

Enhancing the Commissioning Process on Multi-Building Projects with Six Sigma Tools/Techniques

Lawrence Buck

Vice President, Commissioning Manager
Carter & Burgess, Inc.
Los Angeles, CA, USA

ABSTRACT

Commissioning, in many ways, is an optimum quality assurance process. This process, when properly executed, will ensure the highest quality and operational reliability of the completed facility within the allocated budget. Clearly, while one objective of the process is to validate that all systems operate as intended, the process can also be used to ensure optimum quality for everything that is designed, acquired, and constructed - resulting in a facility that is ideally suited for the owner's operations, with sustainable operability (Heinz, 2004).

Six Sigma is a highly disciplined process that enables world-class quality and continuous improvement methods to achieve the highest level of customer satisfaction. The main objective is to deliver near perfect services by improving the process and eliminating defects and thus result in delighting customers/owners.

Integrating Six Sigma tools/techniques into the commissioning process, especially for multi-building complexes such as University campuses, is a natural fit. The implementation of the appropriate tools and methods can lead to improving the overall commissioning process, save money, and enhance the overall commissioning experience of the owners and other stakeholders.

This paper introduces the idea that it is logical to consider utilizing the Six Sigma DMAIC¹ approach to improve various aspects of the commissioning process. It also identifies and discusses the potential application of specific Six Sigma tools/techniques that can be particularly effective when utilized on multi-building new, or existing, LEED projects during different phases of the commissioning process.

INTRODUCTION

Commissioning is a programmed series of quality assurance, documentation, and testing activities that are performed specifically to ensure that the finished facility(s) operate(s) as intended (Heinz, 2004). Essentially, it is a process that intends to result in achieving a high-level of confidence that

the performance of facilities, systems and assemblies meets defined objectives and criteria.

Six Sigma, which traces its roots back to 1987 with Bill Smith of Motorola, was generally considered as a statistics-based methodology useful for reducing defects associated with manufacturing processes. To that point, the term sigma (σ), in the name Six Sigma, is a Greek letter used to describe variability, or more specifically, defects per unit.

The sigma quality level implies how often defects are likely to occur. In other words, a high sigma number indicates a process that is less likely to create defects. Therefore, unlike golf, the higher the indicator number, the better. A Six Sigma quality level is associated with 3.4 defects per million opportunities (DPMO).

Today, the Six Sigma DMAIC approach is widely recognized as a methodology for pursuing continuous improvement in customer satisfaction and profit that goes beyond defect reduction and emphasizes business process improvement in general (Breyfogle, 2003). Table 1 shows the typical magnitude of improvement that the Six Sigma philosophy strives to achieve (Gygi, 2005).

Table 1: How Good is Good

Classic View of Quality ("99% Good" [3.8 Sigma])	Six Sigma View of Quality ("99.99966% Good" [6 σ])
20,000 lost articles of mail per hour	7 articles of lost mail per hour
Unsafe drinking water for almost 15 minutes per day	One unsafe minute of drinking water every seven months
5,000 incorrect surgical operations per week	1.7 incorrect surgical operations per week
2 short or long landings at major airports every day	1 short or long landing at major airports every five years
200,000 incorrect drug prescriptions each year	68 incorrect drug prescriptions each year
No electricity for almost 7 hours each month	One hour without electricity every 34 years
11.8 million shares incorrectly traded on the NYSE every day	4,021 shares incorrectly traded on the NYSE every day

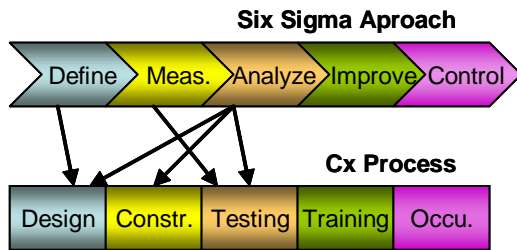
¹ Define, Measure, Analyze, Improve, Control.

In its purest form, the DMAIC model is a set of tools/techniques applied over five sequential phases that are used to characterize and optimize both business and industrial processes. These phases are briefly summarized below.

