



Construction Industry Institute®

Global Project Controls and Management Systems

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Construction Industry Institute

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GLOBAL PROJECT CONTROLS AND MANAGEMENT SYSTEMS

by

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The University of Texas at Austin

A Report to
Construction Industry Institute
The University of Texas at Austin

Under the Guidance of
CII Research Team 244
Global Project Controls and Management System

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Executive Summary

The Project Controls and Management Systems (PCMS) includes the people, processes and tools for the planning and execution of all phases of capital projects including, but not limited to, Estimating, Cost Control, Planning, Scheduling, Change Management, Progressing, and Forecasting. PCMS has received scant research in the last two decades and there is a popular impression that the principles of PCMS has changed due to many trends, such as the use of information technology, globalization, graying of PCMS, etc. To update PCMS knowledge, the Construction Industry Institute (CII) chartered a research team of project controls experts. The research team reviewed modern PCMS practices, identified areas that need improvement, and provided recommendations and guidance for improving PCMS.

The research team concluded that the principles of PCMS functions that were established in the 1970s and 1980s are still valid today. However, the environment that modern day construction projects operate in has changed dramatically and PCMS need to adapt accordingly. The research team provided recommendations regarding how to adapt PCMS to modern project environment, as well as how to improve interface management, forecasting, and PCMS learning and development.

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1. INTRODUCTION

1.1 BACKGROUND AND NEED

A Project Controls and Management System (PCMS) is indispensable to the success of a construction project. Project Controls and Management System (PCMS) includes the people, processes, and tools for the planning and execution of all phases of capital projects including, but not limited to, estimating, cost control, planning, scheduling, change management, progressing, and forecasting.

Although cost and schedule systems have been used and documented since 1900, the rise of project controls came from the late 1950s, when DuPont developed the Critical Path Method (CPM) in 1957 and U.S. Navy developed Performance Evaluation and Review Technique (PERT) in 1958 (O'Brien 2006). Lead by the Department of Defense, the emphasis was shifted to standardization of systems and techniques in the 1960s (Morris 1982a). By the late 1970s and 1980s, the industry started to see mega projects and international work, which demand more versatile and effective project management and controls. By the early 1980s, with aid of hardware and software development, project control system became an integral part of the project life cycle – from initial planning to start-up/commissioning (Ibbs et al. 1987). CII research from the 1980s contains some of the most detailed work completed to date on project controls, but, with limited exceptions like other research and publications, this work has not been updated. Similarly, recent academic textbooks and trade association guides contain concepts and procedures that are largely identical to the 20 plus year old research publications. Changes in our projects and practices require a comprehensive re-examination of the PCMS research.

The Construction Industry Institute (CII) chartered the Global Project Controls and Management System (PCMS) project in 2006 with the main purpose of reviewing

and updating PCMS knowledge. The CII research team that was convened was comprised of sixteen industry members with a total of 489 years of experience. The majority of CII's PCMS related studies were from the 1980s. Many changes have taken place in the industry since then. Advancements in computer hardware and software have revolutionizes how PCMS functions are implemented. Globalization has created new opportunities and challenges for owners and contractors. Other factors, such as the demography of PCMS personnel, also affect PCMS. Given the many changes in the construction industry, there is a perception that PCMS practices and systems have changed.

1.2 PURPOSES, OBJECTIVES, AND LIMITATION

The purpose of the research is to provide a comprehensive review of modern PCMS and provide guidance to owner and contractor companies as they seek to adopt best practices. Essentially, the research team seeks to answer three main questions: 1) what is the current state of PCMS practice within CII member companies, 2) are the principles of PCMS practice still valid today, and 3) what changes are required to reflect modern needs and capabilities in the industry. Some specific objectives include:

- Document the state-of-the-practice of PCMS as implemented by CII member companies with specific reference to issues of global teams, innovative delivery systems, integration of work packaging, differences between small and large projects, and related staffing issues.
- Identify the principles of the PCMS processes and highlight improvements necessary to address a more diverse, innovative and global industry.
- Evaluate existing CII research and implementation publications related to PCMS and make recommendations for their disposition.

- Provide a recommendation of the core competencies necessary to meet best practice.

Since PCMS is a very broad topic, the research team set some boundaries at the beginning of the research project. First, this research focused primarily on CII member companies, which are generally large owner and contractor organizations. Also, the research team decided not to focus on the information technology aspect of Project Controls and Management Systems.

1.3 REPORT STRUCTURE

After introducing the research topic in this chapter, a comprehensive review of PCMS-related literature is presented in Chapter 2. The literature review seeks to summarize the developmental history of each PCMS function as well as presenting some commonly used methods. Then, Chapter 3 details the research methodology. Chapter 4 describes the research process and results of the PCMS Survey and Impact Workshop. Chapter 5 presents the thirteen trends affecting PCMS, their implications, and the research team's recommendations on how to adapt the PCMS program. This chapter also includes details of the validation effort for the thirteen trends affecting PCMS. Chapter 6 presents the research team's recommendations on improving PCMS functions as well as the results and lessons learned from the validation of PCMS Functions Self-diagnostic Assessment Tool. Chapter 7 and 8 details the results and lessons learned from the validation of recommendations for Best Practice Interfaces and Best Practice Forecasting. Chapter 9 concludes the report by summarizing the research findings.

2. RESEARCH METHODOLOGY

The research team RT 244, Global Project Controls and Management Systems, was broadly chartered to provide an update to the project controls research conducted by CII in the 1980s. To address this broad charter, the research team first sought to understand what had changed since the 1980s and then identify specific areas of focus. This divided the research into two phases, first, an exploratory or descriptive phase and second, a more prescriptive phase.

The first exploratory research phase addressed two research questions:

1. What has changed in project controls compared to the original CII research?
2. What is the current state of project controls implementation?

The research team sought to address these questions in a broad manner rather than an exhaustive catalog of detailed differences. In particular, the team was interested in understanding if there were fundamental differences in project controls as detailed in the early publications and modern practice today.

A variety of methods were used to answer these questions. First, the team conducted a review of the current CII literature and compared the principles and practices detailed therein against modern practice as observed by the team. This was augmented with a broader literature review to detail both historical and current practice. The goal of this review was to highlight significant similarities as well as differences. A specific charter from CII was also to provide feedback on the existing CII publications with recommendations about the relevance of those publications; this research method also allowed the team to comment on the publications.

