

## **Quantifying Costs and Benefits, the Sequel: A 6-Year Check-up on Commissioning at the Pentagon**

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### **Synopsis**

Prior to 1998 a number of Pentagon construction projects did not perform as expected at completion of the work. The Department of Defense (DoD) recognized the need for comprehensive building commissioning to help verify that new facilities systems were performing as intended when the decision was made to invest \$1.1 billion into the Pentagon Renovation.

At the 8<sup>th</sup> Annual National Conference on Building Commissioning in 2000, Pentagon staff presented a paper titled *Quantifying Costs and Benefits of Commissioning*. That document and the associated presentation discussed cost and calculated savings data based on the first two years of commissioning on Pentagon Renovation projects. Six years later, with 3 million square feet of Pentagon projects commissioned, this paper revisits the cost/benefit question with substantially more empirical data.

In addition to financial benefits to the DoD, commissioning on the uniquely large and long-lasting Pentagon Renovation Program has offered up a number of lessons learned with respect to the commissioning process itself. These are shared on a very high level in the second part of this paper.

Although the length of this paper may appear daunting, it can be viewed as two separate, but related, papers. As such, the Financial Costs & Benefits section can be read by itself. Similarly, the Commissioning Process Lessons Learned section can be approached as a stand-alone document.

### **About the Authors**

Rebecca Ellis has eighteen years of experience engineering and managing a variety of HVAC system projects. Ms. Ellis is a specialist in the design, analysis, and commissioning of intricate temperature and humidity control systems with a particular strength in direct digital controls. Ms. Ellis is a nationally recognized leader in the commissioning industry as a speaker, author, and trainer.

Wade Shankle has twenty-two years of DoD systems engineering experience managing facilities design and construction projects and operations, maintenance and repair programs. He is a specialist in mission critical facilities design, construction, and operation. Mr. Shankle has led the Pentagon commissioning program for the past 5 years.

Peter Stockard is the Commissioning Specialist program manager providing independent commissioning services for the Pentagon Renovation Program under contract with the Defense Facilities Directorate. Mr. Stockard has thirteen years of experience engineering and managing facility commissioning, utility electrical distribution design, facility operations & maintenance, and energy saving performance contracting programs and projects.

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### **Introduction**

The objective of this paper is to share some of the results of the Pentagon Renovation's commissioning program which has been underway for over eight years at the time of this publication. The results are numerous and various, touching most aspects of the design and construction project delivery, building turn-over and long term facility operations, as well as the health and safety of the building's occupants. It seems that everything ever noted as a "benefit" of commissioning has been experienced at the Pentagon and to an extent unparalleled in other projects. This is due to the size, complexity, and duration of the Renovation and to the strong owner/operator commitment to the process.

The following represents only the beginning of the analysis of the tremendous data available from the Renovation Program commissioning process. Although we went into this analysis with a pretty clear idea of what type of information the data might yield, we have been intrigued and excited by the potential knowledge to be gained by looking at the data from far more perspectives than we had originally anticipated. The data can be analyzed by simply counting certain benefits, by quantifying their financial value, and by evaluating how the metrics are changing over time.

Beyond the individual technical and project-specific benefits data, we have used this opportunity to share some of the commissioning process best practices learned through our experience at the Pentagon. These are universal in application and are intended to transfer the knowledge gained at the Pentagon to other projects and practitioners in an effort to improve commissioning experiences industry-wide.

We have organized this paper as follows:

- Generic introduction to our simple approach to quantifying the financial value of non-energy benefits of commissioning.
- Specific information about and metrics from the Pentagon Renovation.
- Commissioning process lessons learned.

## Financial Costs & Benefits

The benefits of commissioning can be categorized as energy benefits or non-energy benefits, with facility owners/operators more attracted to the non-energy benefits than to the energy benefits.<sup>1,2</sup> Topping the list of reasons why facility owners want commissioning are the following non-energy benefits of commissioning:

- Assurance that owners get the building they want and are paying for.
- Smoother turn over.
- Improved comfort control.
- The opportunity to monitor building performance over the first year of operation.
- Improved building performance.
- Better communication between project team members.
- Reduced construction and warranty issues.

Owners have also identified that the most significant barriers to making commissioning standard industry practice are (in order of importance)<sup>3,4</sup>:

- Lack of budget and perceived high cost.
- Lack of awareness about what commissioning is.

It is virtually impossible to find budget for a perceived high cost process if the process does not present sufficient benefits to justify the costs. Ironically, the less-valued energy financial benefits are relatively easy (but not necessarily trivial) to calculate after the fact than non-energy financial benefits. As such, building owners have been tempted to make a business case for

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<sup>1</sup> Thorne, J. and Baxter, E, *An Assessment of the Market for Building Commissioning in New York State*. National Conference on Building Commissioning, 2001.

<sup>2</sup> Hasl, T., Friedmann, R., Irvine, L., and Baxter, E. *California Commissioning Market Characterization*. National Conference on Building Commissioning, 2001.

<sup>3</sup> Thorne. and Baxter.

<sup>4</sup> Hasl, Friedmann, Irvine, and Baxter.

commissioning by using only projected energy savings numbers. In essence, they are hoping that energy savings alone will be enough to support the cost of commissioning so that they can obtain the more valuable (in subjective terms) non-energy benefits. This may or may not be successful for individual owners, but we'd like to present a methodology and examples for quantifying some of the non-energy financial benefits to supplement the energy savings numbers.

## **Benefits Quantification Approach**

The following three-step process was followed at the Pentagon Renovation to evaluate the financial benefits realized because of the commissioning process.

