PERFORMANCE ASSESSMENT OF BUILDING COMMISSIONING PROCESS AS A QUALITY ASSURANCE SYSTEM

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Someone once told me that, before you start the Ph.D. program, ask yourself what makes you choose this path, write that down on a piece of paper and keep it somewhere safe, because you're going to have to refer to that piece of paper a lot during the course of time. But I didn't have the paper. For the first time, I let my life guide me through its path. Now that I look back, I never felt I needed that piece of paper…

This was not a journey one could finish on his own. Many people have come into my life, and helped and encouraged me during the past few years. Acknowledging their endless support here is the least I can do to thank them.

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SUMMARY

The aim of this thesis was to develop a methodology to systematically investigate the effect of different procurement options on the outcome of a construction project. This methodology combined the qualitative analysis based on experts' performance assessment of each procurement option with quantitative analyses of generic process models for each option, in order to perform a comprehensive analysis of different procurement alternatives. This methodology was further applied to the specific problem of this research which was to assess the performance of Commissioning Delivery Systems (CDS). The goal was to use the findings from the study to provide a comparison between CDS, and assist Construction Owners in identifying the appropriate commissioning delivery option for their project.

The process of each CDS was modeled, and systematic differences between different options were analyzed. Five major internal performance aspects of the commissioning process were identified based on literature: *PAi1: Communication*; *PAi2: Validation*; *PAi3: Collaboration*; *PAi4: Integration*; and *PAi5: Integrity*. These performance aspects were used as a basis for a Delphi study to obtain commissioning experts' assessment of each CDS. Fourteen experts, representing different disciplines in the construction industry, participated in three phases of the Delphi study. A statistical measure was used to validate the expert performance assessments by measuring their level of consensus. Experts did not show any agreement on two performance aspects of *Communication* and *Integration*. These aspects were further investigated through quantitative analyses of process models.

The developed methodology proved to be a valuable technique in analyzing the effect of procurement options on the outcome of a construction project. Based on the findings of the study, Owner-led Commissioning presented a higher performance rating than Designer-led Commissioning in four out of five performance aspects. Hence, Owner-led Commissioning is identified as a better alternative for procuring commissioning services on construction projects. Designer-led Commissioning presented a higher *Communication* performance than Owner-led Commissioning. At the same time, the *Communication* performance of both delivery options was very poor, which further indicates communication difficulties in current commissioning practices. Therefore, this study suggests a more-thorough investigation of the *Communication* aspect of commissioning process as a follow-up investigation.

Chapter 1

INTRODUCTION

1.1. Background

The construction industry is one of the leading sectors of the United States economy, with annual investments equivalent to 11% of the total Gross Domestic Product. Buildings consume more than 36% of total U.S. primary energy, and 40% of the raw materials. Additionally, construction activities produce 136 million tons of waste annually and account for 30% of all U.S. greenhouse emissions [USGBC 2004]. Despite this enormous impact, the building industry struggles with issues involving project quality. Construction projects increasingly suffer from budget and schedule over-runs, low customer satisfaction, and high operation and maintenance costs resulting from low performance of building systems [Butler 2002]. In response to these problems, several quality control and assurance programs have emerged. One of these quality instruments is *Total Building Commissioning*. Originally developed as a tool to control the quality of Heating, Ventilation and Air-Conditioning (HVAC) systems, the application of this practice extended to other building systems. It has since evolved into a comprehensive quality process to ensure a building as-a-whole meets the needs of Owners, and that *all* building systems operate as expected [Dorgan et al. 2000].

Total Building Commissioning is defined as the process of achieving, verifying and documenting that the performance of facilities, systems and assemblies meets defined objectives and criteria [Dorgan 2002]. Total Building Commissioning is a phase-oriented process, meaning that, at the end of each phase in the project life cycle, the results are verified to ensure they meet the Owner's requirements, which are defined at project initiation. This process begins at very the early stages of the project, and continues through the whole life cycle of the facility.

Recent studies on the cost benefits of building commissioning, show commissioning implementation results in an average annual savings of 15% in energy costs [Mills et al. 2005]. At the same time, the benefits of building commissioning are not limited to energy efficiency [Turner 2003]. Other benefits from implementing the commissioning process include [Tseng 1998; Turner 2003]:

- Reduced maintenance costs
- Reduced change orders and claims
- Reduced project delays
- Enforced start-up requirements
- Shortened building turn-over period
- Reduced post-occupancy corrective work
- Minimized effect of design defects
- Improved productivity and indoor environment
- Increased maintainability and reliability

Based on these benefits, Total Building Commissioning has gained tremendous attention in the construction industry in recent years. It has become one of the major components of several national programs for improving the quality of the built environment, such as the Department of Energy's *Rebuild America* and the U.S. Green Building Council's *LEED Rating System*. In addition, with increased complexity of building systems, Owners are considering commissioning as *the* method for improving the overall performance and quality of their facilities. For many public and private entities, building commissioning has become business as usual. The General Services Administration (GSA) requires that all new construction and major renovation projects starting in 2006 adopt some form of Total Building Commissioning as their quality-assurance instrument [Eakin and Matta 2002]. National Aeronautics and Space Administration (NASA) has recognized Total Building Commissioning as the best practice, and is adopting this process to improve the performance of its buildings [NASA 2001]. Wal-Mart, the world's largest retailer, is also considering implementation of building commissioning, both in construction of its new facilities and renovation of its existing buildings [Bert 2005].

Total Building Commissioning has also received special recognition in emerging Project Delivery Systems, such as Design-Build, which define a demand-supply relationship between owners and service providers [Shakoorian and Sadri 2004].

1.2. The Research Problem

Despite the growing demand for implementing Total Building Commissioning, this process is still in its early stages of development. The *American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE)*, in collaboration with *National Institute for Building Sciences (NIBS)*, has recently published *Guideline 0*, a document that defines the process of building commissioning, apart from its application to specific building systems. Guideline 0 provides an overview of the commissioning process, and defines the overall roles and responsibilities of the parties involved in this process. However, many fundamental questions about the best approach in performing the commissioning process remain unanswered. One of the most important questions is the choice of *Commissioning Delivery System (CDS)*.

CDS is defined as the type of contractual relationship, in which the person in charge of the commissioning activities is bound to the other parties in the project. Selection of the most-appropriate commissioning delivery method has been identified as a critical step in the procurement of commissioning services [Holland and Peed 2002]. In recent years, several types of Commissioning Delivery Systems have emerged, including: *Owner-led Commissioning; Designer-led Commissioning; Contractor-led Commissioning;* and *Third-party Commissioning*.

Third-party Commissioning is the most widely used model in the industry. But at the same time, it is suspected that other Commissioning Delivery Systems may be more appropriate [Dunn and Whittaker 1994; Prowler 2003]. For example, even though supporters of Third-party Commissioning argue that an independent, third-party commissioner is the only viable way to fully represent the Owner's interests in the project [Casault 2003], others question the ability of this model to create the collaborative environment that is essential in realizing the true value of the commissioning practice [Sweek 2003; Tseng et al. 1993]. It has been suggested that an Architect/Engineer or the General Contractor, performing the commissioning services, benefits the project, since these parties already have full knowledge about the project and can use the commissioning process to improve the quality of their services [Tseng et al. 1993]. A recent survey of a broad spectrum of construction industry practitioners also showed that, despite strong support from different professional commissioning organizations of independent Third-party Commissioning, most of the participants preferred the Project

Designer as the entity appointed to manage the commissioning process [Potts and Wall 2002].

This ongoing debate has resulted in confusion among construction owners in selecting the most-appropriate Commissioning Delivery System for their project. On one hand, it is strongly suspected that the type of the commissioning delivery used in the project has a direct effect on the outcome of the commissioning process, and on achieving the benefits mentioned in the previous section. On the other hand, there has been no systematic study on the possible outcomes of each of these Commissioning Delivery Systems, and most of the decisions have been based on presumed general advantages and disadvantages of each method. This issue is also of increased importance for commissioning service providers. Since Total Building Commissioning is still in the early stages of development, these providers are likewise trying to find the best service strategies to provide Owners with the highest-possible value.

To resolve these problems, it is crucial to systematically investigate the effect of type of Commissioning Delivery System on the outcome of this process. This evaluation requires research methodologies that can provide a comprehensive analysis of the affect of construction procurement alternatives on the outcome of the construction projects. At the same time, methodologies for performing such analysis in the construction research are underdeveloped. Existing methodologies usually focus on certain aspects of the problem and therefore do not provide a comprehensive analysis of the issues.

1.3. Research Objectives and Scope

The major goal of this research is to develop a methodology that can be used to perform a comprehensive analysis of the effect of procurement options on the outcome of a construction project. This methodology will be tested through its application to the specific problem of this research, which is to assess the effect of each Commissioning Delivery System (CDS) on the outcome of the commissioning process. The result of these analyses will further help to identify the most-appropriate commissioning delivery alternative for construction projects.

The goal of this research can be divided into the following objectives:

- To develop methodologies for evaluating the performance of each CDS, based on a set of defined performance measures.
- To develop appropriate process models for each Commissioning Delivery System.
- To identify a set of performance measures that could quantify the performance of different commissioning alternatives.
- To use the result of performance assessments to rank the different Commissioning Delivery Systems.

The scope of this study will be limited to the construction owners' view, since they are considered to be the major beneficiary of the commissioning process. Also, the building type is limited to institutional buildings, since they are the primary target of commissioning implementation. The source for defining Construction Procurement System and Project Delivery Systems will be the standards and definitions provided by *Associated General Contractors of America (AGC)*. The main source for defining the commissioning practice, as well as entity roles and responsibilities, is Guideline 0, which is provided by NIBS and ASHRAE. Based on this Guideline, commissioning is considered to begin at the pre-design stage and continue through the first year of occupancy. In addition, because the basic process and responsibilities, as defined in Guideline 0, is based on a traditional view of the Project Delivery System (Design-Bid-Build), this delivery system will be the main focus of this study. Process models for delivery options under Design-Bid-Build will be developed, and the performance of each will be evaluated through both the Delphi method and a quantitative analysis described later in this chapter. Commissioning delivery options for other delivery systems will also be defined, and the performance of commissioning delivery options under Design-Build Project Delivery System will also be evaluated through the Delphi method.

1.4. Study Hypothesis

The overall hypothesis of this study is defined as the following:

The type of Commissioning Delivery System used in a project affects the outcome of a commissioning process.

The ‘outcome’ of the commissioning process will be measured in terms of a set of performance aspects defined in the course of the study. This hypothesis will be tested through the methodology developed for this research. Conclusions resulting from testing this hypothesis are provided in Chapter 8.

1.5. Research Outline

The following paragraphs outline the steps taken in this study to address the research problem described in the Section 1.3. Figure 1.1 lists these steps, along with the chapter structure of the dissertation. These steps are described in the following sections:

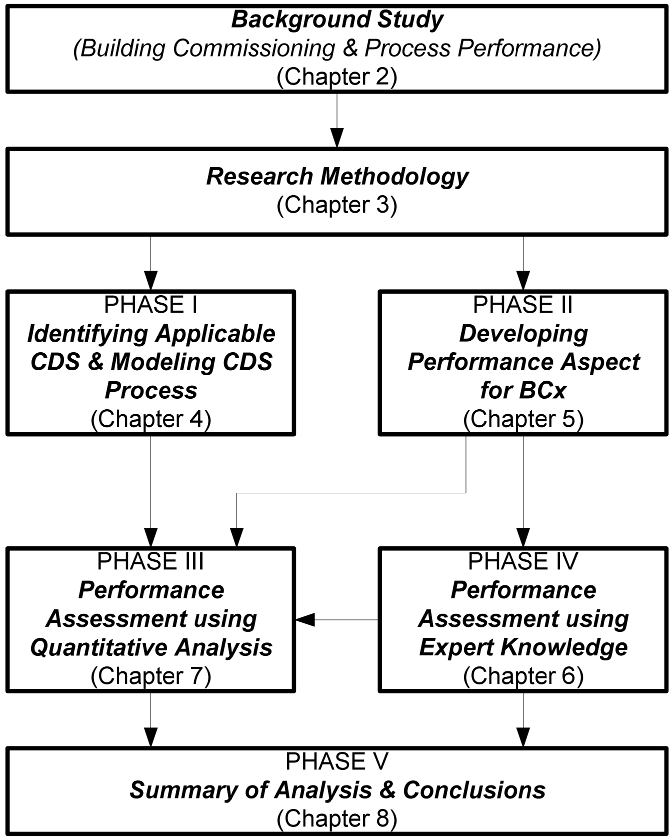

Figure 1. 1 – Study Outline

Chapter 2 - Literature Review: Although the practice of building commissioning has existed for more than 20 years, the concept of Total Building Commissioning is still at a very early stage of development. Therefore, it was important to study the existing literature on building commissioning and Total Building Commissioning, in order to explore the evolution and state-of-the-art developments of this practice. This literature survey also helps to identify the most-accepted definitions and basis for these concepts among varying views and assumptions currently existing in the industry. In addition, since this research defines the outcome of commissioning in terms of performance aspects of this process, a literature survey on the concept of performance measurement and performance of the processes is conducted. Again, the objective is to identify the state-of-the-art on these subjects, and provide a basis for the work in this research.

Chapter 3 - Research Methodology: The result of the literature study performed in Chapter 2 is used to develop a system-wide view of building commissioning and Commissioning Delivery Systems. This system view is crucial to define the relationship between these concepts and the overall system of construction procurement. Next, a review of current methodologies in the construction research is provided. The applicability of each of these methodologies to the problem of this research is analyzed and their strengths and weaknesses are discussed. Based on this analysis, a methodology for this research is designed, and each step is described in detail. The proposed methodology of this research is comprised of five phases. Each of these phases is described in the following paragraphs.

Chapter 4 - Identify and Model Commissioning Delivery Systems: This is the first phase of the methodology and consists of two main tasks. The first task is to develop a framework for classifying CDS, based on major Project Delivery Systems (e.g. Design-Bid-Build and Design-Build). This framework is further used to identify CDS most relevant to this study. The second task is to model the process of each CDS alternative. The purpose is to develop appropriate representations of the flow of activities in each CDS, in order to provide a basis for studying the structural differences. Structural differences are those observable differences that are caused by the unique distribution of roles and responsibilities for entities in each CDS. These models will be based on a commissioning process flowchart provided by Guideline 0. An appropriate modeling technique is identified, and each CDS is modeled, based on both the description of the commissioning process provided in ASHRAE's Guideline 0 [ASHRAE 2005] and the unique characteristics of each delivery system. The models are validated by experts before further application.

Chapter 5 - Identify Appropriate Performance Aspects: In Phase II of the methodology, a systematic process will be used to identify a set of appropriate performance aspects for the commissioning process. The source for developing these performance aspects is existing literature on building commissioning. A comprehensive list of success factors for the commissioning process is generated, and these factors are further grouped into larger categories, in order to develop performance aspects. Each performance aspect is defined and its significance is discussed based on the existing literature. These aspects are also validated by experts before their application. This validation is performed as part of Phase III of this investigation.

Chapter 6 - Performance Assessment Using Expert Judgments: In Phase III, the performance of each CDS will be assessed based on the different aspects developed in Phase II. A group of commissioning experts are identified, and they are asked to assess the performance of each CDS based on their knowledge and experience about the commissioning practice. Expert knowledge is gathered based on a Delphi technique and is comprised of three surveys. In the first survey, experts are asked to validate the importance of each performance aspect. They are also asked to provide other performance aspects that they may find appropriate. The performance framework is modified based on experts' feedback. In the second survey, the modified performance framework is presented to experts, and they are asked to provide an initial performance rating for each aspect of CDS. Experts are also encouraged to provide the underlying reasons for their performance ratings. The result of Survey 2 is summarized and sent back to experts for the third and final survey. In this survey, experts are asked to reconsider their previous ratings, in light of other expert comments and overall group judgments. In order to validate the expert ratings, a statistical measure will be calculated to show the degree of agreement among experts for each performance rating. Performance ratings, in which experts achieve a consensus, are used as a basis to compare CDS. In cases in which experts do not show any consensus on performance assessment, aspects are further investigated. This investigation is performed in Phase IV.

Chapter 7 - Performance Assessment Using Quantitative Analysis: In Phase IV of this study, those performance aspects for which experts did not show any agreement in their assessment are further investigated. This investigation is based on a quantitative analysis of process models developed in Phase I of the study. Results of these investigations are used to make a comparison between these performance aspects of CDS. They are also compared to the results of expert judgments, to identify the issues and problems that contributed to expert disagreement.

Chapter 8 - Summary and Conclusion: In this section, the results of the performance measurements performed in Phase III and IV of the study are used to address the problem of the research and test the research hypothesis. Research findings are analyzed to identify the appropriate Commissioning Delivery System for construction projects. Findings are also used to uncover problem areas in the current commissioning practice, and recommend future investigations to address and improve these issues.

1.6. Research Contributions

The primary contribution of this research is to develop and test a research methodology that can be used to evaluate the effect of different construction procurement options on the outcome of a project. This methodology is applied to the specific problem of this research, which is to assess the effect of different Commissioning Delivery Systems on the outcome of the commissioning process. The result of this assessment can assist Owners in selecting the more-appropriate Commissioning Delivery System for their projects, and eliminate existing confusion within the construction industry. This result will also help service providers to better structure commissioning services with other design and construction services, and provide the building owners with the highest value. In addition to its main contribution, this study also provides other important benefits:

- Identifying the problem areas in the current practice of building commissioning that require more-advanced investigation.
- Developing process models that represent the workflow of activities, as well as specific roles of different parties and their interactions in each Commissioning Delivery System.
- Developing a set of performance aspects for the building commissioning practice.

Finally, the literature review performed in Chapter 2 provides a comprehensive review of building commissioning literature, and maps the evolution of this concept from a quality-control practice to a quality-assurance method.

CHAPTER 2

LITERATURE REVIEW

2.1. Purpose

The purpose of this chapter is to provide a review of the existing literature to establish a point of departure for this research. This literature study is compromised of two sections. The first section focuses on Building Commissioning. The objective is to investigate the evolution of this concept, and identify state-of-the-art research and practice. This investigation is crucial in determining a standard definition and a foundation for Building Commissioning among the various views and perceptions existing in the industry.

The second part of this chapter reviews the existing literature on process performance measurement. The purpose of this section is to look at the evolution of performance measurement, in general, as well as the application of this concept in construction. This investigation provides the theoretical basis for developing proper performance measures for Total Building Commissioning, as described in Chapter 5 of this dissertation.

2.2. Building Commissioning

This section provides an overview of Building Commissioning and existing state-of-the-art research and practice. This overview is further used to establish the systematic framework used for studying the concept of Commissioning Delivery Systems in this research. The literature reviewed in this section was collected through several sources.

First, peer-reviewed journals were obtained through engineering databases, including ASCE, Galileo and Compendex. A small number of papers were identified through these databases, indicating a current lack of systematic research on the subject of Building Commissioning. Another source was the proceedings of the National Conferences on Building Commissioning (NCBC). Held annually since 1992, NCBC is the leading forum for exchange of information and ideas in the area of Building Commissioning. Finally, some useful information regarding the practice of Building Commissioning was found through Google's search engine. This information was used after careful verification of its source reliability.

2.2.1 Background

Historically, the term "commissioning" referred to a series of activities undertaken to prepare naval vessels to ensure they would not face any operational failures [Mauro 2005]. However, the concept of commissioning in buildings goes back to the 1950s and 1960s in Europe, when increasing energy prices provided a major driving force for improving the overall efficiency of building systems [FMI 2001]. At the time, commissioning referred to *test and balance* activities, performed at the end of construction and before building occupancy, to ensure proper operation of building systems. The first commissioning effort in North America was undertaken during the 1970s, when Alberta Public Works Supply and Services (APWSS) in Canada started to develop coordinated efforts in systems start-up and turnover on all of its major projects [Dunn and Whittaker 1994].

Building Commissioning started to gain momentum in United States during the 1980s and 1990s. The first major commissioning project was performed by Disney for its

Epcot facility in Florida in 1981 [PECI 2002]. Disney used a more comprehensive commissioning process, and began the commissioning activities during the design phase, to address issues and problems early on and reduce their overall impact on the project. In 1984, the University of Wisconsin-Madison began offering courses in commissioning. The American Society for Heating Refrigerating and Air-conditioning Engineers (ASHRAE) published the first guideline for commissioning HVAC systems in 1989. The same year, the local government of Montgomery County, Maryland, integrated ASHRAE's commissioning guidelines into a total-quality program called Construction Quality Control (CQC) [Tseng et al. 1994].

Commissioning also gained increased attention in federal projects. The U.S. Energy Policy Act of 1992 served as the major driver in implementing Building Commissioning in federal facilities. This act required the head of each federal agency to adopt procedures necessary to ensure that new federal buildings meet or exceed the federal energy standards established by U.S. Department of Energy (DOE) [FMI 2001]. Commissioning also became a major component of several national programs for improving the quality of the built environment, such as the Department of Energy's *Rebuild America* and the U.S. Green Building Council's *LEED* rating system.

Currently, implementation of Building Commissioning is experiencing exponential growth in the construction industry. General Services Administration (GSA) requires all new construction and major renovation projects, starting in 2006, to adopt some form of Total Building Commissioning as their quality-assurance tool [Eakin and Matta 2002]. The National Aeronautics and Space Administration (NASA) has also recognized Total Building Commissioning as the best practice, and is adopting this process to improve the performance of its buildings [NASA 2001]. Wal-Mart, the largest retailer in the world, is considering implementing building commissioning in construction of all of its new facilities [Bert 2005]. Building Commissioning is rapidly becoming standard practice in a wide range of facilities, including, but not limited to, data centers, laboratories, schools, hospitals, and institutional and office buildings.

It is also expected that the emergence of new types of Project Delivery Systems, such as Design-Build, which define a demand/supply relationship between owners and service providers, adds to the importance of Building Commissioning as a comprehensive tool to ensure the owners' requirements are met in the project [Shakoorian and Sadri 2004].

2.2.2. Evolution of Building Commissioning Practice as Total Quality Assurance System

Although not a new concept, little consensus exists on the exact definition of Building Commissioning. This is due to the fact that the practice of Building Commissioning has evolved tremendously during the past few years. Originally, Building Commissioning started as a quality-control and inspection practice, synonymous with Test and Balance (TAB) of HVAC systems [FMI 2001]. This process included a series of activities performed at the end of construction, and focused on equipment start-up, including testing, adjusting, balancing, and turn-over to the owner [Coleman and Coleman 2004].

However, this narrow definition of commissioning was soon changed. Early commissioning efforts showed that many problems with building systems arise from the early stages of the project [Elovitz 1986]. Therefore, when ASHRAE published its first commissioning guideline in 1989, it introduced commissioning as an independent process that starts at the design stage, and documents and verifies the performance of HVAC systems, according to the design intent [Sterling and Collett 1994]. In the first National Conference on Building Commissioning in 1992, Portland Energy Conservation, Inc, (PECI) a major advocate of commissioning practice, also defined commissioning as [Coleman and Coleman 2004]:

> a systematic process – beginning in the design phase, lasting at least one year after project closeout, and including the training of operating staff – of ensuring, through documented verification, that all building systems perform interactively according to documented design intent and the owner's operational needs.

This definition introduced two major shifts from the traditional view of Building Commissioning. First, the focus of Building Commissioning was extended to the overall performance of building systems and their interactions, as opposed to traditional practice, which only included the HVAC systems [Maisey and Milestone 2004]. The second shift, which was more important, was the introduction of Building Commissioning as a *quality assurance* tool. In other words, Building Commissioning was defined as a set of activities that span over the whole life-cycle of a project, and are aimed at ensuring the adherence to owner-operational needs at any stage of the process. In this approach, Building Commissioning is defined as a two-step process. In the first step, which is performed at early stages of the project, the owner's project requirements are identified and documented. In the second stage of this process, which starts from design and continues through occupancy, deliverables are constantly checked and tested against this project requirements to ensure that they meet the owner's criteria.

In recent years, this total quality management view of Building Commissioning has gained a lot of momentum in the construction industry. Building Commissioning is being viewed more as a comprehensive tool which ensures the building as a whole meets the needs of the users, and *all* building systems operate as expected [Dorgan et al. 2000]. Although real-life examples of implementation of comprehensive commissioning processes do not exist, commissioning is increasingly being used in the quality assurance of building systems other than HVAC. Examples of building systems which are being commissioned today include: Building Shell and Envelope; Communication Systems; Fire and Safety Systems; and Security Systems [Levin 1989; Parzych and MacPhaul 2005; Tseng 2005].

2.2.3. Types of Building Commissioning

Along with the evolution of the underlying concepts behind Building Commissioning, the practice itself has evolved into several branches. Each branch refers to a certain view about the commissioning process. Therefore, it is important to describe each of these practices, and identify the commissioning practice that is the subject of this research:

- ***Building Commissioning (Cx)***: This is the most common practice. In this process a specific building system (usually HVAC) goes through the commissioning process. Building Commissioning usually refers to the traditional view of commissioning, which is performed at the end of the construction phase of a facility.
- ***Retro Commissioning:*** Refers to the commissioning of systems of an existing building that has never been commissioned before. In this process, a detailed diagnosis of current building problems is performed. The result of this diagnosis will be used to modify the building systems and improve the overall building performance [Dorgan et al. 2002].

- ***Continuous Commissioning:*** A process developed and applied by engineers at the Energy Systems Laboratory in Texas A&M University. This application has evolved from improved O&M practices in the Texas LoanSTAR program, and refers to performing commissioning on a regular base in an existing building [Turner et al. 2003].
- ***Total Building Commissioning:*** Also called "Whole Building Commissioning." This process refers to the new definition of the commissioning process, which focuses on the overall performance of all building systems. It usually starts at the early stages of the project (i.e. pre-design) and continues through construction and at least one year of occupancy [Hague 2000].

The focus of this research is on this latter type of Building Commissioning (Total Building Commissioning), which, as a quality-assurance instrument, addresses all building systems through the entire life-cycle of the facility.

2.2.4. Guideline 0 and Total Building Commissioning

To standardize the practice of Building Commissioning, ASHRAE introduced the first guideline (later named Guideline 1) for commissioning HVAC systems in 1989. Later on, in response to growing demand for implementing Total Building Commissioning in construction projects, the National Institute of Building Sciences (NIBS) collaborated with ASHRAE to develop a comprehensive commissioning guideline called *Guideline 0*. Guideline 0 is a document that defines the process of Building Commissioning, apart from its application to specific building systems. In other words, Guideline 0 defines basic procedures and activities that are common in the commissioning of all different building systems.

In practice, Guideline 0 is used in conjunction with system-specific guidelines to commission one or more building systems. Working groups within various professional organizations are in charge of developing system-specific guidelines. Table 2.1 provides a list of proposed guidelines with the organization responsible for developing each of them:

Table 2. 1 - Technical Guidelines for Commissioning Building Systems [NIBS 2003]

Proposed Guideline	**Organization**
Guideline 1 – HVAC&R System	ASHRAE
Guideline 2 – Structural Systems	ASCE
Guideline 3 – Exterior Envelope Systems	BETEC
Guideline 4 – Roofing Systems	NRCA
Guideline 5 – Interior Systems	AWCI
Guideline 6 – Elevator Systems	NEIL
Guideline 7 – Plumbing Systems	ASPE
Guideline 8 – Lighting Systems	IES
Guideline 9 – Electrical Systems	IEEE
Guideline 10 – Fire Protection Systems	NFPA
Guideline 11 – Telecommunication Systems	TIA

Currently, Guideline 0 and Guideline 1 are fully developed and ready for use. Also, Guideline 3-2005[1] is near completion and ready for publication. This guideline includes all exterior envelope components and may include the requirements of Guideline 4 (roofing systems) [Dorgan 2005].