In the Define (D) phase, the customer needs are stated and the processes and deliverables to be improved are identified. The Measure (M) phase determines the baseline and target performance of the process, defines the input/output variables of the process, and validates the measurement systems. The Analyze (A) phase uses data to establish the key process inputs that affect the process outputs. The Improve (I) phase identifies the improvements to optimize the outputs and eliminate/reduce defects and variation. The Control (C) phase also identifies the key input variables (i.e., x's), determines the $y = f(x)$ relationship and statistically validates the new process operating conditions. The Control (C) phase documents, monitors, and assigns accountability for sustaining the gains made by the process improvements (Six Sigma Academy, 2002).

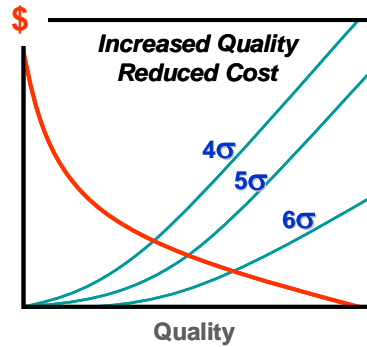
Figure 1 illustrates where the Six Sigma approach may intersect well with the commissioning process.

Figure 1: Process/Approach Intersection



Six Sigma has not only improved processes, but also has delivered real economic value by directly attacking the cost of poor quality (COPQ) (Brefogle, 2003). It used to be accepted that increased quality meant higher cost. Today, as shown in Figure 2, the prevailing belief about the relationship between cost and quality is that increased quality actually lowers cost due to prevention of scrap, rework, re-testing, trouble-shooting time, management time, lost business goodwill cost, etc. Therefore, when you combine improved inspection, test, and quality audits with prevention techniques such as process planning, process control, and training you improve quality levels (i.e, the green lines) and hence reduce costs.

Figure 2: Cost and Quality



Given that Six Sigma, if properly applied, can improve processes and reduce costs, one would naturally conclude that there would be a very appealing fit between commissioning process and Six Sigma. After all, commissioning is a quality process that seeks to maximize owner satisfaction by verifying intended performance. Six Sigma is a methodology designed to drive increased customer satisfaction by improving processes to yield higher quality, more cost-effective output. Therefore, while there are many commonalities between the two, the strongest link is that both are focused on enhancing the customer/owner experience and improving owner satisfaction.

Can applying Six Sigma techniques improve the commissioning process and therefore enhance the owner's experience and satisfaction? I would argue that the answer is a resounding, yes!

To cite some of the more popular success stories surrounding the adoption of the Six Sigma way, General Electric (GE) profited between \$7 to \$10 billion from adapting the methodology corporate-wide over a five-year period (Brefogle, 2003). Moreover, GE's CEO at the time, Jack Welch, described Six Sigma as "the most challenging and potentially rewarding initiative we have ever undertaken at General Electric" (Brefogle, 2003). Bank of America saved hundreds of millions of dollars with three years of launching Six Sigma, cut cycle times by more than half, and reduced the number of processing errors by an order of magnitude. Honeywell achieved record operating margins and savings of more than \$2 billion in direct costs and Motorola, the place where Six Sigma began, saved \$2.2 billion in a four-year period (Gygi, et. al., 2005).

While the above success stories are very high-profile, and sensational examples of how the methodology can produce economic benefits for

corporations with tremendous resources, one certainly may wonder and question whether Six Sigma can do anything for a more low-profile, methodical, although relatively new, commissioning process.

I believe the potential for improving the commissioning process with Six Sigma is very promising. When you consider that commissioning is a process that intends to produce an output that benefits the owner, and Six Sigma is a methodology designed to improve processes by making them more effective, more efficient, or both, applying the Six Sigma methodology to the commissioning process seems to make perfect sense. Furthering this thought, this paper explores the intersection between Six Sigma and the commissioning process by looking at the application of popular Six Sigma tools during different stages of the commissioning process as envisioned by USGBC LEED v2.2 New Construction and LEED v2.0 for Existing Buildings reference guides.

In the Beginning - Critical-To-Quality (CTQ)

Early in the commissioning process, it is vital to accurately document the Owner's Project Requirements (OPR) in order to achieve a successful end result. Typically, as the owner's representative, the Commissioning Agent (CxA) establishes and documents the functional requirements of a project including the expectations of the building's use and operation as it relates to the systems to be commissioned (USGBC, 2006).