- Establish metrics.
- Mine the data.
- Derive conservative benefit numbers.

Not every benefit identified could be quantified. In particular, we did not attempt to put a dollar value on improvements or corrections to life safety systems. Additionally, due to the vast quantity of data available, items were prioritized at a high level according to anticipated financial benefits. Further evaluation of the lower priority items would likely yield additional savings but at minimal return on the time required to perform the analysis. Further discussion of this concept and approach is included in the "Mine the Data" section below.

## **Establish Metrics**

The following is an example list of metrics that will prove important to have in order to perform financial benefits calculations. Note that we have included energy-related metrics as well. Not all metrics will be applicable to every facility.

- Building Services / Utilities
  - Electricity consumption unit costs
  - Electricity demand unit costs
  - Gas unit costs
  - Oil unit costs
  - Central chilled water unit costs
  - Central steam unit costs
- Productivity
  - Maintenance supervisor fully loaded hourly labor rate
  - Maintenance worker fully loaded hourly labor rate
  - Average tenant hourly labor rate
  - Value of daily production (i.e., what is the cost of lost "product" if a manufacturing process, data center, or other mission critical activity is unable to function)
- Working Hours

- Normal labor work week (typically 40 hours)
- Production hours (e.g., 2 shifts, 7 days a week, “7x24”, or some other schedule)
- Analysis Timeframe
  - One time effect (if the benefit will only be realized once)
  - Life cycle effect (if the benefit will be realized continuously over a defined period of time)

## Mine the Data

Each individual project, facility operator, and tenant will have different sources of information about system condition, operation, and associated costs. The following are ideas of where to start looking.

- Project data sources
  - Design review comments
  - Prefunctional checklist results
  - Functional test results
  - Commissioning action lists
  - Commissioning meeting minutes
  - “As built” drawings
  - Test and balance reports
  - Operations & maintenance manuals
- Operations data sources
  - Trouble call log
  - Work order log
  - Preventive maintenance records
  - Service contractor reports and invoices

Depending on the size and duration of the project, the amount of raw data could easily number in the hundreds or thousands. In this case, assigning a financial value to every data item may be unreasonable and we recommend prioritizing the data for quantification.

The data will contain a wide variety of benefits ranging from facility-wide recurring issues to one-time equipment problems. The most important aspect of prioritizing the benefits for quantification is being able to assess the extent of the issue. That is, what portion (square footage or %) of the facility will be affected or how many people will be affected and does the issue have the potential to recur. Obviously, an issue that impacts the entire facility on a periodic basis has the potential of being significantly more costly than an issue that only affects one person in a single office one time. Once you are able to make the distinction between major issues and minor issues, you can start to further refine your prioritization efforts.

Based on our experience, there will come a point at which the accumulated benefits have far outweighed the costs. Depending on the reason for quantifying the benefits (i.e., comptroller

justification for commissioning, academic study, extrapolation and application to other projects, etc.), the point of diminishing return could be when your benefits exceed your costs or when the cost of quantifying the benefits of an item outweighs the actual benefit of the item or outweighs the value of quantifying the results.

## Derive Conservative Benefit

As a first step in determining how information or modifications resulting from the commissioning process are beneficial to a building owner, it is helpful to characterize the type of benefit(s) realized. The following are different ways in which commissioning can benefit an owner:

- Project
  - Reduced change orders
  - Reduced requests for information
  - Expedited problem resolution
  - On-time project completion
  - Reduced warranty calls
  - Improved perception of project success

Figure A illustrates the process of calculating the financial savings associated with a benefit that reduces the number of requests for information (RFI) during the construction phase. The theory is that it will take more time to administer an RFI after the design and/or construction is well advanced than to respond to a commissioning comment earlier in the project. This theory is based on the assumption that fewer people are involved and there is less potential rework involved in responding to early commissioning comments.

### Figure A: Example Project Benefits Calculation

**VARIABLES:**

$X_o$  = Labor time to administer one request for information, including reproduction and distribution of the response (hours)

$X_c$  = Labor time to administer one commissioning comment (hours)

$Y$  = Labor cost, fully load (\$/hour)

$Z$  = Number of total commissioning comments likely to have eliminated future RFIs

**CALCULATION:**

$$SAVINGS (\$) = (X_o - X_c) \times Y \times Z$$

- Facility
  - Reduced energy consumption
  - Decreased O&M staff time finding and correcting problems after turnover
  - Decreased O&M budget demand for correcting problems after turnover
  - Improved preventive maintenance
  - Improved predictive maintenance
  - Improved trouble call responsiveness

Figure B illustrates the process of calculating the financial savings associated with the benefit of improving the accessibility and maintainability of a specific system. The logic behind this calculation is that without commissioning the system would be more time consuming and, thus, more costly to maintain. Although the Figure B calculation is only based on O&M staff time, there are some scenarios where the expense of rigging and/or special lifts for accessing the system may need to be added for each regularly scheduled preventive maintenance work order.

This approach can be applied to any benefit that results in a smaller on-going time commitment from the O&M staff. It will also play into one-time expenditures by the O&M staff to correct problems left over from construction.