Guideline 0 defines the commissioning process as "a quality-oriented process for achieving, verifying and documenting that the performance of facilities, systems, and

[1] At the time writing of this dissertation (Winter 2006), this guideline was still under development.

assemblies meets defined objectives and criteria*"* [ASHRAE 2005]. Based on this guideline, Building Commissioning *begins at project inception (during the Pre-Design Phase) and continues through the life of the facility*. Guideline 0 defines four different phases for the commissioning process: *Pre-design*, *Design*, *Construction*, and *Occupancy & Operations*. It further provides the list of commissioning activities that must be undertaken in each of these phases, as well as commissioning responsibilities of the entities involved in the project.

2.2.5. Commissioning Team and Commissioning Authority

Guideline 0 defines commissioning as a group effort. Commissioning activities are carried out by the *Commissioning Team*, a group of *"individuals who through coordinated activities are responsible for implementing the commissioning process."* Commissioning Team members includes: *Owner Representatives, Commissioning Authority, Pre-design and Programming Professionals, Design Professionals* and *Construction Professionals*.

This guideline defines *Commissioning Authority* as an entity that *"leads, plans, schedules, and coordinates the commissioning team to implement the commissioning process."* In other words, Commissioning Authority (CA) is the entity responsible for the commissioning process. For an entity to be a Commissioning Authority, it must have extended knowledge and experience with different building systems and their interactions. In addition to this expertise, other general qualifications, such as communication skills, management expertise and administrative proficiency, has been identified as essential [Dunn and Whittaker 1994]. Guideline 0 elaborately defines the roles and responsibilities for the Commissioning Authority. A list of these responsibilities is provided in Table 2.2.

Table 2. 2 - Responsibilities of the Commissioning Authority based on Guideline 0 [ASHRAE 2005]

1. Organize and lead the Commissioning Team
2. Facilitate and Document the Owner's Project Requirements
3. Verify that the Commissioning Process activities are clearly stated in all scopes of work
4. Integrate the Commissioning Process activities into the project schedule
5. Prepare a Commissioning Plan that describes the extent of the Commissioning Process to accomplish the Owner's Project Requirements. Update the Commissioning Plan during each phase of the project to incorporate changes and additional information.
6. Review and Comment on the ability of the design documents to achieve the Owner's Project Requirements for the commissioned systems and assemblies.
7. Prepare the Commissioning Process activities to be included as part of the project specifications, Include a list of all individual trade contractor responsibilities for all the Commissioning Process activities
8. Execute the Commissioning Process through the writing and review of Commissioning Process Reports, organization of all Commissioning Team meetings, tests, demonstrations, and training events described in the Contract Documents and approved Commissioning Plan. Organizational responsibilities include preparation of agendas, attendance lists, arrangements for facilities, and timely notification to participants for each Commissioning Process activity. The Commissioning Authority shall act as chair at all commissioning events and ensure execution of all agenda items. The Commissioning Authority shall prepare minutes of every Commissioning Process activity and send copies to all Commissioning Team members and attendees within five workdays of the event.
9. Review the plans and specifications (during Pre-Design and Design Phases) with respect to their completeness in all areas relating to the Commissioning Process. This includes verifying that the Owner's Project Requirements have been achieved, and that there are adequate devices included in the design to properly test the systems and assemblies and to document the performance of each piece of equipment, system, or assembly.
10. Schedule all document review coordination meetings.
11. Attend the project's pre-bid meeting to detail the design professional or contractor Commissioning Process requirements.

Table 2.2 (Continued)

12. Schedule the pre-design and pre-construction Commissioning Process meeting within 60 days of the award of the contract at some convenient location and at a time suitable to the attendees. This meeting will be for the purpose of reviewing the complete Commissioning Process and establishing tentative schedule for the Design Phase and Construction Phase commissioning activities.
13. Develop the initial format to be used for Issues Logs throughout and for each phase of the Commissioning Process.
14. Schedule the initial owner training session so that it will be held immediately before the contractor training. This session will be attended by the owner's O&M personnel, the design professionals, the contractor, and the Commissioning Authority, The Commissioning Authority will review the Owner's Project Requirements and the design professional will review the Basis of Design.
15. Review proposed contractor-provided training program to verify that the Owner's Project Requirements are achieved.
16. Attend a portion of the contractor-provided training sessions to verify that the Owner's Project Requirements are achieved.
17. Receive and review the Systems Manual as submitted by the contractor. Verify that it achieves the Owner's Project Requirements. Insert systems descriptions as provided by the design professional in the System Manual.
18. Witness system and assembly testing. Verify the results and include a summary of deficiencies.
19. Supervise the Commissioning Team members in completion of tests. The test data will be part of the Commissioning Process Report.
20. Periodically review Record Drawings for accuracy with respect to the installed systems and request revisions to achieve accuracy.
21. Verify that the systems Manual and all other design and construction records have been updated to include all modifications made during the Construction Phase.
22. Repeat implementing of tests to accommodate seasonal tests or to correct any performance deficiencies. Revise and resubmit the Commissioning Process Report.
23. Prepare the final Commissioning Process Report.
24. Assemble the final documentation, which includes the Commissioning Process Report, the Systems Manual, and all record documents. Submit this documentation to the owner for review and acceptance.
25. Recommend acceptance of the individual systems and assemblies to the owner (in accord with the defined project requirements).

2.2.6. Commissioning Delivery Systems

Commissioning Delivery System (CDS) defines the type of contractual relationship by which the Commissioning Authority is bound with other parties in the project. In recent years, several types of CDS have emerged. Some more common examples of Commissioning Delivery Systems include:

Third-party Commissioning: The most-common method. In this delivery system, the owner hires a third-party consultant as the Commissioning Authority. The main advantage of Third-party commissioning has been cited as the objectivity of the independent commissioning entity and the fresh perspective that it brings to the project. At the same time, this type of commissioning has been criticized as adding an extra layer of complexity to the project as well as running the risk of antagonizing the traditional participants.

Owner-led Commissioning: This is basically a "do-it-yourself" model, in which the owner performs the commissioning activities by using in-house technical capabilities. In this case, the Owner Representative (which could also be the Construction Manager) acts as the Commissioning Authority. The main advantage of owner-led commissioning is the active involvement of owner's staff, who have direct knowledge of owner's needs and requirements, in the commissioning process. At the same time, it has been argued that in most cases lack the resources and technical capabilities required for commissioning a project.

Designer-led Commissioning: In this model, commissioning services are considered an additional responsibility of the Project Designer. In other words, in this type of commissioning, the Architect/Engineer (AE) of record also acts as the Commissioning Authority. The commissioning work can be part of the existing design contract. However, it is more common to have a separate commissioning contract, in addition to the original design contract. The advantage of Designer-led commissioning over other methods is the use of existing knowledge of the design professional about the project, as well as familiarity of this entity with different sequences of design and construction. At the same time, this method has been criticized as introducing a conflict of interest and lack of objectivity of design professional to commission his work.

Contractor-led Commissioning: The Contractor is in charge of performing the commissioning activities. Again, the commissioning can be part of the original construction contract. However, the more-common method is to have a separate contract for commissioning services between the owner and the contractor. The main advantage of contractor-led commissioning is the well-defined authority of contractor in implementing the commissioning activities and reducing the coordination problems. At the same time, it is argued that this delivery system creates the same problem of lack of objectivity and conflict of interest, discussed for designer-led commissioning. In addition, as in most traditional delivery systems, contractor is not present at the early stages of the project this method can not be used in more comprehensive types of commissioning such as total building commissioning.

Subcontractor-led Commissioning: Similar to Contractor-led Commissioning, in this method different subcontractors are responsible for commissioning the systems. The major difference is that each subcontractor is in charge of commissioning the individual systems that they install in the building. Again, this commissioning method cannot be used in comprehensive types of commissioning, as subcontractor is usually not present at the early stages of the project. In addition, subcontractor-led commissioning limits the focus of commissioning to specific systems, and looses the holistic view of the commissioning, which considers all major building systems and their interactions.

Although, Third-party Commissioning is the most widely used model in the industry, the question of who should be responsible for Building Commissioning is still being debated, since each of these models have their own perceived advantages and disadvantages [Dunn and Whittaker 1994; Prowler 2003]. One side of this discussion is based on the argument that, in order to fully represent the owner's interest, the Commissioning Authority should directly work for the owner [Casault 2003]. On the other hand, it is also argued that introducing another party to an already-complex relationship between the owner and service providers will introduce an adversarial relationship into the project and add to the project complexity [Sweek 2003]. It is also believed that commissioning services performed by the Architect/Engineer or the General Contractor can benefit the project, since these parties already have full knowledge about the project and can use the commissioning process to improve the quality of their services [Tseng et al. 1993].

2.2.7. Summary of Literature Review on Building Commissioning

The first section of this chapter provided an overview of the practice of Building Commissioning and the evolution of this concept over the past 30 years. This review showed how this practice has emerged to a quality assurance tool. Different types of Building Commissioning were presented, and Total Building Commissioning was introduced as the main focus of this study. Also, Guideline 0, the major source for defining the process of Total Building Commissioning, was described. Finally, the concept of Commissioning Delivery System was explained, and an overview of major delivery systems existing in the industry was provided. The next section of this chapter will focus on the subject of performance measurement in regard to processes.

2.3. Process Performance

In this research the outcome of commissioning process is defined in terms of performance measures. Therefore, this section provides an overview of the concept of performance measurement, as it relates to different processes. The goal is to explore the evolution of performance measurement and identify state-of-the-art research, in order to provide a basis for developing performance measures for the commissioning process. The literature identified for this review was obtained through a search of peer-reviewed journals in several fields of study, including Strategic Planning, Process Management, Program Management and Construction Management.

2.3.1. Definition

Performance measurement is a broadly defined concept. Neely et al. [1995] define performance measurement as *"the process of quantifying the efficiency and effectiveness of actions."* Evangelidis [1992] uses a more goal-oriented approach and defines performance measurement as the process of *"determining how successful organizations or individuals have been in attaining their objectives."* Atkinson [1997] also discusses the importance of linking the performance measurement to strategic planning, and defines performance measurement as a tool for monitoring the activities undertaken towards defined strategic goals.

Although each of these definitions focus on a certain aspect of performance, they all point to the main characteristic of performance measurement, which can be defined as a process for measuring an object/action's ability to achieve a pre-defined goal. In this sense, performance measurement can be both a *lagging* and a *leading* activity. In other words, this process can be used to measure the realized capacity of an action of the past, in relation to an achieved goal, or it can be used to measure the potential of an action to render a defined-but-unachieved goal in the future.

2.3.2. Evolution of Performance Measurement Frameworks

The use of performance measurement can be traced back to the 1860s and 1870s when the U.S. railroads started to use planning and control procedures to manage their contracts [Chandler 1977; Kaplan 1984]. In the early 1900s, Dupont Company introduced the *Return on Investment* (ROI) as the first financial performance measure. Since the introduction of ROI, other financial measures such as *Discounted Cash Flow*, *Residual Income, Economic Value Added* and *Cash Flow Return on Investment* have been introduced [Bassioni et al. 2004]. Financial performance measures have been widely used in different industries, due to the fact that they can easily be incorporated into companies' accounting practices. At the same time, the use of financial measures has not been free of criticism. The major criticism towards their use is based on the fact that these are "lagging metrics," in that they measure the past and, therefore, cannot be used for improvements [Ghalayini and Noble 1996]. In addition, critics argue that financial performance measures do not provide decision-makers with information required to manage and improve existing processes [Atkinson et al. 1997]. Neely et al. [1997] identified additional reasons for criticism of financial measures. These criticisms are that they:

- Encourage "short-termism" and lack strategic focus ;
- Fail to provide data on important aspects, such as quality, responsiveness and flexibility ; and,
- Encourage local optimization and do not encourage continuous improvement.

In response to the inadequacy of these traditional measures, new performance measurement frameworks have been proposed in recent years. Maskell [1989] proposed a set of performance measures based on world-class manufacturing elements, such as *quality*, *time*, *process* and *flexibility*. Cross and Lynch [1988] proposed the use of different performance measures at differing levels of the company, in the form of the *Performance Pyramid* (figure 2.1). Finally, an important performance measurement system is Kaplan and Norton's [1992] *Balance Scorecard*. This framework defines four broad perspectives for performance measurement: *financial*, *customer*, *internal processes and innovation*. Balance Scorecard has gained a lot of attention in both industry and academia, and has been used as the basis for many other performance frameworks. A comprehensive review of Balance Scorecard, and other contemporary performance measurement frameworks, is provided in Bassioni et al. [2004] and Kagioglou et al. [2001].

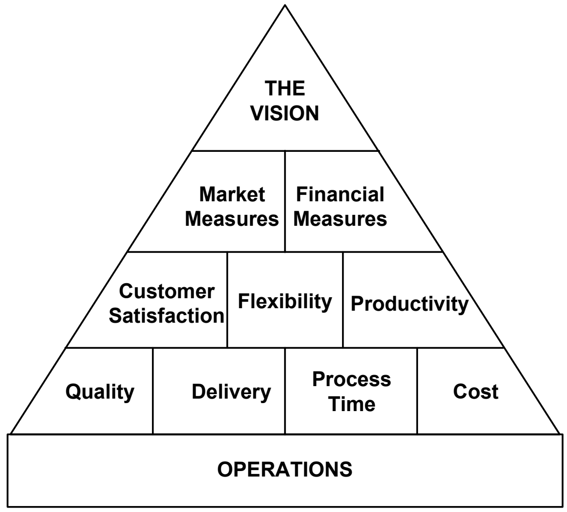

Figure 2. 1: Performance Pyramid (Cross and Lynch 1988)

2.3.3. Performance Measurement in Construction

Performance measurement in the construction industry has taken two different approaches [Kagioglou et al. 2001]. First, in relation to the created product as the facility, and second, in relation to the creation of the product as the process. Performance of construction products and facilities has been a major source of discussion in both academia and industry and has its own rich literature. However, as the focus of this study is to develop performance measures for the commissioning process, this section only concentrates on the performance of the process.

Traditionally, the construction industry has relied on financial measures, such as *return on capital* and *profitability,* in a performance evaluation of construction organizations [Bassioni et al. 2004]. However, the recent need for a more long-term and broader focus on corporate strategy, business process, and stakeholder needs, has been recognized [Love and Holt 2000]. At the same time, the construction industry is a project-oriented industry [Wegelius-Lehtonen 2001]. Therefore, most of the efforts in developing performance measurement frameworks in the construction industry have focused on the performance of the projects [Love and Holt 2000].

Munns and Bjerimi [1996] define *project* as achievement of a specified objective, which involves a series of activities and tasks that consume resources. Therefore, the major performance goal of a project is *success* [Chan and Chan 2004]. At the project level, success has been measured by the *project duration*, *monetary cost* and *project performance* [Navarre and Schaan 1990]. These three aspects of *time*, *cost* and *quality* have been widely used as the major performance indicators for construction projects [Bassioni et al. 2004; Chan and Chan 2004; Kagioglou et al. 2001; Mohsini and Davidson 1992; Ward et al. 1991].

However, use of these indicators has not been without criticism. Kagioglou et al. [2001] argue that these measures by themselves don't provide a balanced view of the project's success. They also mention that these indicators are lagging measures, which focus on the outcomes of the project and, therefore, do not provide any planning value.

Nahapiet and Nahapiet's [1985] research shows no clear relationship between satisfaction expressed by clients and project performance in absolute terms, such as *cost per unit of floor area*, or *floor area constructed per unit of time*. Ward et al. [1991] further suggest that these three measures (cost, time, quality) are inter-related and, in most cases, incompatible in nature. In other words, achieving a high performance in one dimension will reduce the performance in another dimension. They also argue that the overall performance of the project goes back to the owners' memory of the project, which is mostly affected by the quality of relationships in the project.

In response to these critiques, new measures of performance have been proposed in the construction management literature. Chan and Chan [2004] provide a comprehensive overview of the evolution of performance measures during the 1990s. These include: “psychosocial outcomes” by Pinto and Pinto [1991]; “satisfaction” by Wuellner [1990]; “conflict-inducing variables” by Mohsini and Davidson [1992]; “maintenance cost” and “flexibility” by Kometa et al. [1995]; “conformance to user expectations”, “meeting specifications”, “quality workmanship”, and “minimizing construction aggravation” by Songer and Molennar [1997]; and “transfer of technology”, “friendliness of environment” and “health and safety” by Kumaraswamy and Thorpe [1996].

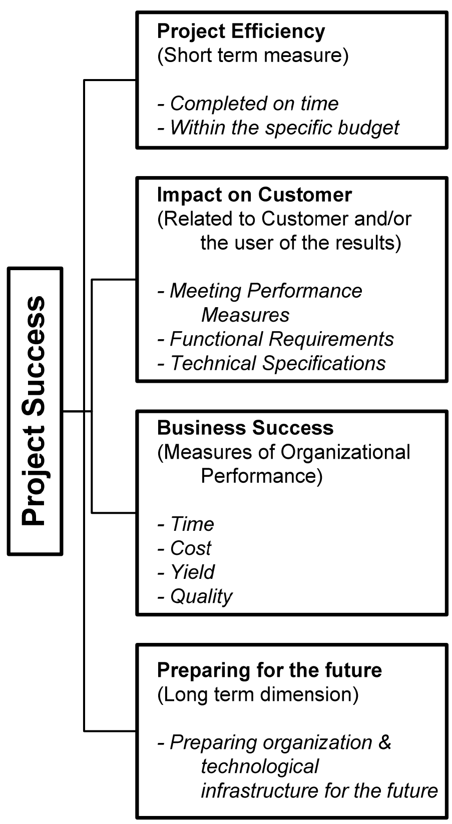

Figure 2.2 - Performance framework by Shenhar et al. (1997)

In addition, other frameworks have been proposed that use a more-comprehensive approach. Shenhar et al. [1997] suggest a framework that presents four performance categories of *Project Efficiency*, *Impact on Customer*, *Business Success*, and *Preparing for the Future* (figure 2.2). Atkinson [1999] uses a different approach, and defines the project success in three stages of a project life-cycle (Figure 2.3). Lim and Mohamed [1999] argue that project performance should be viewed at micro and macro levels (figure 2.4). At the micro level, they suggest use of performance measures that focus on the project itself. The macro level, on the other hand, is compromised of performance measures that focus on the whole life-cycle of the facility. Sadeh et al. [2000] divide project success into four dimensions: *Meeting design goals; Benefit to the end user; Benefit to the developing organization;* and *Benefit to the technological infrastructure of the country and of firms involved in the development process.*

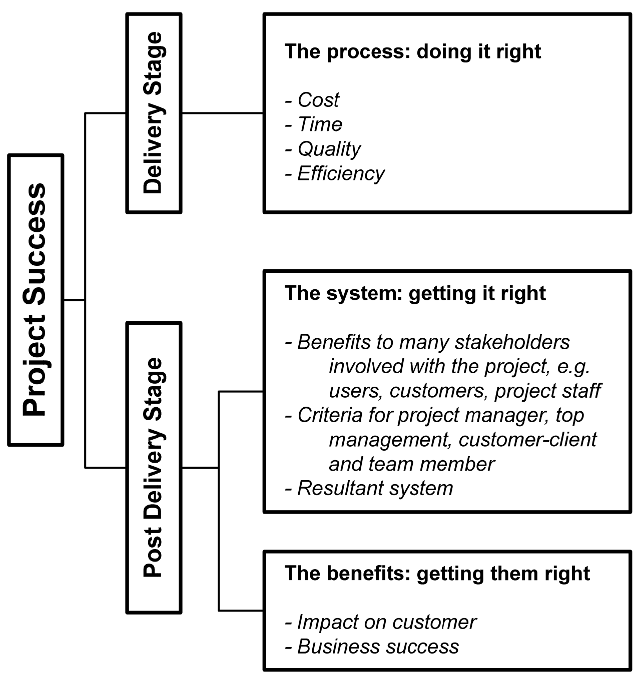

Figure 2. 3 - Performance Framework by Atkinson (1999)

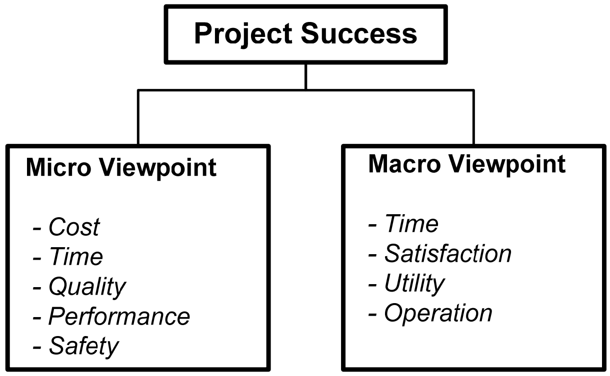

Figure 2. 4 - Performance Framework by Lim and Mohamed (1999)

Another performance framework is Key Performance Indicators (KPI), launched by the United Kingdom's construction best practices program (CBPP). The purpose of KPI is to enable the measurement of the project and organizational performance in the construction industry [The_KPI_Working_Group 2000]. Table 2.3 shows the project and company indicators that KPI proposes. A comprehensive review of KPI is provided in Chan and Chan [2004] and Bassioni et al. [2004].

Table 2. 3 – Key Performance Indicators for Construction Firms (KPI 2000)

Project Performance	Company Performance
Construction Cost	Safety
Construction time	Profitability
Predictability – cost	Productivity
Predictability – time	
Defects	
Client satisfaction – product	
Client satisfaction - service	

2.3.4. Internal Performance Aspects

Most of the performance measures and frameworks that were described previously focus on the overall outcome of the project as the basis for measuring the project performance. Therefore, we call them *External Performance Aspects*. At the same time, a different approach towards performance measurement has been based on the project itself. In this approach, the focus is on characteristics of the internal processes in a project, and the internal mechanics and interactions between different entities in that project. We call these performance measures *Internal Performance Aspects*.

One of the most useful models in explaining the relationship between external and internal aspects has been suggested by Brown [1996]. As it is shown in Figure 2.2, this framework makes a distinction between different measures used for stages of *Inputs*, *Processes*, *Outputs* and *Outcomes*. By using the analogy of baking a cake, Brown explains the process (internal) measures can be defined as *speed of the mixer, length of time the batter/dough is mixed*, and *temperature of the oven*, as opposed to outcome (external) measures which can be the *color* and *taste* of the cake.

Brown supports the use of process measures, as they will guarantee achievement of good outcomes through improving the processes. At the same time, he addresses that process measures should be selected based on their correlation to the performance of the outcome [Brawn 1996].

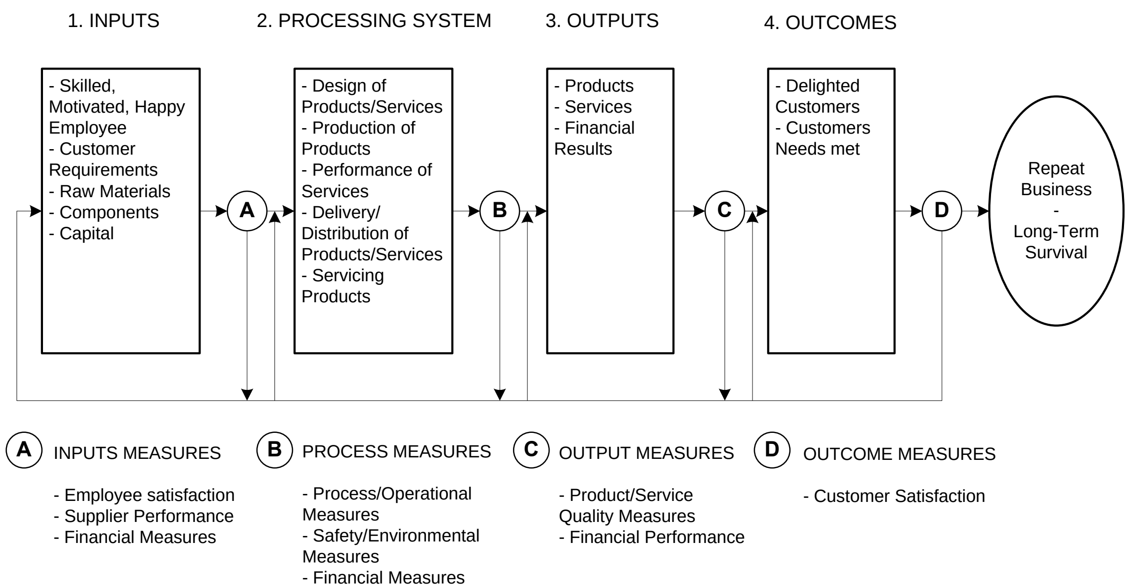

Figure 2. 5 Macro Process Model for an Organization (Brown 1996)

In the construction industry, internal aspects are not as widely used as external measures; however, there are some studies that support this approach of performance measurement. Pocock et al. [1996b; 1997] propose use of performance measures such as *safety* and *degree of interaction*. In his study, Walker [1995] shows the importance of *communication* and the *quality of relationships* among different stakeholders on the construction time performance. Kumaraswamy and Dissannayaka [2001] uses internal factors of *effective and efficient communication* and *effective and efficient decision-making* as the relevant performance criteria for procurement selection. Ward et al. [1991] argue that the best way to compare different project alternatives is to focus on the project itself. They propose a more-comprehensive framework that presents seven internal performance aspects of *adaptation, allocation, coordination, integration, tension management*, *productivity*, and *integrity*.

2.3.5. Summary of Literature Review on Performance Measurement

The second section of this chapter provided an overview of the existing literature on performance measurement as it relates to processes. The objective was to identify state-of-the-art performance research, and to establish a point of departure for utilization of performance measurement in this research.

Different definitions of performance were provided and, as a result, this concept was described as a process of measuring an object/action's ability to achieve a pre-defined goal. A brief overview of the evolution of the concept of performance measurement was provided, and major performance frameworks across industries were reviewed. This chapter also provided an overview of the application of performance measurement in the construction industry, along with major performance frameworks proposed in this industry. The application of internal performance measures, which focus on the process rather than the overall project outcome, was also discussed. The next chapter describes the methodology of this research.

CHAPTER 3

RESEARCH METHODOLOGY

3.1. Purpose

The previous chapter provided an overview of existing literature on the subjects of Building Commissioning and Performance Measurement within the construction industry. This chapter describes the research methodology used in this dissertation. First, based on the definition and characteristics of building commissioning provided in the previous chapter, the position of this practice, in regard to the overall system of construction procurement, is examined. Next, a review of research methodologies applicable to construction management problems, similar to the problem of this research, is provided. Advantages and disadvantages of each methodology are also discussed. Based on this a methodology for this research is designed and presented, and each step is described in detail.

3.2. System View of Building Commissioning

In order to perform a comprehensive analysis of different Commissioning Delivery alternatives, it is critical to define the position of CDS within the context of the overall system of construction procurement. This relationship is established in two steps. First, the position of commissioning practice within the overall context of procurement systems will be defined. Next, Commissioning Procurement, as a sub-system of Building Commissioning, will be defined, and the position of Commissioning Delivery Systems in this overall system will be analyzed.