The team also took a systematic approach to delineate the scope of project controls and management systems by defining a set of seven functions that are applied across the project phases FEP (Front End Planning), Design, Procurement, Construction, and Start-up. These functions were delineated both as a service to the industry (the team did not find a consolidated set of definitions) and as a mechanism to systematically explore the range of project controls practice. In particular, two surveys were conducted to support both research questions. First, a survey was generated to be given to CII member companies about the state of project controls practice. The second survey was conducted within the RT 244 research team in response to the first survey.

The first survey (PCMS Survey) was distributed to CII member companies at the Fall 2006 CII Board of Advisors (BOA) meeting. Respondents either took the survey at the meeting or brought it back to their companies to answer with input from project controls professionals. This PCMS survey asked companies to assess the state of their PCMS along each function and phase (except FEP) with respect to procedures and processes in place, information technology systems that support the processes, and core competency training for the function. Respondents were also asked to assess the quality of the transition or handover of project controls information between phases. Additional questions were asked with respect to the state and position of project controls within the company, specifically with respect to whether or not the company has a dedicated controls group and whether or not PCMS functions are centralized. Final questions were directed to ask whether the company is investing in its PCMS processes, technology, and training. The survey was developed with the RT 244 team with respect to content and wording to ensure comprehension by industry respondents. Once the survey results were compiled, the results were distributed to the team in a group meeting to allow comment and discussion.

While the PCMS survey primarily addressed research question 2 (state of current project controls practice), a second survey was conducted to assess the relative importance of PCSM functions within each phase (e.g., the estimating function during design is likely more important than it is during startup) as well as to help indicate specific areas of changes. For each function and phase, two questions were asked: First to rate the importance of the function within the phase to project success. Second, assess the degree of changes to this function over the past 20 years. Both questions had responses setup in a Likert scale manner. This survey was distributed to RT 244 team members during a group meeting. The survey was distributed as a workshop (“impact workshop” where questions were asked for each question responses were immediately tabulated via an electronic survey tool. Responses were displayed on the screen for the team (split between owner and contractor team members) and allowed discussion of the results. This discussion was captured by the academic research teams as notes for each question.

The results of the literature review, BOA survey, and impact workshop helped the team identify broadly what has changed in PCMS practice, what the current state of practice is, and where practice has changed. As detailed below, main findings are that while the form of PCMS practice has evolved, the principles of PCMS methods remain the same. While CII member companies show strength in some PCMS functions, several remain relatively weak: Change Management, Progressing, and Forecasting. Core competency training was also seen as an area of uniform weakness.

Based on the findings from the first phase of research, the research team identified a series of focus areas for further exploration. In a brainstorming session, twelve potential focus areas were identified. Listed in not specific order, these twelve were the following:

1. Training

2. Change management, progressing, forecasting, and work packaging
3. Tool complexity and the ability to distill useful information
4. Impact of project delivery and contracting strategies
5. Impact of owners pushing PCMS responsibilities to the contractor
6. Characterization of best practice handovers between phases
7. Reporting requirements
8. Global teams
9. Differences between small and large projects
10. Perception differences of PCSM between owners and contractors
11. Centralization vs. decentralization
12. Comparing project controls implementations from multiple companies.

The initial twelve can best be considered as a characterization of the research teams' considered concerns with PCMS practice as augmented by the survey findings. These initial twelve were voted upon in multi-vote process as well as discussed extensively with respect to the actual need and questions that the focus area was addressing. Four focus areas were developed that represent a consolidation of the twelve. These consolidated areas are:

1. Impact of project conditions on PCMS execution. With a research finding that the principles of PCMS have not changed but implementation has, this area seeks to understand the influences of modern project execution on PCMS practice and make recommendations for improvement. Many of the twelve areas first identified fall within this consolidated focus area.
2. Interface management. Interface management (including handovers) between PCMS functions within and across companies is seen as an area

of deficiency in current practice and the team sought to develop tools that would improve practice.

3. Best practice forecasting. Forecasting, progressing, and change management were identified as PCMS functions that required improvement. This focus area sought to better understand current forecasting practice and identify recommendations for improvement. Progressing was seen as ancillary to forecasting (better forecasting would improve progressing), and change management was found to have sufficient extant research that the team did not need to focus on it.
4. Learning and development for PCMS. This focus area sought to distill wisdom from the team and the extant literature regarding recommendations for firms to establish or improve core competency training on PCMS functions. Core competency training is meant to be distinct from tool training such as how to enter activities with scheduling software.

Each of these focus areas was addressed by a sub-group of the research team as well as an academic member of the team. While each area has distinct research questions, the research methodology followed the following process for each area:

1. First, refine and develop scope with the responsible sub-group. Determine specific research objectives. Draw from literature review as needed.
2. Develop within the sub-group an initial set of propositions/findings/tools. Gain feedback from the larger team at meetings. Broadly, development of findings is a modified form of the Delphi process where experts calibrate their understanding of needs in a series of structured discussions.

3. From 2, refine and repeat development as necessary to develop a research product and/or observations that the team collectively endorses.
4. Verify the research findings using experts outside the team (to accomplish external validation). Outside experts would deploy the tools and comment on the research findings. Comments from the outside experts were used to refine the tools and discussion.

These steps ensure that the research products developed by the team underwent a rigorous development process where there were several checks to ensure feedback by both the larger team and outside experts. This helped to calibrate the research by ensuring that the depth of experience from the team was captured while also providing for input from those outside the team to limit potential problems with group-think and to expand and enhance the research findings and tools. Details of the development and validation processes for each focus area, except the Learning and Developments for PCMS focus area, are discussed in the following sections of this report. The details of the Learning and Development for PCMS focus area are not included in this document because the work primarily focuses on implementation rather than research.

3. LITERATURE REVIEW

The literature review chapter is divided into two sections. The first section talks about the Project Controls and Management System (PCMS) functions with light to the different literatures available, while the second half of this chapter provides a review of some of the CII documents pertinent to PCMS.

3.1 PROJECT CONTROLS AND MANAGEMENT SYSTEM (PCMS) AND ITS FUNCTIONS

Project Controls and Management System (PCMS) functions have been used and studied since the beginning of the twentieth century if not earlier, starting with the estimating profession and the development of the Gantt chart in the 1910s. The 1950s, marked by the development of CPM (by DuPont) and PERT (by US Navy), was an important era for PCMS (O'Brien 2006). Then, in the early 1960s, US Secretary of Defense Robert McNamara ordered a review of project scheduling and control systems, which lead to the standardization of systems and techniques within the Department of Defense (Morris 1982b). The Cost/Schedule Control Systems Criteria (C/SCSC) was introduced in 1970 and popularized the use of the earned value method for progress measurement. During late 1970s, an increasing interest in “front-end analysis” developed in DOD (Morris 1982b).