According to the USGBC Guidelines, it is recommended that the OPR address the following issues, as applicable to the project:

- owner and user requirements
- environmental and sustainability goals
- energy efficiency goals
- indoor environmental quality requirements
- equipment and system expectations
- building occupant and O&M personnel requirements

Together, the OPR and the Basis of Design (BOD), developed by the design team, provide the fundamental focus for validating systems' energy and environmental performance and serves as the basic documentation for evaluating whether or not the design and construction have been completed to the owner's satisfaction.

Therefore, it is critical to the commissioning process to accurately develop, document, and communicate the functional requirements and the expectations of how the facility(s) will be used and operated. Therein lays the challenge, especially for multi-facility projects such as those found on college and high school campuses where layers of oversight and multiple decision-makers can potentially create confusion and conflicting direction. Utilizing Six Sigma techniques can help.

Similarly, the Six Sigma methodology begins with understanding the Customer requirements, and ends with meeting the Customer requirements-. Similarly, commissioning is all about making sure that the owner's requirements are verified in the facilities' mechanical, electrical and plumbing (MEP) infrastructure performance.

Starting with the development of a Project Charter and then utilizing any, or all, of the following Six Sigma tools can significantly assist in creating a thorough and comprehensive project OPR:

- Critical-To-Quality (CTQ) Flowdown
- Cause & Effect (C&E) Matrix
- SIPOC

The Project Charter represents a 50,000 ft level perspective on the project goals, boundaries, and team members' roles. Essentially, the Charter clarifies what is expected of the commissioning team, keeps the team focused, and keeps the team aligned with the customer/owner's priorities. It serves as the springboard from which the OPR requirements can be developed.

The six major elements of a Project Charter are:

- Business case: a high-level explanation of why the commissioning project is undertaken.
- Problem statement: a description of the problem/opportunity in clear, concise terms. Ideally, the problem statement will include a description of the problem and the metric used to describe the problem, the timeframe over which the problem has been occurring, and the size/magnitude of the problem. Clearly, a well-written problem statement will help the commissioning team to readily grasp and understand what is trying to be accomplished.

- Goal statement²: directly addresses the information in the problem statement. A really good goal statement contains all of the following elements: improve some metric from some baseline to some target in some amount of time with some positive impact on the owner’s end-state vision.
- Project scope: refers to the boundaries of the project. It attempts to outline the range of the team’s activities.
- Milestones: key steps and dates to achieve the goal. Essentially, these represent a high-level project plan.
- Team roles: a very high-level description of people, expectations, and responsibilities.

An example of the first three elements of a Project Charter for the Retro-Cx of a class-A office space is illustrated in Table 2.

Table 2: Example of Project Charter Elements

Business Case	XYZ office building’s energy performance is not meeting monthly targets even though tenant occupancy levels have not changed. Overall, this is causing concern about implications to tenant retention and fee increases and is increasing the energy cost for the facility.
Problem Statement	Electricity and gas consumption has been growing at a rate of 2.5% per month for the past eight months increasing the incremental energy cost for the facility by \$500,000 on an annual basis.
Goal Statement	Identify and resolve the cause of increased energy consumption within 160 days so that energy use and cost return to normal levels by the end of the second quarter.

As the adage goes, properly defining the problem is the most important part of solving the problem, and in this case, provides a great start on identifying critical requirements for the OPR.

In the context of commissioning, CTQ’s in Six Sigma speak refer to service characteristics that satisfies key customer/owner requirements³. In other words, anything that affects customer/owner satisfaction is critical-to-quality. To put it another way, CTQ’s are the bridge between the

² The Goal statement, together with the Problem statement provides the focus and purpose for the Cx team.

³ Most CTQ’s are customer-driven, but risk, economics and regulation may drive others.

commissioning process output and customer/owner satisfaction. Some examples are:

- accuracy of pre-functional checklists
- timeliness of submittal review/comments
- helpfulness in resolving deficiencies

One tool that is particularly useful in not only identifying important customer/owner requirements but also assists in translating those requirements to quantifiable requirements for the commissioning service is the CTQ Flowdown, or CTQ Tree. To be more specific, the CTQ tree is used as a method to identify, define and analyze customer/owner requirements. Typically, the output of the CTQ Tree is the identification of the critical owner requirements for the commissioning team to satisfy. These can be regarded as the key outcomes, or the “Y’s” of the commissioning process that in turn assists the commissioning team in identifying the high-impact “Xs,” or the activities that influence the achievement of the key outcomes⁴.