3.2.1. Total Building Commissioning as a Sub-system of Project Procurement

In general, procurement has been defined as *"the action or process of acquiring or obtaining material, property or services at the operational level"* [Parker 1994]. CIB W92 - Working Commission on Procurement Systems defines construction procurement as "*the framework within which construction is brought about, acquired or obtained*' [Sharif and Morledge 1994]. In other words, construction procurement consists of all the "front-end" decisions that must be made by a decision-maker (i.e. project owner) to begin a construction project [Kumaraswamy and Dissanayaka 1998].

Although similar in nature, the types of the decisions that are made in a project vary in different project settings. For example, a private owner in the United States is confronted with a set of decisions that can be very different from a public owner in Hong Kong. As a result, in order to identify the elements of a procurement system, it is important to define the external setting in which a construction project is acquired. In this research, the overall setting is defined as the construction of vertical buildings in the U.S. Based on this context, the main source for identifying the elements of procurement is the procurement framework proposed by the *Associated General Contractors of America (AGC) [AGC 2004]*. Based on this model, a typical procurement system is broken down into four principal sub-systems:

1. **Project Delivery System:** This involves the identification of the principal team(s) who is responsible for carrying out the project. Two major issues are addressed at this level:

   a. First, is the functional grouping of design, construction, and management within a project. This functional grouping can be based on a “separate” approach, in which each participating group has a separate contractual relationship with the project owner. Or, it can be based on an “integrated” approach, in which different functions are merged to form a combined contractual relationship with the owner.

b. The second major decision under the project delivery category concerns the methodology used for selecting the entities involved in the project. Common examples of selection methodologies in the construction industry in the U.S. include: Competitive Low Bid, Best Value Selection, or Qualification-based Selection.

2. **Contract Conditions:** This sub-system includes all the decisions regarding the actual contract between entities in the project. These include: the type of contract forms, (which can be either standard forms developed by certain organizations, such as document A201 by the American Institute of Architects (AIA), or a custom contract form); Insurance Issues (including overall project insurance and entity insurance); Securities for Performance (including guarantees, bonds, letters of credit, etc.), and others.

3. **Payment Modalities:** Addresses issues regarding the financial aspects of the project, such as the Valuation Methods (e.g. Fixed Price, Lump Sum, or Guaranteed Maximum Price) and Reimbursements (e.g. Advanced, Milestone, Monthly).

4. **Management Strategies:** This focuses on management of the overall construction project. Management Strategies includes two major sub-

systems. First, are the Management Methods, which can be defined as the mechanics by which the construction project is administered and supervised. Examples include the use of management models, such as Construction Management Agency, Project Management, and Program Management. The second sub-system is the Management Instruments, which refers to the special tools and techniques that are employed to improve the overall execution of the project. Examples include Partnering, Alternative Dispute Resolution, TQM, etc.

Based on this breakdown of overall procurement systems, we need to identify the position of Total Building Commissioning in this overall system. Chapter 2 discussed the evolution of building commissioning, and showed how this practice has emerged as a quality assurance instrument for improving the quality of construction. In this view, Total Building Commissioning can be seen as a tool which is aimed at improving the project execution and, therefore, can be considered as a Management Instrument under the Management Strategy sub-system. Figure 3.1 shows the overall system view of construction procurement, and positioning of Total Building Commissioning within this system.

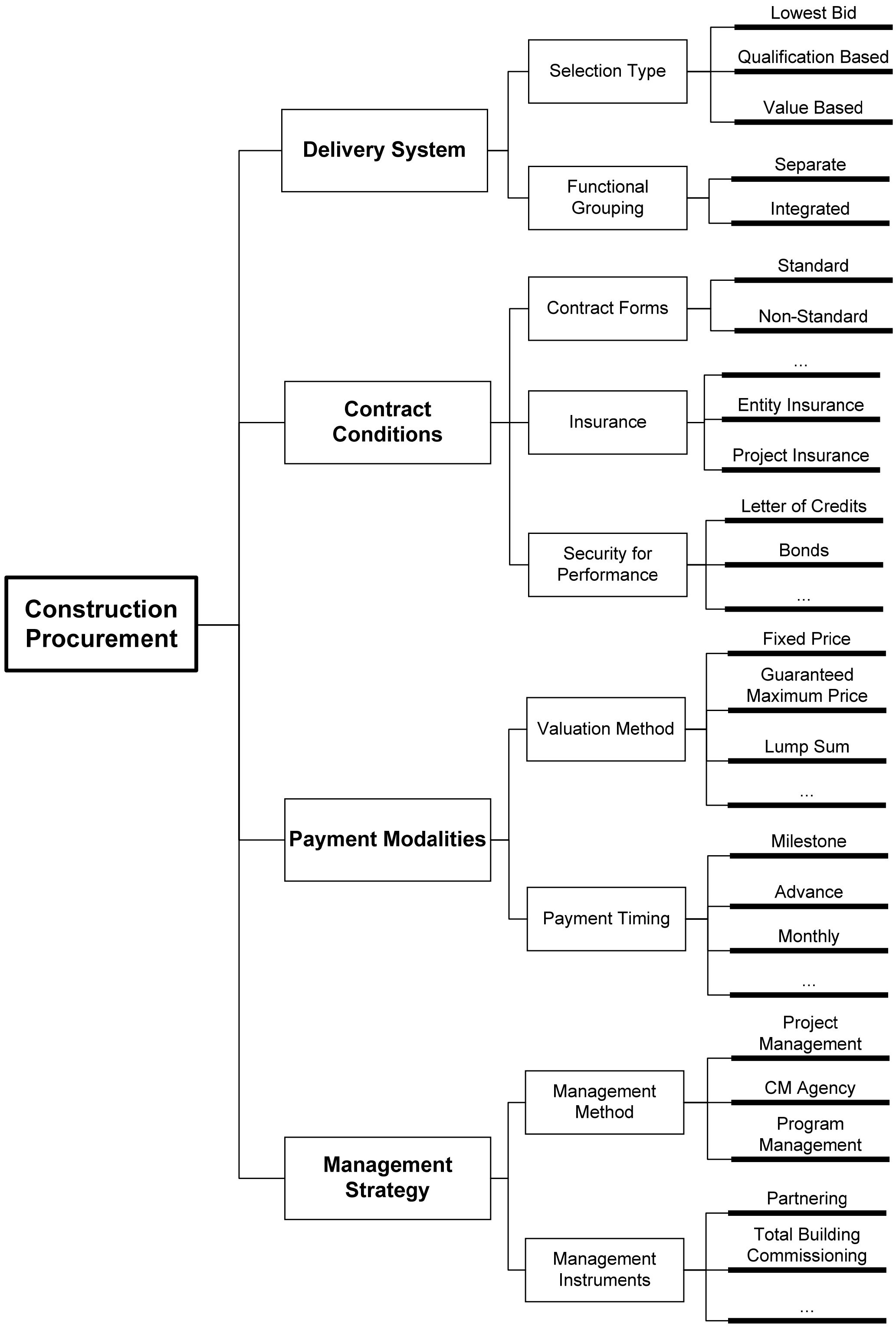

Figure 3. 1 - Construction Procurement System

3.2.2. Commissioning Procurement System and Commissioning Delivery Systems

Now that the overall position of Building Commissioning within the procurement system is identified, the next step is to locate the position of Commissioning Delivery Systems (CDS) within the overall system of building commissioning itself. Similar to the larger system of Construction Procurement, procurement of commissioning services can also be viewed as a system in and of itself. In this view, Commissioning Procurement can also be defined as all of those “front-end” decisions that must be made by a decision-maker (e.g. owner) to secure the commissioning services for a project. Figure 3.2 shows the Commissioning Procurement System suggested by this study and its principal sub-systems.

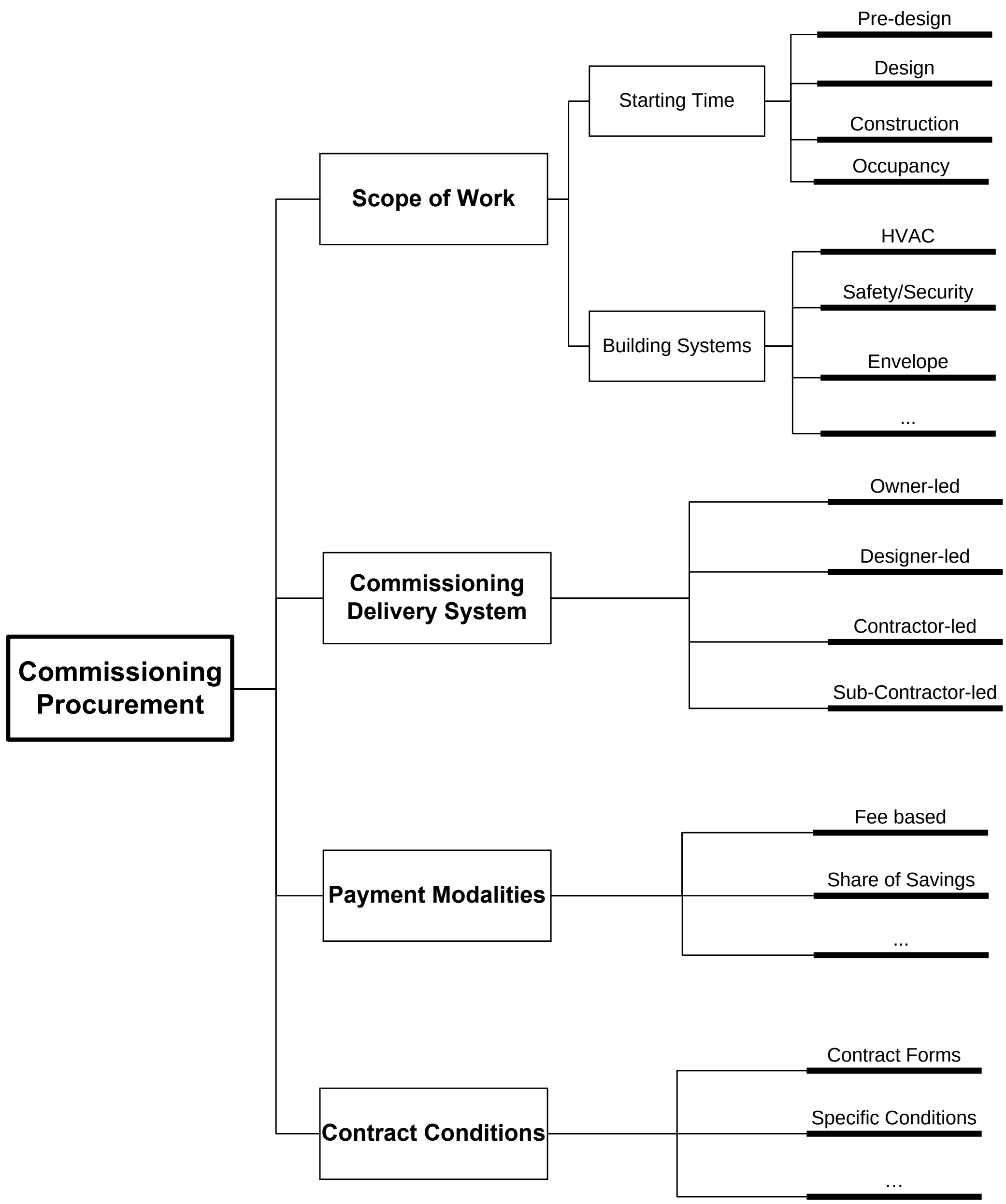

Figure 3. 2 - Commissioning Procurement System

As shown in the figure, the Commissioning Procurement System is compromised of four major sub-systems:

1. **Scope of Work:** This includes the decisions concerning the scope of commissioning work on a project. This scope of work can be defined in relation to two major aspects:
    a. Timing: This deals with determining the construction phase in which the commissioning activities are started in the project. As discussed in Chapter 2, this starting phase is the major differentiator between the types of commissioning practices. At the same time, the focus of this study is Total Building Commissioning, which refers to the type of commissioning that starts at the initial, pre-design stage of the project.
    b. Building Systems: The second defining aspect involves the building systems that will be commissioned within the project. Based on this, commissioning can be focused on one specific system (e.g. HVAC), or can be performed as an activity that involves all the major building systems and their interactions, with a focus on the overall performance of the building. Again, Total Building Commissioning, which is the subject of this study, refers to the latter alternative and focuses on all the major building systems.
2. **Commissioning Delivery Systems (CDS):** As discussed in Chapter 2, Commissioning Delivery Systems deal with the selection of the entity in charge of performing commissioning activities in the project. As a result, the type of CDS further defines the commissioning roles, responsibilities, and

authorities of different stakeholders in the project. Common examples of Commissioning Delivery Systems in the construction industry include: Third-party Commissioning, Owner-led Commissioning; Designer-led Commissioning, Contractor-led Commissioning; and Subcontractor-led Commissioning.

3. **Payment Modalities:** This addresses the financial aspects of the commissioning project. These include the valuation of the commissioning work (e.g. fee-based or sharing the project savings) and timing of payments (e.g. advance, monthly, milestone, etc.)
4. **Contract Conditions:** This deals with contractual aspects of the commissioning process, such as contract forms, general & specific conditions, insurance requirements, bonds, etc.

Although each of these issues could have an impact on the overall outcome of a commissioning project, as described in Chapter 1, the scope of this study is limited to Commissioning Delivery sub-systems. In other words, this study is aimed at analyzing the effect of different Commissioning Delivery Systems on the outcome of this process. This is due to increasing concern within the construction industry about identifying the most appropriate Commissioning Delivery System for construction projects [Casault 2003; Dunn and Whittaker 1994; Holland and Peed 2002; Prowler 2003; Sweek 2003; Tseng et al. 1993].

3.3. Methodologies for Assessing the Effect of Procurement Options on Overall Project Outcome

The previous section provided a system view of the commissioning practice. Based on this view, both Building Commissioning and Commissioning Delivery Systems can be viewed as sub-systems of the overall system of Construction Procurement. Based on this system view, a methodology for analyzing the effect of different Commissioning Delivery Systems on the outcome of the project should be based on methodologies developed for assessing the effect of the procurement system on project outcomes. Therefore, in this section, an overview of common methodologies used in construction management research for performing such analyses will be provided.

3.3.1. Establishing the Relationship between the Procurement System and the Overall Outcome of the Project

There is a general consensus within the construction industry that the outcome of a project is highly affected by the procurement decisions for that project [Chan 1997; Kumaraswamy and Chan 1999; Pocock et al. 1997]. At the same time, procurement-related factors are not the only determining factors for project success, and many other non-procurement factors also affect the outcome of the project. Therefore, in order to analyze the relationship between the procurement system and project outcome, it is important to view this relationship in the overall picture of project outcome determinants. One of the most comprehensive frameworks, identifying the relationship between different project elements and the overall project outcome, has been proposed by Kumaraswamy and Dissanayaka [1998]. This framework is illustrated in Figure 3.3.

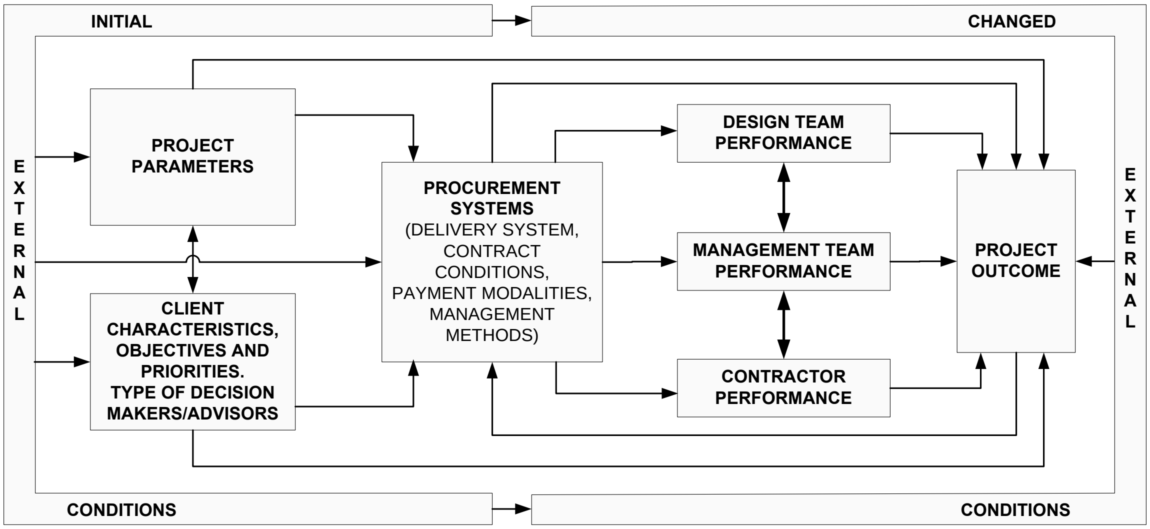

Figure 3. 3 - Model of basic linkages between procurement system and project outcomes (Kumaraswamy and Dissanayaka 1998))

Based on this framework the major determinants of project outcome include:

- **Initial External Conditions:** Refers to the variables affecting the external environment in which the project is being planned and defined. Examples include the overall economical conditions, market settings and legislative environment.
- **Project Parameters:** Refers to specific project characteristics, such as project size, project location and complexity.
- **Client Parameters:** Refers to characteristics of the client, such as client type (i.e. private/public), client's objectives and priorities, and client's background and experience.
- **Procurement System:** Refers to the combination of different options under each procurement sub-system (e.g. project delivery type, contract type and management strategy).

- **Performance of Building Teams:** Refers to the overall performance of different teams involved in the project, including designers, contractors and project managers.
- **Changed External Conditions:** Refers to environmental variables at the time of project execution, such as cost and availability of materials and labor, and weather conditions.

Based on this framework, all of these factors have a direct impact on the overall outcome of the project. At the same time, as illustrated, these factors are also interrelated. In other words, the outcome of a project is not only directly affected by the variations in each of these elements, but it also is indirectly influenced by the effect of these factors on each other. These direct and indirect relationships introduce a high level of complexity in analyzing the effect of procurement systems on the project outcome.

In the face of this complexity, the research in construction management has taken two different approaches: 1. *Quantitative Analysis,* based on empirical data collected on existing projects; and 2. *Qualitative Analysis,* based on gathering the knowledge of the experts in the industry. In the following sections, each of these approaches will be described, and advantages and disadvantages of each will be discussed.

3.3.2. Quantitative Analysis

In this methodology, the overall outcome of the project is defined in terms of a set of quantifiable performance indicators, such as project duration, project cost, number of change orders, etc. This data is collected from a sample of existing projects. Next, the collected data is analyzed using common statistical techniques, in order to assess the effect of different procurement approaches (such as different project delivery systems) on those performance indicators.

Quantitative analysis has been one of the most widely used methodologies in assessing the effect of procurement-related factors on project outcome [Gransberg et al. 2003; Konchar and Sanvido 1998; Ling et al. 2004]. However, literature on construction management research has been critical of this approach in studying different procurement options.

First, it is argued that most quantitative studies, which usually focus on procurement systems as the major determinant of project success, do not account for other factors affecting the project success (such as those presented in Figure 3.3). At the same time, some studies have shown that non-procurement factors may play a stronger role in determining project performance. For example, Dissanayaka and Kumaraswamy [1999] have conducted studies that show factors, such as project complexity, program duration and client characteristics, exert more influence on time and cost of a project than any procurement-related factors.

Second, is the issue of the procurement system itself. As mentioned, most studies generally focus on one sub-system of the procurement system (e.g. project delivery), and fail to control for all the other sub-systems of the procurement system [Kumaraswamy and Dissanayaka 1998]. This further results in comparing procurement options which, although classified under the same name, are vastly different from each other [Curtis 1989]. For example, a design-build project that is procured based on a low-bid may have a very different result than a design-build project that is procured based on qualification-based selection. Therefore, categorizing these two projects as design-build projects may result in misleading outcomes.

Thirdly, it has been argued that implications of such studies are very limited, as their focus on overall performance usually results in advocating one procurement option as the best alternative. They do not provide any information about the internal mechanics of a project, nor are they helpful in gaining any insights for improvements [Ward et al. 1991].

Another common criticism, of using a quantitative approach to analyze the effects of procurement options on the project outcome, is its inability to deal with the human aspects of a construction project. Due to its high degree of importance, a more-detailed discussion of this criticism is provided in the next section.

3.3.3. Role of Human Factors in Determining the Project Outcome

Many construction management studies have pointed out the enormous impact of human factors on the outcome of a project [Ahmad and Sein 1997; Shammas-Toma et al. 1998; Soares and Anderson 1997]. For example, Naoum and Mustapha [1994] showed that time and cost of the project is significantly affected by the level of experience of the building team, rather than any other factors. Pocock et al. [1996a; 1996b; 1997] performed several studies that showed the immense impact of interaction among different project teams on the overall performance of the project.

It has been further argued that construction projects can be seen as adaptive systems, in which participants constantly modify their roles and activities (in spite of the formal provisions defined based on procurement system), in order to make up for external disturbances introduced in the project [Shammas-Toma et al. 1998]. In other words, in many situations, project participants compensate for shortcomings of other determinant factors of the project and reduce the negative affects on the project outcome. The project outcome framework, illustrated in Figure 3.3, also takes into account the importance of human factors by positioning the *performance of project teams* as the closest element to the project outcome, and between the procurement system and project outcome. Based on this framework, although the choice of the procurement system has a direct effect on the outcome of the project, its influence is indirect; rather, its impact is based largely on the performance of different project teams and their interactions [Kumaraswamy and Dissanayaka 1998].

Based on this, quantitative analyses that focus merely on the direct relationship between procurement system and overall measures of project outcome, without considering these human factors, result in inconclusive outcomes [Ward et al. 1991].

3.3.4. Analyzing the Effect of Procurement Systems on Human Factors

In response to this growing criticism, an alternative approach has been proposed. In this approach, instead of focusing on the overall outcomes of the project, the investigation focuses on a more-immediate level; instead, the goal is to measure the effect of procurement systems on the performance of different project teams. In this approach, the performance of project teams is defined by a set of internal performance aspects. Each procurement alternative is then analyzed based on its effect on these internal performance aspects. Several performance aspects have been proposed for this type of analysis. Walker [1995] proposes using aspects such as *communication* and *quality of relationships.* Dainty et al [2003] suggest using measures, such as *team-building*, *decision-making* and *communication*. Kumaraswamy and Dissannayaka [2001] propose using factors, such as *effective and efficient communication* and *effective and efficient decision-making*, as the relevant performance criteria for procurement selection. Ward et al. [1991] suggest a more comprehensive framework, which includes seven internal aspects:

1. *Adaptation:* the ability to adapt favorably to environmental changes.
2. *Allocation:* the ability to deploy and allocate resources in the most appropriate manner.
3. *Coordination:* of energies and efforts to solve the system's problems and objectives.
4. *Integration:* of individual members to develop common organizational values and shared norms.
5. *Tension Management:* the ability to minimize and resolve tensions and conflicts.
6. *Productivity:* an ability to reach and maintain high levels of output, implying an ability to maximize efficient and reliable performance.
7. *Integrity:* an ability to preserve identity and integrity as a distinct problem-solving system, regardless of changes constantly occurring inside and outside the system.

3.3.5. Shortcomings of the Quantitative Approach in Analyzing the Human Factors

As stated in the previous section, it is clear that an analysis of the effect of performance aspects requires an in-depth study of the different project teams and their interactions. At the same time, it has been argued that traditional "scientific methods," which base their investigation on controlled experiments or analysis of empirical data, have a major handicap in tackling systems with such a high degree of soft ingredients, in the form of human factors. The shortcomings of using the so-called "scientific methods" or a "rationalist paradigm" to study human systems have been extensively discussed in the social sciences [Checkland 1999; Checkland and Scholes 1990; Hamel and Prahalad 1994; Morgan 1992; Senge et al. 1994] and in construction management research [Raftery et al. 1997; Rooke et al. 1997; Seymour and Rooke 1995]. In this section, some key points of these discussions are highlighted.

First, is the issue of *Objectivity*. It has been argued that "the chief assumption of the rationalist paradigm is the distinction which is drawn between subjective experience and objective reality"[Seymour and Rooke 1995]. This assumption has been useful in the natural sciences. This is due to the fact that the concepts which natural scientists use are "first-order constructs" [Schutz 1971]. In other words, a researcher imposes a meaning upon a natural order which is, in and of itself, meaning-free [Seymour and Rooke 1995]. At the same time, in social research, where the subject of study is humans and their interactions, there is no simple way to divide subjective and objective realms. In this case, any effort to create clear-cut distinction leads to oversimplified concepts, which are not representative of complex phenomenon [Seymour and Rooke 1995]. To use an example from Scarborough and Corbett [1992], this would be equivalent to separating "dancers from dance" in order to study dance.

Next, is the issue of *Reality*. Traditional scientific approaches presuppose the existence of an empirical world, which exists as something available for observation, study and analysis. It stands in contrast to the scientific observer, and has to be uncovered through observation, study and analysis [Blumer 1969]. In this context, "reality" is perceived as a construct that is external to the observer and is independent from the phenomenon. However, the concept of reality has a much more fluid notion in the social sciences. In the social sciences, reality is something that exists as a reflection of the phenomenon (human beings), and is constantly being changed and re-defined according to the perception of the subjects. As Thomas [1964] states: "if men define situations as real they are real in their consequences."

Finally, is the issue of *Factualness*. It is argued that the "rationalist paradigm" is primarily concerned with finding "factual" answers to the questions of "is" or "is not," and it makes no explicit provision for answering questions with ethical or political dimensions [Seymour and Rooke 1995]. At the same time, most social research deals with questions of "right" or "wrong" for which no "factual" answer may exist. As a result, the traditional "scientific" approach is inherently incapable of dealing with problems in the social and management sciences; an investigation of such problems, thus, requires a different approach.

3.3.6. Qualitative Approach based on Interpretive Analysis

In response to the inadequacies of the traditional scientific approach in analyzing human systems, construction management research has relied on more qualitative methods of inquiry. One of most common forms of qualitative inquiry is called *Interpretive Approach* [Seymour and Rooke 1995].

Interpretive inquiry has its origins from the work of German sociologist Max Weber (1864-1920) and American social psychologist George Herbert Mead (1863-1931). Seymour and Rooke [1995] describe interpretive analysis as a form of inquiry which "*takes the points of view of individual practitioners as the focus of research*" and, based on this, *"their values for performing a practice and their conscious reasons for maintaining them are made clear. Their reactions to attempts to change these practices and values may be explored. Their own views on how improvements might be made can be elicited. Views about the practices of others might be sought."* The main objective in this type of inquiry is to use *"descriptive answers"* as a "*sound empirical basis from which prescription can then be made" [Seymour and Rooke 1995]*. The aim is not to report any single truth, as in the natural sciences. Rather, it is recognized that any particular report or account of how and why things happen is produced for particular purposes, audiences, and circumstances, and is tailored accordingly [Rooke et al. 1997]. The goal is to extract and consolidate not only the explicit knowledge, but also the tacit knowledge that may be hidden beneath the subconscious of experts and the reasoning behind their "rules of thumb" [Palaneeswaran and Kumaraswamy 2003]. In this context, the knowledge of experts is accepted as a valid source of data since they form the "*members of an occupation, who through their skills in the application of instrumental rationality, have played a central role in creating the technology and institutions of the construction industry"* [Seymour and Rooke 1995].

Interpretative Approach has been a major means of inquiry within construction management research. Numerous studies in this field are based on using expert knowledge and views through surveys, expert panels and interviews, to investigate the issues and problems in the industry. Interpretative approach is both used as a means of gathering and analyzing data, in cases which do not lend themselves to quantitative analysis, and as a means of identification and conceptualization of problems, which subsequently may be theorized and be subject to further investigation [Wing et al. 1998].

