CASE STUDY VALIDATION OF THE CONTINUOUS VALUE ENHANCEMENT PROCESS

Michael H. Pulaski,[1] Michael J. Horman[2] and M. Jeya Chandra[3]

ABSTRACT

Sustainable building projects have levels of complexity over conventional building projects that challenge current project management tools at efficiently managing the rigors of sustainable projects. The Continuous Value Enhancement Process (CVEP) is a recently developed tool designed specifically for sustainable building projects. This project management tool enables project teams to systematically generate and evaluate project alternatives for meeting sustainable goals. The goal of this tool is to identify high performance solutions that increase levels of sustainability and *improve project performance. CVEP was experimentally implemented and tested on four case study projects to evaluate its ability to support project management decision making in ways that elevate sustainability and project performance. Reported in this paper, the results show CVEP produced first cost and life cycle cost savings. In particular, the study confirms that CVEP has the capability to: 1.) Provide a systematic evaluation process, 2.) Collect high performance building solutions, and 3.) Be applicable to different project types. These results show that it is possible to employ targeted project management techniques, like CVEP, to improve the cost-effective provision of sustainable buildings.*

KEYWORDS

sustainable development, constructability, value engineering

INTRODUCTION

In the rapidly growing field of sustainable design and construction, several tools are now available to assist designers in achieving sustainable project objectives. Analysis tools such as life-cycle costing aid in the selection of building materials and systems that lower total costs throughout building construction and use; while daylighting and energy modeling software help designers to evaluate and optimize the energy efficiency of the building. These tools, and others alike, have provided the project team with vital and necessary information to make decisions on critical design issues.

In contrast to the important research in sustainable design and construction that is focused on developing and refining design tools, very few tools have been developed for the management process of these complex projects. Additional levels of complexity stem from the involvement of more project team members, increased design iterations, incorporation of the results of sophisticated simulation and analysis in the design, higher construction standards, additional site precautions and the use of new and unfamiliar materials. If executed correctly, intensive decision-making is needed on sustainable projects to balance traditional cost, quality and schedule performance against the impacts of building features on energy efficiency, operating costs, the health and safety of building occupants and the amount of waste generated during construction. These additional considerations make decision-making, and consequently the delivery process, more complex and difficult to manage. This leads to delivery process inefficiencies (waste) and may subsequently increase first costs.

One recently developed project management tool, the Continuous Value Enhancement Process (CVEP), aims to provide the project team with a mechanism to help manage the additional levels of complexity present on sustainable building projects. Developed specifically to address the challenges facing the reno-

1. Ph.D., Dept. of Architectural Engineering, Penn. State Univ., 104 Engr. Unit A, University Park, PA 16802. E-mail: michael.pulaski@gmail.com

2. Associate Professor, Dept. of Architectural Engineering, Penn. State Univ., 211 Engr. Unit A, University Park, PA 16802. E-mail: mjhorman@engr.psu.edu.

3. Professor, Dept. of Industrial Engineering, Penn State Univ, 205 Leonard Bldg., University Park, PA 16802. E-mail: mjc3@psu.edu

vation of the Pentagon, the purpose of CVEP is to empower project teams with the necessary management tools to continuously generate new ideas and identify optimal or high performance building solutions. Specifically, this refers to decisions that improve both project performance and levels of building sustainability. In this paper, the effect of CVEP on project performance and sustainable project objectives are analyzed through a multiple case study analysis.

BACKGROUND

On sustainable building projects structured decision-making tools, such as energy modeling and daylighting analysis software programs, are available for evaluating alternatives during early design stages. These structured approaches are employed due to the additional factors and team members involved in each decision. The most widely used method is life cycle cost analysis (LCCA) which is used to calculate the total-cost-of-ownership associated with installing, operating, maintaining and disposing of products materials or systems. Lower the life cycle costs associated with certain decisions, improve the attraction of those decisions. This type of analysis is typically used for selecting major systems and equipment in buildings, such as the (HVAC) system.

While decisions regarding the selection of systems are made with structured approaches, detailed project decisions (those involving the selection of sub systems, components, elements and construction details) use less structured approaches. Typically these decisions are made based on intuition or a simple pros and cons analysis. These less structured methods are simple and easy to use however they can create process waste by facilitating arguments over subjective criteria and allowing unnecessary research to be performed. Although several structured methods exist to evaluate high performance building decisions, these are primarily focused on early design issues or occur only periodically on projects. More structured decision making tools are needed to guide project teams through the evaluation of detailed project decisions.

Value Engineering (VE) is one widely used rigorous systematic effort to improve value and optimize the life cycle cost of a facility (Dell'Isola 1997; Green and Popper 1990). This differs from constructability improvement efforts which focus on simplifying the construction process by removing unnecessarily difficult demands on the contractor (Soibelman et al. 2003). Significant benefits can be realized through VE practices. For large construction agencies the program cost for VE is between 0.1-0.3% of total project costs which results in a minimum of 5-10% initial costs savings and another 5-10% in life cycle cost savings (Dell'Isola 1997; Green and Popper 1990). VE provides a structured approach to identifying project solutions that improve project performance and increase levels of sustainability on building projects.

Lean production methods were developed in manufacturing, mainly through the Toyota Production System, to improve the efficiency of the production processes and eliminate the concept of waste, or *muda*. Womack and Jones (1996) identified five lean principles; accurately specify *value*, identify the entire *value stream*, make value creating steps for specific products that *flow* continuously, let customers *pull* value from the enterprise, and strive for *perfection* through continuous improvement or *kaizen*. Application of lean principles in the construction industry has resulted in significant improvements to project performance (Freire and Alarcon 2002; Tommelein 1998; Tsao and Tommelein 2001). These principles can also be used to improve the process of delivering projects with sustainable goals.