**Figure B: Example O&M Benefits Calculation**

<p><b>VARIABLES:</b></p> <p><math>X_o</math> = Labor time to perform preventive maintenance procedures <u>without</u> commissioning benefit (hours)</p> <p><math>X_c</math> = Labor time to perform preventive maintenance procedures <u>with</u> commissioning benefit (hours)</p> <p><math>Y</math> = Labor cost, fully load (\$/hour)</p> <p><math>Z</math> = Number of affected systems</p> <p><math>W</math> = Frequency of procedure (procedures/year)</p> <p><math>V</math> = Period of time over which procedure will be performed (years)</p>
<p><b>CALCULATION:</b></p> <p><math>SAVINGS (\\$) = (X_o - X_c) \times Y \times Z \times W \times V</math></p>

- Tenant
  - Staff productivity
  - Process productivity

Figure C illustrates the process of calculating the financial savings associated with the benefit of improving building occupant staff productivity. The example shown is for a scenario where on-going facility conditions (typically indoor quality) decrease personnel productivity due to fatigue, increased break time, increased sick days, etc. The same general thought process would be used to assess the impact of one-time system events that would result in loss of productivity due to power outage, air conditioning system failure, maintenance on non-redundant equipment, etc.

**Figure C: Example Productivity Benefits Calculation**

<p><b>VARIABLES:</b></p> <p><math>X_o</math>= Productive labor time per person <u>without</u> commissioning benefit (hours/week)</p> <p><math>X_c</math>= Productive labor time per person <u>with</u> commissioning benefit (hours)</p> <p><math>A</math>= Number of affected tenants (# of people)</p> <p><math>B</math>= Tenant labor cost, fully load (\$/hour)</p> <p><math>C</math>= Work hours per year (hours/year)</p> <p><math>D</math>= Period of time over which benefit will be realized (years)</p>
<p><b>CALCULATION:</b></p> <p><b>SAVINGS (\$) = <math>(X_c - X_o) \times A \times B \times C \times D</math></b></p>

**Commissioning Costs**

When calculating and tracking the “cost” of commissioning, it is important to be specific regarding how this is defined. Is it the third party commissioning professional’s fees? Is it the owner’s additional cost of project management associated with the commissioning process? Is it the owner’s O&M staff time participating in the commissioning process? Is it an increased construction cost due to the existence of a commissioning process/specification?

There is no industry standard approach to this question. However, for future evaluation and comparison with studies performed by others, the cost definition is key to allowing for apples-to-apples assessments.

## **Benefits at the Pentagon Renovation**

The Pentagon Renovation encompasses over 6 million square feet of mixed use facility, including office, command and data centers, food service, retail, conference and fitness centers, and a medical clinic. The scope of the renovation is a total gut and rebuild of the interior walls, ceilings, vertical transportation, and infrastructure support systems. In addition, there are a few new construction projects associated with other facility projects on the Pentagon Reservation.

Commissioning was introduced to the Renovation Program in 1998 and is expected to continue through the completion of the program in 2011. Commissioned systems include mechanical, electrical, lighting and lighting control, plumbing, building automation, fire alarm, fire protection, and central steam, heating hot water, and chilled water distribution systems.

Although initial projects followed the traditional design-bid-build model, projects since 2001 have been delivered via performance-based design-build contracts.

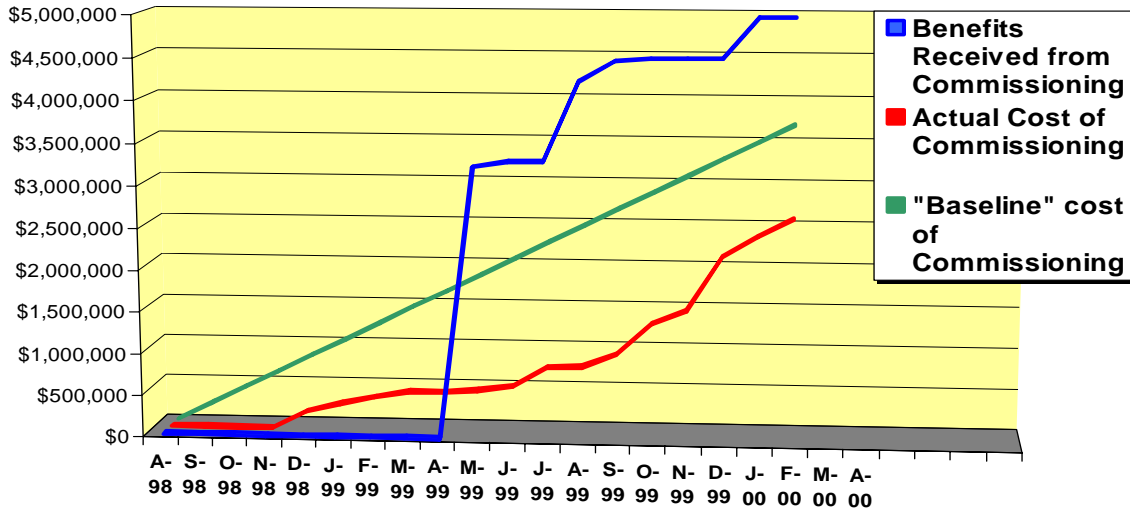
## **Pentagon Renovation Data**

When commissioning was introduced to the Pentagon Renovation Program in 1998, the commissioning specialist was required to develop and maintain a Lessons Learned database to document benefits of commissioning. Over the course of the first 18 months, the database was populated by the commissioning specialist's project managers with issues that the commissioning process had identified and helped resolve each month.

Sixty-eight (68) items were entered into the database and evaluated for their quantitative impact on project delivery costs, future operating costs, and tenant productivity. We were able to calculate savings for 23 of the 68 items, whereas the other items defied quantification primarily due to their impact on life safety and national security issues. The total life cycle (project, facility and/or tenant) cost savings calculated for the relatively small sample set of benefits was over \$5 million.