3.3.7. Application of Interpretive Approach in Performance Assessment of Procurement Systems:

As discussed earlier in this chapter, a quantitative analysis, which focuses on empirical data collected from existing projects, has a number of shortcomings in analyzing the performance of different procurement options. Because on this, interpretive analysis is considered a viable alternative. In this approach, researchers use both implicit and tacit knowledge, along with the experiences of experts, to assess the advantages and disadvantage of each procurement strategy. The main advantage of using interpretive approach over quantitative analysis is that this approach enables the investigator to assess the impact of procurement alternatives on the performance of project teams, and, therefore, provides a more insightful comparison between different alternatives.

There are numerous studies within the construction literature which use expert knowledge, within the context of an interpretive study, to evaluate the performance of different procurement options. Chan et al. [2001] used expert judgments collected from a Delphi method as a basis for developing a multi-attribute model for procurement system selection. Kumaraswamy and Dissanayaka [2001] used experts' evaluation of perceived impact of different procurement and managerial options as a basis for developing a decision-support system for building procurement. Alarcon and Ashley [1996] used the experience captured from a panel of experts to develop a model for evaluating different combinations of project-execution options.

3.3.8. Methodological Considerations of Interpretive Approach

At the end of this section it should be noted that, despite the extensive use of Interpretive Approach in construction management research, the application of this methodology has not been free of criticism. It has been argued that the qualitative nature of this approach makes it unfit to provide any "scientific" results [Runeson 1997]. At the same time, whether qualitative research can be considered "scientific" or not, is an ongoing debate both in the discipline of construction management research, as well as in the bigger context of social and managerial sciences. While some authors, such as Morgan [1996], claim that qualitative methods are not "scientific," others consider qualitative methods as legitimate "scientific" methods [Sherrard 1997; Stevenson and Cooper 1997].

In general, it is argued that what defines a method as "scientific" or "non-scientific," is not its quantitative or qualitative nature. Each of these approaches serves a unique function in the process of inquiry and in creating new knowledge [Csete and Alberecht 1994]. Being "scientific" depends on the rigor in applying the methodology, and the explicit notion of logic underlying any assumptions in the adopted approach [Wing et al. 1998].

Another issue that should be pointed out is the nature of findings in a study based on an interpretive approach. As in any qualitative research, the nature of the results of this investigation is very different from the type of findings in a study based on traditional scientific approach. Findings of latter studies tend to reveal objective facts (e.g. law of gravity), which are independent from the subjective perceptions and worldviews of observers and therefore produce 'repeatable' results. At the same time, findings of a qualitative study has more volatility and are constantly challenged in the face of changing perceptions of the observers about world and the (negotiated) reality that surrounds them. Based on this nature, validity of such findings does not come from the ‘repeatability of the results’, but rather from ‘repeatability of the methodology’ used to produce the findings [Checkland 1999]. This ‘repeatability of methodology’ is in turn a direct function of level of ‘rigor’ both in performing each step of the methodology and reporting the result of these steps.

In other words, the validity of findings in an interpretive study depends on the diligence in defining the overall process of research, and the rigor by which each step of the research is implemented. In Checkland’s [1999] words:

> Action research should be conducted in such a way that the whole process is subsequently recoverable by anyone interested in critically scrutinizing the research. This means declaring explicitly, at the start of the research, the intellectual frameworks and the process of using them, which will be used to define what counts as knowledge in this piece of research. By declaring the epistemology of the research process in this way, the researchers make it possible for outsiders to follow the research and see whether they agree or disagree with the findings. If they disagree, well-informed discussion and debate can follow.

3.4. Dissertation Methodology

The previous section provided an overview of the common methodologies used in the construction management discipline. This section will discuss the research methodology proposed for this investigation. First, the research problem is described and applicability of different methods is examined. Next, we will focus on the methodology proposed for this research. The overall research approach is presented, and each phase is explained in detail.

3.4.1. Applicability of Different Methods to the Problem of this Research

As discussed in Chapter 1, the main objective of this research is to compare different Commissioning Delivery Systems, based on their effect on the performance of the commissioning process. The previous section in this chapter presented two common methodologies for such investigations in construction management: 1) Quantitative methods, based on statistical analysis of collected data on exiting projects; and, 2) Qualitative methods, based on interpretive analysis of data gathered from expert knowledge.

However, as previously discussed, quantitative analysis of empirical data has major handicaps in analyzing the effect of procurement systems on the outcome of the project and their application has been widely criticized in construction management research. The overall shortcomings of quantitative methods in capturing the human aspects of the process becomes of even greater concern in this study, because, as a quality assurance system, human factors play an even greater role on the success of commissioning process [Ahmad and Sein 1997].

Additionally, Total Building Commissioning is a fairly new concept, and the number of existing projects implementing TBC practice is very limited. The developed standards and procedures (such as Guideline 0) are fairly new, and most of the exiting projects have used varying standards and procedures in implementing this practice. Therefore, sufficient empirical data that could be used as basis of any statistical analysis does not exist.

Another approach would be to investigate the effect of CDS on human factors, based on formal relationships that are defined between entities in each different contract setting. At the same time, not every aspect of these human factors can be analyzed by focusing solely on contractual relationships. As Seymour and Rooke [1995] state:

> … our concern is that research on contracts can easily become dominated by the rationalist diagnosis, which dwells exclusively on tools of controls. Its attention to the formal provisions of contract tend to ignore all the taken-for-granted

> conventions of everyday life which make any contract possible… as is frequently observed on construction projects, a good project is one where the formal provisions stay on a shelf gathering dust. Meaning is exchanged and shared without recourse to them.

In other words, although, analysis of contractual relationships has value in revealing the underlying factors that affect the project outcome, by itself it cannot capture all those soft aspects of a project that are even a greater determinant of the project outcome. As discussed earlier, the only appropriate methodology for investigating such issues would be a qualitative analysis.

Therefore, this study proposes a methodology that takes advantage of both quantitative and qualitative approaches in investigating the problem of this study. This methodology is described in the following section.

3.4.2. Proposed Research Methodology

This research proposes a methodology in which the qualitative approach of the interpretive analysis is coupled with further quantitative analysis of contractual relationships, in order to provide a comprehensive analysis of the research problem. The aim of Interpretive Approach in this study is to define a systematic process, through which explicit and tacit knowledge of experts about the commissioning process, and specific characteristics of each Commissioning Delivery System, is obtained based on established criteria. The collective knowledge of experts is then analyzed to assess the performance of each commissioning delivery alternative and provide a basis for comparison. In cases where the collective knowledge presents inconsistencies among experts, the formal procedure of activities and relationships among different entities will be analyzed using quantitative methods. The purpose of these analyses is to provide a comparison between different CDS, and also investigate the issues and problems, which have led to inconsistency in experts' responses. The results of these investigations can be used to identify the areas of concern and current problems in the commissioning practice, and provide a roadmap for further investigation and improvement of this practice. This study is comprised of five distinct phases:

1. Exploring the systematic differences between commissioning delivery alternatives.
2. Developing a Framework of success for Commissioning Process in the form of performance aspects for this process.
3. Performance Assessment of each commissioning delivery system based on expert knowledge.
4. Performance Assessment of commissioning delivery systems based on quantitative analysis
5. Summary and Analysis of the overall research results

As this study takes an interpretive approach, a high degree of rigor must be applied in performing each of these steps. Therefore, each step of the study is precisely defined and activities are described in detail. These descriptions are provided in the following sections:

3.4.2.1. Exploring the Systematic Differences between Commissioning Delivery Alternatives

The first phase of this investigation is aimed at exploring the effect of each commissioning delivery alternative on the way the commissioning process is executed. This investigation will be used to analyze the systematic differences between each

Commissioning Delivery System, and compare the overall structure of each alternative. This phase of the investigation will consist of two steps:

1. **Developing a framework in identifying the commissioning activities.** As discussed in the previous chapter, currently, a number of different Commissioning Delivery Systems exist in the construction industry. At the same time, not all of these CDS can be used on every project setting or for all different commissioning types. Therefore, the first step in this investigation will focus on developing a framework for identifying the applicable Commissioning Delivery Systems for implementing Total Building Commissioning in three major project delivery systems (Design-Bid-Build, Design-Build, and CM-at-Risk).

2. **Modeling the flow of commissioning activities in each commissioning delivery system.** In this step, the flow of activities in each commissioning delivery alternative will be modeled using a workflow modeler. The purpose of this step is to develop appropriate representation of each Commissioning Delivery System process, based on unique roles and responsibilities defined for different parties in that CDS. These models will be validated through experts to make sure that they represent the actual commissioning practice. The resulting process models will be used to explore the systematic differences between each Commissioning Delivery System. Systematic differences are those observable variations in commissioning process that are a direct result of different distribution of roles and responsibilities of the entities

involved in the process defined by each commissioning delivery system.

3.4.2.2. Developing a Framework of Success for Commissioning Process

In this stage, the focus is to develop a framework for defining "success" in a commissioning practice. "Success" of building commissioning will be defined in terms of a set of performance aspects for this process. The aim of developing this framework is to provide a basis for gathering experts' knowledge about the commissioning process, and the advantages and disadvantages of each Commissioning Delivery System, which can be used for further comparing different commissioning delivery alternatives. Therefore, it is crucial that a comprehensive framework is developed that includes all the important aspects of the commissioning process.

As discussed before, like any other procurement system, the success of building commissioning can be defined at two different levels: (1) In relation to the overall outcome of the project (i.e. External Performance Aspects or *PAe*); and, (2) In relation to the effect of this system on the performance of internal process and different project teams (Internal Performance Aspects or *PAi*). As discussed in the previous sections, external performance aspects are too broad and therefore are not appropriate for analyzing the affect of different procurement alternatives on the project outcome. Therefore, the focus of this research will be on assessing the performance of CDS at the internal level, through using internal performance aspects of this process. These internal performance aspects are developed in three steps:

1. **Identifying a comprehensive list of performance aspects based on literature review.** In this step, an exhaustive search of existing literature on

building commissioning will be performed. The goal is to prepare a list of all cited aspects of the commissioning process that play a role in its success.

2. **Grouping identified aspects into larger performance categories.** In this step, the cited characteristics of the commissioning process will be grouped in larger categories of performance aspects. The goal of this categorization is two-fold: first, to remove redundancy and repetition, and second, to provide a manageable list of aspects that can be used as a source of discussion among experts.

3. **Detailed description of each performance aspect.** After major performance aspects are identified, a detailed description of each performance aspect will be provided. The goal of this description is to assure that different experts participating in the study have a clear understanding of these performance aspects to reduce any systematic error in their judgments.

3.4.2.3 Performance Assessment of Each Commissioning Delivery System Based on Expert Knowledge

After the appropriate performance aspects of the commissioning process have been developed, they will be used as a basis to compare different CDS. This comparison will be based on performance ratings collected from a group of experts with high-level of experience and familiarity with the commissioning process. The aim is to provide a defined context, in which representatives of different stakeholders on a construction project can discuss the strength and weaknesses of each methodology. Based on this, the group can come up with a collective performance rating for each Commissioning Delivery System. This phase of the study includes the following steps:

1. **Identification of Appropriate Experts for the Study.** In this stage, all different stakeholders involved in the commissioning process will be identified. Representative experts from each stakeholder group will then be chosen. These experts will be individuals who have extensive familiarity and experience with commissioning projects. Selection of experts will be based on a systematic selection process, as proposed by Okoli and Pawlowski [2004].
2. **Selecting an appropriate knowledge-gathering technique.** After the appropriate experts for the study are identified, a knowledge-gathering technique will be used to collect the groups' rating of each performance aspect of the process. The aim is to initiate a structured discussion among experts about each Commissioning Delivery System, and attain a collective rating of each performance aspect for different delivery systems. A comparison among various knowledge-gathering techniques was performed (Appendix 1), and, as a result, the Delphi method was identified as the most-appropriate technique for this study. Delphi is a structured process which utilizes a series of questionnaires or rounds to gather and provide information [Keeney et al. 2001]. In a Delphi study, the participants are asked individually, via a questionnaire, to provide their estimates for a variable in question. Feedback is then collected and summarized in a way to conceal the origin of original estimates. The results are circulated, and participants are asked if they wish to refine their previous answers based on the summary results.
3. **Performing the Delphi Study:** The Delphi study in this research will be compromised of three rounds.

a. In the first round, the experts will be asked to assess the importance of different performance aspects, developed in the previous stage, and provide any other performance aspect of this process that they may find appropriate.

b. In the second round, experts will be provided with a hypothetical project to fix non-procurement issues, and reduce the systematic judgment errors among experts. Experts will be asked to rate the performance of each Commissioning Delivery System based on their experience. They will also be encouraged to provide their underlying reasons for their assessment in the form of feedbacks.

c. In the third round, comments and feedbacks provided by each participant will be circulated among the participants. They will be asked to reconsider their previous assessment, in light of these comments. Results will be analyzed, both in overall groups and in functional groups, in order to show the differences among each stakeholder about perceptions of this process.

4. **Analyzing the degree of agreement among experts.** At the end of each round of Delphi, a statistical measure (Kendall's coefficient of concordance) [Siegel and Catellan 1988] will be calculated, in order to examine the degree of agreement among experts. For performance aspects where this measure indicates an agreement among experts, the results will be accepted and used as a basis for comparison. In cases where no agreement among experts is found,

performance measures will be further analyzed. This analysis is discussed in the next section.

3.4.2.4. Quantitative Analysis

If experts do not reach an agreement on their ratings for a particular performance aspect, that performance aspect will be further investigated. The investigation will be based on analyzing the workflow models developed in Phase I of this study. The purpose of this investigation is two-fold. First, is to compare the performance of each Commissioning Delivery System, based on quantitative analysis of process models in each delivery alternative. The second purpose is to investigate the underlying reasons that resulted in disagreement among experts. The result of this investigation will be further used in Phase V of the study to identify the problem areas and concern about the current practice of building commissioning.

3.4.2.5. Research Results

In Phase V, the overall results of phases III and IV will be used to compare the overall performance of commissioning delivery alternatives. This comparison will provide a basis for identifying the more appropriate commissioning delivery system for construction projects. The result of analysis performed in previous phases will also provide a basis for determining the issues and problems with the current practice of building commissioning that will require further investigation. Based on these, recommendations for follow-up studies will be provided.

3.5. Summary

This chapter discussed the proposed methodology for this investigation. First, a systematic view of Building Commissioning and Commissioning Delivery Systems was suggested. Next, an overview of different methodologies in construction management, that are applicable to problems addressed in this research, was provided. Finally, the specific methodology proposed in this research was presented, and each step was discussed in detail. Chapter 4 will discuss, in further detail, the first phase of this investigation's methodology, which is aimed at developing process models for each Commissioning Delivery System (CDS).

CHAPTER 4

DEVELOPING PROCESS MODELS FOR COMMISSIONING DELIVERY SYSTEMS

4.1. Purpose

The previous chapter described the methodology of this research. This chapter presents the first step of this methodology, which is aimed at developing process models for Commissioning Delivery Systems (CDS), in order to analyze the structural differences among these CDS. These structural differences are those observable differences between CDS that are caused by different distribution of roles and responsibilities in each system.

To do this, first, a framework for identifying applicable CDS for performing a Total Building Commissioning (TBC) process will be developed. This framework will be used to select CDS alternatives applicable to this study. Next, a generic process model for each of these selected CDS will be developed and validated. These models will further be used to investigate the structural differences between different delivery alternatives. They will also provide a basis for quantitative process analysis performed in Chapter 7.

4.2. Developing a Framework for Commissioning Delivery Systems

As mentioned in the previous chapter, a number of different commissioning systems currently exist in the construction industry. These include: Owner-led Commissioning; Third-party Commissioning; Designer-led Commissioning; Contractor-led Commissioning; and Subcontractor-led Commissioning. At the same time, development of these CDS has occurred organically, in response to specific requirements of different projects. Not all of these delivery systems can be used for all commissioning types and every project delivery system. This study proposes a framework for classifying applicable commissioning delivery alternatives for a *Total Building Commissioning Process* based on different *Project Delivery Systems (PDS).*

In the following sections, the relationship between CDS and PDS will first be discussed and major delivery systems in the construction industry will be reviewed. Then, the proposed framework for identifying Commissioning Delivery Systems will be presented and the CDS selected for this study will be described.

4.2.1. Project Delivery Systems (PDS) & Commissioning Delivery Systems (CDS)

A Project Delivery System (PDS) defines the roles and responsibilities of parties involved in a project, in addition to their contractual relationships [Konchar and Sanvido 1998]. At the same time, the introduction of building commissioning in a construction project defines a new set of roles and relationships based on the selected Commissioning Delivery System (CDS). In other words, each CDS defines a new layer of responsibilities and communication channels, in addition to the existing responsibilities and communication lines that are already defined by the PDS of the project. As a result, in order to properly define a CDS, it must be viewed in the context of different Project Delivery Systems.

Several frameworks for defining a PDS exist. This study uses the framework proposed by the Associated General Contractors of America (AGC). In this framework, project delivery systems are based on two *defining characteristics* [AGC 2004]: first, the number of contracts for design and construction services; and second, the methodology used for selecting the service providers. This framework is presented in Table 4.1.

Table 4. 1 - AGC Project Delivery Framework (AGC 2004)

		Number of Contracts	
		Two Separate Contracts	**One Combined Contract**
Selec	**Low Bid**	Design-Bid-Build	Design-Build (Low Bid)
	Best Value	CM at-Risk (Best Value)	Design-Build (Best Value)
	Qualification Based Selection	CM at-Risk (QBS)	Design-Build (QBS)

Based on this framework, three distinct project delivery systems can be defined:

Design-Bid-Build: A Project Delivery System in which the owner holds two separate contracts for design and construction services. In this delivery method, the contractor will be selected based on competitive bids.

Construction Management at-risk: Similar to Design-Bid-Build, the owner holds separate design and construction contracts with the designer and construction manager. The difference between this method and Design-Bid-Build is that the selection of the construction manager is based either on a *best value* selection methodology or *qualification- based selection*.

Design-Build: A Project Delivery System in which the owner holds one combined design and construction contract with the design-builder, the entity in charge of both designing and construction the project. The design-builder can be selected through all three different selection types.

4.2.2. Proposed Framework:

The focus of this study is Total Building Commissioning, which starts at the very early stage of the project (during pre-design) and continues for at least one year of occupancy. As a result, the options for Commissioning Delivery Systems in each delivery method will be limited to the number of entities that can be present at the pre-design stage of the project. Table 4.2 summarizes available CDS options under each delivery method.

Table 4. 2 - Commissioning Delivery Framework

PDS vs. CDS		*Project Delivery System*		
		Design-Bid-Build	Design-Build	CM @ Risk
Commissioning Delivery Systems	Owner-led	X	X	X
	A/E-led	X		X
	DB-led		X	
	CM-led			X
	Contractor-led			

As shown in the table, in a Design-Bid-Build delivery system, the commissioning delivery options are limited to *Owner-led Commissioning* and *Architect/Engineer-led (AE-led) Commissioning,* as these are the only entities that can be present at the pre-design stage. In Design-Build Delivery System, CDS options are *Owner-led Commissioning* and *Design/Builder-led (DB-led) Commissioning*. In this delivery system, *AE-led Commissioning* and *Contractor-led Commissioning* are not considered as separate options, as both of these entities are part of the Design-Build entity. In Construction Management at-Risk, CDS options are *Owner-led Commissioning*, *AE-led*

Commissioning, and *Construction Manager-led (CM-led) Commissioning,* as all of these entities can be present at the pre-design phase of the project. Again, *Contractor-led Commissioning* is not an option, as the contractor will be part of the CM entity. In this framework, *Subcontractor-led Commissioning* is not considered an option, as this type of commissioning can only be used for single systems for which the subcontractor is responsible. Therefore, is not applicable to the concept of Total Building Commissioning, which is the subject of the study in this research. Finally, in this framework, *Third-party Commissioning* is not considered a separate CDS, but rather is classified as a sub-type of *Owner-led Commissioning*.

As the scope of this study is limited to Design-Bid-Build and Design-Build Project Delivery Systems, only the CDS options for these delivery systems (Owner-led Commissioning, A/E-led Commissioning and DB-led Commissioning) will be studied. In addition, developing the CDS models will be limited to delivery options under a Design-Bid-Build PDS.

4.3. Modeling the Commissioning Delivery System Process

After the appropriate CDS alternatives for each Project Delivery System were identified, the processes for commissioning delivery alternatives were modeled, in order to provide a basis for investigating the structural differences between them. Structural differences are those process variations that are caused by unique distribution of roles and responsibilities among project entities, defined by the different CDS. Modeling the commissioning process in each CDS was based on the description of the commissioning process provided in ASHRAE's Guideline 0 [ASHRAE 2005].

In the following sections, the process of building commissioning, as defined by Guideline 0, will first be presented. Next, the modeling methodology used for developing the process models based on Guideline 0's description will be described. Finally, the developed models will be presented, along with a discussion of these structural differences.

4.3.1. Guideline 0 and Commissioning Process

Commissioning Delivery Systems were modeled based on the description of the commissioning process provided by ASHRAE's Guideline 0 [ASHRAE 2005]. Guideline 0 is a document that defines the process of Building Commissioning, apart from its application to specific building systems. In other words, Guideline 0 defines basic procedures and activities that are common in the commissioning of all different building systems.

The commissioning process, presented in Guideline 0, was developed after applying the commissioning process to a number of projects, and represents the best practice [ASHRAE 2005]. Guideline 0 defines this process in a flow chart, which outlines the major steps in performing commissioning activities. This flow chart is accompanied by a set of detailed descriptions of each of these steps.

Figure 4.1, illustrates the flow chart of the commissioning process provided in Guideline 0. As shown in Figure 4.1, the flow chart defines the major activities that must take place in a commissioning process and their interdependencies. However, it does not illustrate the entities in charge of these activities. These roles and responsibilities are shown as part of the activity descriptions provided in the guideline. In defining these roles and responsibilities, Guideline 0 takes a generic approach and assumes the most-common scenario in which the project owner of a Design-Bid-Build project hires a third-party commissioning consultant (this scenario is equivalent to the Owner-led Commissioning alternative, under a Design-Bid-Build Project Delivery System, described in previous section of this chapter). In other words, Guideline 0 does not take into account the other distributions of roles and responsibilities for entities that are defined by different combinations of Project Delivery Systems and Commissioning Delivery Systems.

Therefore, the generic process of the commissioning process provided in Guideline 0 cannot be used to investigate the structural differences between different Commissioning Delivery Systems. Such investigation requires more-detailed process models, which present the distribution of roles and responsibilities among different entities as a function of PDS and CDS. The development of these models is described in the next section.

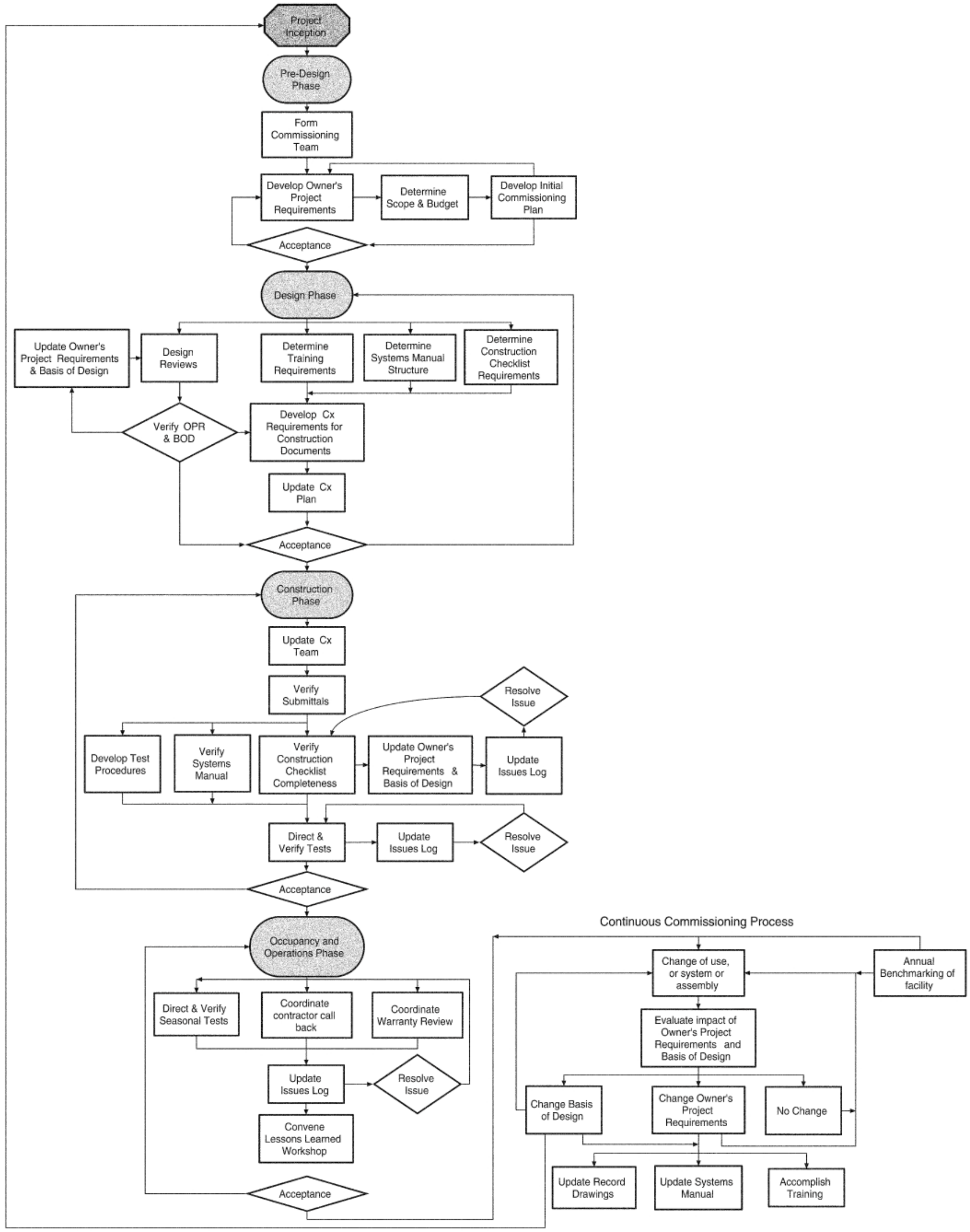

Figure 4. 1 - Process of Total Building Commissioning provided in Guideline 0 (ASHRAE 2005)

4.3.2. Modeling Methodology

Models are basically abstractions of real-world phenomenon, in order to provide a basis for analysis. Checkland [Checkland 1999; Checkland and Scholes 1990] defines a model as "*an intellectual construct, descriptive of an entity in which at least one observer has an interest.*" Real-world problems are usually too complex to be analyzed. A model, on the other hand, provides a simplified version of the phenomenon, focusing on major elements and relationships from a certain point of view that helps to analyze the problem.

The purpose of modeling Commissioning Delivery Systems in this research was to provide a tool to represent different distribution of activities performed by each participant in their interactions. This representation helps to identify the structural differences between varying commissioning delivery alternatives, and provides a basis for analyzing the performance of each CDS. Figure 4.2 shows the steps taken in developing the process models. Each of these steps is described in the following sections.