The 1980s marks the widespread use of personal computers and the start of development of project controls-related programs. The computer technology decreased the amount of time it takes to perform project controls function drastically, but it also created the problem of information overload for project managers and project controls personnel, who are challenged with the task of identifying useful information. The 1980s was also when the Construction Industry Institute (CII) formed and started to study

PCMS functions as a coherent system. Throughout the late 1980s and 1990s, CII lead the effort in studying many PCMS functions, the most noticeable areas include pre-project planning, schedule reduction, and change management.

PCMS includes the planning, change management, estimating, scheduling, cost control, progressing, and forecasting functions. The first part of this chapter aims to provide a brief history of the development of each of the PCMS functions and highlight the prevalent methods for those functions.

3.1.1 Planning

Planning is one of the most fundamental functions of a Project Controls and Management System. Planning is the process of choosing the method and order of work to be adopted for a project to achieve the optimum results (Antill and Woodhead 1970). Another way to put it is planning is a process of deciding what to do and how to do it before it is done. Good planning is paramount for the effective execution of a construction project.

Planning is a complicated process that requires the participation of many people, including but not limited to the project manager, superintendent, project engineers, project controls personnel, contract engineer, owner representatives, design leads, subcontractors, etc. Planning also requires the project team to make decisions on many aspects of project execution. Nine areas that may require planning include engineering and method, organization and contract, schedule, cost and cash flow, major equipment, site layout logistics, work methods, manpower (Laufer et al. 1993).

The planning process on a contraction project can be roughly divided into four stages: pre-project planning or front end planning, pre-bid planning, pre-construction planning, and planning during construction. Pre-project planning starts with a project concept for a business need, ends with a decision of whether to proceed with detailed

design, and encompasses all the tasks in between those points (Gibson et al. 1995). The pre-project planning process can be summarized into four steps, including organize for pre-project planning, select project alternatives, develop detailed scope definition of a project, and decide whether to proceed with the detailed of the proposed project (Gibson et al. 1995). Pre-bid planning is performed by a contractor to prepare for bid submission (Laufer et al. 1993). Pre-construction planning, which usually lasts less than three months, starts from contract award to a certain point in the construction process (Laufer et al. 1993). Construction planning focuses on anticipating and overcoming possible field problems in advance and providing solutions to current problems and delays to meet overall objectives (Barrie and Paulson 1992).

Pre-project planning has been a popular area of study in the last two decades. It is widely recognized that early project phases have a significant impact on project outcomes while the ability to influence project outcomes diminishes as the project moves into execution. Lead by Gibson, researchers at The University of Texas have conducted five major studies on pre-project planning, which found that the pre-project planning process can positively impact project performance by enhancing the predictability of project outcomes and improve cost and schedule (Gibson Jr et al. 2006). In the early 1990s, Laufer conducted a comprehensive study to study the involvement, effort, plan issuance, and formats of the pre-bid planning, pre-construction planning, and during-construction planning processes (Laufer et al. 1993). More recently, Menches evaluated the relationship between pre-construction planning and project performance and established a model pre-construction planning process for electrical contractors (Menches et al. 2005) (Menches and Hanna 2006).

3.1.2 Change Management

A change is any event that results in a modification of the original project scope, schedule, cost, or quality of work (Ibbs 1995). Change is one of the major worries of a contractor or owner; it can cause significant increase to project duration and cost (Ibbs 1997). Five general types of change are change in scope, differing site conditions, delays, suspensions, and accelerations (Ibbs 1997). Changes can also be classified into anticipated change, a change that is planned for ahead of time and processes as intended, and emergent change, a spontaneous change that arose out of situations that were not intended or anticipated (Hallock 2006). Since change cannot be avoided, it must be effectively managed. Change management is the process of effectively identifying, evaluating, decision making, and monitoring new or revised work in a planned, expeditious, and systematic fashion.

Literature on the topic of change can be grouped into four categories, legal issues, cost and schedule impacts, analytical models for representing changes and their impacts, and methods for managing changes (CII 1991). The Construction Industry Institute (CII) has been a leader at studying the magnitude and impact of change as well as how to effectively manage changes. CII detailed the research findings regarding the impact of changes in three reports from 1991 (CII 1991), 1995 (CII 1995a), and 2001 (CII 2001). Through the process of studying the quantitative impacts of change, CII research team developed a vision of a comprehensive change management system (CMS). The change management system (CMS) is based on five principles of effective change management, including 1) promote a balanced change culture, 2) recognize change, 3) evaluate change, 4) implement change, and 5) continuously improve from lessons learned (CII 1994; Ibbs et al. 2001). A balanced change culture can be created through three steps: 1) committing all parties to recognize change, 2) planning for potential changes early, and 3)

establishing consensus that changes should be evaluated and agreed to expeditiously (CII 1994). Most recently, Ibbs lead an effort to quantify the effect of changes on labor productivity (Ibbs 2005; Ibbs et al. 2007).

3.1.3 Estimating

Estimating is perhaps the oldest PCMS function; estimators were once considered the center of the project universe (Radford 1919). Perhaps because the estimating profession has been established for more than a century, its practices and principles are well established and documented in the textbooks published from the 1970s to the 1990s. Recent research related to estimating focused on automation and integration of estimating with computer technology, such as CAD (Karshenas 2005; Underwood 1997).

Estimating is the art and science of predicting the cost, time, and resources to deliver a scope. It's important to recognize that estimates are approximations based on the estimator's judgment and experience.

There are three main types of estimates, conceptual/preliminary estimates, detailed estimates, and definitive estimates (Barrie and Paulson 1984). Conceptual and preliminary estimates are usually based on very little, if any design or drawings (Siddens 2001). The purpose of this estimate is to assist the owner decide whether to proceed with the project. Most of the existing conceptual and preliminary estimating methods use one or more of the following methods: time-referenced cost indices, cost-capacity factors, component ratios, and parameter costs (Barrie and Paulson 1992). Detailed estimate usually takes place after most or all of the detailed design work is complete. This estimate has two components, direct cost and indirect cost. Direct cost is the product of quantity takeoff and unit costs while indirect cost includes equipment, home-office overhead, profit, escalation, contingency, etc. The definitive estimate is usually developed with the

detailed estimate plus an evaluated contingency to cover anticipated changes; it forecasts the final project cost with little margin of error (Barrie and Paulson 1984).