Figure D illustrates the results of the initial 18 month cost-benefit analysis. The straight (green) line represents the cumulative amount budgeted for commissioning. The lower (red) line represented the cumulative actual cost of commissioning (commissioning specialist fees), and the upper (blue) line represents the cumulative quantified benefits from the database analysis.

**Figure D: Early Commissioning Benefits Evaluation**



At the end of 18 month study period and sharing of these results, there was no longer a need to justify the cost of the commissioning process on the Pentagon Renovation Program. As such, the formal collection and analysis of benefits was discontinued as a commissioning specialist responsibility.

Fast forward six (6) years to 2006 and a renewed interest in learning from and sharing the immense amount of data gathered as a result of the Pentagon commissioning program. We have reached back into our design review comments and commissioning action lists for the individual issues that have benefited the owner as a result of the commissioning process.

Due to the large data set and the limited time available to quantify individual benefits prior to publication of this paper, we have evaluated the data in terms of the categories defined above – Project, Facility, and Tenant benefits – and in terms of when in the project cycle the benefit was recognized, i.e., during the design phase or during the construction phase.

This provides the beginning of a statistical analysis tool for extrapolating the results calculated through detailed analysis of a sample of benefits to the entire data set of benefits. The more benefits analyzed, the more value there will be to the statistical results. The work performed to date has resulted in a database framework which can incorporate the quantification of individual benefits as time and budget allows for the detailed calculations to be performed. Over time the percentage of total benefits evaluated may increase, but it may also decrease, as the total benefits database continues to grow with each day of commissioning at the Renovation.

Currently, the available data for the past six years includes the quantities of benefits realized, as well as the costs of commissioning and cost of construction. With this data we can characterize the types of benefits and when they occur, as well as evaluate any possible correlation between the cost of commissioning and the number of benefits.

In addition, by comparing the available metrics over time (from early Pentagon projects to more recent projects), we may see trends at the Pentagon Renovation that could be predictors of what will happen in the wider design and construction market as commissioning becomes more “business as usual.” The industry as a whole is somewhere mid-way up a learning curve when it comes to commissioning. At the Pentagon, that learning curve is flattening out as the designers, contractors, and project managers have accepted the commissioning process and started to use it to everyone’s benefit. This was a 4-5 year process at the relatively self-contained Pentagon Renovation Program. It may be another 10-15 year process in the wider community, as there are many more variables involved in introducing and facilitating a consistent commissioning process across the full spectrum of design and construction projects.

## **Pentagon Renovation Commissioning Costs**

Table 1 on the following page summarizes commissioning costs as a percentage of construction costs. The projects are arranged in chronological order.

Commissioning at the Pentagon includes a number of value-added items which are not necessarily part of a traditional commissioning process but which have proven to be essential to the Pentagon operations staff. These “extras” increase commissioning cost and are discussed further in the Best Value Commissioning Documentation subsection below. However, there is a trend towards commissioning becoming less costly (as a percentage of total construction) as the Renovation Program has matured. As noted above, we believe this is a function of the Program’s team members accepting commissioning and incorporating it into their project delivery systems over time.

The Phoenix project was the reconstruction of the Pentagon following the 9-11 terrorist attack which occurred at the intersection of Wedge 1 and Wedge 2 at the completion of the Wedge 1 renovation project. The Wedge 1 contractors performed the Phoenix project work immediately after finally “getting” the commissioning process on Wedge 1. The relatively low cost of commissioning on the Phoenix project represents the commissioning team’s most efficient work, as they had climbed much of the learning curve on Wedge 1.

Finally, the major Wedge renovation projects tend to have lower commissioning cost percentages than the smaller projects. This is a reflection of economies of scale and is expected to be true of non-Pentagon Renovation projects as well.

**Table 1: Pentagon Project Construction & Commissioning Costs**

<b>Project</b>	<b>Area (Sq. Ft.)</b>	<b>Cx \$ vs Const \$ (%)</b>
Wedge 1 <sup>1</sup>	1,077,000	0.8%
Remote Delivery Facility	215,000	2.7%
Metro Entrance Facility	21,000	1.1%
Phoenix (9-11 Reconstruction)		0.6%
Wedge 2+ including Basement	1,415,000	1.0%
Pentagon Athletic Center	150,000	1.2%
Pentagon Library and Conference Center <sup>2</sup>	250,000	1.8%
<b>TOTALS</b>		<b>1.0%</b>

<sup>1</sup> Wedge 1 was construction phase commissioning only. It was also the only commissioned Design-Bid-Build project. All subsequent projects were Design-Build.

<sup>2</sup> This project is in early construction at the time of this report. Final numbers are likely to be different.

### **Pentagon Renovation Commissioning Benefits Analysis**

Tables 2 and 3 break down our initial findings, based on a snapshot (partial) 1,519 item database with only 23 of those items quantified to date.

**Table 2: Breakdown of Benefits by Project Phase**

<b>Breakdown of Benefits by Project Phase</b>	
Design Phase	49%
Construction Phase	51%

The Table 2 metrics are still somewhat skewed towards construction phase benefits, because we have yet to incorporate design review comments for some of the Pentagon Renovation projects into our database.

**Table 3: Breakdown of Benefits by Type**

<b>Breakdown of Benefits by Type</b>	
Project Benefit	16%
Facility Operations	71%
Tenants/Productivity	13%

Based on the initial 18 months of benefits (i.e., the initial 68 item database) analysis, Table 4 contains metrics based on the 23 quantified benefits. Our intention is to quantify substantially more benefits in the near future in order that these metrics become more meaningful as averages. The “Overall Cx Cost per Identified Benefit” and the “Identified Benefits per Square Foot” metrics in Table 4 include all identified (not just quantified) benefits through 2005.