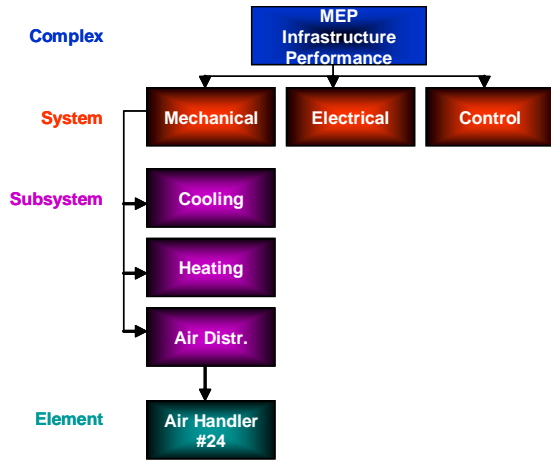
The starting point for creating a CTQ Tree is identifying a key owner requirement, such as “facilities’ MEP infrastructure performance verification.” This is referred to as the complex level of the tree and describes the final service that is delivered to the owner. The system level is then filled out.

The system level is a more detailed breakdown of the complex level. Moving on, the next step is to complete the subsystem level, which in turn, is a more detailed breakdown of the system level. Finally, the element level is completed. This level is the lowest level of the tree and its components are not divisible.

Note that the eventual size of the tree is dependent on the complexity of the service provided. In addition, a service requirement at any level of the hierarchy in the tree can have quality, delivery, and/or cost issues that concern owners. Within the hierarchy, the commissioning team must consider whether it is satisfying those owner needs. In the end, the main intent of breaking high-level, “complex” requirements down into smaller, more bite-size requirements is to better understand and identify the critical requirements that will eventually flow into the OPR. Figure 3 illustrates a simplified CTQ Tree example.

⁴ Remember the equation $Y = f(X1, X2, X3, \dots Xn)$

Figure 3: CTQ Tree for Portion of MEP Infrastructure



The C&E Matrix is another tool that can be used to cull out owner requirements. It also has the added benefit of prioritizing those requirements and matches them with commissioning process outputs. Hence, the end product is a quantitative representation of where the greatest opportunity for achieving the requirements lies.

To build the matrix, you start by identifying customer/owner needs/requirements, the “what’s.” These requirements are then ranked on a scale of 1-10 with respect to their importance to the customer/owner. You may potentially have to interview one or more customers/users of the facility to get a comprehensive list. Figure 4 illustrates how those requirements can be captured on a spreadsheet

The “hows,” or “X’s” are listed and then compared to the “what’s” by a force-ranking on the following scale: 0, 1, 4, and 9, were a rank of 9 indicates that a particular X would significantly impact a “what,” or “Y.”

Figure 4: Elements of the C&E Matrix

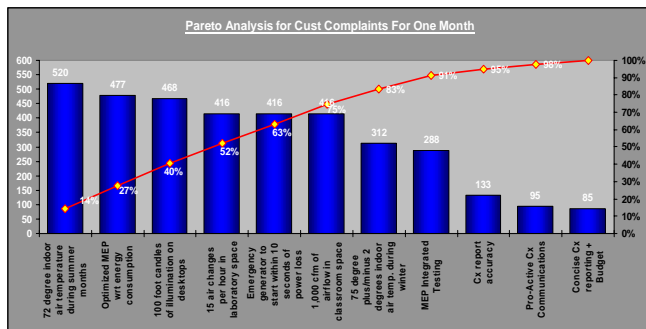
Cust. Needs/ Req./ WHAT's	Cust. 1	Cust. 2	Cust. 3	Cust. 4
What 1				
What 2				
What 3				
What 4				
What 5				
What 6				
What 7				
What 8				
What 9				
What 10				
What 11				
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What 26				
What 27				
What 28				
What 29				
What 30				

For each row, the sum-product is calculated by multiplying the cell rating by the importance rating from the “what” in that row. The products across each row are added together and stored in the top row. The end result, as illustrated by the simple example in Figure 5, provides significant insight into critical owner requirements as well high-impact commissioning activities in the commissioning process. The output also lends itself to be easily displayed in a Pareto Chart format as shown in Figure 6.

