Enhancing The Commissioning Process
On Multi-Building Projects
With Six Sigma Tools/Techniques

Presentation to International Conference for Enhanced Building Operations

2007 ICEBO
San Francisco, CA
The Life of a Facility

Phase 1: Infant Mortality Period

Phase 2: Random Failure Period

Phase 3: Wear-Out Period

Failure Rate

Probability Distribution Function

Random Variable (i.e., hours)

TIME (Years)

Cx Focus
Six Sigma - A Context

Why don't we jump on a fad that hasn't already been discredited?

Sorry, I'm late. What did I miss while innovating?

It's new to us.

Let's see for fortune magazine says... most companies that used six sigma have trailed the S&P 500.

New six sigma was developed in the 80s.

There's nothing wrong with six sigma, all it does is reduce defects.

Our company has decided to try something new.

Six sigma. That way the false hope might sustain us.
"I don't give a damn if we get a little bureaucracy as long as we get the results. If it bothers you, yell at it. Kick it. Scream at it. Break it!"

Jack Welch, 1998
Process Fit:

6σ

- Disciplined Methodology
- Customer Focused
- Proven
- Comprehensive
- Flexible
- Consistent

COMMONALITY

- Quality
- ROI
- Focus on the Owner/Customer
- Customer Satisfaction

VALUE

- Increased Customer Satisfaction
- ROI

Build on Shared Interests to Deliver Value
Agenda:

- Very Brief Overview of Six Sigma
- Six Sigma Tools Applied to Commissioning
- Case Study
Getting Grounded in Reality

- You don’t know what you don’t know
- If you don’t benchmark, you’ll never start to know
- If you can’t express what you know numerically, you really don’t know much about it
- If you don’t know much about it, you can’t control it
- If you can’t control it, you are at the mercy of chance
What is It?

- Letter in the Greek alphabet.
- Used to describe the distribution of any process.
- The “Sigma Value” is a metric. It indicates how well a process is performing.
- “Six Sigma” is a philosophy aimed at increasing the sigma value of all processes.

Reducing Process Variation
Two Types of Variation


2. Special Cause – Not Random -- Assignable

Key factors which contribute to variation and are feasible to detect, identify & eliminate.
Special Cause Variation - 6 M’s

- **Man** – swimmer has the flu
- **Machine** – vault height set incorrectly
- **Material** – defective surface of starting block
- **Method** – broke form on strokes
- **Measurement** – timing clock wrong
- **Mother Nature** – 100 degrees & humid
The Statistical Objective of Six Sigma

- Process Off Target → Excessive Variability
- Center Process
- Reduce Spread
- Defects
What percentage of the population data is outside of $\pm 3\sigma$?

100% - 99.7% = .3%
0.3% doesn’t sound bad – does it?

Let’s look at a business example.

99.7%
Company processed 250,000 credit card bills/month
0.3% outside of customer specs on accuracy
750 unhappy customers every month due to accuracy

99.7% within spec may sound good, but it may not be good for the customer
Six Sigma . . . More Is Better!

**99% Good (~ 4σ)**
- 20,000 lost articles of mail per hour
- Unsafe drinking water for almost 15 minutes each day
- 5,000 incorrect surgical operations/week
- Two short or long landings at most major airports each day
- 200,000 wrong drug prescriptions/year
- No electricity for almost 7 hours/month

**99.99966% Better (6σ)**
- Seven articles lost per hour
- One unsafe minute of drinking water every seven months
- 1.7 incorrect operations/week
- One short or long landing every five years
- 68 wrong prescriptions/year
- One hour without electricity every 34 years
<table>
<thead>
<tr>
<th>Performance Level</th>
<th>SIGMA</th>
<th>DPMO</th>
</tr>
</thead>
<tbody>
<tr>
<td>A+</td>
<td>6</td>
<td>3.4</td>
</tr>
<tr>
<td>A</td>
<td>5</td>
<td>233</td>
</tr>
<tr>
<td>B</td>
<td>4</td>
<td>6,210</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>66,811</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>308,770</td>
</tr>
<tr>
<td>F</td>
<td>1</td>
<td>697,672</td>
</tr>
</tbody>
</table>
The DMAIC Methodology