The highly evolved practices of continuous improvement, or *kaizen*, in companies that have applied it over many years are just now being understood. Spear and Bowen (1999) in an in-depth study of the core activities of the Toyota Production System, showed how a core behavior of Toyota employees is the search for continuous improvement in their work. Time is carved out of their busy schedules to examine new opportunities for improvement. What is noticeable is their disciplined use of the "scientific method" to systematically hypothesize and test potential improvements. Crucially, they manage to strike a balance between providing rigid parameters for completing work, and giving flexibility to identify better methods. Toyota's success proves the power of this approach, and construction can learn much from it to advance its efforts in continuous improvement.

CONTINUOUS VALUE ENHANCEMENT PROCESS

CVEP is a project-level process designed to continuously extract ideas from project team members and quickly assess the impact of each potential solution on project performance and sustainable building objectives (Pulaski and Horman 2005). Drawing together previous research on methods to improve value engineering, constructability, lean production, and continuous improvement, CVEP enables project teams to harness the knowledge and competencies of owners and construction professionals at generating solutions to meet owner priorities. Specifically the research sets out to develop a process that was designed to perform four primary functions. First, provide a systematic process for evaluating alternative project solutions. Second, collect high performance building solutions which are defined as those which improve project performance *and* enhance levels of sustainability. Third, accurately and concisely describe the potential impact a decision has on overall project performance. Fourth, facilitate the generation of ideas that produce first cost and life cycle cost (LCC) savings. By performing these functions, CVEP then provides a systematic, replicable, and documented process to evaluate the potential impact of generated ideas on the project.

The five-step CVEP process model is summarized in Figure 1 using IDEF0 format. The first step is to create the CVEP organization which involves two separate teams: 1.) The CVEP Project Team generates potential value enhancements (PVEs); and, 2.) the CVEP Oversight Team evaluates the PVEs for applicability to the project and the CVEP Project Team's accuracy at defining the effect of the PVE. In the second step, the project values or priorities are determined by the owner using the CVEP Weighting Matrix (a tool developed to determine weighted factors for each category). In step 3, PVEs are generated and assessed by the CVEP Project Team to determine the likely impact (positive, negative or no impact) on performance compared to a base case (industry standard or existing practice). The specific rating system instructions, assumptions and justification for determining the likely impact are fully described in Pulaski and Horman 2005. Impacts are assessed by completing estimations (e.g., of costs) of the PVE in different performance categories. There are eight performance assessment categories, four representing project performance (first cost, quality, schedule and process effi-

FIGURE 1. Continuous Value Enhancement Process model.

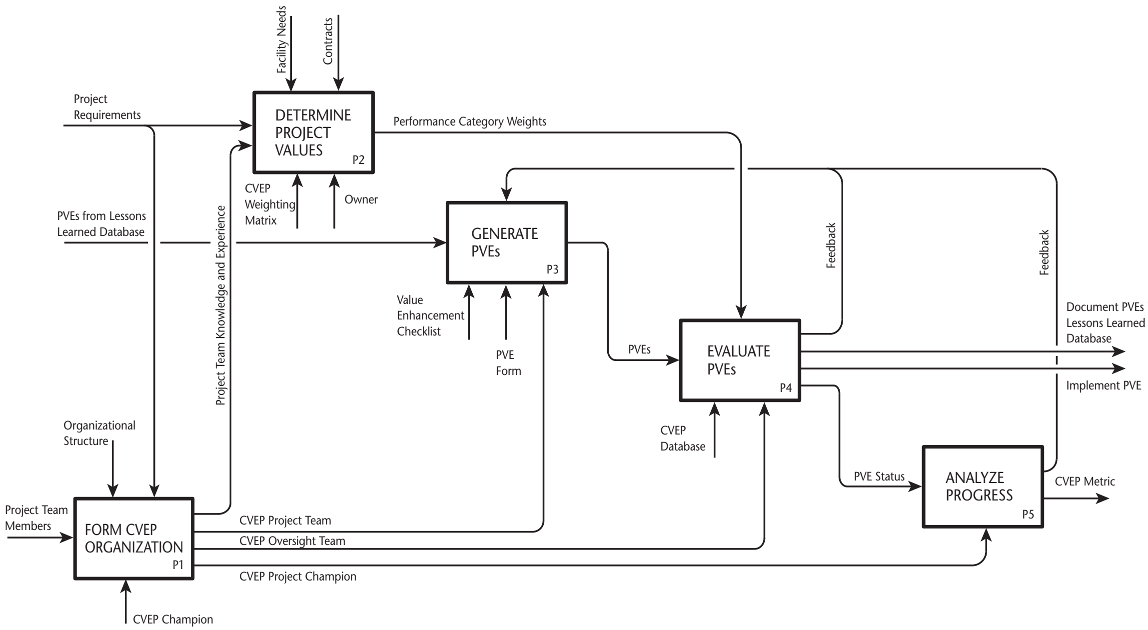


FIGURE 2. Sample Potential Value Enhancement assessment.

1. **Project:** Early Childhood Learning Center
2. **PVE Title:** SIPS Roof Panels
3. **Description:** Compare contractor-installed Agriboard SIPS in lieu of volunteer-installed R-controlled roof panels. The insulation material in Agriboard is compressed straw. The insulation material in R-controlled SIPS panels is EPS foam.
4. **Cost Estimate:** $6.50/sq. ft. for Agriboard; $7/sq. ft. for R-Control
5. **Assess Impact to Project (Provide Short Description or Reasoning):**

Note: Detailed descriptions of each category can be found in the CVEP information packet

Weight	Rating	(+) Positive; (-) Negative; (0) No Impact
0.107	-	**First Cost:** $2,360 extra shipping for Agriboard + Contractor fees
0.107	+	**Quality:** Higher quality due to contractor installation
0.107	0	**Schedule:** Both products can be installed at a similar pace
0.250	0	**Process Efficiency:** Similar amount of effort required for both
0.143	0	**Life Cycle Cost:** Both have high R-values
0.214	+	**Safety/Health:** Contractor installation reduces safety hazards
0.036	0	**Maintainability:** Both have similar maintenance characteristics
0.036	+	**Resource Use:** Agriboard is made of compressed straw vs. EPS foam
0.250	**Total weight score**	

If you had the chance to evaluate this idea on your next project, when would be the ideal time to incorporate this example into the project?