An estimate is composed of estimating of quantities, which is accomplished by utilizing an estimating method, and estimating of the unit price to be applied to the quantities, which is arrived at through gathering and analyzing of data (Clark and Lorenzoni 1978). The most commonly seen methods of estimating include the following: time-referenced cost indices, cost-capacity factors, component ratios, parameter costs, and the detailed approach. Time-referenced cost indices document changes in cost, technology, methods, productivity, and inflationary trends over time. If applied properly, such indices can yield accuracies within 20 to 30 percent of actual costs and can provide this information with almost negligible time and effort (Barrie and Paulson 1992). Cost-capacity factors reflect the nonlinear increase in cost with size, scope, or capacity of projects of similar types. Component ratios refer to the “equipment-installation-cost-ratios” or “plant-cost-ratios” techniques that can be used once price quotations from manufactures can be obtained. The parameter cost approach, also called the unit area/volume cost, relates all costs of a project to a few physical measurements (e.g. gross floor area) that reflect the size or scope of that project (Kassabaum 1967). Sophisticated firms often maintain their own records as well as use published sources. The detailed approach is based on the specific requirements of the project rather than the average project, where the cost estimator collects quantities, vendor quotations, execution plans, etc. and translates these data into the estimate of what it will cost to build the project (Clark and Lorenzoni 1978).

3.1.4 Scheduling

Scheduling is the determination of the timing of the operations comprising the project and their assembling to give the overall completion time (Antill and Woodhead

1970). Scheduling has been in use since when Henry L. Gantt and Frederick W. Taylor popularized their graphical presentations of work versus time in the early 1910s (O'Brien 2006). Then, in 1956, the E. I. du Pont de Nemours Company developed a Critical Path Method (CPM) schedule for a ten million dollar chemical plant in Louisville, Kentucky, using a UNIVAC computer (Gould 1997). At about the same time, the U.S. Navy Polaris program developed its own network system known as performance evaluation and review technique (PERT) (Antill and Woodhead 1970). On the Polaris program, neither cost nor time could be accurately estimated. Therefore, the contractors were asked to estimate their operational time requirements on three bases: optimistic, pessimistic, and most likely date. These estimates were then mathematically assessed to determine the probable completion date for each contract. By the 1970s, the value to computerize CPM has been proven; the acceptance of CPM was facilitated by several factors, including adoption of CPM in engineering school curricula, dramatic increase in construction litigation that cite delay as a reason for damages, and dramatic evolution in computer capabilities (O'Brien 2006). Since the 1980s, the widespread use of personal computer-oriented scheduling programs decreased amount of time required for scheduling dramatically and allowed the widespread use of scheduling software. Now, CPM scheduling has become a standard project control tool for both owners and contractors (Galloway 2006).

Recent research on the topic of scheduling concentrate on three areas, improving scheduling methods through statistical approaches (Yamin 2001) (Nassar et al. 2005), schedule coordination and integration, and schedule reduction techniques. Construction Industry Institute (CII) has studied schedule reduction techniques in 1988 (CII 1988), 1995 (CII 1995b), and 2004 (CII 2004).

3.1.5 Cost Control

Cost control is vital to the success of a construction project because it provides the opportunity to initiate remedial action and increase the chance of eliminating overruns or minimizing their impact. Cost control requires the project controls personnel to determine whether activities are currently under, on, or over budget and schedule, what the trends are, and what the sources of difficulties might be (Neil 1985). Once the unfavorable situations or trends are discovered, corrective actions need to be taken. The three purposes of construction cost control include (1) to provide a means for comparing actual with budgeted expenses and thus draw attention, in a timely manner, to operations that are deviating from the project budget, (2) to develop a database of productivity and cost performance data for use in estimating the costs of subsequent projects, and (3) to generate data for valuing variations and changes to the contract and potential claims for additional payments (Bennett 2003; Halpin 1985);.

The four main elements that make up an effective cost control system are budget development, incremental cost reporting, quantity reporting, forecasting (Bessa 1983). Developing a budget is the first step to setting up the basis for cost control. After reviewing the contract documents to determine the project scope, the project team should develop the work breakdown structure for the project and select the control work packages that serve as the framework for the control schedule and budget. Each control account is then analyzed to determine amount of work, work methods, crew size, duration, and other resource requirements (Neil 1985). The project logic diagram should also be developed using the control work packages as activities. The schedule is generated when the logic diagram is combined with durations and the budget is generated when the schedule is loaded with resources. The schedule and associated budgets become the baseline for control. While the budget is the baseline for control, incremental cost

reports provide comparisons between the budget and the actual cost of work performed and its corresponding resource type. The incremental cost report, often done weekly, would include direct and indirect labor costs, material costs, equipment costs, subcontract costs, and change orders (Burgess et al. 1982). While cost reporting compares cost information against the baseline, quantity reporting compares the actual quantity measurements with the budget quantities. The last important element of cost control is cost forecasting report, which should be initiated upon achieving 20%-25% project completion and repeated every one to two months until project completion (Bessa 1983). The elements that need to be considered in the preparation of the cost forecast report include schedule performance and projected completion date, historical productivity data, normal learning curve, contract conditions, unit rate performance in cost/person-hour/quantity rates (Bessa 1983).

3.1.6 Progressing

Progress control determines whether a project has gone as intended by calculating variances between actual cost and progress and planned budget and schedule. Progressing cannot be accomplished without an established work plan, budget, and schedule. The budget and schedule are the necessary benchmarks for comparing actual work to planned work, so the progress of a project can be measured, evaluated, and controlled (Oberlender 1993). An integrated cost and schedule reporting system must include budget and actual cost and schedule data as well as cost and schedule status (Abudayyeh and Rasdorf 1993). The methods for progress management of measuring planned and actual costs over a project's schedule have been researched by many (Abudayyeh and Rasdorf 1993; Barrie and Paulson 1992; Carr 1993; Clark and Lorenzoni 1978; Yang et al. 2007).

Progress measurement is a two step process; progress of different work tasks need to be determined first, and then the different work tasks are combined to determine the

overall percent complete for the project. Six methods for measuring task progress are Units Completed, Incremental Milestone, Start/Finish, Supervisor Opinion, Cost Ratio, and Weighted Units (Oberlender 1993). The Units Completed method applies to repetitive tasks that only need one unit to define. The Incremental Milestone method applies to tasks that include subtasks that must be executed in sequence, where each subtask is considered a milestone and represents a certain percentage of completion. The Start/Finish method is applicable to tasks that do not have well-defined milestones. The Cost Ratio method is applicable for administrative tasks that involve a long period of time; the percentage complete would equal to actual work hours divided by forecast work hours at completion. The Weighted Unit method is applicable for tasks that require several overlapping subtasks that each has a different unit of measurement.

After the progress of work tasks is determined, the earned value system can be used to define overall percent complete for the project. The earned value system was made popular by the Cost and Schedule Control Systems Criteria (C/SCSC) (DEPARTMENTS OF THE ARMY 1970).