Figure 5: Example Commissioning C&E Matrix

	Importance Weighting (scale: 1 - 10)	How CxA Can Impact the Customer CTQ											
		Develop OPR	Review BOD for traceability to OPR	Develop Cx Plan	Design Reviews	Develop Cx Specifications & Flow into Contractor Bid Packages	Submittal Reviews	Construction Observations	Review Pre-Functional Checklists	Functional Testing	Operator Training		
Totals:		521	486	342	316	313	289	139	215	723	282		
Owner CTQ (i.e., Customer Expectation): Science/Tech Facility													
1	72 degree indoor air temperature during summer months	10	9	9	4	4	4	4	1	4	9	4	526
2	100 foot candles of illumination on desktops	9	9	9	4	4	4	4	1	4	9	4	468
3	15 air changes per hour in laboratory space	8	9	9	4	4	4	4	1	4	9	4	416
4	75 degree plus/minus 2 degrees indoor air temp. during winter	6	9	9	4	4	4	4	1	4	9	4	312
5	Emergency generator to start within 10 seconds of power loss	8	9	9	4	4	4	4	1	4	9	4	416
6	Cx report accuracy	7	0	0	9	0	0	0	0	1	9	0	133
7	Concise Cx reporting	3	0	0	1	1	0	4	9	4	4	0	59
8	MEP Integrated Testing	9	4	1	4	4	9	0	1	0	9	0	288
9	Optimized MEP art energy consumption	9	4	4	4	9	4	9	1	0	9	9	477
10	Cx Budget Compliance	8	1	0	1	0	0	0	0	0	0	0	16
11	Pro-Active Cx Communications	5	0	0	0	0	0	0	9	0	9	1	95
12	11,000 cfm of airflow in classroom space	8	9	9	4	4	4	4	1	4	9	4	416

Figure 6: Pareto Chart Showing Key Commissioning Requirements



SIPOC - A KEY COMMUNICATIONS TOOL

Another very useful tool for drawing out owner requirements is the SIPOC flowcharting technique. The acronym SIPOC stands for Suppliers, Inputs, Process, Outputs, and Customers. In addition to helping to identify key requirements (i.e., outputs) it can serve as a very useful communication tool during commissioning kick-off meetings, for example, that helps team members view the project the same way and helps the customer/owner know where the team is focusing its efforts.

In the context of a commissioning project, at the 50,000 ft level, the SIPOC helps the team answer the following questions:

- Who are the owners (i.e., “stakeholders) for whom the commissioning process primarily exits?
- What value does the commissioning process create? What output does it produce?
- Who is the owner of the commissioning process?
- Who provides inputs to the commissioning process?
- What are the inputs?
- What resources does the commissioning process use?
- What steps create value?

A great way to begin the dialogue to answering the above questions is to schedule a brainstorming session with the facilities’ owners/representatives and representatives from the design team. If possible, having a representative from the general contractor participating would add significant value. Figure 7 shows the steps in creating a SIPOC. The numbers in

the graphic correspond to the numbers of the steps presented below:

Figure 7: Creating a SIPOC

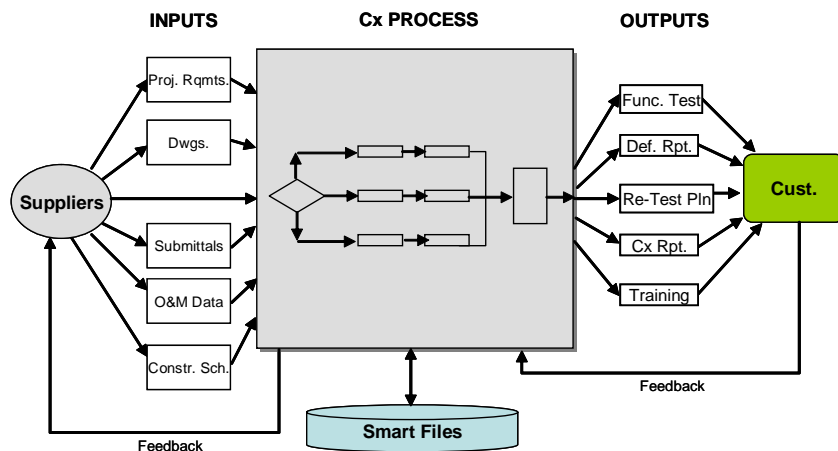
Suppliers	Inputs	Process	Outputs	Cust.
Providers of the process (6)	Inputs into the process (5)	Process Descr. (1) Process Map (2)	Outputs of the process (3)	Receiver of the process outputs (4)