6. **Timing of Decision:**

RFP Schematic Design 15% **35%** 50% 75% 95% 100% Design Documents

Construction Documents Procurement Construction Commissioning

ciency) and four representing sustainability (life-cycle cost, safety/health, resource use and maintainability). Each category has a definition describing the objective criteria for making an assessment (Pulaski and Horman 2005). A sample assessment of a PVE is provided in Figure 2. The fourth step is where the CVEP Oversight Team evaluates the performance ratings, cost estimate, and timing of decision of each PVEs for accuracy. Additionally, this team provides comments based on their expertise, performs further research if necessary and determines if the PVE should be implemented on the project and entered into the lessons learned database for reference on future projects. In the final step, the PVEs are entered into the CVEP Metric and reported on a regular (e.g., monthly) basis to the Project Manager and Senior Management.

The CVEP Metric provides information about the focus and quality of effort by the project team at balancing project performance with sustainable building objectives. A sample CVEP Metric is provided in Figure 3. The metric is calculated by summing the relative impacts (+1, –1) of the PVE's in each rating system category and totals are plotted on a graph. This metric is vital. Ideally, teams should be striving to find solutions that produce peaks on both sides (project performance and sustainability) of the graph, while focusing on those areas of highest priority to the owner. When this occurs, project teams are able to increase levels of sustainability *and* improve project performance, rather than pursuing one or the other as commonly occurs on current projects. The CVEP Metric provides a mechanism to clearly measure and summarize this emphasis and enables project teams to make adjustments as necessary as they continue through the project.

METHODOLOGY

The goal of the research is to evaluate whether CVEP increases the levels of project sustainability *and* improves project performance. A multiple case study approach using experimental design allows CVEP to be implemented and tested in different project conditions (i.e., project scope). Propositions are devised about the effect of CVEP on the project that are then scientifically tested (Yin 1994). The propositions stem directly from the intended primary functions of CVEP. The research aims to analytically demonstrate that CVEP performs these functions.

The validation process for the model, summarized in Table 1, uses independent data to compare actual project outputs with anticipated model outcomes. The first phase of conceptual validation evaluates the conceptual framework of the model which assesses the ability of CVEP to perform the first two intended functions. If the model output exceeds the established criteria, then the model is validated (Fellows and Liu 1997). This methodology parallels the procedure for establishing construct validity on case study projects (Yin 1994). A second phase of validation is the numerical phase, which demonstrates the accuracy of the data collected and impact CVEP has on key performance measures. The final external phase examines the ability of CVEP to be applied on other projects outside of the Pentagon renovation.

Case Study Projects

Project I: Pentagon Renovation Wedges 2-5. The Wedges 2-5 project is a phased design-build renovation of 4.5 million square feet of office space in the Pentagon. The scope of work includes removal of all hazardous materials, replacement of all building systems, the addition of new elevators and escalators to improve vertical circulation, and installation of new security and telecommunications systems. The project is a complex office renovation and is on target for

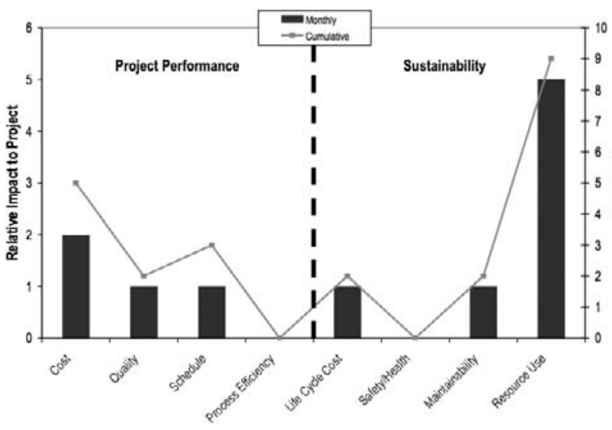


FIGURE 3. Sample CVEP metric.

TABLE 1. Summary of data collection and analysis methods.

Phase	Purpose	Proposition	Data Collection Instruments	Dataset	Data Analysis Techniques	Data Analysis Method
Conceptual	Demonstrate ability of the model to perform the intended functions	1. Ability to provide a systematic evaluation of key performance impacts for project decisions	CVEP database	Comments and actions, field notes	Comparative analysis, hypothesis testing	Compare five criteria of TPS to CVEP
		2. Capability of collecting high performance building solutions	CVEP database	PVE ratings	Sign test, hypothesis testing	Sum PVE ratings for project performance and sustainability. If Sum > 0 then record as a success
Numerical	Demonstrate the accuracy of data and impact on key performance measures	3. Ability to accurately describe the impact each PVE has on the performance attributes	CVEP database, focus group, questionnaire, documentation review	PVE ratings, PVE description for 'new' PVEs or 'in review'	Hypothesis testing	Compare original PVE ratings to the rating of comparable examples by independent research team
		4. Capability of producing first cost and life cycle cost savings	CVEP database	'New' PVEs from Proposition 4	Documentation review	Provide first cost and LCC savings information
External	Demonstrate applicability on other projects	5. Potential to be implemented on different project types	Questionnaire (Project IV)	PVE assessment	Hypothesis testing	Appropriateness of descriptions and performance ratings

Silver certification under the U.S. Green Building Council's LEED rating system.

Project II: Ancillary Project. The Ancillary Project consists of a cluster of small projects (typically under $5 million) on the Pentagon reservation. The majority of projects involve renovating "swing" space (or temporary office space) in areas throughout the Pentagon. Additional projects involved upgrading the central heating and refrigeration plant and electrical feeders to the Pentagon building.