3.1.7 Forecasting

Forecasting is the process of continuously predicting the final outcome of cost, time and resources required to complete a project. Forecasting is essential to effective project controls because large variances in costs and/or schedules can impact profitability, cash flow, and the viability of projects. A good forecasting system should generate forecasts that are accurate, unbiased, timely, and stable. Also, the forecasting system should be based on easily obtained information that is collected on a regular basis and it should be simple enough to be integrated into the existing cost system (Teicholz 1993).

The Construction Industry Institute (CII) described three basic methods of Forecasting in the comprehensive study conducted in the late 1980s (CII 1987). The first method assumes that work from this point forward will progress at planned rates. This method can be used for forecasting costs and work hours. Forecast at completion equals to the sum of actual cost of work performed to date and the budget for remaining work. The second method assumes that the current rate of progress will continue until the end of the project. Therefore, the forecast at completion equals to the current budget at completion divided by the cost performance index. The third method extrapolates a trend curve to make the projection.

Forecasting methods developed in the past two decades can be categorized into stochastic methods, deterministic methods using earned value, social judgment theory, and methods based on fuzzy logic (Li et al. 2006). Stochastic methods use the cost of unit earning, which is the mean of the actual cost of the work performed for each cost account, and its standard deviation to predict project cost at completion. The methods assume that the monthly progress of each cost account is a stationary process with a mean and standard deviation. Deterministic methods using earned value generally assume that either the performance efficiency achieved up to the reporting date remains unchanged throughout the rest of the project, or that the performance will be as planned beyond the reporting date. Methods based on the social judgment theory provide a way to predict the future based on a set of cues, originating from human judgment rather than from purely mathematical algorithms. Forecasting based on fuzzy logic refers to methods by which conclusions about future behaviors are derived from fuzzy data and fuzzy rules (Kumar and Reddy 2005).

3.2 CII DOCUMENT REVIEW

Twenty two CII documents pertinent to PCMS were identified for review by the research team. A document evaluation template was created and used for evaluating the identified documents. The evaluation mainly concentrated on verifying whether the principles and implementation methods are still valid in today's construction industry.

Each research team member was responsible for reviewing one or more of the identified documents. The documents were classified into 12 PCMS knowledge areas. The results of the evaluation showed that the principles have not changed much and are still valid, whereas most of the implementation methods have become outdated due to advancements in techniques and computer applications.

Table 1 shows a summary of all the CII documents that were reviewed by the research team. Details of the assessment were delivered in a separate report to CII for review by the Knowledge Management Committee.

Table 1 Summary of CII Documents Review by RT 244

Knowledge Area	Document Number	Document Title	Publication Date	Principles	Implementation Methods
3.01 Materials Management	IR 7-3	Procurement and Materials Management: A Guide to Effective Project Execution	1/1/1999	Valid	Outdated
3.02 Supplier Relationships	RS 130-1	Reforming Owner, Contractor, Supplier Relationship: A Project Delivery System to Optimize Roles in EPC Projects	6/1/1998	Valid	Valid
4.02 Lean Construction	RS 191-1	Lean Principles in Construction	10/1/2005	Valid	Valid
7.03 Organizational Work Structure	RS 204-1	The Owner's Role in Project Success	10/1/2006	Valid	Valid
7.04 Leader Selection	IR 134-2	Tools for Effective Project Team Leadership	5/1/1999	Valid	Valid
7.05 Project Teams	IR 170-2	Virtual Teams – A Successful Guide to Implementation	11/1/2001	Valid	Valid
8.09 Change Management	SP 43-1	Project Change Management	11/1/1994	Outdated	Outdated
	RS 43-2	Quantitative Effects of Project Change	5/1/1995	Valid	Outdated
	RS 158-1	Quantifying the Cumulative Impact of Change Orders for Electrical and Mechanical Contractors	10/1/2000	Valid	Valid
9.01 Cost & Schedule Control	RS 6-1	Project Control for Engineering	7/1/1986	Outdated	Outdated
	RS 6-3	Model Planning and Controlling System for EPC of Industrial Projects	4/1/1987	Outdated	Outdated

	RS 6-10	The Impact of Changes on Construction Cost and Schedule	4/1/1990	Valid	Valid
	RS 41.1	Schedule Reduction	4/1/1995	Valid	Valid
	RS 124-1	Exceptional Projects and Methods of Improving Project Performance	6/1/1999	Valid	Valid
	RS 185-1	Effectiveness of Innovative Crew Scheduling	9/1/2003	Valid	Valid
10.02 Project Delivery and Contract Strategies	RS 5-1	Impact of Various Contract Types and Clauses on Project Performance	7/1/1986	Valid	Valid
	RS 165-1	Owner's Tool for Project Delivery and Contract Selection Strategy	7/1/2001	Outdated	Outdated
	BM 2002-10	Measuring the Impacts of the Delivery System on Project Performance - Design Build and Design-Bid-Build	11/1/2002	Valid	Valid
	RS 205-1	Commodity vs. Value Added Contractor Services	1/1/2006	Valid	Valid
10.03 Use of Project Incentives	RS 114-1	Innovative Contractor Compensation	9/1/1998	Valid	Valid
10.04 Risk Management	RS 6-8	Management of Project Risks and Uncertainties	10/1/1989	Valid	Valid
12.02 Electronic Commerce	RS 180-1	eCommerce Applications in Construction	11/1/2002	Outdated	Outdated

From the evaluations conducted by the research team, it has been found out that the most of the principles are valid, but in some of them the language used to describe these principles is dated. Outdated principles that have been identified are mainly due to expansion and enrichment of the topics. Introduction and adoption of new technologies like 3D CAD modeling, data systems, estimating and work packaging systems and newer Project Controls systems have resulted in outdated these principles. Globalization has also played a major role in the construction industry and has led to various changes in the core PCMS principles.

Projects are growing more and more complex day by day. Over the past 25 years, introduction and adoption of new technologies, advancements in the old technologies, changes in amount and form of usage, changes in contracting methods and globalization have played a major role in outdated most of the implementation methods represented in the documents. Tools like 3D CAD modeling are nowadays implemented extensively to provide material quantities. The amount of information processed for a project has grown multiple folds, and thus forcing dependency on various computer applications for processing them. One major problem faced by the companies today, is integration of all these tools and making maximum usage of all the available project information.

