part of the system all the time or do not affect everyone, but arise because of specific circumstances

- Special cause of variation
- Assignable cause
- Unstable process
- Process not in statistical control
Shewhart Charts

The Shewhart chart is a statistical tool used to distinguish between variation in a measure due to common causes and variation due to special causes.

(Most common name is a control chart, more descriptive would be learning charts or system performance charts)
The Method of Shewhart Charts

- Selection of a measure and a statistic to be plotted.
- A method of data collection: observation, measurement and sampling procedures.
- A strategy for determining subgroups of measurements (including subgroup size and frequency).
- Selection of the appropriate Shewhart chart.
- Criteria for identifying a signal of a special cause.
“Three-Sigma” Control Limits

Shewhart called the control limits "three-sigma" control limits and gave a general formula to calculate the limits for any statistic.

Let $S$ be the statistic to be charted, then

- the centerline: $CL = \bar{u}_s$
- the upper control limit: $UCL = \bar{u}_s + 3 \cdot \sigma_s$
- the lower control limit: $LCL = \bar{u}_s - 3 \cdot \sigma_s$

where $\bar{u}_s = \text{average of the statistic}$ and $\sigma_s = \text{standard error of statistic calculated in a way to estimate common cause variation}$
Standard rules for a special cause signal

1. A single point outside the control limits.

![Diagram showing a single point outside control limits]

2. A run of eight or more points in a row above (or below) the centerline.

![Diagram showing a run of points above the centerline]

3. Six consecutive points increasing (trend up) or decreasing (trend down).

![Diagram showing six consecutive points increasing]

4. Two out of three consecutive points near (outer one-third) a control limit.

![Diagram showing two out of three points near outer one-third]

5. Fifteen consecutive points close (inner one-third of the chart) to the centerline.

![Diagram showing fifteen points close to the centerline]
Shewhart’s and Deming’s rationale for the use of Shewhart’s three-sigma limits

1. The limits have a basis in statistical theory

2. The limits have proven in practice to distinguish between special and common causes of variation

3. In most cases, use of the limits will approximately minimize the total cost due to overreaction and under reaction to variation in the process

4. The limits protect the morale of workers in the process by defining the magnitude of the variation that has been built into the process.
Using Shewhart Chart to Guide Improvement Work

FIGURE 4.1 Using Shewhart Charts to Give Direction to an Improvement Effort

Select a Key Measure Related to the Aim of the Improvement Effort

Develop an Appropriate Shewhart Chart for the Measure

Change the System (Remove Common Cause(s))

Responsibility (ordered by importance)
1. Management
2. Technical Experts

Learn from and Act on Special Cause(s)

Responsibility (ordered by importance)
1. Local supervision
2. Technical experts
3. Management
4. Workers in the system

Is the System Stable Relative to this Measure?

Yes

Identify Common Cause(s)

Tools/Methods:
- Planned Experimentation
- Rational Subgrouping

Responsibility (ordered by importance)
1. Technical experts
2. Supervisors
3. Workers in the system

No

Identify Special Cause(s)

Tools/Methods:
- Shewhart Charts
- Cause and Effect Diagram
- Rational Subgrouping
- Planned Experimentation

Responsibility (ordered by importance)
1. Workers in the system
2. Supervisors
3. Technical experts

HC Data Guide
Updating Limits

Shewhart Control Chart (P Chart)

- Baseline Data - Team Formed
- Testing and adapting changes
- Implementing Changes
- Maintenance Period (sustainability)
Updating Limits to Reflect Improvement in a Measure

Which Shewhart Chart should I use?

Different Shewhart Charts depending on the type of data and statistic used for the measure of interest.

Five basic charts and numerous advanced charts to handle special situations.
What is Rational Subgrouping?

• The concept of *subgrouping* is one of the most important components in using the Shewhart chart method.

• Shewhart’s concept is to organize (classify, stratify, group, etc.) data from the process in a way that ensures the greatest similarity among the data in each subgroup and the greatest difference among the data in different subgroups.

• The aim of rational subgrouping is to include only common causes of variation within a subgroup with all special causes of variation occurring between subgroups.

• The most common method to obtain rational subgroups is to hold time “constant” within a subgroup.
Case #3: Understanding Variation in National Economic Data

Gross Domestic Product (GDP)

Current Numbers:
• 3rd quarter 2015: 2.1 percent
• 2nd quarter 2015: 3.9 percent

Next release: December 22, 2015

Quarterly data: Real gross domestic product -- the value of the goods and services produced by the nation's economy less the value of the goods and services used up in production, adjusted for price changes -- increased at an annual rate of 2.1 percent in the third quarter of 2015, according to the "second" estimate released by the Bureau of Economic Analysis. In the second quarter, real GDP increased 3.9 percent.

http://www.bea.gov/newsreleases/glance.htm
Reacting to the Variation

• The business press reports reactions whenever the quarterly value is released or revised.