Project III: Remote Delivery and Metro Entrance Facilities. In addition to the Wedges renovation, further projects were undertaken at the Pentagon including the construction of a new Remote Delivery Facility and Metro Entrance Facility. Essentially designed to protect the Pentagon from attack, these facilities enhance the secure delivery of packages and arrival of people to the Pentagon.

Project IV: Early Childhood Learning Center. The American Indian Housing Initiative (AIHI) is a collaborative partnership between Penn State University, University of Washington and Chief Dull Knife College. In 2005, this partnership using a multidisciplinary college-level course in sustainable methods, including strawbale construction, designed and built an Early Childhood Learning Center on an American Indian Reservation (Grommes 2005).

Data Collection

CVEP was experimentally implemented on the case study projects and data was collected through participant-observation. Both qualitative and quantitative data were collected in this research, including a description of each PVE identified, the impact ratings to each performance category and explanations, the comments of and actions taken by the CVEP Oversight team, and other items on the PVE form (Figure 2). The primary instruments for collecting data were focus group interviews, the PVE form and the CVEP database. Secondary instruments including, archival records and questionnaires were used to collect supplementary data.

The data collection process for Projects I, II and III followed the general procedures outlined in the following five steps. The procedure for collecting data on Project IV varied slightly as described below.

1. Solicit participants for CVEP Project Team.
2. Explain CVEP to project team. A 45-minute *CVEP Training Presentation* was provided to all participants prior to the first CVEP Team meeting.
3. Conduct focus group interview meetings with CVEP Project Team members. Discuss upcoming design and construction issues and opportunities to improve the project.
4. CVEP Project Team members identify PVEs and complete the PVE form.
5. CVEP Oversight Team evaluates each PVE for accuracy and completeness.

The following steps outline the data collection procedure for Project IV.

1. An overview presentation of CVEP was provided to the participants.
2. One week after the overview presentation, participants submitted an initial CVEP evaluation of an alternative material, system or design.

Data Analysis

Statistical Procedures. Hypothesis testing was employed to evaluate the impact of CVEP on the project. The purpose of the hypothesis test is to provide sufficient evidence to reject the null hypothesis (H_0) and accept the alternative hypothesis (H_A) (Ott and Longnecker 2001). In this analysis, the null hypothesis (H_0) reflects the most straightforward reason for a particular phenomenon. When there is a lack of an existing precedent (as is the case of this research), the most straightforward reason is often defined as chance, meaning that a particular relationship identified between two variables is due to no other reason than chance. By contrast, the alternative hypothesis (H_A) is typically aligned with an identifiable reason other than chance for the relationship. Thus, the purpose of the hypothesis tests in this analysis is to observe whether chance can be eliminated and CVEP accepted as the reason for any improvements in the levels of sustainability and project performance.

The data collected from the research is analyzed using success rate analysis (Ott and Longnecker 2001). Success rate analysis is used to study events where there are only two possible outcomes—success or failure. Importantly, this analytical procedure allows the probability of success of a given phenomenon to be determined. In this analysis, the statistic $\hat{p}$ (probability for a sample or estimated value) is used in the hypothesis tests. The parameter p is the estimated probability for a population, i.e., it is the p of the pooled sample $\hat{p}$ (Ott and Longnecker 2001). In this research, p is the success rate in all possible project teams and $\hat{p}$ is the success rate of Project I, II, and III individually. These case studies are representative of the larger population of project teams and represent the sample proportion $\hat{p}$. The sample proportion $\hat{p}$ is known as a good estimator for the population proportion (p). Given $\hat{p}$, the intervals where p would lie with high probability can be estimated and this is defined as the Confidence Interval (CI).

In general, the equation for the approximate 95% CI has the following structure:

Estimated Mean Value

$$\pm Z_{0.025}\sqrt{\frac{Variance(Estimated\_Mean\_Value)}{n}} \quad (1)$$

The right side of the "±" is the "Margin of Error" or "Maximum Possible Error" (Hogg and Tanis 2001). In this research, the success rate analysis is used which follows a Bernoulli distribution where the outcomes are classified as either a success or failure. In a Bernoulli distribution, x has estimated mean value of $\hat{p}$ and variance of $\hat{p}(1 - \hat{p})$. When these values are substituted into Equation (1), the resulting equation for the 95% Confidence Interval is:

$$\hat{p} \pm Z_{0.025}\sqrt{\frac{\hat{p}(1-\hat{p})}{n}} \quad (2)$$

where $\hat{p} = x/n$, $\hat{p}$ = estimated mean probability, x = number of successes, n = sample size, $Z_{0.025} = 1.96$ (confidence coefficient for 95% Confidence Level). Therefore, when interpreting the results, we claim with 95% confidence that the population success rate (p) lies between

$$\hat{p} - Z_{0.025}\sqrt{\frac{\hat{p}(1-\hat{p})}{n}}$$

and

$$\hat{p} + Z_{0.025}\sqrt{\frac{\hat{p}(1-\hat{p})}{n}}$$

for a specified number of successes (x).

Since this is a new experimental investigation, there is a lack of an existing precedent to compare the results to, thus making it difficult to select a standard value. However, in a Bernoulli distribution, the probability of success occurring "by chance" is 50%; the same as flipping a coin. Thus, 0.50 was selected as the standard value. Each analysis is designed to demonstrate that with 95% confidence the probability of success occurring "by chance" is minimal or insignificant. Recognizing that this is a conservative value, the research seeks to demonstrate that the stated propositions do not occur by chance, they occur, (at least) to some extent because of the use of CVEP. This is a conservative approach, but the only way to be scientifically sure that CVEP has effected levels of sustainability and project performance.