**Table 4: Benefits Analysis Metrics**

<b>Overall Cx Cost per Identified Benefit</b>	
Cx Cost per Identified Benefit	\$2,500/Benefit
<b>Benefit Values<sup>3</sup></b>	
\$\$ Value per Quantified Benefit (All)	\$125,000/Benefit
\$\$ per Benefit/Square Feet (All)	\$0.57/Benefit/Sq Ft
\$\$ Value per Quantified Design Phase Benefit	\$200,000/Benefit
\$\$ per Design Phase Benefit/Square Feet	\$0.85/Benefit/Sq Ft
\$\$ Value per Quantified Construction Phase Benefit	\$80,000/Benefit
\$\$ per Construction Phase Benefit/Square Feet	\$0.35/Benefit/Sq Ft
<b>Relative Value of Quantified Design &amp; Construction Benefits</b>	
\$\$ Total Design Phase Benefits per \$\$ Total Benefits	80%
\$\$ Total Const Phase Benefits per \$\$ Total Benefits	20%
<b>Identified Benefits per Square Foot<sup>4</sup></b>	
Square Feet per All identified Benefits	2,000 Sq Ft/Benefit
Square Feet per Identified Design Phase Benefit	4,200 Sq Ft/Benefit
Square Feet per Identified Const Phase Benefit	4,100 Sq Ft/Benefit

**Notes:**

1. “Identified Benefits” are all database items for which a benefit is identified.
2. “Quantified Benefit” is all database items for which a quantified cost benefit has been calculated.
3. These values are likely the most-Pentagon-specific numbers included here. Given the magnitude of the projects, each “issue” identified impacted a very large base project. We have provided the \$/benefit/square foot values in hopes of being more useful to the industry as a whole.]
4. The value of this metric improves as its numerical measure decreases.

The purpose behind normalizing these metrics to building area is to allow other facility owners, most of whom will have significantly smaller buildings, to eventually project and apply these numbers to their proposed projects. **WARNING: The values provided in this paper are intended to illustrate potential metrics, their derivation, and their use. However, the sample size of quantified benefits is too small to be applied with confidence to any other projects at this time. These metrics will be updated prior to the formal presentation at the NCBC 2006 conference and, hopefully, continuously over the next coming years.**

## Commissioning Process Lessons Learned

The commissioning process is relatively new to the design and construction business. As such, the industry is on a steep learning curve regarding how to best plan and implement commissioning. The following are a few lessons learned and recommended best practices from the Pentagon Renovation commissioning team. These are based on the assumption that improving the commissioning process will increase the effectiveness of commissioning while decreasing the human and financial resources required to implement commissioning.

Although the Pentagon Renovation clearly has some unique circumstances, we believe these lessons learned are universally applicable.

### ***Test Sampling Strategies***

The Pentagon Renovation commissioning team learned relatively early on that the requirement of 100% functional performance testing of “like” systems was not necessarily the most effective or efficient use of resources. The Remote Delivery Facility relied on 100% testing, and that contributed to the relatively high commissioning cost as a percentage of total construction cost shown in Table 1 above. Now the Pentagon team only uses 100% testing on mission critical and life safety systems.

Some contractors look at the 100% testing requirement as their license to avoid their own quality control. After all, “The commissioning professional is going to check all our work for us.” A random sampling strategy that motivates the contractors to do an excellent job on *every* system in return for not having to schedule and support 100% testing seems more logical.

The key to this, of course, is in the details. If a certain percentage of sampled systems need to pass their functional performance tests (FPTs) the first time in order to avoid testing the rest of the systems, what is the definition of “pass”? (Refer to subsection on Failure Definition and Management below). What is the right initial sample size? Are there “second chances” to test a larger, but not 100%, random sample after correcting systems that failed the initial round of testing? Also, the schedule needs to allow for the potential added time required if failures from random sampling drive the team to additional testing

Another issue the Pentagon Renovation is addressing deals with systems that have a very small historical failure rate. With a high level of standardization in system design, manufacturers, and contractors, it is possible that – unlike the financial services industry - “past performance *is* an indicator of future results.” In evaluating the required test sample size (or the need to test at all), standardization factors can weigh into the owner’s decision on where to spend commissioning dollars. Low failure rates would likely mean that the contractor’s quality construction processes are working, thus allowing commissioning resources to be focused on other aspects of the project. Secondary voltage transformers, switchboards, and panelboards are examples of systems where sampling rates have been reduced due to low failure rates.

Table 5 lists some typical Pentagon Renovation systems and their associated sampling rates and failure limits. If the initial sample size experiences failure rates greater than the tabulated failure limits, additional testing is required.

**Table 5: Example Sampling Strategies**

System	Sample Rate	Failure Limit
Variable air volume terminal units	20%	5%
Fan coil units	20%	10%
Unit heaters	20%	10%
Fan-powered induction terminal units	20%	5%
Computer room air conditioning units	30%	5%
Secondary voltage transformer	10%	1%
Switchboards/Panelboards	5%	0%

### ***Best Value Testing Strategies***

Care should be taken in differentiating between the contractors' responsibilities with respect to quality control testing and commissioning functional performance testing. Do not let the commissioning professional be drawn into performing the contractors' quality control planning and execution. Functional performance testing witnessed and documented by the commissioning professional is the contractors' demonstration of proper, comprehensive, and integrated operation of each system, which should follow the contractors' quality control process.