For Each Product or Process CTQ – Define, Measure, Analyze, Improve, and Control

\[ Y = f(x_1, x_2, ..., x_n) \]

<table>
<thead>
<tr>
<th>Define</th>
<th>What is the scope of the problem?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure</td>
<td>What is the frequency of defects?</td>
</tr>
<tr>
<td>Analyze</td>
<td>Where and why do defects occur?</td>
</tr>
<tr>
<td>Improve</td>
<td>How can we fix the process?</td>
</tr>
<tr>
<td>Control</td>
<td>How can we make the process stay fixed?</td>
</tr>
</tbody>
</table>
Six Sigma Tools & Techniques Applied to Cx
Some of the Intersection Points

Six Sigma Approach

Define → Meas. → Analyze → Improve → Control

Design Phase → Construction Phase → Testing Phase → Training Phase → Occupancy Phase

Cx Process
Start At The Beginning - Define

6σ

Project Charter

CTQ Flowdown

Cause & Effect Matrix

SIPOC

Owner's Project Requirements
What Is Our Objective?

Project Charter

Process Map

CTQ Flowdown

C&E Matrix

+15 Inputs

10-15

8 - 10

4 - 8

2- 4

Y’s & X’s

1st “Hit List”

Screened List

Significant X’s

Critical X’s

OPR
Five Major Elements of a Charter

- Business Case
  - Explanation of why to do the project

- Problem and Goal Statements
  - Description of the problem/opportunity or objective in clear, concise, measurable terms

- Project Scope
  - Process dimensions, available resources

- Milestones
  - Key steps and dates to achieve goal

- Roles
  - People, expectations, responsibilities
Business Case Definition & Example

Project Title: Data Center Commissioning

Business Case:
(A broad definition of the issue as well as the rationale for why this project should be a business priority.)

Example: The company did not invest in commissioning two previous data centers. Those facilities experienced a number of start-up issues that resulted in cost/schedule overruns. Senior management is concerned about implications to their stock price of not commissioning the company’s new flagship data center.
Project Title: Data Center Commissioning

Problem/Opportunity Statement:
1 or 2 sentences describing the symptoms such as where is the problem, how big is the problem, or what is the impact.

Example: The two previous non-commissioned data centers had air distribution and delivery problems on the raised floor which reduced annual uptime by 20%. Cooling issues on the new center could potentially reduce uptime by 45% and cut revenues by 50%.
How Do You Identify What’s Important? Start with SIPOC

**Suppliers** > **Inputs** > **Process** > **Output** > **Customer**
Creating a SIPOC

<table>
<thead>
<tr>
<th>Suppliers</th>
<th>Inputs</th>
<th>Process</th>
<th>Outputs</th>
<th>Cust.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Providers of the process</td>
<td>Inputs into the process</td>
<td>Process Descrip.</td>
<td>Outputs of the process</td>
<td>Receiver of the process outputs</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

**Inputs**
- Proj. Rqmts.
- Dwgs.
- Submittals
- O&M Data
- Constr. Sch.

**Outputs**
- Func. Test
- Def. Rpt.
- Re-Test Pln
- Cx Rpt.
- Training

**Suppliers**

**Cust.**

**Cx PROCESS**

**Feedback**
What Is Our Objective?

Project Charter
Process Map
CTQ Flowdown
C&E Matrix

+15 Inputs
10-15
8 - 10
4 - 8
2 - 4

Y’s & X’s
1st “Hit List”
Screened List
Significant X’s
Critical X’s

OPR
What Does It Do?