The *null hypothesis* (H_0) seeks to prove that the probability of the proposition occurring is by chance, therefore H_0: $\hat{p} = 0.50$. The *alternative hypothesis* (H_A) is always in support of the proposition, and aims to demonstrate that the probability of the proposition being successful is greater than 50%, therefore H_A: $\hat{p} > 0.50$. This research is not concerned with CIs less than 0.50, as this does not provide any conclusive evidence, and therefore useful information. The lower bound limit of the 95% Confidence Interval (CI) is the statistic used to determine if H_0 can be rejected and H_A accepted. Therefore the *evaluation criterion* for each analysis is, if the lower bound limit of CI is larger than 0.50, there is sufficient evidence reject H_0 and accept H_A. This means that with 95% confidence the proposition is satisfied, thus indicating that CVEP possesses the specific capability under study in the particular hypothesis test.

Devised Propositions. Propositions to test specific capabilities of CVEP are analyzed using hypothesis testing through a comparative analysis. Comparative analysis is commonly used in qualitative research to compare empirically based descriptions with predicted ones (Patton 2002).

Proposition 1: CVEP provides a systematic evaluation process. The Toyota Production System (TPS) was selected as the base model for a systematic evaluation process because of the great success this system has had over the years (Shingo and Dillon 1989; Spear and Bowen 1999; Spear 2004). Although there are numerous principles to TPS, the systematic evaluation of alternatives through explicit use of the scientific method is a crucial element to its success (Liker 2004). The system demonstrated significant achievements, shortening lead times by 48%, improving productivity by 53% and enhancing quality by 65% while reducing the engineering hours spent during product development by 48% (Womack et al. 1990). The TPS provides a good benchmark of a well-documented and proven systematic evaluation process to assess the systematic nature of CVEP.

Each PVE is evaluated against the five criteria established in Table 2. A success ($x = 1$) is noted if the data supports the evaluation criteria (i.e., the answer to the question is "yes"). If there is not sufficient evidence to support the question (i.e., the answer is "no"), a failure is noted ($x = 0$). Data from the "comments" and "actions" assigned to each PVE, as well as CVEP Oversight Team meeting minutes and the investigators field notes were used to evaluate the criteria for each PVE collected in the study.

To determine if CVEP is aligned with the TPS, the following null hypothesis (H_0) and alternative hypothesis (H_A) are defined:

H_0: $\hat{p} = 0.50$, CVEP is not aligned with TPS

H_A: $\hat{p} > 0.50$, CVEP is aligned with TPS

TABLE 2. Pattern matching criteria for comparing TPS evaluation process to CVEP

Key elements of TPS evaluation process	Further explanation of TPS process	Research evaluation criteria
Finding out what is really going on, including *genchi genbutsu*	Go and see it for yourself to thoroughly understand the situation	Was a site visit conducted to see the issue on hand or, originator contacted to ensure a thorough understanding of the PVE? Or, during the review process was someone on the CVEP Oversight team familiar with PVE?
Understanding underlying causes that explain surface appearances—asking "Why" five times	The 5 whys is a method to pursue the deeper, systematic causes of a problem to find correspondingly deeper countermeasures	If the suggestion indicates a problem with the current design, was the root cause of the problem identified? (Note: may not be applicable to all suggestions)
Broadly considering alternative solutions and develop detailed rationale for the preferred solution	N/A	Were additional solutions identified or new information brought to the table in the evaluation of the PVE?
Building consensus within the team including Toyota employees and outside partners	Feedback is solicited from all different perspectives, including individuals without the applicable technical background	Was input provided by individuals who did not have the same technical background as the originator?
Using very efficient communication vehicles to do one through four, preferably one side of one sheet of paper	Simple visual approaches are almost always used. This helps to streamline the consensus building process	Was the analysis kept to 1 page?

where $\hat{p} = x/n$, $\hat{p}$ = estimated mean probability for the *combined criteria*, x = total number of successful criteria, n = total number of applicable criteria.

Proposition 2: CVEP collects high performance building solutions. The first proposition evaluates the capability of collecting high performance building solutions; those which improve project performance *and* enhance levels of sustainability. To evaluate this capability, the ratings of PVEs for project performance (P) categories are compared to the ratings for sustainability (S) categories. By assessing the ratings in category groups, CVEP can be assessed on whether ideas being identified are balanced between project performance and sustainability. A success is defined if the sum of (P) ratings *and* the sum of (S) ratings are greater than zero ($\Sigma P > 0$ and $\Sigma S > 0$). The null hypothesis (H_0) and alternative hypothesis (H_A) are defined as:

H_0: $\hat{p} = 0.50$, CVEP does not collect high performance building solutions

H_A: $\hat{p} > 0.50$, CVEP does collect high performance building solutions

where $\hat{p} = x/n$, $\hat{p}$ = estimated mean probability of success for *all projects*, x = number of PVEs where $\Sigma P > 0$ and $\Sigma S > 0$, and n = total number of PVEs.

Proposition 3: CVEP accurately describes performance impacts. This proposition seeks to demonstrate the ability of CVEP to accurately describe the performance attributes of each PVE. The purpose of this proposition is to demonstrate that the performance impacts assigned to the PVEs as part of the CVEP procedure are accurate. This is done by demonstrating consistency with equivalent ideas that have been implemented on other projects and proven elsewhere.

Documented cases of "green" buildings and value engineering studies were reviewed to identify comparable PVEs in terms of application, scope, size and general theme (RS Means 2002; Dell'Isola 1997; Mendler 2001; Mendler and Odell 2000; Wilson et al. 1998). Comparable PVEs were identified for 23 of the 41 applicable PVEs. An independent research team was assembled to evaluate each comparable PVE and rate the impact on the CVEP categories. Participants were selected from the graduate students studying construction management in the Architectural Engineering Department at Penn State University. For each category, if the original PVE rating (1, 0, –1) matched the comparable PVE rating from the independent research team, a success was recorded. The null hypothesis (H_0) and alternative hypothesis (H_A) are defined as:

H_0: $\hat{p} = 0.50$, CVEP does not consistently describe the impact PVEs have on the performance categories

H_A: $\hat{p} > 0.50$, CVEP consistently describes the impact PVEs have on the performance categories

where $\hat{p} = x/(n \times 9)$, $\hat{p}$ = estimated mean probability of success for *all projects*, x = number of successful matches of performance categories between original PVE rating and comparable PVE, n = total number of PVEs used in the analysis.