The FPT procedures, however, can be used independently (i.e., not with oversight and witnessing by the commissioning professional) by the contractors in developing and executing their quality control and assurance plans. Because the FPT procedures are shared with the contractors early in the commissioning process, they are an "open book test" for which the contractors have months to prepare.

One of the traps commissioning providers should avoid is the request by contractors to conduct partial FPTs. In an ill-advised attempt to show "progress," the contractors may want to check off various test steps as individual parts of the system are completed and programmed by the controls contractor. This results in multiple trips to the field by the commissioning professional and the owner's operations and maintenance (O&M) staff, along with increased documentation, as there is a minimum level of technical and administrative record keeping required after each testing episode. It also requires more overhead effort on the part of the contractors who need to prepare for and staff each site test.

This approach has a financial impact on the owner and the contractor, but, more importantly, piecemeal functional performance testing defeats the purpose of proving integrated *system* performance prior to owner acceptance. An aspect of the system operation which passes a partial FPT could be compromised by system modifications undertaken in completing other aspects to be tested later.

The best use of the combined commissioning team's resources is to have the contractors work on their own to confirm that their systems will pass the entire FPT in a single testing session. This should include running through FPT steps as often as the contractors find helpful. However the commissioning professional should be called in to witness only a complete test procedure after the contractors have full confidence – through their own preparatory testing - that the FPT will pass.

We found that, in a random sampling environment each project team must learn the hard way that failures increase testing which drives up costs. In both Wedge 1 and Wedge 2-5 the contractor went through a learning curve on this fact before they understood the quality control=reduced cost implications of this strategy. Once the lesson was learned the contractor became a champion for better quality control.

### ***Flexibility in Commissioning Approach***

Because the Pentagon Renovation consists of multiple projects of varying size, complexity, and criticality, the need for flexibility when applying the commissioning process to “all” projects is paramount. It is not cost effective or schedule-sensitive to wield a one-size-fits-all sledge hammer at a project that requires a surgeon's scalpel.

It has been important to move from a rigidly defined step-by-step process to a broader understanding of the goals and objectives of commissioning. Bringing the goals and objectives to a level of rigor and cost appropriate to each individual project requires a box of tools from which the appropriate type, size, and quantity can be taken. Individual project commissioning plans at the Pentagon are evolving into a customized set of tools and processes instead of a copy-paste-edit of the original prototypical commissioning plan. As an example of this, the Pentagon team has developed a Commissioning “Lite” Plan for application to small and less critical projects where full-blown commissioning would not be cost effective.

### ***Testing and Verification Techniques for Mission Critical Facilities***

After 9-11 and the anthrax threats in the Fall of 2001, multiple added security and protection requirements were levied on the Department of Defense. Many of these collective protection efforts were incorporated into the renovation designs on-the-fly due to the fast-paced evolution of the requirements. The commissioning process proved once again that a clear design intent and design criteria leads to a clean design and construction which can be effectively commissioned.

In the past year the Pentagon team has commissioned two facilities with collective protection. The first had requirements being finalized as construction was completed and testing was already started, whereas the second had the benefit of the complete design-build process. Needless to say, the second was commissioned cleanly and at minimal cost to all parties. The first had many fits and starts, multiple rounds of testing, and maximum cost to all parties before success was achieved. This underscored our belief that following the standard commissioning process, i.e.,

starting in the design phase, achieves the best success rate with minimal cost, especially on mission critical facilities.

A second impact to keep in mind for mission critical facilities is that upon completion of the commissioning phase the facility will typically be “locked down” in preparation for security verification. Commissioning needs to be truly complete as additional testing or retesting involves security escort and other added costs. Therefore, it is imperative to get it right the first time!

Finally, since mission critical facilities require 100% testing rather than sampling, the schedule needs to recognize the shear volume of testing that will occur. Traditionally in Pentagon projects, construction schedule slippage has impacted commissioning because the tenant move-in dates come right on the heels of commissioning (just in time delivery). With mission critical facilities, the impact of potentially delayed tenant move-ins brings great pressure on the commissioning team to make up time lost in construction. In order not to rush the critically important functional performance and integrated system testing, it is imperative to ensure that the initial schedule recognizes the full complement of tests to be conducted.

### ***Coordination with other Owner-Contracted Suppliers, Contractors, and Consultants***

If possible have the owner purchase the entire construction project from a single entity. At the Pentagon multiple “other Government contractors” (OGCs) are used on each project. This has been done for a variety of reasons, e.g., multiple sources increase competition and standardization of control, fire alarm, information technology and vertical transportation systems across the renovation program. The down side of this approach is that this has added to commissioning and prime construction contractor costs due to added coordination requirements. Perhaps more importantly, this arrangement has complicated and obscured the assignment of responsibility for problems. Because each of the Pentagon construction contracts involve an award fee, the OGCs become an easy target for blame when responsibility for failure is a consideration of the award fee board.

### ***Project Phasing***

The Wedge 1 construction project involved very large areas for each turnover and tenant move-in date. Therefore, that project did not have very many turnovers. However, after the 9-11 terrorist attacks, large building sections were no longer available for construction activities due to the tenant displacements related to the recovery effort. As such, the Wedge 2-5 team has faced a different reality - many smaller areas for turnover resulting in approximately three times as many turnovers. This has the net effect of creating more frequent critical dates for construction and commissioning. Each of these requires added coordination with the construction team, the building operations staff, tenants, and of course, the OGCs. This added churn has increased construction and commissioning costs and complicated scheduling for the team.