4. CURRENT STATE OF PCMS: PCMS SURVEY AND IMPACT WORKSHOP

The research team conducted a comprehensive survey and a workshop to document current PCMS practice and to identify the impact of current PCMS functions on project performance. Prior to conducting the survey and workshop, research team members discussed their thoughts on what important changes have occurred in PCMS practice over the past twenty years. Research team members recognized that a clear definition of a Project Controls and Management System (PCMS) and its functions was needed because no standardized definition existed. PCMS is about people, processes, and tools and their interactions.

Consequently, the research team defined Project Controls and Management System (PCMS) as follows:

Project Controls and Management System (PCMS) includes the people, processes, and tools for the planning and execution of all phases of capital projects including, but not limited to, estimating, planning, scheduling, change management, cost control, progressing, and forecasting.

Essentially, PCMS include seven functions (estimating, planning, scheduling, cost control, change management, progressing, and forecasting) across four project phases (design, procurement, construction, and start-up). Initially, Front-End Planning was not included in the project phases but was added later in the research process. The PCMS functions are defined below.

1. **Planning.** The process devoted to clearly identifying, defining, and determining the execution means and methods necessary to achieve project goals and objectives before execution of means and methods. Planning may involve work packaging.

2. **Change Management.** The process of effectively identifying, evaluating, and making decisions on new or revised scopes of work and monitoring implementation, all in an expeditious and systematic fashion.
3. **Estimating.** The art and science of predicting the cost, time, and resources to deliver a scope.
4. **Scheduling.** The art and science that results in a time-phased plan of activities that indicates what is to be done, when, by whom, and with what resources. Work packaging is included in scheduling.
5. **Cost Control:** The process to catalog and analyze budgeted and actual expenditures of activities for purposes of timely identification of cost trends, problems and opportunities during the course of the project. Cost control is not cost accounting.
6. **Progressing.** Determining the status of project completion using a consistent method, which should include earned value.
7. **Forecasting.** The process of continuously predicting the final outcome of cost, time, and resources required to complete a scope.

4.1 METHODOLOGY

The methodology consisted of conducting a comprehensive survey followed by an impact workshop. The purpose of the survey was to document the current state of PCMS practice. The purpose of the workshop was to identify the impact of PCMS functions on project performance during different project phases.

4.1.1 The PCMS Survey

The PCMS survey included two sections: (1) a section on the structure of PCMS in companies, and (2) current PCMS practices. The complete survey is included in Appendix A: Project Controls and Management Systems Survey. The survey was distributed to all 110

Construction Industry Institute member companies at the December 2006 CII Board of Advisors meeting. Some responses were collected at the meeting while majority of the survey responses were received through fax and e-mail. Twenty-eight (28) survey responses, from 25 unique companies, were received from owner companies while 25 survey responses, from 23 unique companies, were received from contractor companies. Five responses were received from branch offices. Of the 25 owner companies, 13 companies are in the heavy industrial sector, 11 companies are in the light industrial sector, and four are in the building sector. The majority of the contractor companies are large Engineering/Procurement/Construction (EPC) contractors.

Structure of PCMS in Companies

In order to identify how PCMS is setup in various companies and whether companies are improving their project controls resources, the survey asked the respondents to answer the following five questions:

- Do you have a dedicated project controls group?
- Is your PCMS centralized or decentralized?
- Is your company investing in PCMS processes?
- Is your company investing in technology?
- Is your company investing in core competency training?

Current PCMS Practices

For each of the seven PCMS functions in each of the four project phases, the survey asked the respondent to indicate the existence and effectiveness of their (1) Formal/Documented PCMS Process, (2) IT System to Support Process, and (3) PCMS Core Competency Training. Effectiveness was rated on a Low-Average-High scale. The effectiveness scale was defined as follows:

Low (L) – Process/System/Training provides poor/minimal support for projects;

Average (A) – Process/System/Training provides adequate support (typical industry

practice);

High (H) – Process/System/Training provides superior than typical support for projects.

Questions were asked in the following format: *do you have a formal/documented process for the forecasting function in the construction phase and how effective is it on a scale of Low-Average-High.*

Also included in section one was a set of questions about transition between project phases. Two questions were asked for each between-phase transition. For example (1) is the handover between *procurement* and *construction* processes seamless and (2) are the IT systems used in the *procurement* and *construction* phases integrated. These two questions were repeated for design-procurement, procurement-construction, and construction-start-up transitions.

4.1.2 The Impact Workshop

Although the broad PCMS survey aided the identification of strengths and weakness in owner and contractor companies' PCMS, it was unclear whether all the weaknesses identified were critical areas that require immediate attention. The research team wanted to answer two questions: 1) does an apparent weakness warrant immediate attention, and 2) does an apparent strength mean that it is good enough. For example, if forecasting processes were ineffective, does this mean forecasting needs to be improved or forecasting is unimportant to project performance and therefore improving forecasting would not add value to project controls? Similarly, if current change management processes were rated as moderately effective in the survey results, does this mean no improvement is needed?

In the impact workshop, participants rated and discussed the impact of PCMS functions on project performance. The workshop had one owner group and one contractor group with five panelists in each group. Owner panelists included project controls experts from petro-chemical, pharmaceutical, power, and building industries. Contractor panelists were project controls experts from major EPC contractors. Each panelist was given a clicker and each group's answers

were collected separately. The question below was asked for each PCMS function during each phase – 35 questions total. (Describe process)

Question 1. What is the impact on project performance – in terms of cost and schedule – if “function” (i.e., estimating) is performed poorly during “phase” (i.e., front-end planning)?

1. *No impact.* This function (estimating) will not impact the cost or schedule if performed poorly during this phase (front-end planning).
2. *Minor impact.* This function (estimating) might cause a slight increase in the cost or schedule if performed poorly during this phase (front-end planning).
3. *Moderate impact.* This function (estimating) might cause a moderate increase in the cost or schedule if performed poorly during this phase (front-end planning).
4. *Major impact.* This function (estimating) might cause a significant increase in the cost or schedule if performed poorly during this phase (front-end planning).

After both groups answered each question, results were shown on two separate screens. The results were discussed by the panelists and sometimes, especially towards the beginning of the workshop, questions were re-voted on because individual panelists or groups interpreted the questions differently or failed to consider certain aspects when answering the first time. Discussions during the workshop were captured and are included in the results section.

4.2 SURVEY RESULTS

4.2.1 Structure of PCMS in Companies

The research results demonstrated that 68% of owner companies have a dedicated project controls department and the 92% of contractor companies have a dedicated project controls department (Table 2). However, 68% of owner companies have a centralized project controls department while only 40% of contractor companies have a centralized project controls department. A project controls department is considered centralized when standard practices and

procedures are followed closely by all project teams throughout the company. A project controls department is considered decentralized when project teams are not required to follow a standard set of corporate practices and procedures and instead develop their own practices to accommodate their project. Many contractors indicated that their PCMS implementation and performance vary, sometimes greatly, by location and business line/area/unit.