Proposition 4: CVEP produces first cost and life cycle cost savings. The fourth proposition seeks to show the ability of CVEP to produce solutions that improve first cost and generate life cycle savings. Actual first cost and life cycle cost savings from new PVEs implemented on the case study projects is reported. Cost data was gathered from a review of documentation and unstructured interviews with project team members. Rather than setting a hypothesis and threshold values for this proposition, qualitative analysis is used to evaluate this proposition. The proposition is satisfied if there is sufficiently compelling descriptions of the first cost and life cycle cost savings achieved through CVEP.

Proposition 5: CVEP is applicable to different project types. The purpose of this proposition is to analyze the external applicability of the tool on a project outside of the Pentagon renovation. CVEP was implemented on an entirely different type of project from the first three case study projects. The goal of CVEP implementation on Project IV replicates earlier case study projects; identify optimal solutions that improve project performance and increase the level of sustainability. The proposition analyzes the appropriateness of the descriptions and performance ratings assigned. The ratings and descriptions from the PVE assessment are examined for accuracy by the lead project manager (course instructor) and by the research investigators. A success was recorded if the (positive or negative) rating assigned was appropriate *and* a logical description was provided that aligned with the definition for the respective category. The null (H_0) and alternative hypothesis (H_A) for this analysis are:

H_0: $\hat{p} = 0.50$. The descriptions and performance ratings are not appropriate

H_A, $\hat{p} > 0.50$. The descriptions and performance ratings are appropriate

where $\hat{p} = x/(n \times 9)$, $\hat{p}$ = estimated mean probability of success, x = number of appropriate ratings and descriptions, and n = number of PVEs returned by students.* If there is sufficient evidence to reject H_0 and accept H_A, then the analysis shows students clearly understood the CVEP categories, properly evaluated the PVEs, thus providing evidence that CVEP was successfully implemented on the project.

RESULTS

Systematic Evaluation Process

The results indicate that CVEP successfully satisfies the criteria for a systematic evaluation process. Illustrated in, Figure 4 the results show that at a 95% CI, the lower bound limit for the "combined criteria" (0.66) is higher than the standard value $p = 0.5$. With this result, the null hypothesis (H_0: $p = 0.5$) can be rejected and the alternative hypothesis (H_A: $p > 0.50$) accepted. Thus, concluding with 95% confidence, CVEP is aligned with the TPS process indicating the CVEP evaluation process is systematic.

Collect High Performance Solutions

The results indicate that CVEP successfully facilitates the collection of high performance building solutions. This research defines high performance building solutions as those which improve project performance *and* increase levels of sustainability. The

* n is multiplied by 9 to arrive at the total sample size because 9 CVEP categories were used for this project, thus there are 9 possibilities for success when evaluating each PVE.

FIGURE 4. 95% confidence intervals comparing CVEP to TPS.

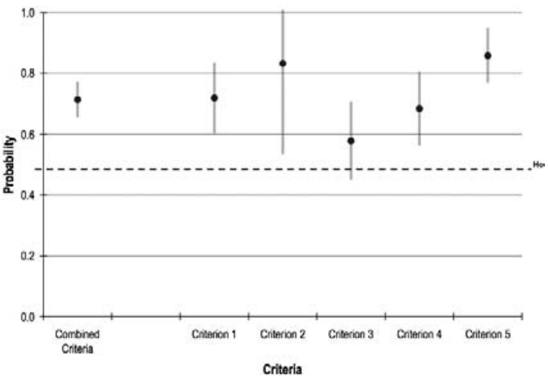
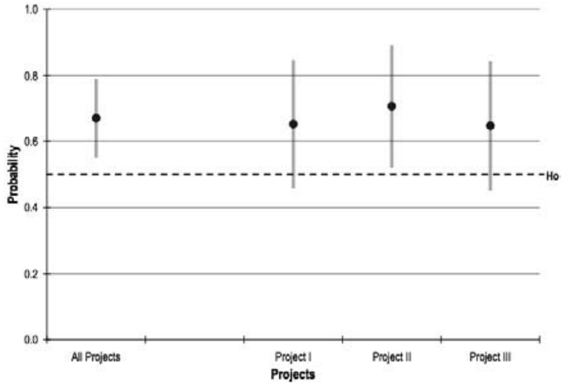


FIGURE 5. 95% confidence intervals for collecting high performance solutions.



results are presented in Figure 5. The lower bound probability for all projects (p = 0.55, n = 57) is greater than the standard value, p = 0.50. This provides sufficient evidence to reject the null hypothesis (H_0: p = 0.50) and accept the alternative hypothesis (H_A: p > 0.50). Thus, satisfying the criteria for this proposition, it is concluded with 95 % confidence that CVEP has the capability of collecting high performance building solutions.

Accurately Describe Performance Impact

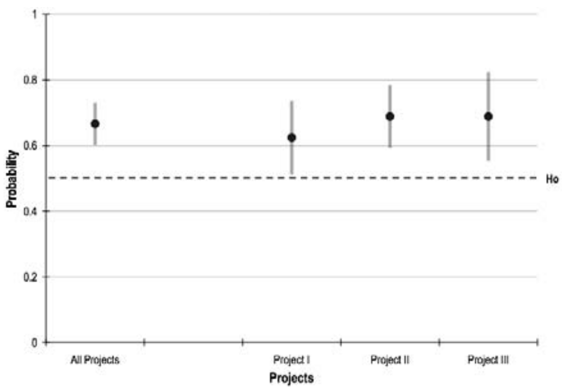
The ability of CVEP to accurately describe the impact each PVE has on the performance attributes is illustrated in Figure 6 at 95% CI. The lower bound limit for all the projects (p = 0.60) is larger than the standard value (p = 0.50), thus providing sufficient evidence to reject null hypothesis (H_0: p = 0.50), and support the alternative hypothesis (H_A: p > 0.50). This means that with 95% confidence, the performance ratings collected in the study were consistent with ratings assigned to comparable ideas by an independent research team between 60% and 73% of the time. This demonstrates the ability of CVEP to accurately describe the impact each PVE has on the performance measures.