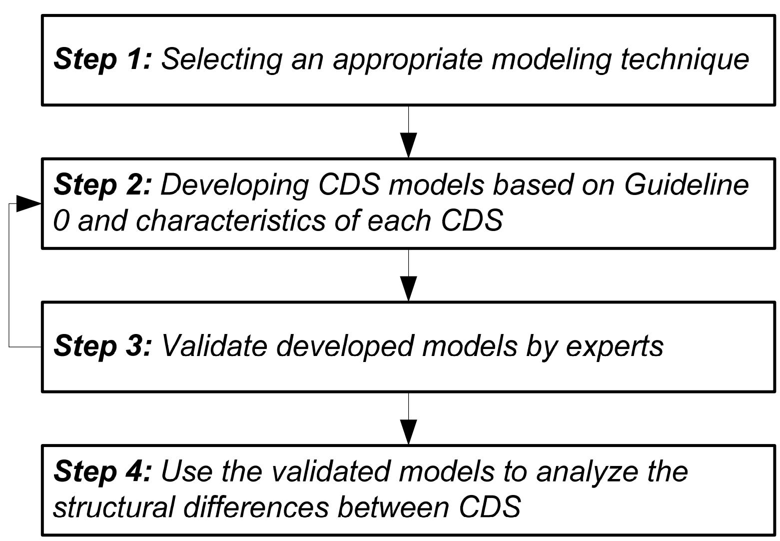

Figure 4. 2 - Steps in modeling the CDS Processes

4.3.2.1. Selecting the Appropriate Modeling Technique

A process can be viewed as a system [Pajarek 2000]. Therefore, in modeling a process, like modeling a system, a process is de-composed into its elements, which are activities and their dependencies [Browning 2002]. Several techniques for modeling processes based on their activities and dependencies exist. These include *Flow Charts, Program Evaluation and Review Technique (PERT), Critical Path Method (CPM), Petri Nets* and *IDEFx*. However, all these techniques have a major handicap in modeling the commissioning delivery process. None of these modeling techniques provide a means of presenting activities as the roles and responsibilities of different parties involved in the process. At the same time, as most of the differences between CDS alternatives are related to the distinct roles for participating parties, it was crucial to find a modeling technique that could represent the various entities in charge of commissioning activities and how they are inter-related.

Further investigation of modeling techniques revealed an appropriate modeling technique for this purpose, called *Workflow Process Definition Language (WPDL).* Developed by Workflow Management Coalition (WfMC), WPDL is a meta-data model, which identifies commonly used entities within a process definition [WfMC 1999]. Figure 4.3 shows a graphical representation of these entities in the meta-model, and Table 4.3 provides a brief description of the generic building blocks of a WPDL model. As shown, WPDL provides information about different activities in a process and their linkages in the form of transitions. In addition, it couples the activities with process participants, which are basically entities in charge of performing those activities. Based on this, WPDL is an appropriate technique for modeling Commissioning Delivery Systems.

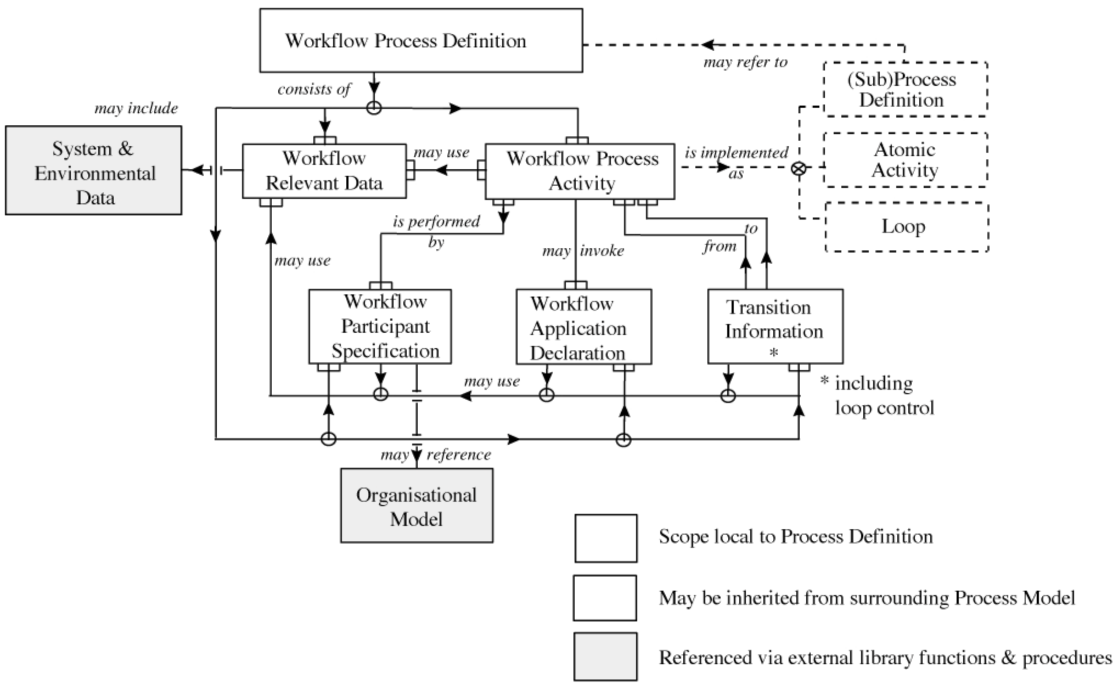

Figure 4. 3 - WPDL Meta-Model Top Level Entities [WfMC 1999]

Table 4. 3 - List of entities in WPDL and their descriptions [WfMC 1999]

Meta Model Entity	**Description**
1. Activities	Items of work performed in the process
2. Participants	Entities in charge of executing activities
3. Applications	IT applications for executing activities
4. Transitions	Relationships between activities
5. Workflow relevant data	Input / Output of activities
6. System and environmental data	Situational information

4.3.2.2. Developing Commissioning Delivery Models

In order to model the Commissioning Delivery Systems based on WPDL, the *Java Workflow Editor (JaWE)* was used. JaWE is the first open-source graphical editor based on WfMC specifications. This software was developed by Enhydra (Enhydra.org), using Sun's Java programming language, and can be freely accessed on the Web (http://jawe.objectweb.org). The advantage of JaWE is its graphical interface, which uses a concept of "swim lanes" to represent the participants in the process. This characteristic of JaWE made it possible to graphically represent the roles of each participant, along with their interactions in a commissioning process.

The workflow in each CDS was modeled based on the description of the commissioning process provided in Guideline 0, as well as the unique characteristics of each delivery alternative. Four different participants were defined in each process: Owner, Designer (A/E), General Contractor (GC) and the Commissioning Authority (CA). The flow chart for the commissioning process provided in Guideline 0 was used to model the base process (Figure 4.1). To increase the accuracy of the model, other activities, which were defined in Guideline 0 but not presented in this flow chart, were added to the model. The next step was to divide the activities among the participants. This was accomplished by studying the roles and responsibilities of each entity, defined in Guideline 0, and unique characteristics for each delivery system.

The modeling process was limited to Design-Bid-Build, since the overall process described in Guideline 0 is based on this delivery system. Two different workflow models were developed: one for Owner-led Commissioning; and one for AE-led Commissioning. In the first model, the Commissioning Authority was shown as an entity hired or selected by the Owner. In Designer-led Commissioning, on the other hand, the process was modeled based on the AE hiring or selecting the Commissioning Authority.

4.3.2.3. Validation of the developed models

To ensure that developed models represent real-life processes, they were validated. The validation was performed in two steps. In the first step, the commissioning report for an exiting commissioning project was used to validate commissioning activities and their sequence in the course of the commissioning process. This validation resulted in addition of some activities and modifications of some activity sequences. In the second step of validation, models were presented to two experts. The first expert was a commissioning consultant, who was part of the original team that developed Guideline 0 and had extensive experience with commissioning projects under both delivery strategies. The validation was done based on the four phases of the commissioning process (pre-design, design, construction, and occupancy). For each phase, the expert was asked to validate the activities and their dependencies, as well as participants in charge of each activity. Both models were reviewed in parallel, so the differences between them could also be validated. Due to this extensive analysis, the validation process was completed in two separate meetings. Resulting models were further presented to another expert for final validation. Again, the models were presented to the expert, and he was asked to validate the activities and dependencies in the model. Final validation resulted in no further modifications of the model.

4.3.3. Commissioning Delivery Workflow Models

The previous section described the methodology used to develop the workflow models for the commissioning delivery processes. In this section, these models will be provided, along with a discussion of structural differences between two delivery systems. In order to provide a better representation, the models are broken down into four phases of *Pre-design, Design, Construction, and Occupancy*.

4.3.3.1. Pre-design

The Total Building Commissioning process starts at the pre-design phase of the project. Based on Guideline 0, the major commissioning activity during the pre-design phase is developing the *Owner's Project Requirement (OPR).* Approved OPR will then be used to develop the *Scope and Budget* for the commissioning process, in addition to the *Initial Commissioning Plan*.

Figures 4.4-4.6 show developed workflow models for Owner-led and AE-led Commissioning, during the pre-design phase. Tables 4.5-4.6 further list the activities performed by each entity in the phase of the commissioning process. As shown in Figure 4.4, Owner-led Commissioning starts by Owner hiring the Commissioning Authority (CA). This starts a two-way relationship between the Owner and CA, in which the owner will be the entity responsible for approving the deliverables of the CA. Therefore, in this alternative, the involvement of the design entity is very minimal and limited to reviewing the final OPR.

In AE-led Commissioning (Figures 4.5 & 4.6) on the other hand, the Designer will play a very active role. This process starts with Owner hiring the project designer, and project designer hiring the CA. As a result of this contractual relationship, the AE is present in every step of the process, and is the major entity in charge of approving the CA's deliverables. At the same time, as shown in the graph, the Owner's approval is still required for most of the commissioning deliverables.

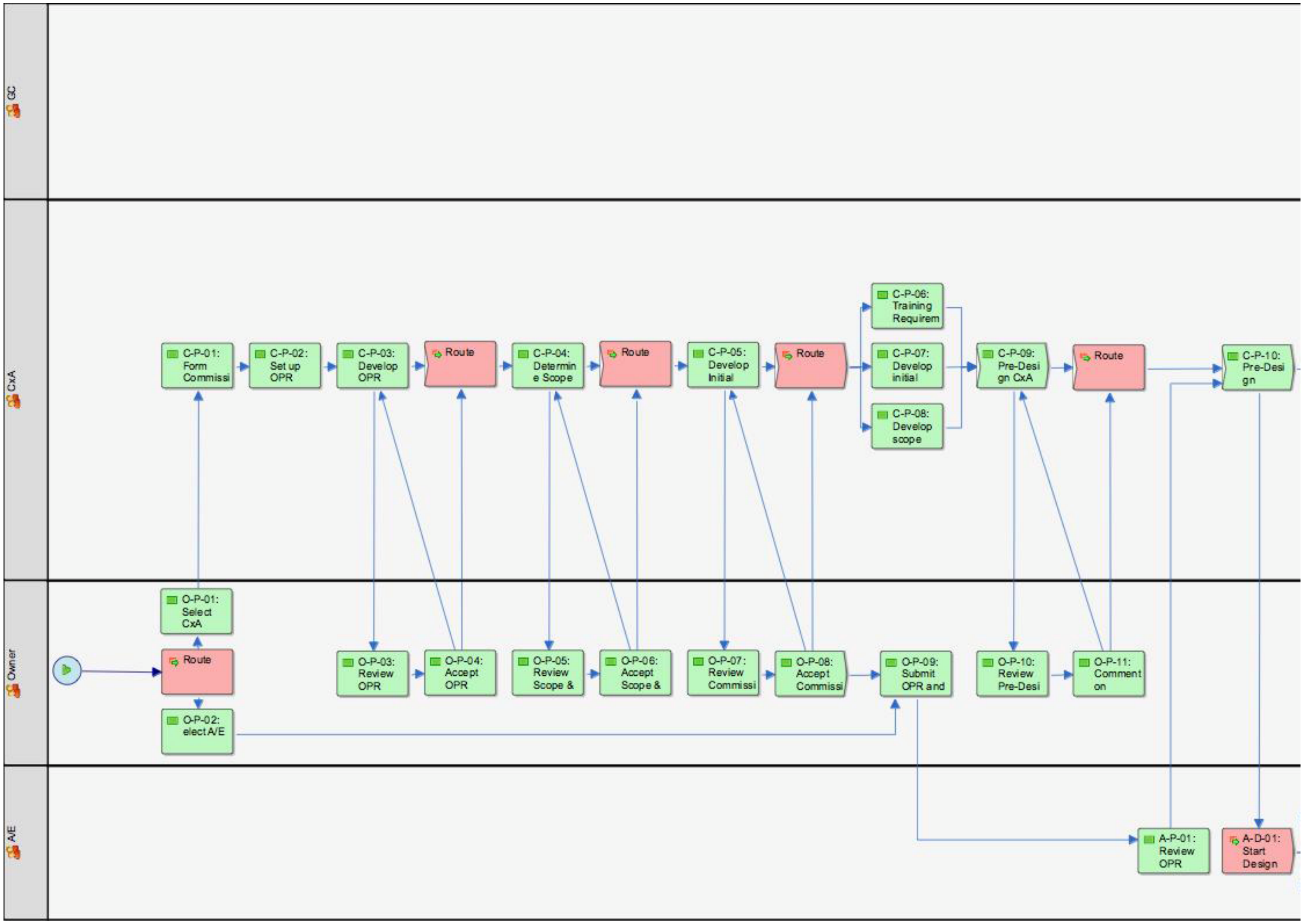

Figure 4. 4 - Owner-led Commissioning Process Model (Pre-design Phase)

Table 4. 4 - Responsibilities of different entities in Pre-design phase of Owner-led Commissioning

Designer Activities	Owner Activities	CA Activities	GC Activities
A-P-01: Review OPR and Cx Plan	O-P-01: Select CxA	C-P-01: Form Commissioning Team	
A-D-01: Start Design	O-P-02: Select AE	C-P-02: Set up OPR Meeting	
	O-P-03: Review OPR	C-P-03: Develop OPR	
	O-P-04: Accept OPR	C-P-04: Determine Cx Scope & Budget	
	O-P-05: Review Cx Scope & Budget	C-P-05: Develop Initial Cx Plan	
	O-P-06: Accept Scope & Budget	C-P-06: Develop Training Requirement Outline	
	O-P-07: Review Cx Plan	C-P-07: Develop Initial Format for Issues Log	
	O-P-08: Accept Cx Plan	C-P-08: Develop Scope & Format for Project System Manual	
	O-P-09: Submit OPR and Cx Plan for AE	C-P-09: Develop Pre-Design Cx Report	
	O-P-10: Review Pre-Design Cx Report	C-P-10: Set up Pre-Design Cx Meeting	
	O-P-11: Accept Pre-Design Cx Report		

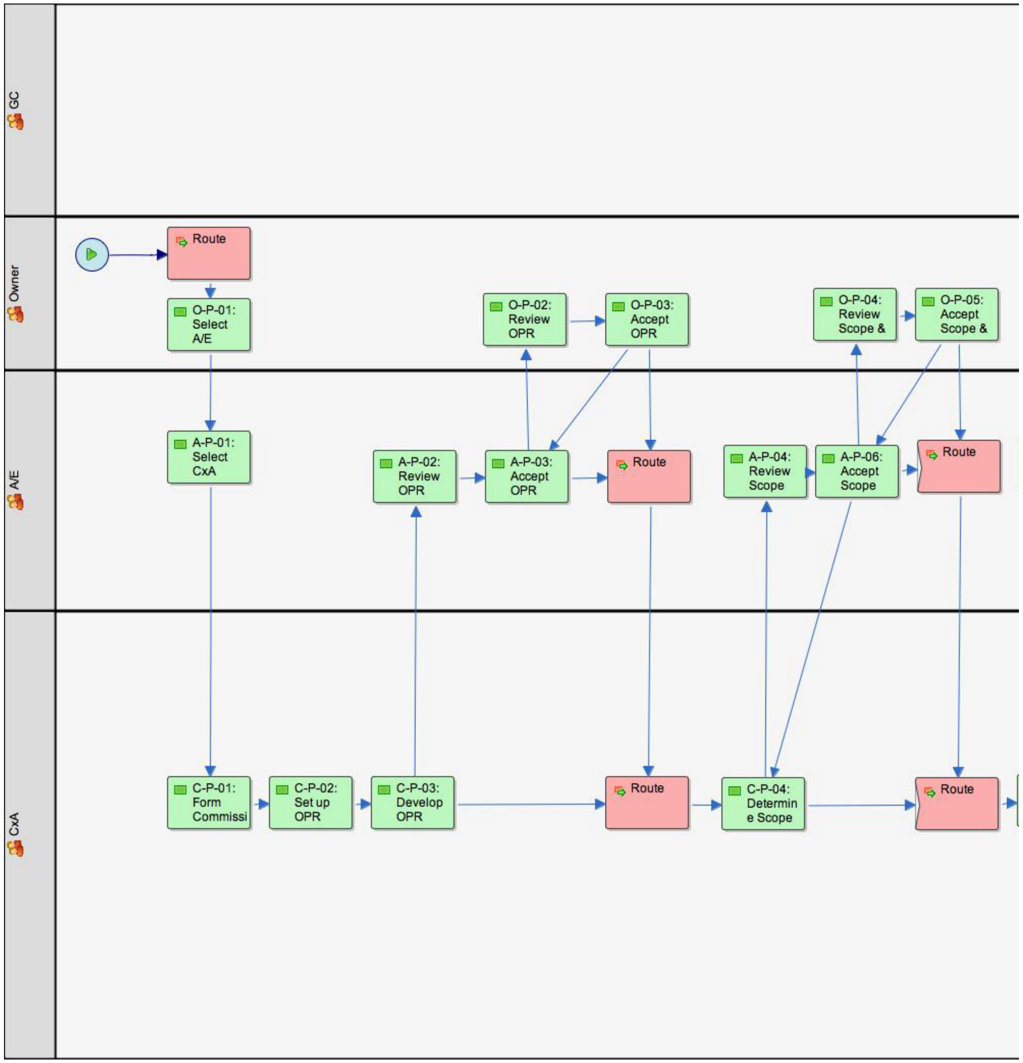

Figure 4. 5 - AE-led Commissioning Process Model (Pre-design Phase)

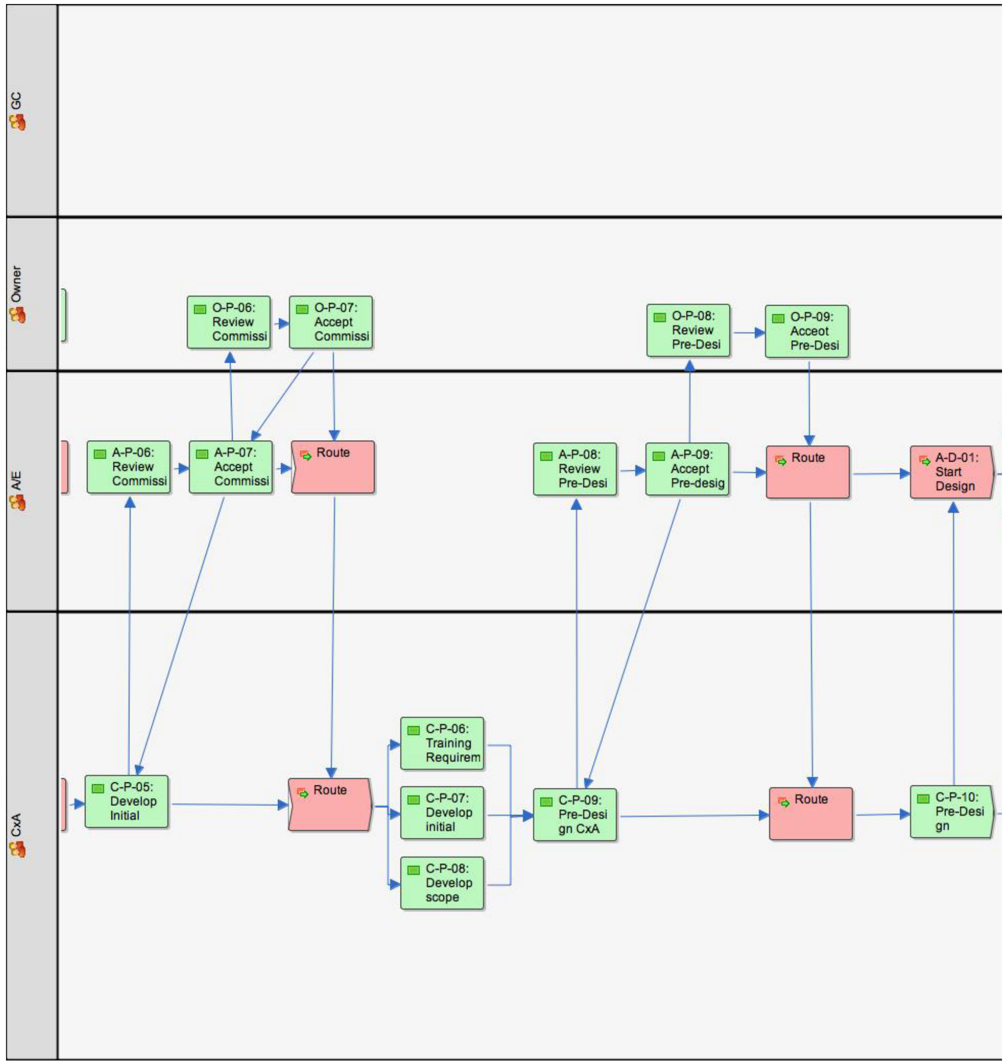

Figure 4. 6 - AE-led Commissioning Process Model (Pre-design Phase -Cont'd)

Table 4. 5 - Responsibilities of different entities in Pre-design phase of Owner-led Commissioning

Designer Activities	Owner Activities	CA Activities	GC Activities
A-P-01: Select CxA	O-P-01: Select AE	C-P-01: Form Commissioning Team	
A-P-02: Review OPR	O-P-02: Review OPR	C-P-02: Set up OPR Meeting	
A-P-03: Accept OPR	O-P-03: Accept OPR	C-P-03: Develop OPR	
A-P-04: Review Cx Scope & Budget	O-P-04: Review Cx Scope & Budget	C-P-04: Determine Cx Scope and Budget	
A-P-05: Accept Cx Scope & Budget	O-P-05: Accept Cx Scope & Budget	C-P-05: Develop Initial Cx Plan	
A-P-06: Review Cx Plan	O-P-06: Review Cx Plan	C-P-06: Develop Training Requirement Outline	
A-P-07: Accept Cx Plan	O-P-07: Accept Cx Plan	C-P-07: Develop Initial Format for Issues Log	
A-P-08: Review Pre-Design Cx Report	O-P-08: Review Pre-Design Cx Report	C-P-08: Develop Scope & Format for Project System Manual	
A-P-09: Accept Pre-Design Cx Report	O-P-09: Accept Pre-Design Cx Report	C-P-09: Develop Pre-Design Cx Report	
A-D-01: Start Design		C-P-10: Set up Pre-Design Cx Meeting	

4.3.3.2. Design Phase

In the design phase, the A/E of record will design the facility and its systems. Based on Guideline 0, the main commissioning responsibility during the design phase is to verify that the Owner's project requirements have been achieved. This is done through performing design-reviews and verification of *Basis of Design (BOD)*, based on the OPR document developed in the pre-design phase. In addition to design reviews, the CA will use the design documents to develop the commissioning requirements for the construction phase of the project. These requirements will be submitted to the project designer to be included in the bidding documents.

Figures 4.7 through 4.10 show the commissioning activities during the design stage for Owner-led and AE-led Commissioning. As these figures illustrate, CA responsibilities are almost identical in both of these delivery alternatives. At the same time, these two models differ in the way they distribute the responsibilities between the Owner and AE. In Owner-led Commissioning (Figures 4.7 and 4.8), the Owner plays a more active role and becomes the interface between the AE and CA. This requires the Owner to act as the repository of information, since almost all communications between AE and CA will pass through this entity. In AE-led Commissioning (Figures 4.9 and 4.10), on the other hand, the Designer acts as the interface between the parties. This time, all the communication lines will go through the Designer, and, as a result, this entity will be the major source of all information in the project. Again, there is a two-level approval structure for some of the commissioning activities, in which both the Designer and Owner must approve commissioning deliverables.