- Prioritizes customer requirements (Y’s)
- Calculates a customer “Pain” Index
- Screens Our X’s - Prioritizes Steps and Inputs
Cause & Effect Matrix Steps

- Identify key customer requirements (outputs) from Process Map
- Rank order and assign priority factor to each output (Usually on a 1 to 10 scale)
- Identify all process steps and materials (inputs) from the Process Map
- Evaluate correlation of each input to each output
  - **Low Score:** changes in the input variable (amount, quality, etc.) have small effect on output variable
  - **High Score:** changes in the input variable can greatly affect the output variable
- Cross multiply correlation values with priority factors and add across for each input
## Example of C&E Matrix

### How CxA Can Impact the Customer CTQ

<table>
<thead>
<tr>
<th>Importance Weighting (Scale: 1-10)</th>
<th>Develop OPR</th>
<th>Review BOD for Traceability to OPR</th>
<th>Develop Cx Plan</th>
<th>Design Reviews</th>
<th>Develop Cx Specifications to Flow into Contractor/Build Packages</th>
<th>Submittal Reviews</th>
<th>Construction Observations</th>
<th>Review Pre-Functional Checklists</th>
<th>Functional Testing</th>
<th>Operator Training</th>
</tr>
</thead>
<tbody>
<tr>
<td>Totals:</td>
<td>521</td>
<td>486</td>
<td>342</td>
<td>316</td>
<td>313</td>
<td>289</td>
<td>139</td>
<td>215</td>
<td>723</td>
<td>282</td>
</tr>
</tbody>
</table>

### Owner CTQ (i.e., Customer Expectation): Science/Tech Facility

<table>
<thead>
<tr>
<th>CTQ Description</th>
<th>Importance</th>
<th>Impact</th>
<th>Develop OPR</th>
<th>Review BOD for Traceability to OPR</th>
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<th>Review Pre-Functional Checklists</th>
<th>Functional Testing</th>
<th>Operator Training</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 72 degree indoor air temperature during summer months</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>2. 100 foot candles of illumination on desktops</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>3. 15 air changes per hour in laboratory space</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>4. 75 degree plus/minus 2 degrees indoor air temp. during winter</td>
<td>6</td>
<td>9</td>
<td>9</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>5. Emergency generator to start within 10 seconds of power loss</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>6. Cx report accuracy</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>9</td>
<td>0</td>
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<tr>
<td>7. Concise Cx reporting</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>4</td>
<td>9</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>8. MEP Integrated Testing</td>
<td>9</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>9</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>9. Optimized MEP wrt energy consumption</td>
<td>9</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>9</td>
<td>0</td>
<td>4</td>
<td>9</td>
<td>1</td>
<td>0</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>10. Cx Budget Compliance</td>
<td>8</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>11. Pro-Active Cx Communications</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>12. 1,000 cfm of airflow in classroom space</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>9</td>
<td>4</td>
</tr>
</tbody>
</table>
Pareto Analysis for Cx Project

- 72 degree indoor air temperature during summer months
- 75 degree plus/minus 2 degrees indoor air temp during winter months
- 15 air changes per hour in laboratory space
- 100 foot candles of illumination on desktops
- 1,000 cfm of airflow in classroom space
- Emergency generator to start within 10 seconds of power loss
- 175 degree plus/minus 2 degrees indoor air temperature
- Pro-Active Cx for budget + reporting accuracy
- Concise Cx report
- MEP integrated testing
- 100 foot candles of illumination on desktops
Moving Forward - Analyze

Retro-$C_x$

Where Are The Potential Areas of Variation?

$6\sigma$

Establish Process Capability

Define Performance Objective

Identify Variation Sources
A Process is
“A Distribution of Distributions”

Variation is the problem
Process Capability

Blue line is \textit{process} spread (car)
Red line is \textit{customer spec} spread (garage)

Pp measures how wide the garage is!
Ppk indicates how well you park the car – is it centered?
Process Capability Example

Aggregate kWh for all three Electric Meters

Process Data
- LSL: 950000
- Target: *1.3e+006
- USL: 1.3e+006
- Sample Mean: 1.17085e+006
- Sample N: 30
- StDev (Within): 87894.4
- StDev (Overall): 90086.1