Produces First Cost and Life Cycle Cost Savings

The implementation of CVEP over a four-month period generated two "new" ideas that produced first cost and life cycle cost savings at the Pentagon. Two ideas may not seem to be a significant number of ideas generated however; the power of these ideas lies in the size of savings generated and the ability to effect *both* first and life cycle costs. Verified cost data for each example is presented in the ensuing descriptions.

The watt-hour meter is a device used by electrical engineers to measure the amount of power entering a space over a given period of time. Prior to purchasing this device for \$2,000 as a result of PVE #27, the team would hire a consultant to conduct a load survey to determine the capacity power usage in a particular space. This function can now be self-performed, eliminating the need for hiring a consultant and will conservatively save an estimated \$1,500 for each survey. In the four months since the device was acquired, it was used six times, producing an estimated savings of (6 × \$1500 – \$2,000) \$7,000. This information

FIGURE 6. Consistency of PVE ratings at 95% confidence interval.



was verified from unstructured interviews with two electrical quality assurance specialists at the Pentagon. Over the next seven years, the anticipated savings is estimated to be $189,000 (7 years × 18 uses/year × $1500 savings/use).

The watt-hr meter has an additional application that will continue to generate far greater savings over the next seven years. This device is capable of determining how much power a tenant actually uses. This is important as the requested (designed) power requirements are typically well over (300%) what is actually needed. Knowing the actual electrical load required for a given space, enables the project team to downsize, or "right-size" the electrical equipment based on actual loads, not estimates. The electrical quality assurance manager at the Pentagon estimates this application will reduce each project's initial cost by $15,000. With an anticipated 18 projects per year, the device has the potential to save *$1,890,000* over the next seven years. In addition, life cycle costs savings will be realized from reduced equipment size, less maintenance and fewer replacement costs.

Several reusable materials and a number of outlets for salvageable products were identified from PVE #6 on Project III. This led to the discovery of 36 historic wooden suite entry doors and frames (42" × 89") that were salvaged and donated to a local non-profit organization for reuse. The doors are valued at $4,035 each and weigh 175 lbs. Although additional time and effort was necessary to remove the doors from site, waste removal and disposal fees were reduced. In addition, salvaging materials contributed to a Leadership in Energy and Environmental Design (LEED) Credit for "Construction Waste Management." Although it is uncertain if first cost savings were realized from this PVE, the contractor did receive a sizable tax deduction of $145,260 for their donation. More importantly, the contractor now has established a working relationship with this local non-profit organization and will continue to donate reusable materials throughout the entire renovation of the Pentagon. These examples suggest that only a small number of ideas need to be generated to have a significant impact on project first and life cycle costs.

Applicable to Different Project Types

The results from the final proposition indicate that participants provided appropriate descriptions and performance ratings for the PVEs collected from Project IV. The analysis identified 97 successes (x) from a total sample size (n) of 126 possible ratings. The lower bound limit of the 95% CI was determined to be 0.70. This result provides sufficient evidence to reject the null hypothesis (H_0: $p = 0.50$) and accept the alternative hypothesis (H_A: $p > 0.50$). This means that with 95% confidence the descriptions and performance ratings assigned by the participants were appropriate, thus satisfying this aspect of the proposition.

DISCUSSION

The results from the research demonstrate three significant issues. First, CVEP is capable of actually impacting the performance of a project by facilitating the generation of new improvement ideas that would not have otherwise surfaced. Nine new ideas were identified and two were actually implemented on case study projects. The second is that single decisions can enhance both sustainability and constructability performance on building projects. The research identified 38 high performance building solutions that exemplify these significant decisions. One new idea generated through CVEP was the watt-hour meter which enabled an immediate first cost savings of $7,000 and additional life cycle cost savings of potentially $2 million over the next seven years. Third, the research shows that existing project management practices can be adopted to manage sustainable objectives and generate synergies in performance outcomes.

Several outcomes of the research appear to be closely aligned with other current project management practices and research findings. For example, one very successful continuous improvement program that focuses primarily on improving constructability has generated over 33,600 ideas and saved approximately $51,800,000 (Jones 2004). The mean acceptance rate of this program is 67%, which is just below the mean approval rating for CVEP (72%), indicating CVEP is comparable to this program and may be slightly more efficient at generating valid ideas for improvement. Several value engineering studies have reported on the ability to generate first cost and life cycle cost savings (Dell'Isola 1997; Green and Popper 1990) and this capability of CVEP was demonstrated in the analysis. In addition, CVEP possesses some characteristics of the state-of-the-art knowledge management and lessons learned systems. The Army Corps of Engineers utilizes an internet-based design review checking process (DrChecks) and a corporate lessons learned system that is very similar to CVEP. This system collects tacit knowledge from personal experiences, success stories, and good work practices and transposes them into an explicit form to guide future projects. A team of experts review potential lessons learned just as the CVEP Oversight team reviews the PVEs. According to Soibelman et al. (2003), 88 out of 139 potential lessons learned were approved by the team of experts resulting in an acceptance rate of 63%, which is less than the CVEP acceptance rate (72%). Given the rigorous systematic nature for the evaluation of PVEs, this comparison indicates CVEP may be more efficient at extracting lessons learned from project team members. The critical difference between CVEP and these other industry-accepted programs is the ability of CVEP to integrate several practices (i.e., constructability, sustainability, value engineering, knowledge management) into one model that produces comparable, or in some cases, superior outcomes than current project management practices. For high performance sustainable projects, where project challenges impede current PM tools, this is a significant advancement.