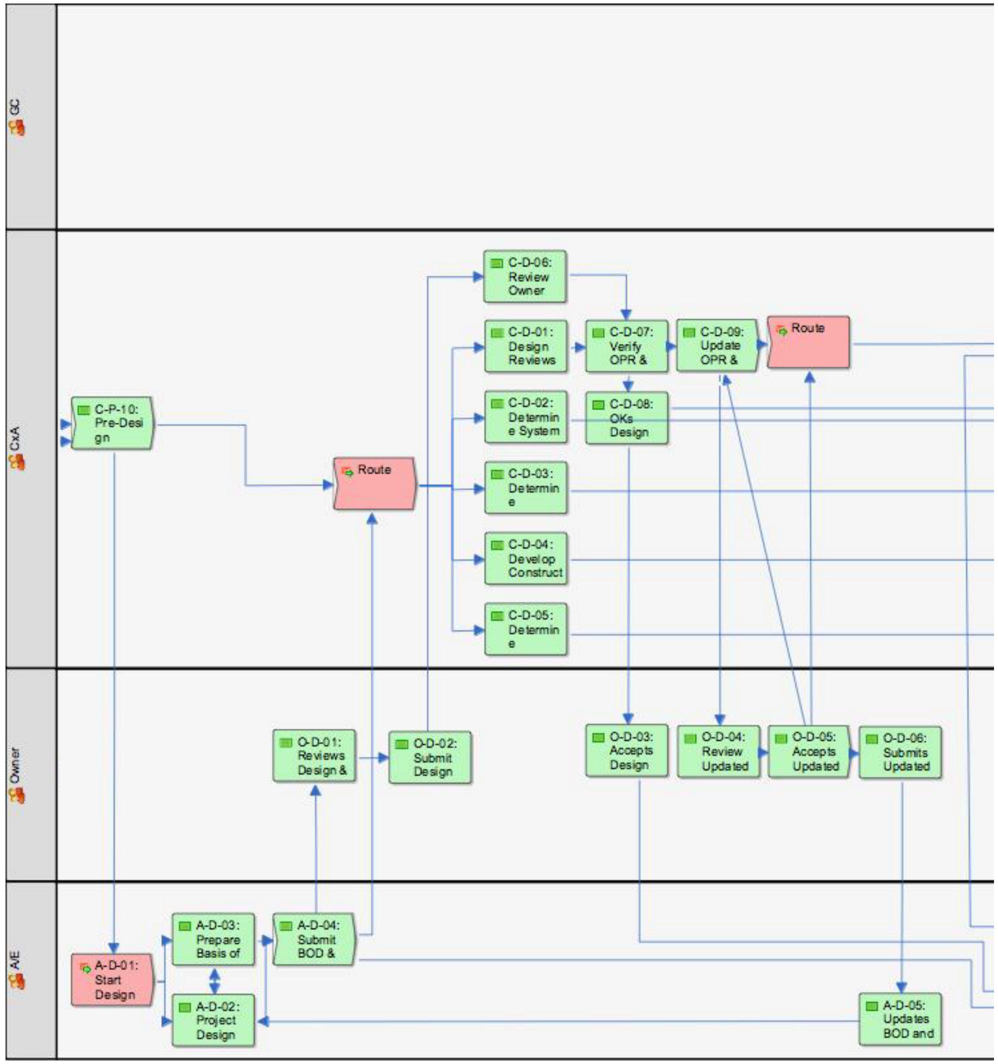

Figure 4. 7 - Owner-led Commissioning Process Model (Design Phase)

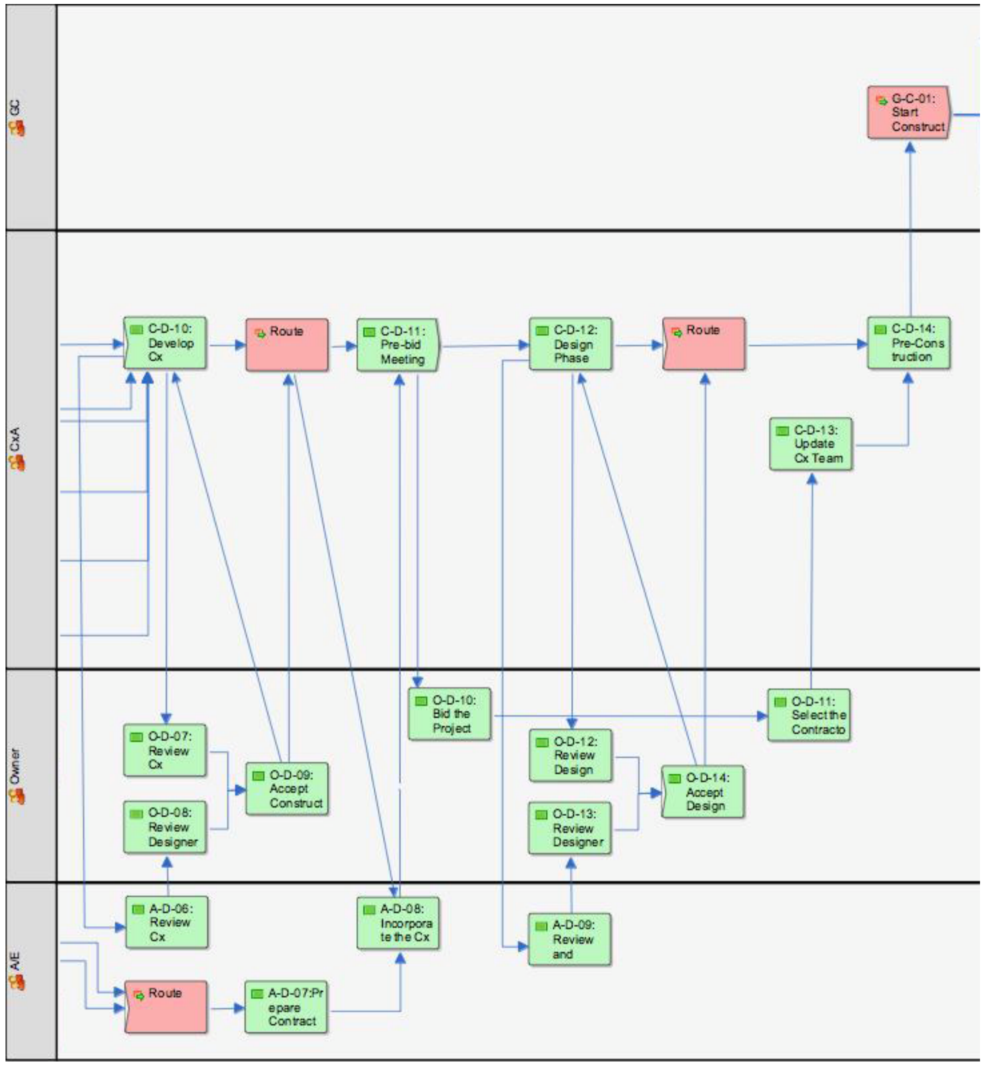

Figure 4. 8 - Owner-led Commissioning Process Model (Design Phase – Cont'd)

Table 4. 6 - Responsibilities of different entities in Design phase of Owner-led Commissioning

Designer Activities	Owner Activities	CA Activities	GC Activities
A-D-01: Start Design	O-D-01: Review Design & BOD	C-P-10: Set up Pre-Design Meeting	G-C-01: Start Construction
A-D-02: Design	O-D-02: Submit Design & BOD Comments to CxA	C-D-01: Review Design & BOD	
A-D-03: Prepare Basis of Design	O-D-03: Accept Design	C-D-02: Determine System Manual Structure	
A-D-04: Submit Design & BOD for Review	O-D-04: Review Updated OPR & BOD	C-D-03: Determine Construction Checklist Review	
A-D-05: Update OPR & BOD	O-D-05: Accept Updated OPR & BOD	C-D-04: Develop Construction and O&M Tests	
A-D-06: Review Cx Requirements for Construction	O-D-06: Submit Updated OPR & BOD for AE	C-D-05: Determine Training Requirements	
A-D-07: Prepare Contract Documents	O-D-07: Review Cx Requirements for Construction	C-D-06: Review Owner Comments	
A-D-08: Incorporate Cx Requirements in Contract Documents	O-D-08: Review AE Comments on Cx Requirements	C-D-07: Verify OPR & BOD	
A-D-09: Review Design Phase Cx Report	O-D-09: Accept Cx Requirements for Construction	C-D-08: OK Design	
	O-D-10: Bid the Project	C-D-09: Update OPR & BOD	
	O-D-11: Select the Contractor	C-D-10: Develop Cx Requirements for Construction	
	O-D-12: Review Design Phase Cx Report	C-D-11: Set up Pre-bid Meeting	
	O-D-13: Review AE Comments on Cx Report	C-D-12: Prepare Design Phase Cx Report	
	O-D-14: Accept Design Phase Cx Report	C-D-13: Update Cx Team	
		C-D-14: Set up Pre-construction Meeting	

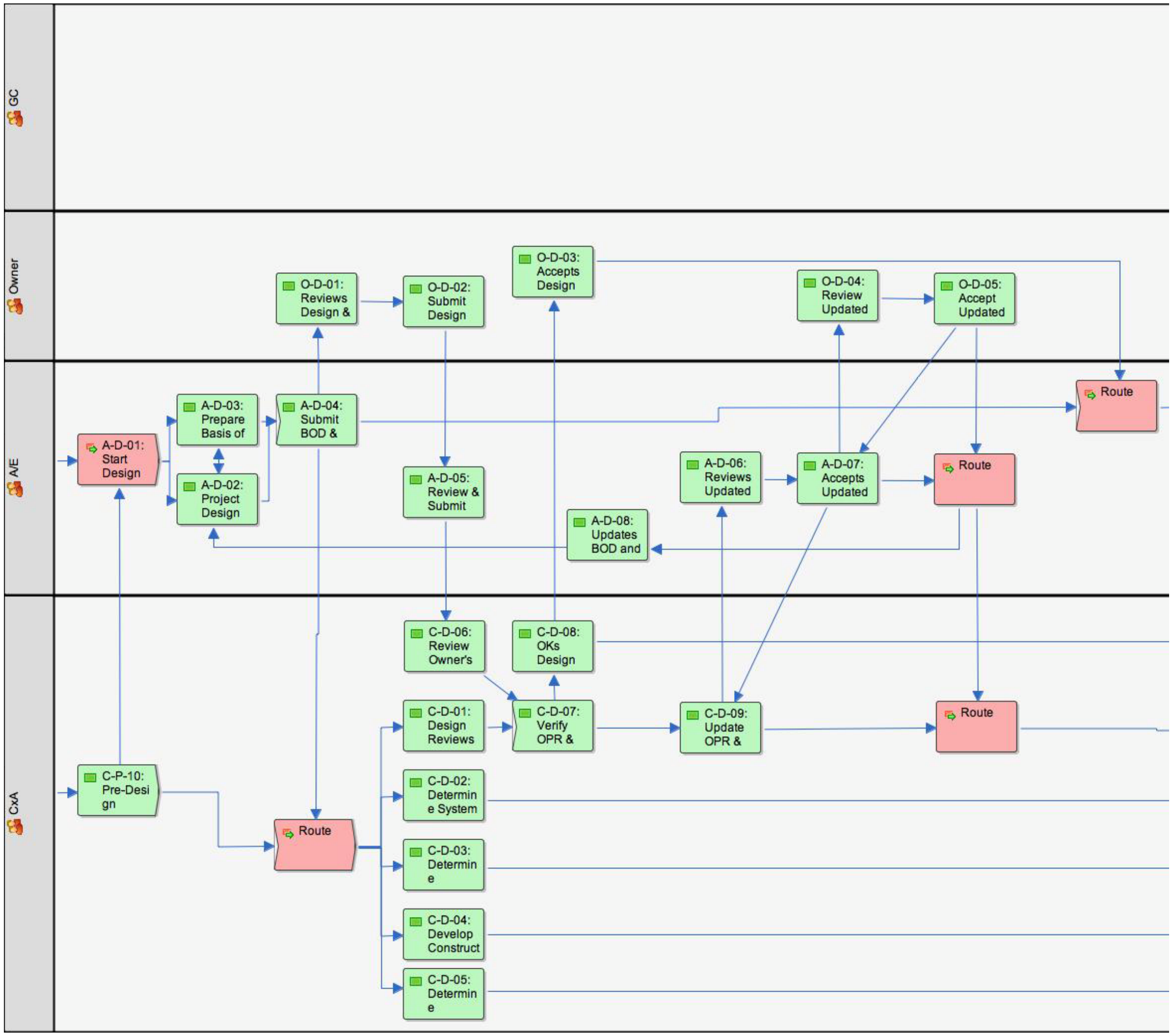

Figure 4. 9 - AE-led Commissioning Process Model (Design Phase)

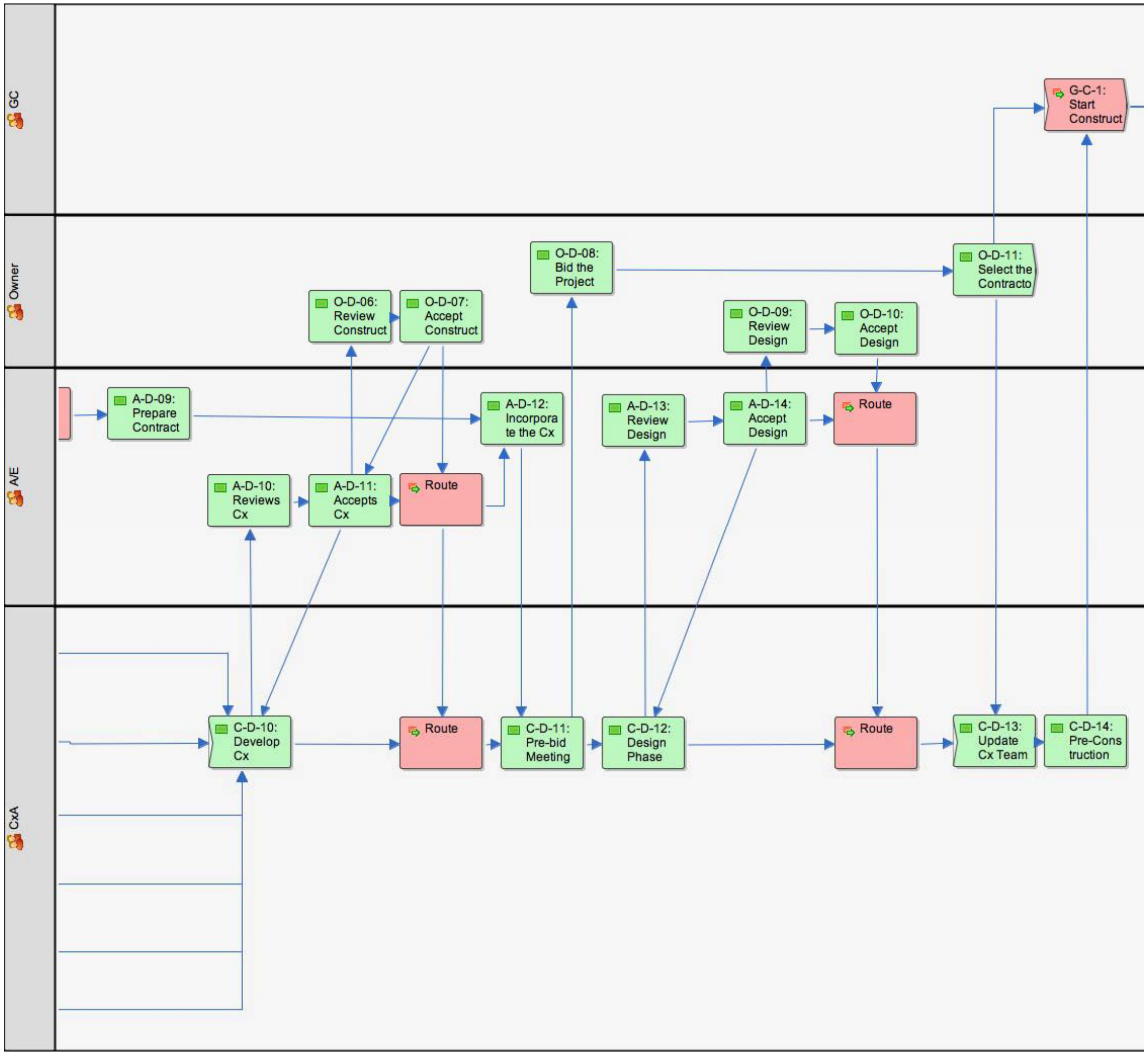

Figure 4. 10 - AE-led Commissioning Process Model (Design Phase – Cont'd)

Table 4. 7 - Responsibilities of different entities in Design phase of AE-led Commissioning

Designer Activities	Owner Activities	CA Activities	GC Activities
A-D-01: Start Design	O-D-01: Review Design & BOD	C-P-10: Setup Pre-Design Meeting	G-C-1: Start Construction
A-D-02: Design	O-D-02: Comment on Design & BOD	C-D-01: Review Design & BOD	
A-D-03: Prepare Basis of Design	O-D-03: Accepts Design	C-D-02: Determine System Manual Structure	
A-D-04: Submit Design & BOD for Review	O-D-04: Review Updated OPR & BOD	C-D-03: Determine Construction Checklist Requirements	
A-D-05: Review & Submit Owner Comments to CxA	O-D-05: Accept Updated OPR & BOD	C-D-04: Develop Construction and O&M Test Requirements	
A-D-06:Review Updated OPR & BOD	O-D-06: Review Construction Cx Requirements	C-D-05: Determine Training Requirements	
A-D-07: Accept Updated OPR & BOD	O-D-07: Accepts Construction Cx Requirements	C-D-06: Review Owner's Comments	
A-D-08: Updates BOD	O-D-08: Bid the Project	C-D-07: Verify OPR & BOD	
A-D-09: Prepare Contract Documents	O-D-09: Review Design Phase Cx Report	C-D-08: OK Design	
A-D-10: Reviews Construction Cx Requirements	O-D-10: Accept Design Phase Cx Report	C-D-09: Update OPR & BOD	
A-D-11: Accepts Construction Cx Requirements	O-D-11: Select the Contractor	C-D-10: Develop Construction Cx Requirements	
A-D-12: Incorporate Construction Cx Requirements into Contract Documents		C-D-11: Set up Pre-bid Meeting	
A-D-13: Review Design Phase Cx Report		C-D-12: Prepare Design Phase Cx Report	
A-D-14: Accept Deign Phase Cx Report		C-D-13: Update Cx Team	
		C-D-14: Set up Pre-Construction Meeting	

4.3.3.3. Construction Phase

During the construction phase of the project, the General Contractor (GC) constructs the designed facility and installs the systems, as well as performs some commissioning activities, such as preparing systems manuals and training the Owner's Operations and Maintenance (O&M) staff. The GC will report the completion of each activity to all entities involved in the project (Owner, AE, CA) in the form of project submittals. Owner and CA will review the submittals and send their comments to the project designer. The Designer uses these comments, in addition to his own review of the submittals, as a basis for approving the submittals or requiring modifications. If approved, the GC submittals will be used by the CA to develop test procedures. The CA will then direct and verify the tests performed by GC. The results of the tests will be used to either accept the systems or require modifications.

Figures 4.11 through 4.14 show the process models for two commissioning alternatives during the construction phase of the project. As shown in these models, both GC and CA perform the same activities during the construction phase. At the same time, the distribution of commissioning activities between the Owner and AE is very different in two alternatives. Similar to the design phase, in Owner-led Commissioning, the Owner will take an active role as the interface between the CA with other entities involved in the project. As a result, most of the communications will pass through this entity, and the Owner will be the main source of information in the project. In AE-led Commissioning (Figures 4.13 and 4.14), the situation is reversed, as AE will be in the communication interface and in charge of distributing information among different parties. Another difference among these two models is, in Owner-led Commissioning, the Owner will have the comments of two independent entities (AE and CA) as a basis of accepting the contractor's deliverables, whereas in AE-led Commissioning, the AE and CA will be part of the same organization and they will provide collective advice to the Owner.

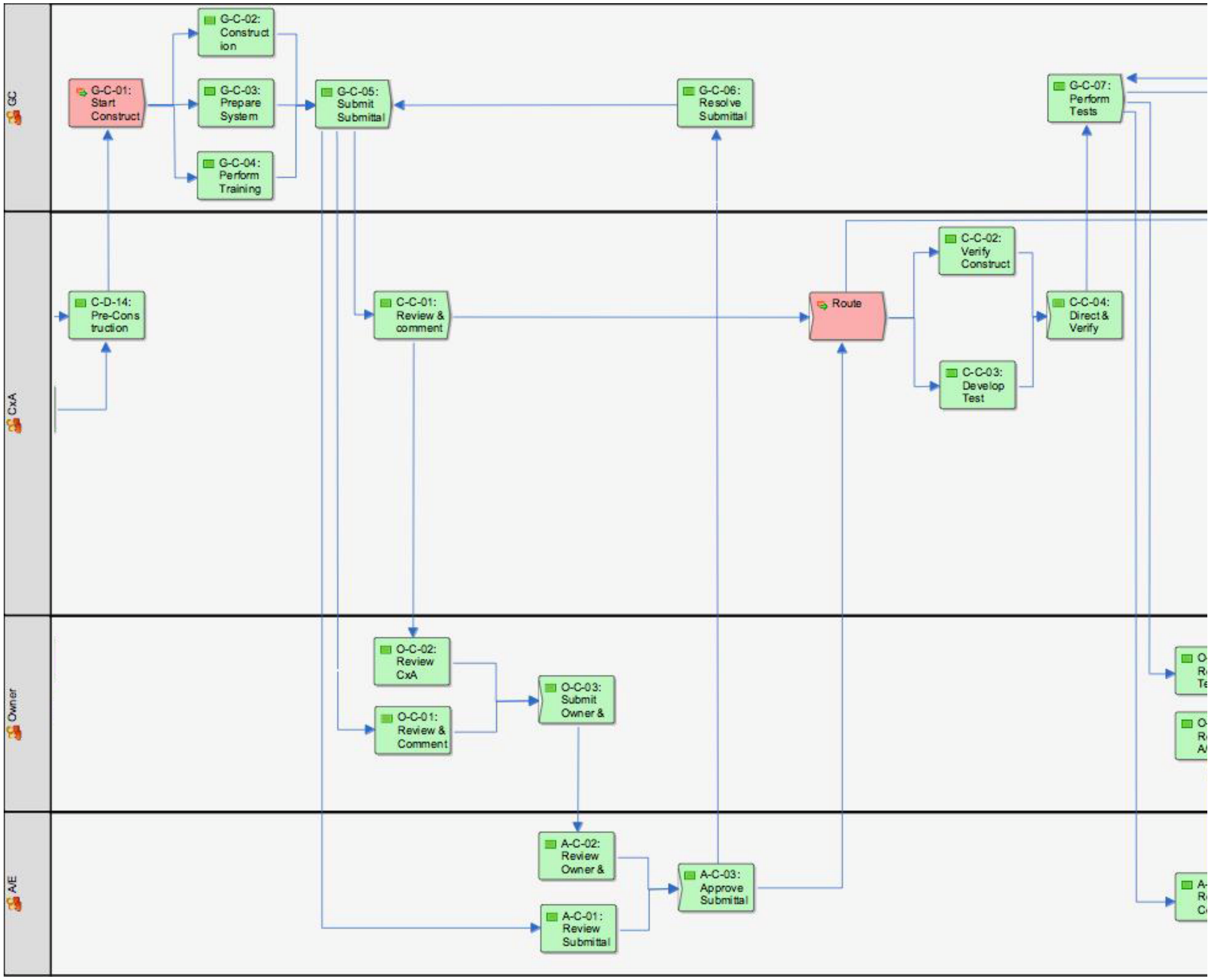

Figure 4. 11 - Owner-led Commissioning Process Model (Construction Phase)

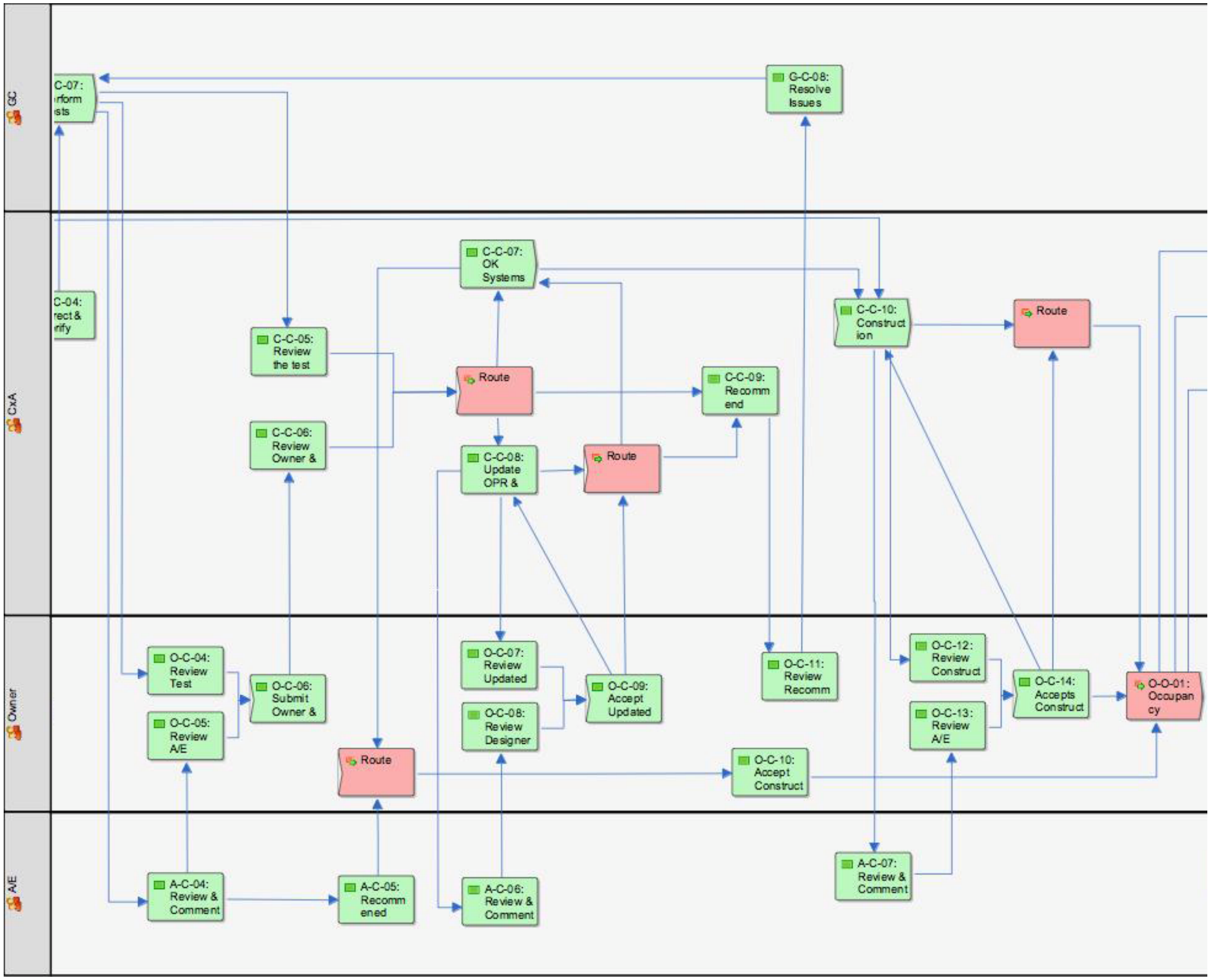

Figure 4. 12 - Owner-led Commissioning Process Model (Construction Phase – Cont'd)

Table 4. 8 - Responsibilities of different entities in Construction phase of Owner-led Commissioning

Designer Activities	Owner Activities	CA Activities	GC Activities
A-C-01: Review Submittals	O-C-01: Review & Comment on Submittals	C-C-01: Review & Comment on Submittals	G-C-01: Start Construction
A-C-02: Review Owner & CxA Submittal Comments	O-C-02: Review CxA Comments on Submittals	C-C-02: Verify Construction Checklist	G-C-02: Construction
A-C-03: Approve Submittals	O-C-03: Submit Owner & CxA Submittal Comments to AE	C-C-03: Develop Test Requirements	G-C-03: Prepare System Manual
A-C-04: Review & Comment on Test Results	O-C-04: Review Test Results	C-C-04: Direct & Verify Tests	G-C-04: Perform Training
A-C-05: Recommend Final Acceptance	O-C-05: Review AE Comments on Test Results	C-C-05: Review Test Results	G-C-05: Submit Submittals
A-C-06: Review & Comment on Updated OPR & BOD	O-C-06: Submit Owner & AE Test Comments to CxA	C-C-06: Review Owner & AE Test Comments	G-C-06: Resolve Sumittal Issues
A-C-07: Review & Comment on Construction Cx Report	O-C-07: Review Updated OPR & BOD	C-C-07: OK Systems	G-C-07: Perform Tests
	O-C-08: Review Designer Comments on Updated OPR & BOD	C-C-08: Update OPR & BOD	G-C-08: Resolve Issues
	O-C-09: Accept Updated OPR & BOD	C-C-09: Recommend Modifications	
	O-C-10: Accept Construction	C-C-10: Prepare Construction Cx Report	
	O-C-11: Review and Require Modifications		
	O-C-12: Review Construction Cx Report		
	O-C-13: Review AE Comments on Construction Cx Report		
	O-C-14: Accept Construction Cx Report		
	O-O-01: Occupancy		