Table 2 Company Characterization

Number of Companies that:	Contractor	Owner
Participated in Survey	25	28
Has a Dedicated Project Controls Group	92%	68%
Has a Centralized PC Group	40%	68%
Is Investing in PCMS Processes	96%	82%
Is Investing in Information Technology	92%	64%
Is Investing in Core-Competency Training	76%	46%

Table 2 also shows that the majority of owner and contractor companies are investing in project controls resources. More specifically, 96% of contractor companies are investing in (establishing) PCMS processes, while it is only 82% in owner companies. 92% of contractor companies are investing in (establishing) PCMS information technology against 64% of the owner companies. Also, only 46% of owner companies and 76% of contractor companies are investing in (establishing) PCMS core competency training. Many companies commented that project controls has high priority and projected them as a differentiator among peers. Many also indicated that they are in the process of developing corporate-wide PCMS processes, IT systems, and core competency training to enable more automation and integration and achieve more

effective project control. Some companies also mentioned that certain projects that cross the monetary threshold would be subjected to the full project controls process.

4.2.2 PCMS Practices: Functions that Need Attention

One of the primary purposes for conducting this survey was to identify those PCMS functions that are problematic. Survey results identified three major areas of PCMS that are generally weak links for both owners and contractors in the overall process. These include (1) core-competency training, (2) control functions during start-up phase, and (3) interface/handover management between phases for both owner and contractor companies. Owners have reported having less effective PCMS. Two main questions were addressed in this survey.

1. Do you have
 - a. formal/documented PCMS process?
 - b. IT system to support process?
 - c. core competency training?
2. If yes, how effective is it on a Low-Average-High scale?

Table 3 summarizes the percentage of responders that has a particular resource (For example, an IT system to support the Estimating process) and how they rated the effectiveness of that resource. For example, 77.6% of owners that responded to the survey reported of having a formal/documented process during the design phase and they rated the average effectiveness as 2.1, which is slightly above average. Detailed tables that show percentages and average effectiveness of each PCMS function can be found in Appendix B: PCMS Survey Results.

Table 3 Summary Effectiveness Score for Owner and Contractor Companies

Do you have a PCMS		Design		Procurement		Construction		Start-up	
		% ¹	Avg. ²	% ¹	Avg. ²	% ¹	Avg. ²	% ¹	Avg. ²
Owner	Formal/Documented Process	77.6%	2.1	54.6%	2.1	75.5%	2.2	52.0%	2.0
	IT System to Support Process	50.5%	2.1	41.3%	2.2	44.4%	2.2	32.7%	2.2
	Core Competency Training	53.6%	2.2	48.0%	2.2	53.1%	2.2	36.7%	2.1
Contractor	Formal/Documented Process	88.0%	2.3	82.9%	2.2	83.4%	2.1	57.1%	1.9
	IT System to Support Process	77.7%	2.2	79.4%	2.2	80.0%	2.2	46.9%	2.1
	Core Competency Training	75.4%	2.1	70.3%	2.0	73.7%	2.0	43.4%	1.5

1. % = Percent of companies that have that particular resource
2. Avg. = Average effectiveness (Low = 1, Average = 2, High = 3) of that particular resource

Generally, a significant percentage (on average 71%) of owners and contractors has formal/documented PCMS processes. However, the number of owner companies that have IT systems to support the process was low compared to contractors (about 41% vs. 71%). Many owner companies justified this difference by commenting that they rely on their contractor's IT systems. Furthermore, survey results showed that fewer companies have formal/documented PCMS functional processes, IT systems to support the process, and core competency training during the start-up phase, when the project is in its final stage of completion.

Both owner and contractor companies indicated that their PCMS core competency training was insufficient. In fact, in most cases, only slightly more than 50% of the owner companies reported having a training program for PCMS, whereas more than 70% of contractors reported having a training program for PCMS. However, the owners gave their training programs a slightly higher effectiveness rating than the contractors.

The survey results also identified the management of the handover (interface) of information between project phases as potentially problematic. As shown in the Table 4, less

than 40% of the companies reported a seamless handover for almost all project phase transitions, which means over 60% of the companies are having problems during the handover process. Even fewer reported having an integrated IT system to support the handover of information.

Table 4 Handover of Information between Phases

		Owner	Contractor
Number of Survey Responses		28	25
Design - Procurement	Seamless Handover	32%	28%
	Integrated IT Systems	25%	40%
Procurement - Construction	Seamless Handover	36%	40%
	Integrated IT Systems	36%	40%
Construction - Start-up	Seamless Handover	46%	24%
	Integrated IT Systems	29%	28%

Aside from the three weak links discussed in the previous paragraphs, the following problematic areas were noted from the survey.

- Both owner and contractor companies indicated ineffectiveness for their forecasting processes, IT system, and training.
- Owner companies indicated ineffectiveness in their scheduling processes and change management tools.
- Contractor companies indicated ineffectiveness in their estimating processes for the procurement phase.

4.2.3 PCMS Practices: Functions that are performing well

According to the survey results, contractor companies have strong formal/documented processes, IT system, and core competency training for the design, procurement, and construction phases where strength is indicated by the number of companies that have that

resource and how they rated its effectiveness. More specifically, contractor companies indicated strength in scheduling, change management, and cost control processes. They also indicated that their scheduling and estimating IT systems are effective. It is interesting to note that these are the two functions that have established off-the-shelf software packages. Owner companies have strong formal/documented processes for the design and construction phases. Owner companies showed strength in their estimating and cost control processes, IT systems, and core competency training. They also indicated comparatively high effectiveness for their core competency training for estimating, scheduling, planning, and cost control functions for the construction phase.

4.2.4 Team Thoughts on Survey Results

Survey results sparked discussions within the research team. Overall, research team members were surprised by how poorly companies rated their PCMS. Many of the weak links reflected in the survey were also echoed by team members' experiences. Many indicated that poor forecasting performance and core competency training were especially problematic. Project team also commented on the criticality of developing PCMS resources, including people, processes, and tools. Research team agreed that core competency training is an area that requires attention. The skill sets within the project controls group determine how effective PCMS is. Core competency training deals with developing the understanding of core competencies and this differs from IT system training. Companies may need more guidance as to how to invest and develop core competency training.

4.3 IMPACT WORKSHOP RESULTS

The impact workshop not only identified owner and contractor companies' perceptions of which PCMS functions are important in each phase but also lead to in depth discussion on why is that PCMS function important. Table 5 summarizes the results of the PCMS impact workshop. A score of 4 indicates that the function has major impact on project cost and schedule if performed

poorly during that phase. The following paragraphs discuss impact of PCMS functions and some lessons learned from the impact workshop.