One other noteworthy observation is the influence of several lean production characteristics encapsulated in CVEP. Specific lean elements include the *systematic* nature of the evaluation process, the ability to define *value* and strive for *perfection*. The results from the second proposition demonstrated alignment between the TPS systematic evaluation process and CVEP, illustrating its ability to efficiently follow the scientific method when evaluating alternative solutions. Additionally, CVEP provides a mechanism to define *value* on a project and focus team decisions on those ideas which increase value. Value is explicitly identified through the eight categories and tailored to each specific project with the CVEP Weighting Matrix. The resulting weighted factors objectively define value on the project and are used to determine how well aligned each idea is with the specified project priorities. This function was applied during the implementation of CVEP on Project IV to assist the design team in determining which ideas to implement on the project. CVEP also provides a method to strive for *perfection* in the building industry through continuous improvement. Just as the Toyota Production System provided a mechanism to stop the production line and fix a defect, CVEP carves time out of a project to identify ways to make improvements. These lean production elements are engrained in CVEP. This is important as it provides a method to integrate them into current project management practices.

CONCLUSION

Results of the detailed case study investigation show CVEP produced first cost and life cycle cost savings. The results also show that CVEP provides a systematic method to capture ideas and evaluate them effectively. Furthermore, the results show that CVEP collects high performance building solutions, accurately describes the performance impact, improves project performance and is applicable to different project types. The capabilities of CVEP were evaluated by assessing the validity of a number of propositions crafted to directly assess the use of this project management tool on sustainable projects.

As sustainable project development continues to mature, new ways to achieve environmental objectives while improving project performance must be discovered. Further studies should apply CVEP to additional projects for extended periods of time. Further research should continue to cultivate and exploit the relationship between "lean" and "green" project delivery to maximize project value while minimizing the resources consumed to achieve it. Additional research is also necessary to examine the optimal methods for stimulating project team members to identify alternative solutions and the team dynamics associated with process. To continue the advancement and growth of sustainable projects, opportunities to streamline the delivery process must also be identified.

REFERENCES

Dell'Isola, A. (1997). *Value Engineering: Practical Applications ...for Design, Construction, Maintenance and Operations*, RSMeans CMD, Kingston, MA.

Green, S., and Popper, P. (1990). *Value Engineering: the Search for Unnecessary Cost*, Charter Institute of Building, Ascot.

Grommes, A. (2005). "Sustainability Education for the Built Environment: An Educational Model and Case Study," Penn State University, University Park, PA.

Fellows, R., and Liu, A. (1997). *Research Methods for Construction*, Blackwell Science Ltd., Oxford.

Freire, J., and Alarcon, L. (2002). "Achieving Lean Design Process: Improvement Methodology." *Journal of Construction Engineering and Management*, 128(3), 248-256.

Hogg, R., and Tanis, E. (2001). *Probability and Statistical Inference*, Prentice-Hill, Inc., Upper Saddle River, New Jersey.

Jones, D. (2004). "E-mail Correspondence with the Director of Continuous Improvement, Hensel Phelps Construction Company."

Liker, J. (2004). *The Toyota Way*, McGraw-Hill, New York.

Mendler, S., and Odell, W. (2000). *The HOK Guidebook to Sustainable Design,* John Wiley and Sons, Inc., New York.

Mendler, S. (2001). "The Greening Curve: Lessons Learned in the Design of the New EPA Campus in North Carolina." EPA 220/K-02-001, U.S. Environmental Protection Agency.

Ott, L., and Longnecker, M. (2001). *An Introduction to Statistical Methods and Data Analysis*, Wadsworth Group, Pacific Grove, CA.

Patton, M. (2002). *Qualitative Research and Evaluation Methods*, Sage Publications, Thousand Oaks, CA.

Pulaski, M., and Horman, M. (2005). "Continuous Value Enhancement Process." *Journal of Construction Engineering and Construction Management*, 131(12), 1274-1282.

RSMeans (2002). *Green Building: Project Planning and Cost Estimating*, Construction Publishers and Consultants, Kingston, MA.

Shingo, S. and Dillon, A. P. (1989). *A study of the Toyota production system from an industrial engineering viewpoint*. Productivity Press, Cambridge.

Soibelman, L., Liu, L., Kirby, J., East, W., Caldas, C., and Lin, K. (2003). "Design Review Checking System with Corporate Lessons Learned." *Journal of Construction Engineering and Management*, 129(5), 475-484.

Spear, S. and Bowen, H. K. (1999). "Decoding the DNA of the Toyota production system." *Harvard Business Review*, (September-October), 96-106.

Spear, S. J. (2004). "Learning to lead at Toyota." *Harvard Business Review*, (May), 78-86.

Tommelein, I. D. (1998). "Pull-driven scheduling for pipe-spool installation: simulation of lean construction techniques." J*ournal of Construction Engineering and Management*, 124(4), 279-288.

Tsao, C., and Tommelein, I. (2001). "Integrated Product-Process Development by a Light Fixture Manufacturer." 2001 Annual Conference on the International Group for Lean Construction (IGLC-9), Singapore.

Wilson, A., Uncapher, J., McManigal, L., Cureton, M., and Browning, W. (1998). *Green Development Integrating Ecology and Real Estate*, John Wiley & Sons.

Womack, J. P., and Jones, D. (1996). *Lean Thinking*, Simon & Shuster, New York.

Womack, J. P., Jones, D. T., and Ross, D. (1990). *The Machine that Changed the World: The Story of Lean Production*, Harper-Perennial, New York.

Yin, R. (1994). *Case Study Research Design and Methods*, SAGE Publications, Thousand Oaks.