SIPOC steps:

1. Provide a description of the process, in this case the commissioning process.
2. Define the start and end of the process.
3. List the outputs of the process. Here is where the focus on drawing out the owner’s requirements comes to play. Note: the requirements of the outputs should be listed as well as how the requirements will be measured.
4. List the customer(s) of each commissioning process output.
5. List the inputs required for the commissioning process, as well as how these inputs will be measured.
6. List the suppliers of the process.

Figure 8, illustrates a simplified SIPOC for a commissioning project.

Figure 8: Commissioning SIPOC



CONTROL CHART - ESTABLISHING THE ENERGY BASELINE

Expected energy savings may fall in the range of 7 - 29% when existing buildings are commissioned (Mills et. al. 2004). A Six Sigma tool for helping to baseline and validate energy savings associated with commissioning existing buildings, is the Control Chart. The Control Chart is one of the most important tools used in the Six Sigma methodology.

Typically, the Control Chart:

- focuses attention on detecting and monitoring process variation overtime
- helps distinguish “special” from “common” causes of variation
- serves as a tool for ongoing control of variation
- assists in monitoring process behavior - creates evidence when the process is no longer operating at predictable levels
- helps to improve a process to perform consistently and predictably for higher quality, lower cost, and higher effective capacity
- provides a common language for discussing process performance

While this tool has many applications for helping to monitor, control, and improve process performance overtime, in the commissioning world, the control chart can be very useful for establishing an energy consumption performance before, and after, a Retro-Cx opportunity.

The steps to constructing Control Charts are relatively simple. The following steps are presented in the context of commissioning an existing building to yield energy savings.

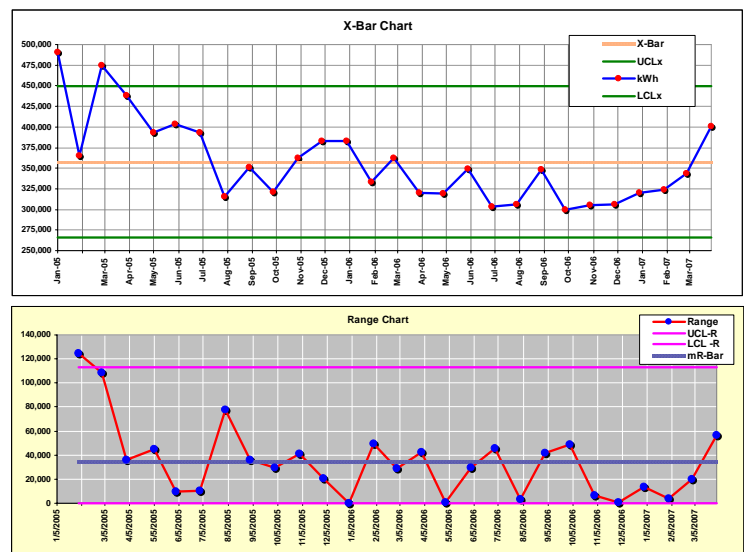
1. Select the process, output variable, or input variable to be charted - in this case, we will use energy consumption (i.e., kWh) as the output variable.
2. Determine the sampling method and plan. The sampling method in this case will utilize the utility bills.
3. Initiate the data collection.
4. Calculate the appropriate statistics. In this case, the Individual and Moving Range (X-MR) control chart is used because we are using continuous data and each subgroup consists of only a single, individual measurement (i.e., monthly kWh).

5. Calculate the control limits and construct the Control Chart.
6. Interpret the results.

Because this is not a tutorial on Six Sigma Control Charts, I will not go into the many details surrounding the calculation and interpretation of the statistics involved. Instead, I will use a real example to illustrate how to interpret a control chart used for commissioning an existing building. For a good summary of the formulas to calculate the control chart statistics and the means to interpret the charts, please see (Gygi, 2005).

Figure 9 illustrates a Individual and Moving Range chart for the measured energy consumption of one of three electric meters in a relatively new million sqft Class-A office building in California.