## **Failure Definition and Management**

At the Pentagon, where performance metrics are critical to managing immense amounts of data and evaluating team member performance (for allocation of a performance-based award fee), the quantitative definition of “failure” is a topic of much discussion. Currently, the Pentagon is moving towards the following definition: *Failure of any step of the FPT to perform as documented in the FPT procedure.*

Failure of a single step of the test procedure will constitute a failure of the entire FPT. The important lesson learned here is that this applies even to failures that are corrected in the field during testing (categorized at the Pentagon as “passed with corrected measures.”). Although there is no follow-up action item associated with such “corrected” failures, the contractors are evaluated on their ability to pass tests the first time.

When only failures that remain at the end of testing are counted towards a metric, there is huge pressure from the contractor to be allowed to stop the test, correct the problem, retest the failed step, and then move on. Although this should be allowed within reason (a rule of thumb would be to give the contractors 5 minutes to fix the problem), it is likely to be abused if there is a “scoring” incentive to field-correcting deficiencies. Interrupting tests for work that should have been performed as part of the contractor’s quality control program is not a good use of the commissioning team schedule and budget resources. In addition, the abuse of this time allowance, either in duration or frequency, will compromise the value of data gathered in a sampling strategy scenario.

To accommodate schedule demands at the Pentagon, especially in the mission critical environment, the commissioning team sometimes violated the 5 minute rule of thumb. However, it is clear from that experience that one must be careful to prevent this from becoming a habit due to the loss in efficiency and very real impact on the bottom line for each of the commissioning team members.

## **System Un-Readiness for Testing**

Despite all of the best efforts to require Prefunctional Checklists that document system “readiness” for testing, commissioning professionals are frequently called to job sites to witness FPTs on systems that aren’t ready for testing. These tests are determined “failures” before they even begin.

System un-readiness is often apparent before the first FPT step is attempted. In the process of documenting current system status and setpoints, the commissioning professional may find that computer graphics are not complete, alarms haven’t been programmed, communication with a front-end work station isn’t working yet, test and balance coordination of flow and pressure setpoints hasn’t happened, sensors are not calibrated, required interfaces with other systems aren’t complete, etc. In the more egregious situations, electrical power is not hooked up to certain system components or piping to coils or humidifiers is not complete.

In this case, there is often pressure on the commissioning professional from other project team members to proceed with testing anyway. On the surface, because a testing team is present, it is hard to make the argument to have them leave and “waste” the day (or days) otherwise scheduled for testing. Commissioning professionals should not bow to this pressure, and the owner needs to back this position. Continuing with testing on a non-ready system not only takes time that will have to be repeated at a later date when the system is ready, it also results in more paperwork (more deficiencies to track) than a ready system will have. In addition to having a time and cost impact on all commissioning team members, it facilitates the circumvention of necessary quality control processes.

Another more subtle condition of “un-readiness” is associated with the status of other systems in the facility and the integrated nature of today’s buildings. Contractors need to be well coordinated with respect to what is happening simultaneously on multiple systems. For example, they may think they’re all ready for an air handling system FPT but forgot about electrical system quality control tests that would intermittently interrupt power to the air handler. These tests are incompatible, and one of them should be cancelled in order to allow the other test to be conducted efficiently and effectively. If the commissioning FPT is cancelled for this reason, it should be considered a “failure.”

## ***Failure Management***

In most commissioning professionals’ processes, failures are documented in some type of database/action list. We’ll call this the Cx Action List. At the Pentagon, the Cx Action List is diligently populated and tracked by the commissioning professional. The “tracking” process is primarily through regular commissioning team meetings where the status of open action items is reported and documented until corrected and retested.

Every owner’s classic struggle between commissioning and schedule goals is as real for the Pentagon as for anywhere else. In fact, at building turnover it is not uncommon for as many as 8% of all FPTs to remain incomplete for one reason or another. In some cases, 5% of all FPTs remain incomplete for several months after turnover. There is little sense of urgency with respect to correcting deficiencies. It often seems that the team believes that commissioning is complete when the FPTs have all been performed, as opposed to when they have all passed. This is partially due to the owner’s tolerance for failures when it comes to judging the contractor’s performance and evaluating a project for turnover.

The result is a project that is “accepted” by the owner with documented deficiencies for which there are no strongly enforced incentives to correct in a timely fashion. The time spent by the commissioning professional tracking and dealing with action items is excessive when the Cx Action List grows instead of shrinks towards construction completion.

We recommend the development and strict use of test failure metrics when evaluating contractor pay applications. This will involve creative contract requirements that allow withholding payment to contractors based on the metrics. The metrics should not only include a measure of

failure quantity (see previous sub-section) but also the average “life” of unresolved action items. If action items linger beyond a certain time period, there may need to be shift of compensation from the contractor to the commissioning professionals (for unbudgeted, unplanned, and excessive “tracking and handling” fees). It should be noted that Government contracting methodology is particularly unwieldy for implementing this type of compensation transfer.

### ***Training Building Users and Operators***

If there is one predominant lesson learned, it is that the benefits to the operations and maintenance (O&M) staff will only be realized if the O&M staff is interested in representing their own interests in the commissioning process. No one can represent the O&M issues as a surrogate, and there needs to be a commitment on the part of O&M management to taking advantage of the benefits to be gained by active participation in the commissioning process.

Although the commissioning professional can take on responsibility for administrative and logistical coordination activities, the owner’s O&M personnel need to be responsive, if not proactive, in communicating their needs and expectations with respect to operational documentation and training. If there is no input from the O&M professionals, the commissioning professional has to operate in the dark and make his/her best guess as to what is in the best interest of the owner’s O&M staff. Because there is only one best guess and multitudinous possible answers, the commissioning professional will inevitably be wrong in some respect.