• The Wall Street Journal had the following headlines for three sequential quarters in 2014:

  4th quarter, 2013: 3.5% increase   WSJ JAN. 30, 2014 - U.S. Economy Shows Signs of Gearing Up


  2nd quarter, 2014: 4.0% increase, WSJ JULY 30, 2014: Growth Rebound Stokes Fed Debate
Reacting to Variation

2nd quarter, 2014: 4.0% increase, WSJ JULY 30, 2014: Growth Rebound Stokes Fed Debate

The headlines are followed by explanations of the variation such as for the 2nd quarter, 2014:

Federal Reserve officials delivered a modestly more upbeat assessment of the economy Wednesday amid a second-quarter growth rebound and deepening debate inside the central bank about when to start raising interest rates. U.S. gross domestic product, a broad measure of the nation's output of goods and services, advanced at a seasonally adjusted annual rate of 4.0% in the second quarter, the Commerce Department said Wednesday, a significant rebound from a wintry 2.1% contraction during the first three months of the year.
Shewhart I Chart for GDP measure

GDP Percent Change (basis in 2009 dollars)
Limits updated to reflect patterns of special causes

GDP Percent Change (basis in 2009 dollars)

Limits for 2011-2016
Do Shewhart Charts lead to better Decision Making?

A randomized controlled trial of league tables and control charts as aids to health service decision-making

TOM MARSHALL, MOHAMMED A. MOHAMMED AND ANDREW ROUSE
Study Design

- 122 Directors of public health in UK mailed three case studies and a questionnaire
- Randomized to receive the same data in the form of ranked histograms (league tables) or control charts.
- Asked to indicate whether they would take action as a result of the data and to identify the providers on whom they would take action.
Two Key Findings

1. Health service decision-makers identify fewer outliers for further action when performance data are presented as control charts.

2. Using control charts rather than league tables would reduce over-investigation of performance.

**Note** – virtually all the variation in the control charts is common cause so not acting on the data is the correct action based on Shewhart’s theory and reduces the risk of tampering.
Paradigm Shift

The facts don’t change but how we see them do.

Thomas Kuhn
Shewhart Chart Challenge

The authors ask that you send them interesting examples that illustrate how appropriately using Shewhart’s method would lead to more effective learning and better decision making.

To submit your case study, email Lloyd Provost at lprovost@apiweb.org

ADDITIONAL CASE STUDIES ON VARIATION SOUGHT

The authors presented four examples of publicly reported data in which using Shewhart’s theory and method would lead to better reporting and decision making. They are seeking to increase the number of examples to help build the case for broad adoption of Shewhart’s method.

The authors ask that you send them interesting examples that illustrate how appropriately using Shewhart’s method would lead to more effective learning and better decision making. They have four recommendations for obtaining a better return on the substantial investment in public and private data systems by using this method:

1. Make data available over time. Any effective analytic strategy must allow users to understand variation in the systems they are responsible for over time to gain new knowledge as conditions change, and as new programs and initiatives are attempted. Move away from judging or defining a system or results of improvement efforts or policy decisions based on single data points.

2. Provide data in formats that allow for construction of Shewhart charts. The data should be made available in formats that allow Shewhart charts to be easily constructed—even if automated chart generation is not possible. For many current data reports, it is either not possible or it takes considerable effort to acquire data needed to construct a Shewhart chart.

3. Determine whether a process is stable. Always ask one simple question when making an important decision based on data: Is the process stable over time? Because we live in an era of accountability, there is intense pressure to demonstrate positive results. Yet, decisions we make on variation from one time period to another, often lead to increased variation, poor performance, failure to learn, and misattribution of credit and blame.

4. Think carefully and creatively about how to stratify data. Always consider approaches to segment and stratify data that are being presented to inform the public. This increases our ability to learn about the effect of context on variation in the system and understand the impact of changes made to the system over time and whom they affect. To submit your case study, email Lloyd Provost at lprovost@apiweb.org.

—T.N., R.P., and L.P.

Nolan, Perla, Provost, Understanding Variation – 26 Year’s Later, Quality Progress, ASQ, November, 2016
“As it is well documented, in 2008 president Felipe Calderón declared war on the drug cartels. This frontal attack caused the mafia cells to explode and divide, diversifying their activities from international drug export to local kidnapping and extortion.

I've heard about this many times but I never quantified and analyzed it before.”
from Miguel Quivira
Summary

How can we improve our learning from variation in health care?
Any time that data is presented, we recommend asking two questions: Is the process currently stable (are there special causes we can learn from)? And based on this knowledge, what type of action makes sense?

When presenting public data:
• Make data available over time.
• Provide data in formats that allow for construction of Shewhart charts.
• Determine whether a process is stable before drawing conclusions or making decisions.
• Think carefully and creatively about how to stratify data.
Shewhart's theory distinguishes between common and special causes of variation in data. This session reviews the implications of this theory of variation and extends the application of Shewhart’s control chart method to publicly available data sets from health care organizations. Any time that data is presented, we recommend asking two questions: Is the process currently stable (are there special causes we can learn from)? And based on this knowledge, what type of action makes sense?

**Objectives**

- Describe Shewhart’s theory of variation
- Identify data reports that should incorporate the use of Shewhart charts
- Implement Shewhart’s method of control charts to promote learning from their data reports