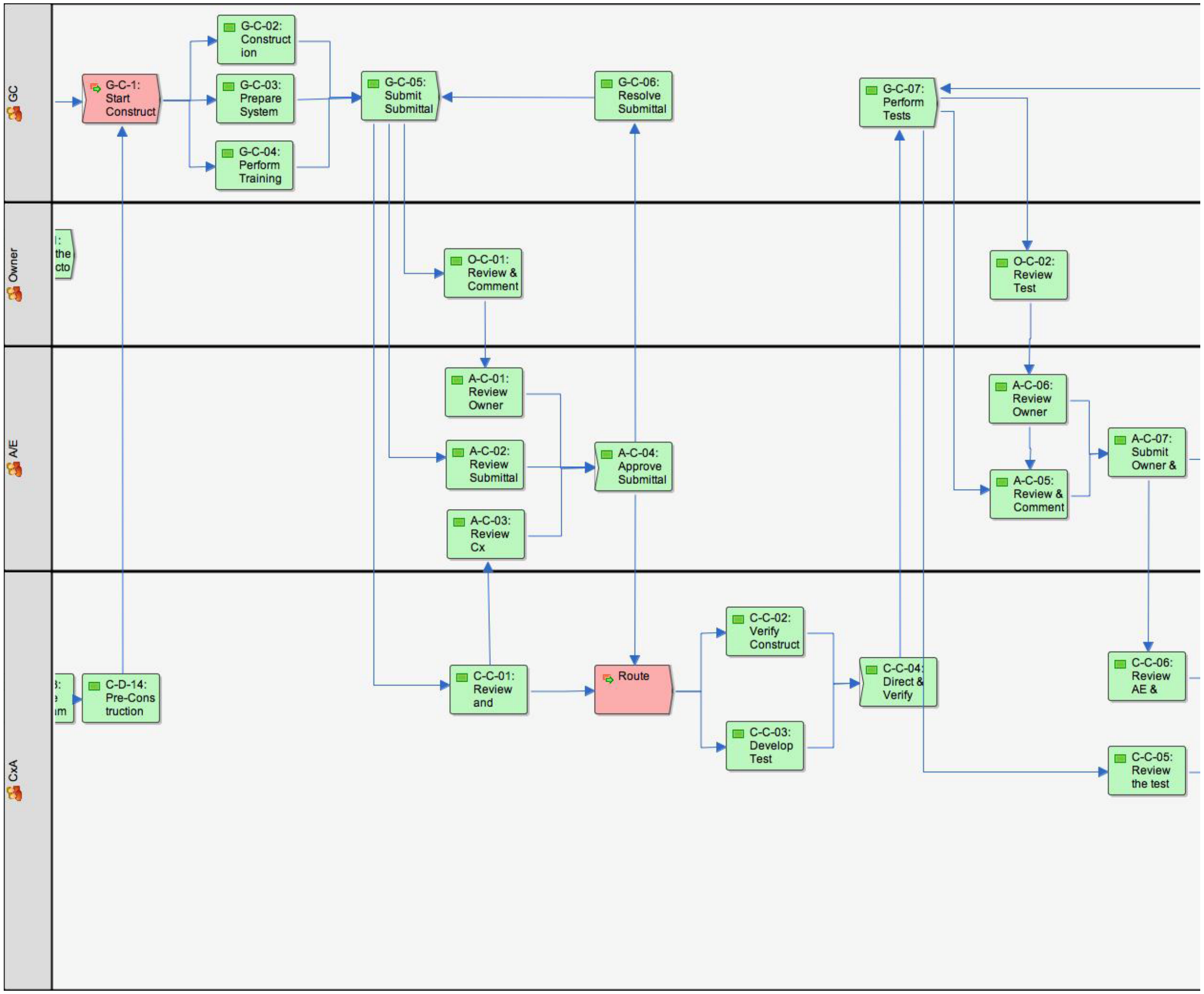

Figure 4. 13 - AE-led Commissioning Process Model (Construction Phase)

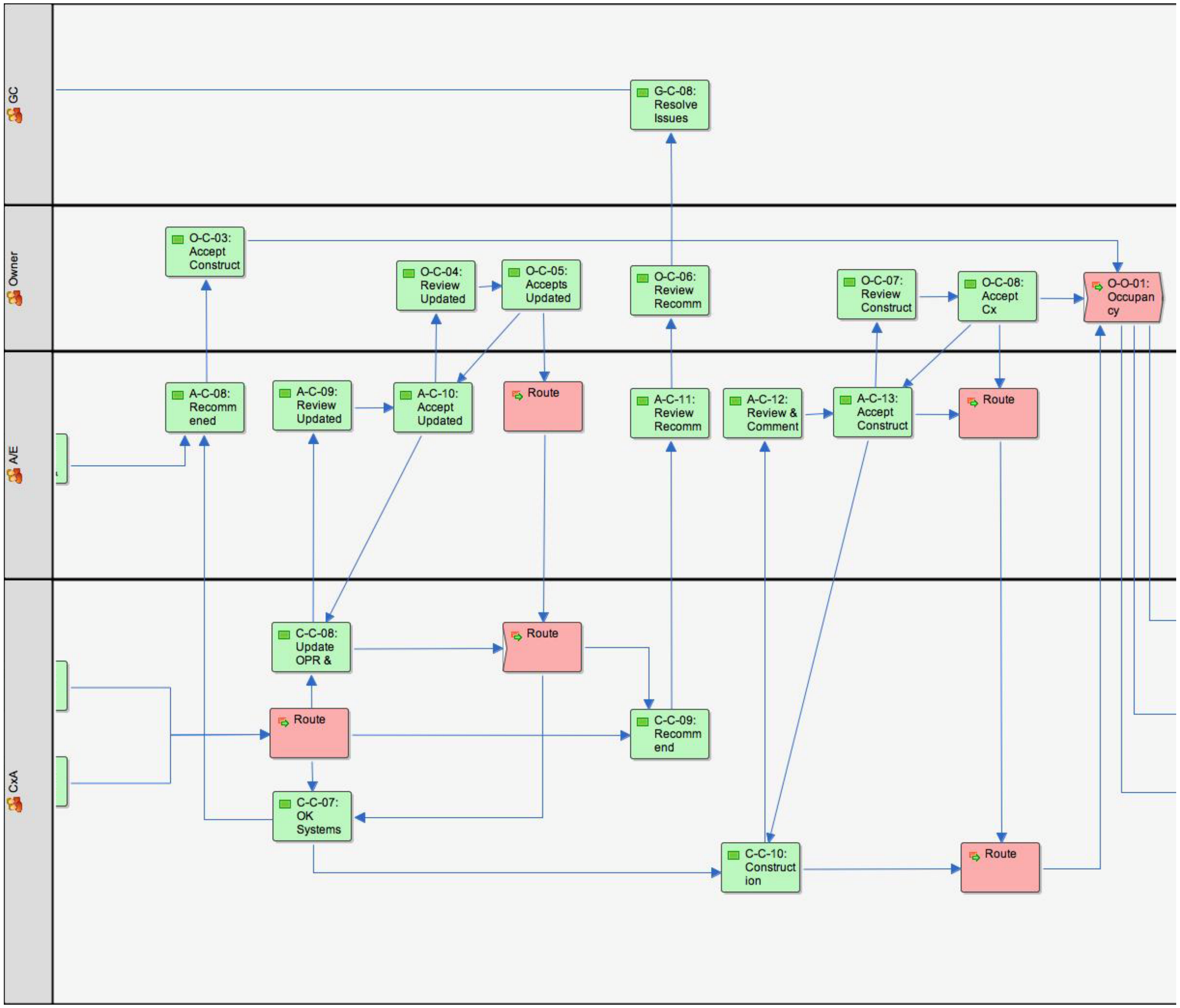

Figure 4. 14 - AE-led Commissioning Process Model (Construction Phase – Cont'd)

Table 4. 9 - Responsibilities of different entities in Construction phase of AE-led Commissioning

Designer Activities	Owner Activities	CA Activities	GC Activities
A-C-01: Review Submittals	O-C-01: Review & Comment on Submittals	C-C-01: Review & Comment on Submittals	G-C-01: Start Construction
A-C02: Review Owner's Submittal Comments	O-C-02: Review & Comment on Test Results	C-C-02: Verify Construction Checklist	G-C-02: Construction
A-C-03: Review CxA Submittals Comments	O-C-03: Accept Construction	C-C-03: Develop Test Procedures	G-C-03: Prepare System Manuals
A-C-04: Approve Submittals	O-C-04: Review Updated OPR & BOD	C-C-04: Direct & Verify Tests	G-C-04: Perform Training
A-C-05: Review & Comment on Test Results	O-C-05: Accept Updated OPR & BOD	C-C-05: Review Test Results	G-C-05: Submit Submittals
A-C-06: Review Owner's Test Comments	O-C-06: Review and Require Modifications	C-C-06: Review AE & Owner Comments	G-C-06: Resolve Submittal Issues
A-C-07: Submit Owner & AE Test Comments for CxA	O-C-07: Review Construction Cx Report	C-C-07: Ok Systems	G-C-07: Perform Tests
A-C-08: Recommend Final Acceptance	O-C-08: Accept Construction Cx Report	C-C-08: Update OPR & BOD	G-C-08: Resolve Issues
A-C-09: Review Updated OPR & BOD		C-C-09: Recommend Modifications	
A-C-10: Accept Updated OPR & BOD		C-C-10: Prepare Construction Cx Report	
A-C-11: Review & Submit CxA Recommendation			
A-C-12: Review Construction Cx Report			
A-C-13: Accept Construction Cx Report			

4.3.3.4. Occupancy Phase

The main responsibilities of the Commissioning Authority, during the occupancy phase, are to direct and verify the seasonal tests, and to coordinate the warranty reviews and contractor call-backs. Also, at the end of this stage, the Commissioning Authority will prepare the final commissioning report.

Figures 4.15 and 4.16 show the commissioning processes during the occupancy phase for two delivery alternatives. As shown in these graphs, the main difference between the two alternatives at this phase of the project is the level of involvement of the AE in the project. In AE-led commissioning, AE takes an active role and is involved in the project through the end of the process, and is in charge of approving CA deliverables. In Owner-led Commissioning, on the other hand, the AE has a passive role and only reviews test results and the final commissioning report.

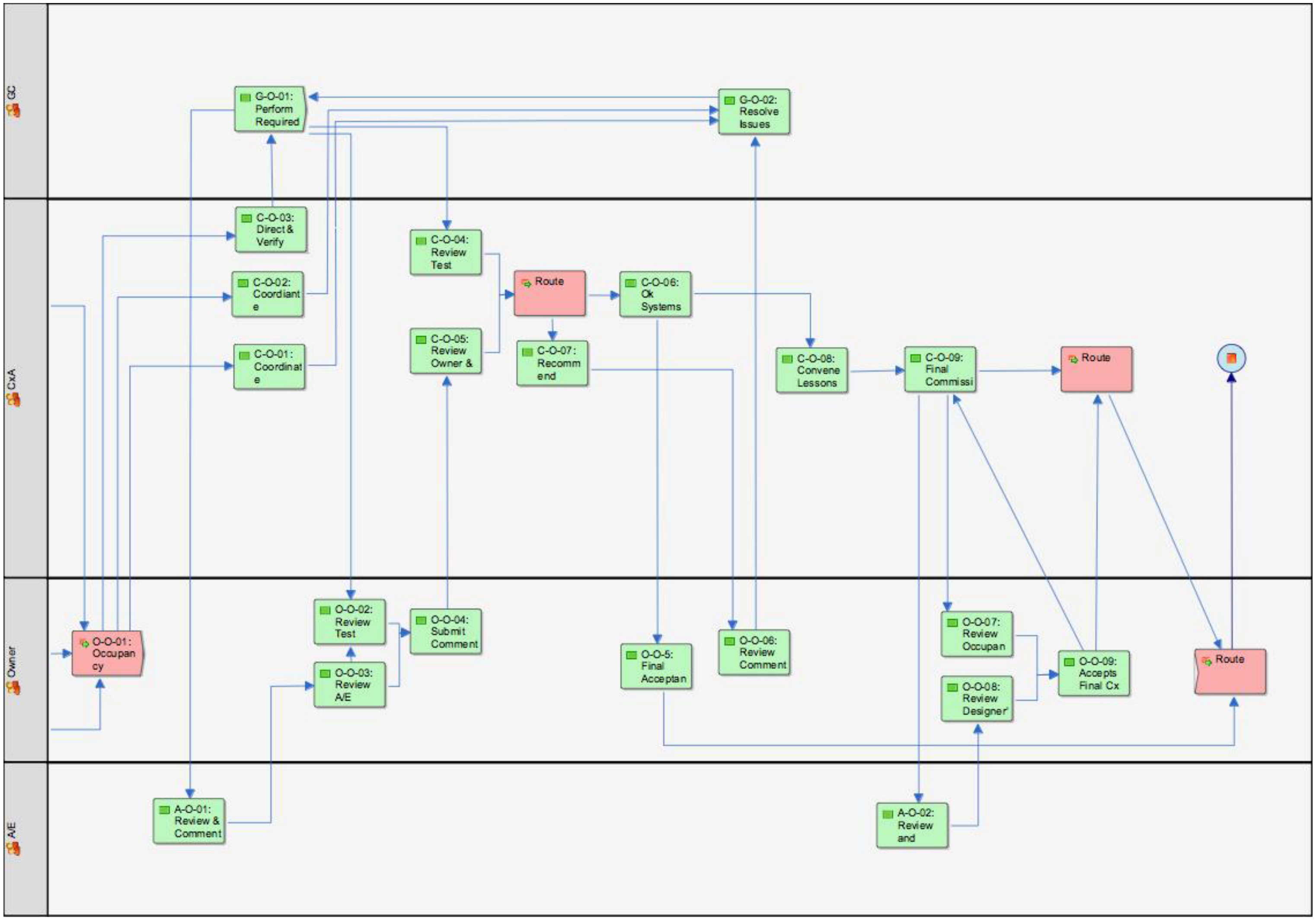

Figure 4. 15 - Owner-led Commissioning Process Model (Occupancy Phase)

Table 4. 10 - Responsibilities of different entities in Occupancy phase of Owner-led Commissioning

Designer Activities	Owner Activities	CA Activities	GC Activities
A-O-01: Review & Comment on Test Results	O-O-01: Occupancy	C-O-01: Coordiante Contractor Call Backs	G-O-01: Perform Required Tests
A-O-02: Review & Comment on Final Cx Report	O-O-02: Review Test Results	C-O-02: Coordinate Warranty Reviews	G-O-02: Resolve Issues
	O-O-03: Review AE Comments	C-O-03: Direct & Verify Seasonal Tests	
	O-O-04: Submit AE & Owner Test Comments to CxA	C-O-04: Review Test Results	
	O-O-05: Final Acceptance	C-O-05: Review Owner & AE Test Comments	
	O-O-06: Review and Require Modifications	C-O-06: OK Systems	
	O-O-07:Review Final Cx Report	C-O-07: Recommend Modifications	
	O-O-08: Review AE Comments on Final Cx Report	C-O-08:Convene Lessons Learned Meeting	
	O-O-09: Accept Final Cx Report	C-O-09: Prepare Final Cx Report	

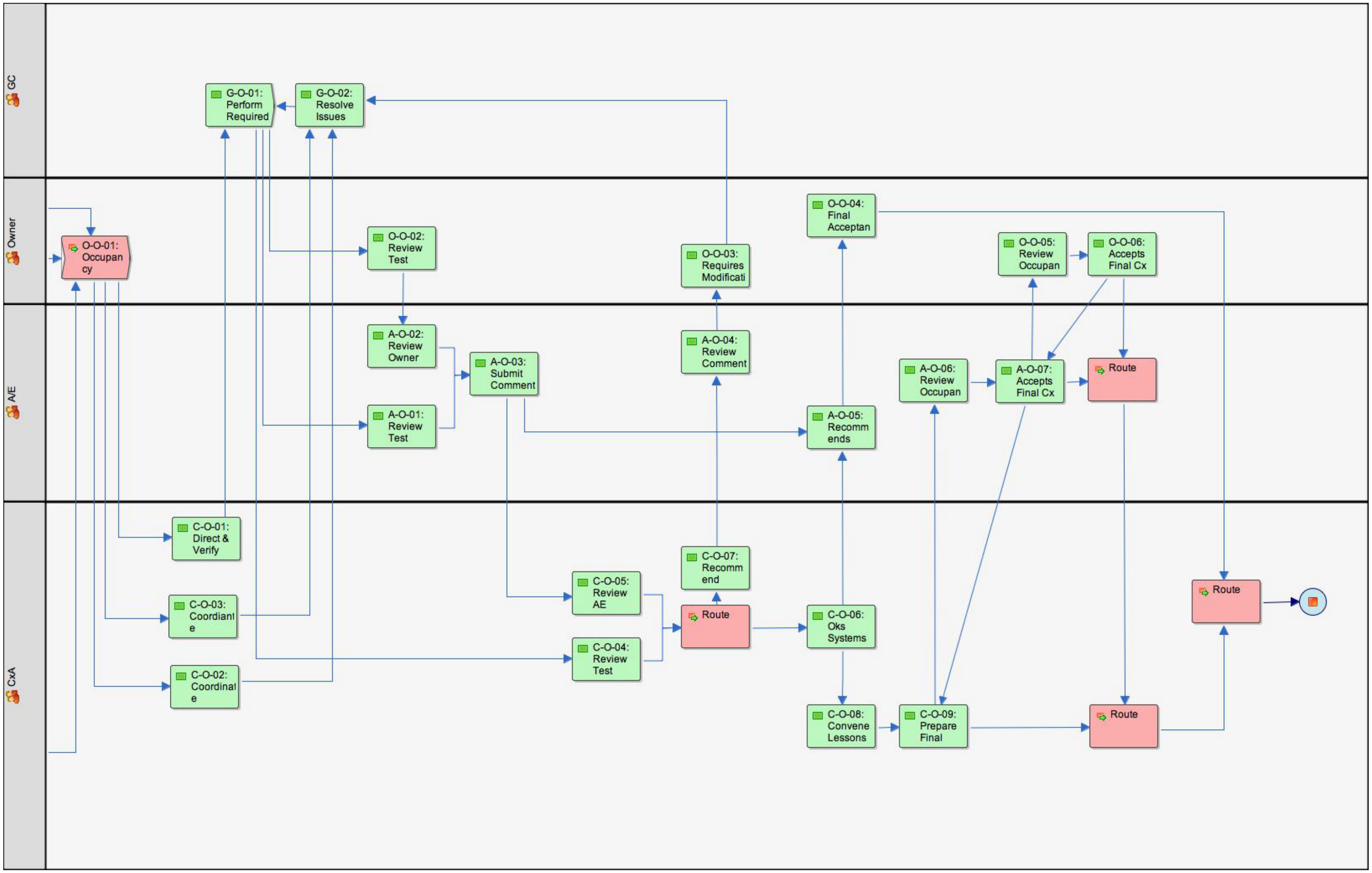

Figure 4. 16 - AE-led Commissioning Process Model (Occupancy Phase)

Table 4. 11 - Responsibilities of different entities in Occupancy phase of AE-led Commissioning

Designer Activities	Owner Activities	CA Activities	GC Activities
A-O-01: Review Test Results	O-O-01: Occupancy	C-O-01: Direct & Verify Seasonal Tests	G-O-01: Perform Required Tests
A-O-02: Review Owner Comments	O-O-02: Review Test Results	C-O-02: Coordinate Contractor Call Backs	G-O-02: Resolve Issues
A-O-03: Submit Owner & AE Comments to CxA	O-O-03: Require Modifications	C-O-03: Coordinate Warranty Reviews	
A-O-04: Review Recommendations & Submit for Owner	O-O-04: Final Acceptance	C-O-04: Review Test Results	
A-O-05:Recommend Final Acceptance	O-O-05: Review Final Cx Report	C-O-05: Review Owner & AE Comments	
A-O-06: Review Final Cx Report	O-O-06: Accept Final Cx Report	C-O-06: OK Systems	
A-O-07: Accept Final Cx Report		C-O-07: Recommend Modifications	
		C-O-08:Convene Lessons Learned Meeting	
		C-O-09: Prepare Final Commissioning Report	
		C-O-10: End of Cx	

4.3.4. Summary of Structural Differences between CDS alternatives:

In summation, three main structural differences between Owner-led and AE-led Commissioning Delivery Systems are observed.

First, is the issue of AE's involvement in the commissioning process. In AE-led Commissioning, the Designer plays a very active role and is involved in every step of the commissioning process. In Owner-led Commissioning, on the other hand, the Designer's role is very passive. The Designer's passive involvement can be observed during the pre-design and occupancy phases of the project.

Second, is the difference in the approval process. In Owner-led Commissioning, the Owner is the sole entity responsible for approving the deliverables of the project. The structure of the approval process in AE-led Commissioning is very different. In this delivery system, most deliverables of the commissioning agent goes through a two-step approval process, which requires the approval of both Designer and Owner.

Third, is the issue of information. In AE-led Commissioning, the Designer becomes the interface between Owner and CA, and most of the communications between these two entities must pass through the Designer. This results in the Designer becoming the repository of information in the project. In Owner-led Commissioning, on the other hand, the Owner plays the role of interface between the AE and CA, and becomes the repository of information.

As it was mentioned before, this Phase of the study focused on developing commissioning process models under the design-bid-build project delivery system. This was due to the fact that Guideline 0, defines the process of building commissioning and commissioning roles and responsibilities on different entities in the context of this project delivery system. At the same time, it is suspected that the DB-led Commissioning presents very similar structural differences that were discovered for AE-led Commissioning and Owner-led Commissioning. In DB-led Commissioning, DB becomes the interface between the owner and all the other entities involved in the project (A/E, GC, and CA), and therefore becomes the repository of information in the project. Additionally, this results in a very active role for Design-Builder during all phases of commissioning process. Finally, in DB-led Commissioning all the deliverables of commissioning process requires the approval of two entities: Design-Builder and Owner. This further results in a two-step approval process similar to AE-led Commissioning,

4.4. Summary

This chapter proposed a framework to identify the applicable commissioning delivery options for each Project Delivery System. Based on this framework, two different commissioning delivery options (Owner-led Commissioning and AE-led Commissioning) in Design-Bid-Build, and two different options (Owner-led Commissioning and DB-led Commissioning) in Design-Build, were identified and selected for this study.

In addition, process models for two CDS options under Design-Bid-Build were developed and validated. The modeling methodology was discussed, and the developed models were presented. These models were further used to analyze the structural differences between these two commissioning delivery alternatives.

CHAPTER 5

PERFORMANCE ASPECTS OF TOTAL BUILDING COMMISSIONING

5.1. Purpose

In Chapter 4, workflow models presenting the formal process of each Commissioning Delivery System were developed, and the systematic differences between different commissioning delivery alternatives were discussed. The purpose of this chapter is to identify a set of performance aspects for the commissioning process. These performance aspects will be used as a basis of the performance assessment using experts' judgments in Chapter 6.

In the following sections, the overall methodology used to identify performance aspects is first described, and results of each step are presented. Next, each of the performance aspects identified as a result of this investigation will be discussed in detail.

5.2. Methodology

The literature review on the concept of performance measurements in Chapter 2 revealed two types of performance measures that can be used for measuring the outcome of different procurement options: *External performance measures* and *Internal performance measures*. External performance measures are those aspects that relate to the overall outcome of the project. In other words, external aspects are the prime objectives of implementing a project. Internal aspects, on the other hand, focus on the internal mechanics of the project itself, and the interaction among its elements. As described in the methodology chapter, in this investigation, the focus is to compare different Commissioning Delivery Systems (CDS) based on the internal aspects of this process. Therefore, the purpose of this chapter is to identify a set of Internal Performance Measures (PAi) for the commissioning practice.

The methodology used for identifying the appropriate performance measures for the commissioning practice was based on a literature review and is compromised of four major steps. These steps are further described in the following section.

5.2.1. Generating a list of "Success Factors"

The first step of this process was to generate a comprehensive list of factors that contribute to the success of a commissioning process. This list was generated through a comprehensive review of the existing literature on building commissioning. Existing literature was located through proceedings of the National Conferences on Building Commissioning (NCBC), as well as databases, such as Galileo and Compendex.

Based on this literature review, every factor that had been cited as an important element in performing a successful commissioning was identified. In cases where the same factor was cited by different authors, they were grouped together. Figure 5.1 shows the result of these investigations. As this figure shows, a total of 21 "success factors" were identified.

5.2.2. Grouping the "Success Factors" into larger categories and developing the performance aspects

After all cited success factors for the commissioning process were identified; those factors that referred to the same underlying concepts were grouped together to generate the larger categories of Internal Performance Aspects (PAi). For example, *Cooperation* and *Teamwork* were both grouped under the larger category of *Collaboration*. The categorization had two major outcomes. First, it removed repetition and helped to develop major aspects, each of which points to a certain dimension of the commissioning processes and, therefore, do not overlap. The second outcome of this categorization was to identify a manageable number of unique aspects, which would further assist to facilitate a structured discussion among experts.

As a result of this categorization, five major internal performance aspects (PAi) for commissioning process were identified: *PAi1: Communication*; *PAi2: Validation*; *PAi3: Collaboration*; *PAi4: Integration*; and *PAi5: Integrity*. Figure 5.2 illustrates the categorization of each success factor into these five internal performance aspects.

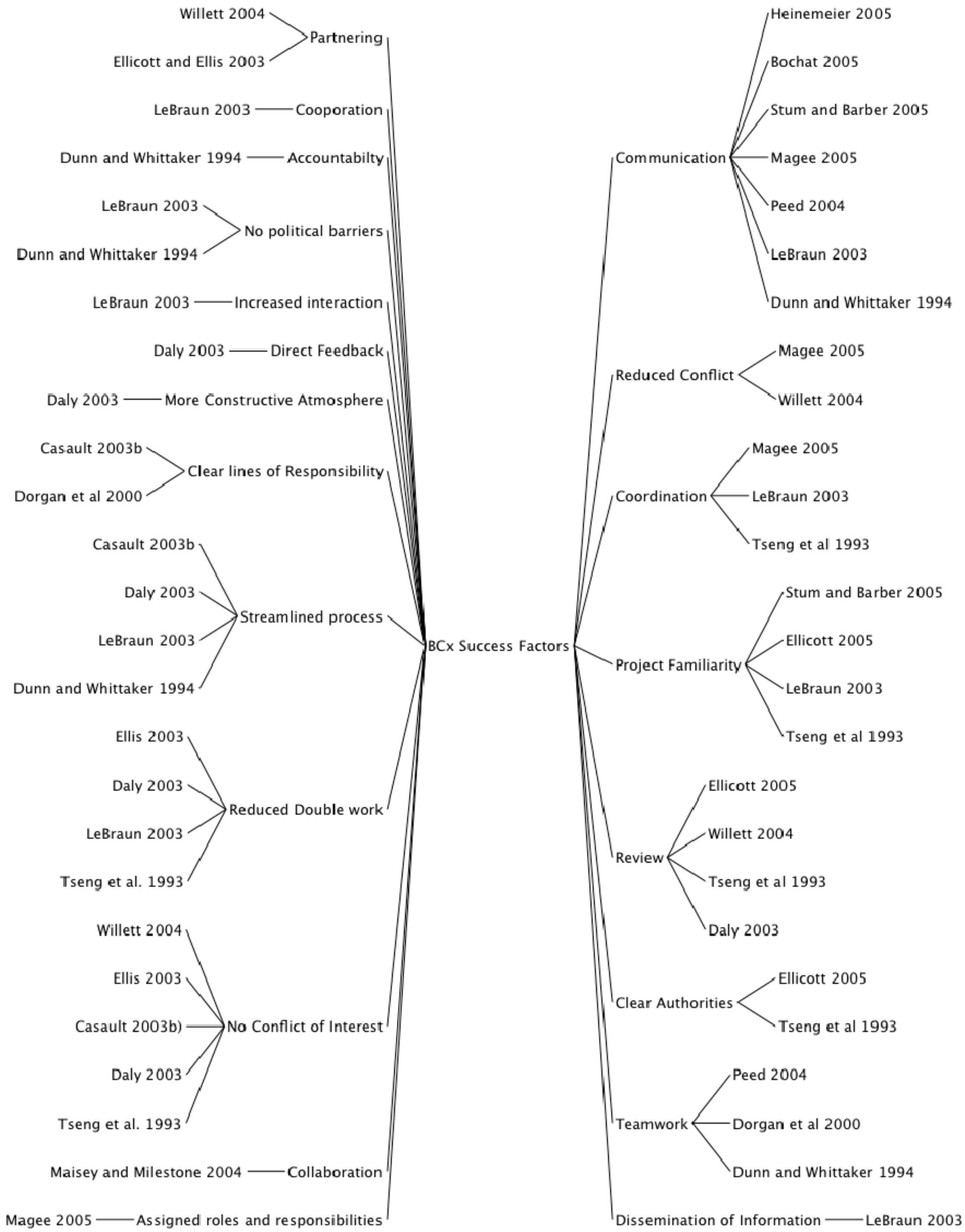

Figure 5. 1 – Summary of factors affecting the success of a commissioning process.