If the owner isn’t interested in committing O&M staff resources, effort, and enthusiasm to the commissioning process, the value of incorporating on-going O&M preparation aspects of commissioning into new/renovation project commissioning is questionable. To fully realize these benefits, it may be necessary to undertake a cultural change in the owner’s O&M organization that allows workers to feel empowered to contribute and make a difference in the successful future operation of the new systems.

The owner needs to recognize that commissioning will pull resources away from day-to-day operations. Our experience is that we have had less operator participation over time. The owner was extensively involved in the early training and performance of functional performance tests for Wedge 1 and the Remove Delivery Facility with much less involvement in Wedge 2 and other more recent projects. This could be due to a number of issues, e.g., downsizing limits staff availability, a “been there-done that” attitude, management expectations, etc.

### ***Planning and Scheduling Commissioning***

It is critical to maintain a single master construction schedule which incorporates commissioning activities and milestones. A separate commissioning schedule for which the commissioning professional is responsible will not only be irrelevant in the eyes of the contractor but will be extremely time consuming (i.e., expensive for the owner) for the commissioning professional to maintain in response to the ever-changing and evolving contractor construction schedule.

In instances at the Pentagon where commissioning was decoupled from the master schedule, the owner lost the visibility of commissioning impacts as construction schedules slipped. This was demonstrated in Wedge 2, and best practices gleaned from that experience have led to incorporating commissioning into the master schedule for the Wedge 3 and Pentagon Library and Conference Center projects.

Contractually binding the contractor to incorporate commissioning activities into the master schedule starts with a well defined and enforceable specification. The specification should clearly define which commissioning milestones need to be incorporated into the contractors' schedule and needs to define specific time frames in which the milestones need to be met. The time frames should reference milestones/activities normally found in contractors' schedules, e.g., shop drawing review, substantial completion, etc.

### **Best Value Commissioning Documentation**

The Pentagon operations staff requires that the commissioning specialist and construction contractor provide a variety of documentation during request for proposal (RFP) development, design, construction, and turnover phases of a design-build project. The most significant of these are:

- Performance Requirements and Criteria – Ensure that the owner's requirements for serviceability, maintainability, and operability are incorporated into the design-build contract.
- Design Intent Documents – Ensure that the designer has captured the owner's requirements and are used in FPT development to ensure that the system operates as the designer intended.
- Systems Operations and Maintenance Manuals (SOMMs) including design master equipment lists (DMELs) – Document systems operations and maintenance requirements in a clear, standardized format for the building operator and provide equipment inventories for upload into the owner's computerized maintenance management system and can provide a tested systems/equipment inventory.
- Master Test Procedures for Re-commissioning – Provide the owner with the tools for on-going commissioning.
- Commissioning and Decommissioning Plans - Provide the commissioning roadmap and rules of engagement for the commissioning team from project inception through turnover.
- Training plans, material, and videos – Provide the owner a clear understanding of training to be provided, materials to be received and historical documentation so that future personnel can receive the same level of training.
- Lock-out, tag-out (LOTO) Procedures – Provide the owner with correct procedures for maintaining a safe work environment for maintenance personnel.
- As-Built Drawings – Provide the owner with a clear set of documents so that systems troubleshooting and future modifications are expedited.

As previously stated some of these items are not part of the traditional commissioning process. In each instance the owner has had the commissioning specialist either prepare the documents (filling a gap between the owner's requirement and the design-build contract requirement) or provide a technical review for accuracy and consistency (providing the owner confidence in the documents being developed and submitted by the design-build contractor). Each item adds cost over and above the traditional commissioning cost and is a driver for the cost ratios identified in Table 1. In a best value environment this list can be viewed as an ala carte menu with each owner choosing those additional services that suit the requirements of the individual project.

## Conclusions

Based on our early analysis of a partial, though substantial, database of commissioning benefits, we are comfortable concluding the following general points:

- Design phase commissioning activities have at least as much, if not more, value than construction-phase activities. This does not diminish the value of construction phase commissioning activities but does support the industry's position that best value commissioning starts before or during the design phase.
- The greatest number of benefits are accrued by the facility owner/operator in long term savings. The number of non-facility benefits appears to be split evenly between project cost savings and benefits to the building occupants.
- When the database of benefits with quantified financial values grows to a more meaningful size, we anticipate that the value distribution of the benefits will be different than the quantity distribution. Projecting forward, we believe there will be a significantly greater "value" of commissioning accrued to the building occupants simply due to the fact that occupancy costs (wages and processes) typically far outweigh the costs of constructing or operating a building. Therefore, even a small percentage savings associated with a tenant benefit has the potential of resulting in a large absolute dollar amount. In addition, the tenants are those that will benefit most from the impossible-to-quantify health and life-safety benefits of commissioning.
- We see a trend over time towards decreased commissioning costs as a percentage of total construction cost. This will occur as construction teams become more comfortable with incorporating the process into their projects and realizing the financial benefit accrued to them as a result of participating in a commissioned job. The lessons learned and best practices documented in this paper provide guidance to commissioning teams industry-wide interested in implementing a best value commissioning process.

Our work here has just begun. Benefits to the Pentagon Renovation Program accrue daily; at a much faster pace than we can realistically keep up with quantifying their financial value. However, early numbers from the benefits that can and have been valued indicate that there is no question that commissioning pays for itself very quickly, if not before the construction project is complete.