Potential (Within) Capability
- Cp: 0.66
- CPL: 0.84
- CPU: 0.49
- Cpk: 0.49

Overall Capability
- Pp: 0.65
- PPL: 0.82
- PPU: 0.48
- Ppk: 0.48
- Cpm: *

Observed Performance
- PPM < LSL: 0.00
- PPM > USL: 100000.00
- PPM Total: 100000.00

Expected Within Performance
- PPM < LSL: 5990.33
- PPM > USL: 70870.32
- PPM Total: 76860.65

Expected Overall Performance
- PPM < LSL: 7111.53
- PPM > USL: 75844.49
- PPM Total: 82956.02

2007 ICEBO
San Francisco, Ca
Control chart vs. frequency distribution

Detect and monitor process variation over time

Snapshot

Moving picture
Look For Variation Sources: Control Chart (kWH/month)

X-Bar Chart

Points Outside Control Limits

Range Chart
The MEP Is The Facility’s Process

**X’s**

**Inputs**

- Factor 1
- Factor 2
- Factor 3
- Factor 4
- Factor 5

**Process**

**Outputs**

- Response variables – We don’t have control over, but can measure
- Measured variable(s)
- Dependent variable(s)
- Output(s)
- Y’s

**Y’s**
We Started By Looking At Some General Trends

Trend Analysis Plot for Total$ELEC (DATA: 2003 - 2007)

Variable
- Actual
- Fits

Accuracy Measures
- MAPE: 5
- MAD: 5928
- MSD: 53552329

TIME

Jun-03 Oct-03 Mar-04 Aug-04 Jan-05 Jun-05 Nov-05 Apr-06 Sep-06 Feb-07

Total$ELEC

80000 90000 100000 110000 120000 130000 140000
Looked For Clues To “Special Cause” Variation

I Chart of kWH M531

- Observation: 1 to 46
- Individual Value: X = 351576
- UCL = 440095
- LCL = 263056

I Chart of kWH M530

- Observation: 1 to 46
- Individual Value: X = 388278
- UCL = 486815
- LCL = 289740

I Chart of kWH M532

- Observation: 1 to 46
- Individual Value: X = 388808
- UCL = 494305
- LCL = 283312

Control Chart for Water Use

- Data: Water Consumption per Month - Total Building
- Observation: 1 to 28
- Individual Value: X = 1109.1
- UCL = 1492.4
- LCL = 725.9
Business Case:
Executive management has decided to pursue LEED Certification for the _______ in Los Angeles. It is desired to have the facility stand out as a “Model” facility that sets the standard. To that end, in addition to meeting the requirements for LEED certification, improving the energy performance of the facility is an objective that is desired for tenant retention.

Problem Statement:
It appears that the HVAC process is currently operating at a 1.4 Sigma level. This performance manifests itself in energy cost. Hence, electricity cost has increased by an average of 7.2% from 2005 to 2007 increasing the incremental energy cost for the facility by $4,000 on an annual basis.

Goal Statement:
tbd.
Total kWh (Data 2005 - 2007)

Mean 1170853
StDev 89313
N 30

Normal - 95% CI

Frequency

kWh

Frequency
kWH Process Performance (Data: 2005 - 2007)

SUM kWH Process Performance

Process Data
- LSL = 950,000
- Target = 1.17085e+006
- USL = 1,300,000
- Sample Mean = 1.17085e+006
- Sample N = 30
- StDev(Overall) = 90086.1

Overall Capability
- Pp = 0.65
- PPL = 0.82
- PPU = 0.48
- Ppk = 0.48
- Cpm = *
Process Capability - kWH

**Process Performance:** \( Pp = 0.65 \)

Specs are only 65% of the Process Spread . . . Car doesn’t fit in the garage. Good target value is 1.5

**Process Centering:** \( Ppk = 0.48 \)

Process is not centered. Process is centered when \( Ppk = Pp \).
Conclusion:

- Commissioning is a quality process
- Six Sigma is a process improvement methodology
- End goal is to delight the customer/client
Questions?

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