Figure 9: X-Bar and Moving Range Chart



The green lines on the top chart represent plus or minus three standard deviations from the mean (shown as the orange line). These lines are referred to as the ‘control limits.’ This means that if a measurement falls within plus or minus three standard deviations of its average, it is considered “expected” behavior for the process. Expected behavior is also known as common cause variation.

Common cause variation results from the normal operation of a process and is based on the design of the process, process activities, materials, and other process parameters. If, however, a data point falls outside of the control limits, something special has happened to the process. In other words, something

out of the ordinary has caused the process to go out of control. This is known as special cause variation. To the retro-commissioning agent, this sends up a red flag because statistically, what it says is that the probability that a process measurement could be that far from the average, based on the behavior of the process up to that point is less than 0.3 percent. A measurement with such a low probability of occurrence suggests that there were special circumstances affecting the process. This presents the retro-commissioning agent with a clue of where to start exploring to find where the process may be less than optimized.

In this particular case (i.e., Figure 9) although not conclusive, one can see that in 2005 there were points above the upper control limit that suggests there was a special cause⁵ affecting the normal HVAC process. Since that time, electricity consumption has stayed within the control limits. However, in late 2006 and early 2007 there seems to be a continued rise in a series of chart points in the X-Bar chart that indicates that there could be special cause sources of variation that is affecting the HVAC process. To emphasize the point, when you detect patterns, or see points outside of the control limits, it is an indication that something out-of-the-ordinary has happened in the process.

Another benefit of control charting this type of metric, especially for Retro-Cx projects that are focused on improving energy efficiency, is that they enable a quantitative-based conversation with the owner to establish a mean (i.e., average) target and spec-limits for energy consumption. Once those are established, the performance of the system can be monitored to determine if in fact the HVAC process drifts “off-center” over time, and/or energy consumption dispersion is wider than specification limits reasonable for the facility(s).

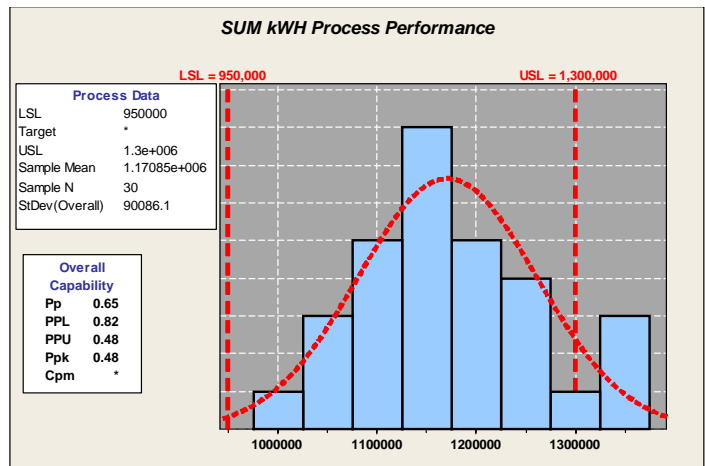
For example, Figure 10 provides a real example of a Class-A office building’s energy consumption over a period from 2005 to mid-summer 2007. The owner set an upper specification limit (USL) of 1.3 million kWh/yr and a lower specification limit (LSL) of 950,000 kWh/yr. Super-imposing the facility’s energy consumption histogram over the specification limits shows that the existing HVAC process is not meeting the customer’s expectations for energy performance. In fact, the current HVAC process is performing at a 1.4 sigma level which is equivalent to

⁵ Special cause variation is caused by something special. For example, if it normally takes 15 minutes to process a credit card application, but the network connection goes down, that’s a special cause (Gygi, 2005).

a manufacturing process that produces approximately 540,000 defects per million pieces - not a very cost efficient process.

Setting the energy performance baseline as such enables the commissioning agent, on a retro-commissioning project, to then compare the “after commissioning” results to the “before commissioning” results and quantitatively determine not only process improvement, but also cost savings.

Figure 10: Histogram of Energy Consumption



CONCLUSION

Commissioning is a quality process that intends to look after the customer/owner’s best interest. Six Sigma is a process-improvement methodology that begins with understanding the customer/owner’s requirements and ends with meeting those requirements. With the customer/owner as the most significant lynch pin between the two, it is natural to use elements of Six Sigma to improve the commissioning process with the end goal of delighting the customer and improving the cost-effectiveness of the end result.

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