Table 5 Impact Rating of PCMS Functions

		FEP	Design	Procurement	Construction	Start-Up
Estimating	Owner	3.8	3.8	3.2	2.6	1.8
	Contractor	4.0	3.6	3.2	3.4	1.8
Cost Control	Owner	2.6	3.2	3.6	3.6	2.4
	Contractor	1.8	3.2	2.8	3.8	2.2
Planning	Owner	3.6	3.4	3.8	3.2	2.2
	Contractor	4.0	4.0	3.4	3.8	2.4
Scheduling	Owner	4.0	3.6	3.6	4.0	3.0
	Contractor	2.8	3.6	3.6	4.0	3.4
Change Management	Owner	3.4	4.0	3.6	4.0	3.2
	Contractor	4.0	4.0	3.6	4.0	2.2
Progressing	Owner	1.6	2.4	3.2	4.0	2.8
	Contractor	2.2	3.4	3.2	4.0	2.0
Forecasting	Owner	2.8	3.8	4.0	4.0	3.0
	Contractor	2.8	4.0	3.2	4.0	2.2

Impact Rating: 4 - Major Impact, 3 - Moderate Impact, 2 - Minor Impact, 1 - No Impact

 - High Impact Function in Phase

Estimating during the Front-End Planning (FEP) phase can have a major impact on project cost and schedule if performed poorly at the beginning of the project and the impact decreases toward the end of the project. During FEP, estimate determines funding availability and therefore overall constraints. According to contractor panelists, the estimate has a high impact if the owner already has a cost baseline at that time. During the procurement phase, equipment availability and pricing under the current delivery constraints can have a significant impact. For Estimating during Construction phase, owner suggested that contracting strategy plays a big role – if the project is based on lump-sum contract, this estimate is not as important to owners as if the project is based on cost-reimbursable contract. However, if the contractor is unsophisticated, this estimate is important regardless of contract type.

Cost Control has greater impact on project performance during phases that have big expenditures. Since Change Management is a separate function, Cost Control during FEP only includes tracking engineering cost. However, during the Design phase, Cost Control reporting becomes much more frequent – daily comparing to monthly cost control reports. For Cost Control during Procurement phase, different owner and contractor point of views emerged. Owner panelists viewed procurement as contracting while contractor panelists perceived procurement as equipment sourcing. Project execution strategy also affects the impact of Cost Control during Procurement. During the Construction phase, more risks are shifted to the contractor if it is a fixed-price project.

Planning has high impact on project performance throughout all phases. Many panelists commented that Planning is much more process-based now as opposed to expert-based. For Procurement phase, contractor panelists had two schools of thoughts – some perceived that procurement plans are fixed during the design phase while others thought planning is an on-going process. For Planning during the Construction phase, owner panelists believed that the potential for planning has past for them and contractors are more responsible for planning at that stage. Impact also depends heavily on local conditions – Gulf Coast projects require continuous planning to manage risks. Most thought Planning for Start-up phase is important but it is done throughout the project and not just during the Start-up phase.

Scheduling has high impact on project performance throughout all phases, especially toward the beginning of the project. Panelists found difficulty in completely separating planning and scheduling in their thinking process but all agreed that scheduling is important. Scheduling for the entire project during FEP has very high impact on overall project schedule. Owners from different industry sectors were divided on the impact of scheduling during Start-up phase.

Change Management was perceived as having high impact on project performance throughout all phases. For Change Management during Procurement, panelists commented that changes in prices have lower impact while changes in scope have major impact on project cost

and schedule. The contractor panelists were less concerned about Change Management during Start-up phase than owner panelists.

Progressing has higher impact on project performance during the middle phases. Owner panelists indicated that meeting major milestones is the main concern during the Procurement phase. Comparing to contractors, owners perceived progressing as having relatively high impact during Start-up phase.

Forecasting was perceived as having high impact on all project phases. For Forecasting during FEP, some panelists believe in the value of having an early forecast, perhaps from an external organization, to validate the baseline. For Forecasting during Procurement, the impact score is lower if the forecast focus on cost and ignores schedule. Owner panelists continued to place more value on the Start-up phase than contractor panelists.

The PCMS Impact Workshop not only provided insights into the impact of PCMS functions on project execution but also shed lights on owner and contractor companies' point of views and wisdoms. Some of the lessons learned are shared below:

- Owner companies have a more holistic view to Front End Planning. Establishment of FEP Package more or less sets the project scope in stone. Comparing to twenty years ago, there are more emphasis on managing risks.
- Owner companies view procurement as a contracting phase while contractor companies view procurement mainly as ordering equipments.
- The contract type affects how owner companies treat functions in the design and construction phases. If the contract type is lump-sum, the owner company is more likely to rely on contractor than if the contract type is reimbursable.
- Owner companies place more emphasis in Start-up than contractors.
- Across the industry, contractors and owners are spread in sophistication. The problem is not always that the industry need better/more sophisticated PCMS processes, rather it is to help the less-sophisticated firms improve.

4.4 COMPARISON OF PCMS SURVEY AND PCMS IMPACT SCORES

PCMS survey results and impact scores of PCMS functions, shown in Appendix C: Comparison of PCMS Survey and Impact Workshop Results, were examined to determine areas where improvements would bring high value. Effectiveness scores from PCMS survey were scaled to a four-point scale to ease comparison. By comparing the two scores, most weaknesses that surfaced in the PCMS survey were confirmed and other areas of potential improvement were identified.

Weaknesses in core competency training, forecasting processes, owner's scheduling processes and change management tools became more apparent under the comparison. For example, few companies have forecasting processes and effectiveness of forecasting processes are low for companies that have it. Forecasting was rated as having major impact on project cost and schedule if performed poorly during Design, Procurement, and Construction phases. An exception is the general weakness found in PCMS capabilities during the Start-up phase. As shown in the table, the effectiveness scores were on par with the impact scores. Research team interpreted this as although the effectiveness is lower than other phases the ability to impact project performance is also lower.

Cross examination of PCMS function's effectiveness and impact scores also showed areas of potential improvement that weren't apparent in PCMS survey results. Change Management during Design, Procurement, and Construction phases and Progressing during Construction phase showed very high impact score but low effectiveness score.

4.5 CONCLUSION

PCMS survey results revealed general PCMS strengths and weaknesses and Impact workshop helped pinpoint areas where improvements would bring the highest value. From these, research team was able to identify high impact focus areas for research effort.