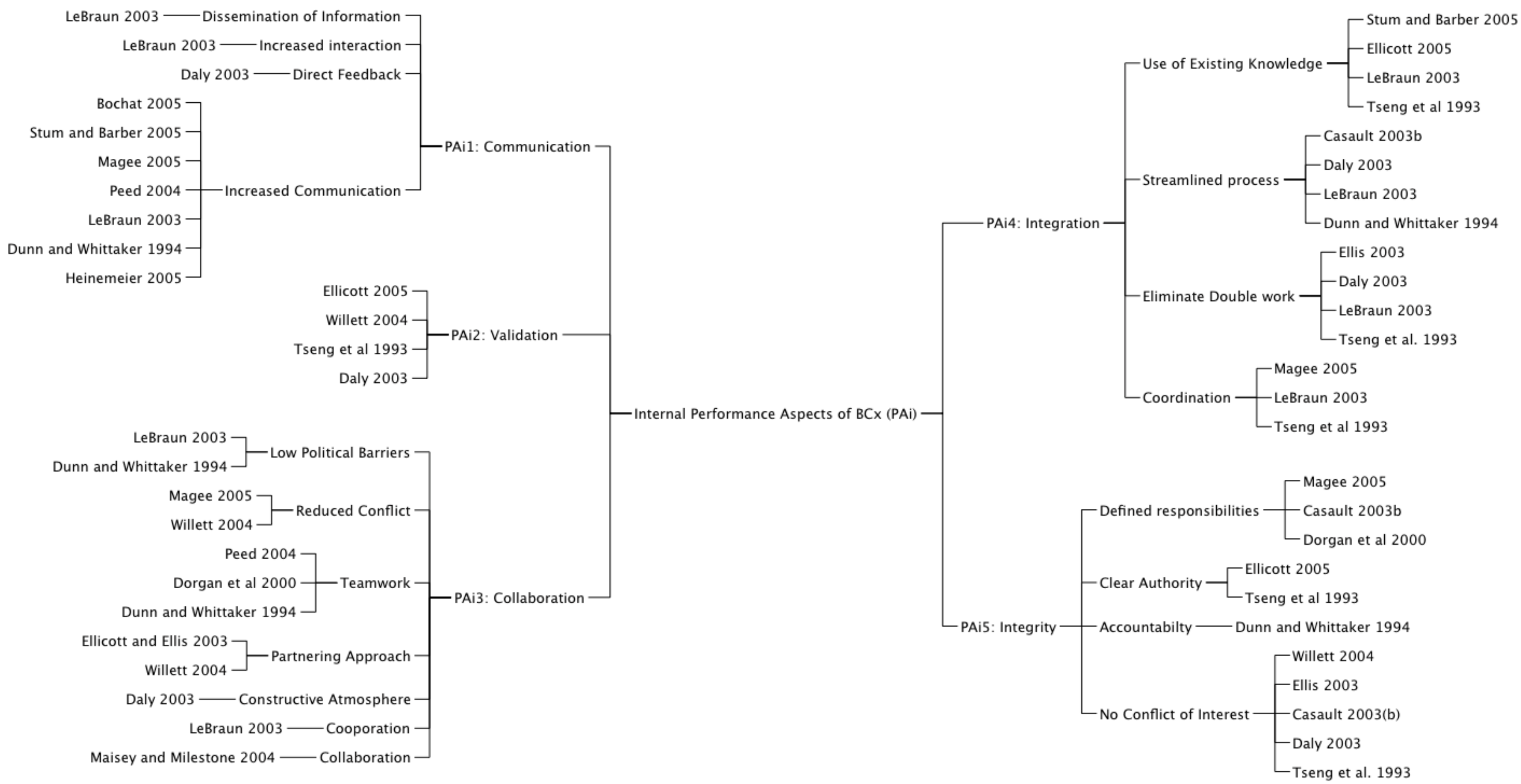

Figure 5. 2 - Categorization of 'success factors' into five major 'Internal Performance Aspects (PAi)'

5.2.3. Defining each performance aspect

After five major performance aspects were identified, a general definition of each performance aspect was provided. This general definition was developed based on identifying major elements of the aspect used across different disciplines, and choosing the definition that would best fit the concepts cited in each performance aspect. In some cases, the definition was tailored to reflect the specific characteristics of the commissioning practice.

In addition to the general definition, the significance of each aspect was discussed based on the cited literature. The goal was to provide a holistic description for each performance aspect, to ensure a similar understanding of each aspect among experts who are participating in the study. This would help to minimize the systematic biases that result from the experts' different perceptions about each of these performance aspects.

Finally, for each performance aspect, a set of *evaluation criteria* was developed. The goal was to highlight the important elements of each PAi for experts, and, again, reduce systematic biases in performance evaluations. The sources for developing these evaluation criteria was derived from the same literature review used for identifying the performance aspects, as well as discussions with commissioning experts about the important factors of each these aspects. These discussions were performed as part of the expert interviews described in the next chapter. The overall definitions, along with the significance and evaluation criteria for each of the five performance aspects, are provided later in this chapter.

5.2.4. Validation of performance aspects through experts

The last step in developing the performance aspects was to validate each aspect by presenting them to commissioning experts. The purpose of this validation was to ensure the importance of each performance aspect, as well as uncover other performance aspects that may have been overlooked in the literature survey. Expert validation was done as part of the Delphi study presented in the next chapter. As a result of this validation, all five performance aspects were identified as being "very important." In addition, experts proposed no other performance aspects. The validation process is further explained in the next chapter, and research data is provided in Appendix D.

5.3. Internal Performance Aspects of the Commissioning Process

As a result, five major performance aspects for the commissioning process were identified. These aspects are: *PAi1: Communication; PAi2: Verification; PAi3: Collaboration; PAi4: Integration;* and *PAi5: Integrity*. These internal performance aspects are presented in the following sections. For each aspect, a general definition will first be provided. Then, the significance of the aspect will be discussed, based on the results of the literature review. At the end of each section, evaluation criteria for each performance aspect will be proposed. The purpose of these evaluation criteria is to highlight the important elements of each performance aspects, and establish a common ground for the performance assessments by experts.

5.3.1. PAi1: Communication

Definition:

Communication is the process of exchanging appropriate information among all different entities involved in the project.

Significance:

One of the most-cited factors for a successful commissioning process is improved communication. Most of the problems in a project arise from the communication breakdowns among different entities, and building commissioning is focused on eliminating these problems [Peed 2004]. Communication has such a high importance in the building commissioning process that Heinemeier [2005] defines the commissioning process as an *improvement in the communication process* during design and construction. Bochat [2005], Stum and Barber [2005], Magee [2005] and Dunn and Whittaker [1994] all emphasize the essential role of clear communication among all different entities in the commissioning process. In addition, Daly [2003] points to the importance of the direct feedback between team members in the commissioning process, and the opportunities that this feedback provides to learn from each other.

Evaluation Criteria:

- *Clarity:* Refers to the degree by which two parties have a clear understanding of the message that is been transmitted.
- *Integrity:* Information is complete and its intent is not altered or destroyed.
- *Directness:* Direct communication lines between parties exist and the message doesn't need to pass through different entities to reach the recipient.

5.3.2. PAi2: Validation

Definition:

Determination of correctness of project deliverables, with respect to the user needs and requirements.

Significance:

External validation, or having an "extra set of eyes," is one of the major characteristics of the commissioning process [Daly 2003; Ellicott 2005; Willett 2004]. Validation activities make up for a large part of the commissioning process. These include reviewing the building design and providing feedback on the ability of the designed systems to meet the owner's requirements, as well as verification and testing of the installed building systems. Therefore, the ability of the commissioning team to review the design and test the systems is one of the most important aspects of the building commissioning process and plays a major role in achieving its objectives.

Evaluation Criteria:

- *Thoroughness:* Validation is comprehensive and addresses all related issues.
- *Accuracy:* Refers to the preciseness of validation.

- *Practicality:* The validation is performed based on realistic goals and standards.

5.3.3. PAi3: Collaboration

Definition:

Cooperation of all entities involved in the project working at goodwill, in order to achieve the common goal.

Significance:

The importance of team work and collaboration among different entities is emphasized by many authors [Dorgan et al. 2000; Dunn and Whittaker 1994; LeBrun 2003; Peed 2004]. Daly [2003] highlights how a collaborative atmosphere will help to make the commissioning process more efficient and LeBrun [2003] stresses that, in order to achieve the commissioning benefits, political barriers must be eliminated. Collaboration in the building commissioning process is so important that Willet [2004] and Ellicott and Ellis [2003] all argue that a successful building commissioning requires a *partnering* approach, which is considered as part of the collaboration aspect.

Evaluation Criteria:

- *Teamwork:* Commissioning is not fostered by a single entity, and all entities take an active role in performing commissioning activities.
- *Cooperation:* Degree to which different parties are willing to support others efforts and recommendations in the project.
- *Interaction:* Adequate amount of active interaction among different entities exist.

5.3.4. PAi4: Integration

Definition:

The process of incorporating commissioning activities into the overall process of pre-design, design, construction and occupancy.

Significance:

A successful commissioning process will not add to the complexity of the delivery system, but will help to streamline the process [Dunn and Whittaker 1994]. A seamless integration of commissioning activities into the delivery system is essential for successful commissioning [Daly 2003; Dorgan et al. 2000; LeBrun 2003]. This integration can be achieved through proper division of commissioning roles among entities, as well as coordination of commissioning activities with other activities in the project [Magee 2005]. Responsibilities should be assigned in a way that takes advantage of existing knowledge and capabilities in the project [Ellicott 2005] and minimizes any double work [Daly 2003].

Evaluation Criteria:

- *Efficiency:* Efficient use of existing resources on the project and reduction in any double work.
- *Simplicity:* Streamlining the execution of commissioning process and reducing any complexity.
- *Coordination:* Between all project entities in performing commissioning and non-commissioning activities in the project.

5.3.5. PAi5: Integrity

Definition:

Ensuring the completeness and totality of commissioning processes in the project.

Significance:

One of the key features of the building commissioning process is that one single entity represents the project, from the beginning through one or more years of occupancy [Dorgan et al. 2000]. Therefore, the process should be designed in a way that this entity, in collaboration with the commissioning team, can perform all activities of the building commissioning without any conflict of interest [Casault 2003; Ellis 2003; Willett 2004]. In addition, lines of authorities and accountabilities should be defined in a way that any conflict and ambiguity about roles and responsibilities be avoided [Casault 2003; Dunn and Whittaker 1994; Ellicott 2005; Tseng et al. 1993].

Evaluation Criteria:

- *Authority:* Existence of a clear line of authority for implementing the commissioning process.
- *Accountability:* Clear and defined responsibilities for commissioning responsibilities of different entities in the project.
- *Ethicality:* Establishing a high-level of confidence in the reliability of the commissioning activities.

5.4. Summary

This chapter described the methodology used for identifying the appropriate performance aspects for the commissioning process. As a result, a total of five internal performance aspects for the commissioning process were identified. Each aspect was defined and its significance was discussed, based on the existing literature. In addition, evaluation criteria for each performance aspect were provided to establish a common ground for experts' performance assessments. The next chapter will describe the methodology used for measuring each of these performance aspects of each commissioning delivery alternative based on experts' knowledge.

CHAPTER 6

PERFORMANCE ASSESSMENT BASED ON EXPERT JUDGMENTS

6.1. Purpose

The previous chapter presented a set of internal performance aspects of the commissioning process that was developed based on an in-depth review of the existing literature. This chapter is aimed at assessing the performance of each commissioning delivery alternative based on these internal performance aspects. The result of this performance assessment will be used to compare different commissioning alternatives. The performance assessment is performed by soliciting expert judgments through use of the Delphi technique.

In the following sections, the methodology used in this study will be described in detail, and findings of each step will be presented. At the conclusion, a summary of overall results and their implications will be provided.

6.2. Expert Knowledge Gathering Methodology

This investigation uses the expert judgments in order to assess the performance of each Commissioning Delivery System. The aim is to initiate a structured discussion among experts about advantages and disadvantages of each CDS, and attain a collective rating of each performance aspect for different delivery systems.

In order to identify the most appropriate technique for this investigation, a comprehensive study of expert knowledge gathering techniques is performed. The findings of this study are presented in Appendix A of this dissertation. As a result, the Delphi method [Delbecq et al. 1975] was identified as the most appropriate technique for this study. This technique was chosen due to its ability to provide an environment of discussion among a panel of experts and gain a level of consensus among them, while minimizing the difficulties and negative impacts involved with face-to-face meetings. Delphi is a structured process which utilizes a series of questionnaires or rounds to gather and provide information [Keeney et al. 2001]. In a Delphi study, the participants are asked individually, via a questionnaire, to provide their estimates for a variable in question. Feedback is then collected and summarized in a way to conceal the origin of original estimates. The results are circulated, and participants are asked if they wish to refine their previous answers based on the summary results.

6.3. The Delphi Study

The Delphi study in this research is compromised of three questionnaires. First questionnaire aims at validating the Internal Performance Aspects (PAi) for commissioning process, identified in the previous chapter. The second questionnaire, asks experts to provide a preliminary performance assessment of each CDS based on their knowledge and experience about this process. Experts are also asked to provide the reasoning behind their performance assessments. Experts' ratings and comments resulting from the second survey are then summarized and reported back to experts in the third questionnaire and experts are asked, if they wish to change their initial ratings based on the overall group ratings, as well as the provided comments.

A statistical measure is calculated for the overall assessments in order to measure the degree of agreements among experts. In cases, where experts reach a degree of agreement the results will be used as a basis for comparing different CDS. Where experts do not reach an agreement on the performance ratings, performance aspects will be further analyzed based on quantitative analysis of workflow models developed in chapter 4. These quantitative analyses are provided in chapter 7.

Figure 6.1 shows the steps taken in performing the Delphi study. Each of these steps will be further described in the following section.

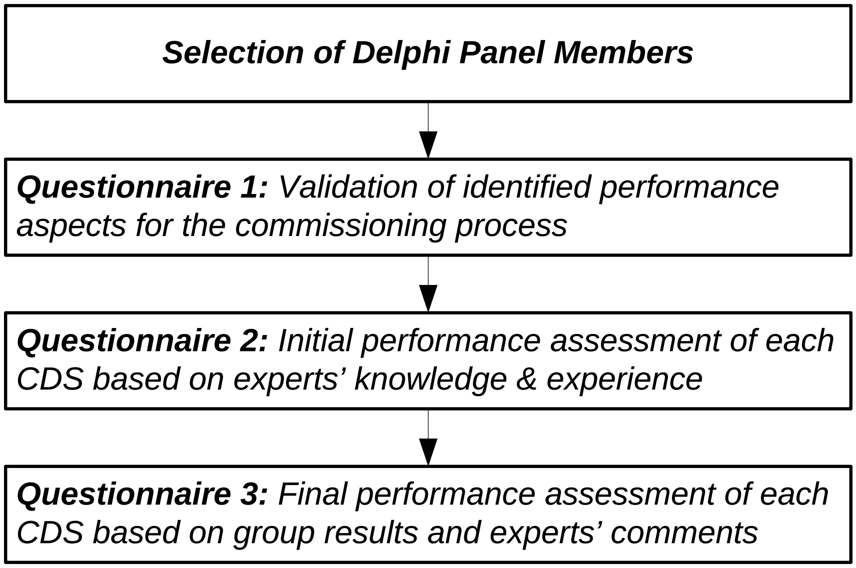

Figure 6. 1 – The approach using Delphi technique

6.3.1. Expert Selection and Initial Interviews

Careful selection of panel members plays a major role in success of a Delphi study [Chan et al. 2001]. Therefore, a *purposive* sampling methodology was used. Experts for this study were defined as individuals who have extensive knowledge about the commissioning process and have working experience with different types of commissioning delivery systems. The experts were identified and selected through a five-step methodology, as proposed by Okoli and Pawlowski [2004][2]. Each of these steps is described below:

[2] A detailed overview of this procedure, in addition to other criteria for selection of Delphi panelists are provided in Appendix A.

Step 1. Prepare a Knowledge Resource Nomination Worksheet (KRNW). Based on the proposed procedure, the first step is to prepare a KRNW to identify the relevant disciplines, organizations and academic and practitioner literature. Identification of relevant disciplines is an important step, as numerous studies insist on using a heterogeneous sample and experts from varying backgrounds to gain a wide knowledge base [Keeney et al. 2001; Rowe et al. 1991]. Based on literature and process models developed in chapter 4, four major disciplines were identified as relevant to this study: *Owners*, *Architect/Engineers (Design Professionals)*, *Contractors* and *Building Commissioners*. It was decided that the Owners should be the majority number of the group, as they are considered the major beneficiaries from a commissioning process. The publications of the *National Conference on Building Commissioning (NCBC)* were identified as the major source of literature on the subject of building commissioning and a good resource to identify the experts on this subject. The *Building Commissioning Association (BCxA)*, the major professional association for the commissioning community, was also identified as another source to select the experts.

Step 2. Populating the KRNW with names. The next step was to prepare a preliminary list of possible candidates. The preliminary list was prepared by identifying the individuals who had several publications in NCBC conferences. Contact information for most of these individuals was found through the BCxA Website. Additional individuals were identified through contacting construction experts in Atlanta, Georgia.

Step 3. Nominate additional experts. The candidates were first contacted by phone. They were given a very brief description of the study and were asked to give the names of other individuals who could be good candidates for the study. The objective was to identify the most qualified individuals in the United States.

Step 4. Rank Experts. Four sub-lists (Owners, Designers, Contractors and Commissioners) were created and candidates were categorized according to their expertise. Each candidate was interviewed in person. In these interviews, candidates were provided with a more-detailed description of the research. They were also asked questions to determine their level of knowledge and their experience with the commissioning process. These interviews provided a basis for ranking the candidates in each category. A total of 22 experts were interviewed and ranked during this process.

Step 5. Inviting Experts. After the rankings in each category were finalized, the experts were invited to participate in the study. The result of literature review on Delphi technique revealed that the maximum validity of a Delphi study is reached with 8-12 panelists [Hogarth 1978; Parente and Anderson-Parente 1987]. A panel size of 16 experts was chosen for this study, in order to compensate for any dropouts during the course of surveys. Candidates were contacted based on the rankings in each category. All experts that were contacted agreed to participate in the research. The solicitation process ended ONCE the required panel size was reached. Table 6.1 shows the breakdown of panelists in each category. In order to preserve anonymity, detailed information about the panel members has not been provided. However, the general demographics of participants will be provided in the results of the first questionnaire of the survey.

Table 6. 1 – Breakdown of Panel Members by Disciplines

Discipline Category	**No. of Panel Members**
Building Owners (Including Owner's PM)	7
Architect/Engineers	3
Contractors	3
Commissioning Consultants	3
Total Panel Members	**16**

6.3.2. Delphi Structure

The Delphi designed for this was comprised of three surveys:

The *first survey* was aimed at validating the internal performance aspects identified in the previous chapter. It was also expected to use the experts' knowledge and experience to explore other performance aspects of the commissioning process, which would be appropriate for the purpose of the study. This survey was comprised of two main sections. The first section included some demographic questions about the respondent's background, their level of experience with the construction industry and the commissioning process, and the roles they have taken in commissioning projects. In the second section, five internal performance aspects were described in detail, and respondents were asked to identify the importance of each aspect on a 5-point Likert scale [Fellows and Liu 1997], as shown in Figure 6.2. At the end of this questionnaire, the respondents were also asked to provide any additional performance aspect for the commissioning process that they would consider appropriate.

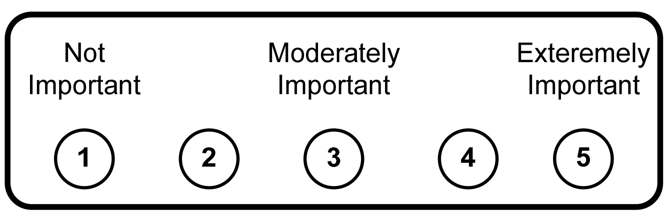

Figure 6. 2 – Likert scale used for identifying the importance of Performance Aspects

The *second survey* was aimed at performance assessment of each commissioning delivery alternative, based on experts' knowledge. In order to limit the criteria, and reduce the systematic errors in experts' judgments, the questions were designed in the form of a scenario in which the construction of an institutional building on a university campus was described. The survey was compromised of two sections. In the first section, the scenario was described as Design-Bid-Build and experts were asked to evaluate the performance of the two commissioning delivery options (Owner-led Commissioning and AE-led Commissioning) within this delivery method. The second section of the survey presented a Design-Build project and participants were asked to rate the performance of Owner-led Commissioning and DB-led Commissioning. Each performance aspect was accompanied by the evaluation criteria, highlighting its important elements. Experts were asked to measure each performance aspect on a 15-point ordinal scale. Again, to reduce systematic error in judgments, examples of extreme ratings were given.

The *third survey* was aimed at giving participants an opportunity to reconsider their previous ratings, in light of the average group responses and comments of the other panel members. The same structure used in Survey 2 was used for this survey. In addition, participants were provided with the average group ratings and comments for each performance aspect.

Before conducting the Delphi study a course in The Protection of Human Research Subjects (CITI) was taken and the CITI certification was received. This certification is required for performing any study involving human subjects. Also Institutional Review Board (IRB) at Georgia Institute of Technology reviewed and approved the surveys. All surveys were conducted through an online survey service (Surveymonkey.com). The link for each survey was sent to each participant through e-mail. Participants were given seven days to complete each survey. In cases where participants required more time, deadlines were extended. Overall, execution of the three surveys took five weeks. In the next section, each survey will be described in detail and their findings will be presented. The actual questionnaires used in these surveys and the detailed results of each survey are provided in Appendixes C-H.

6.3.3. Survey Results

6.3.3.1. Survey 1: Evaluation of identified performance aspects

The first survey was aimed at validating the internal performance aspects identified in the previous chapter. The survey was also expected to use the experts' knowledge and experience to explore other performance aspects of the commissioning process, which would be appropriate for the purpose of the study.

A survey package was sent to the panel members with a link to the online questionnaire. The survey package included a brief description of the study, glossary of some key commissioning terms based on Guideline 0, study criteria, and the study methodology. The package also provided a detailed description of internal performance aspects that were identified based on the literature survey. All 16 participants responded to the first survey. The detailed results of survey one is provided in Appendix D.

Demographics:

Answers to the first part of the questionnaire showed a high level of familiarity and experience with the construction industry among participants. Eleven respondents indicated having more than 20 years experience in the construction industry, and three respondents had 11-20 years of experience. Also, 13 panel members indicated they had experience in more than one discipline in the industry. Figure 6.3 shows the number of experts who indicated experience in each the disciplines.

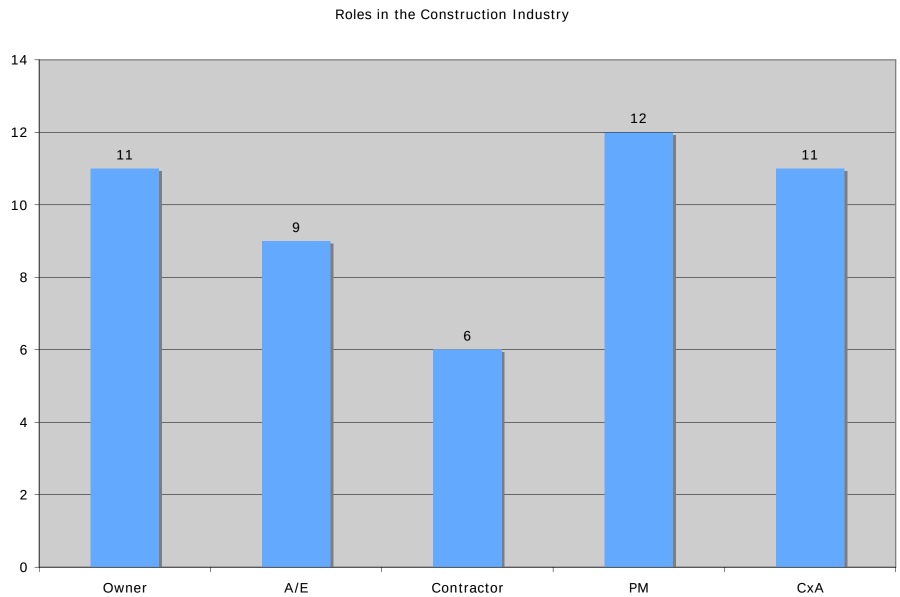

Figure 6. 3 – Number of Experts Who Have Experience in Each Discipline

Results also showed a high level of experience with the commissioning process. Ten of respondents indicated involvement in more than 10 commissioning projects. Two respondents indicated involvement in six to 10 commissioning projects, and four indicated involvement in one to five projects. As for the responsibilities in the commissioning process, the distribution of duties was very similar to the basis of selection. However, four of the respondents indicated that they had performed different roles in different projects (Figure 6.4).

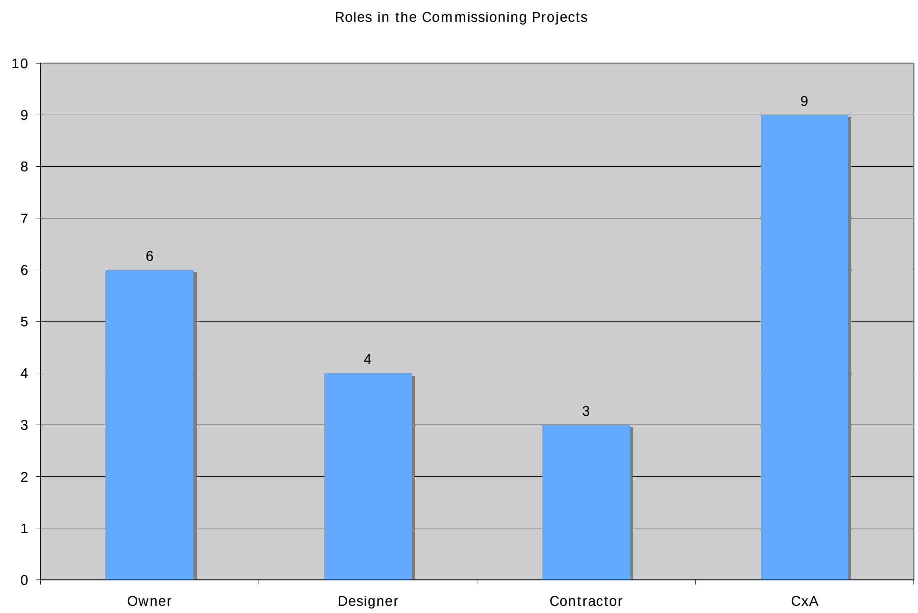

Figure 6. 4 – Number of Experts Who Have Experience in Each Commissioning Role

Validation of PAi

Table 6.2 shows the results of the second section of the first survey. As shown in the table, all the performance indicators were rated between 4 and 5. This indicates that respondents considered all the provided aspects to be "very important." Among these aspects, *Validation* received the highest group average rating (4.63), followed by *Collaboration* and *Integrity*, both with average rating of 4.50. *Integration* (4.25) and *Communication* (4.38) received the lowest average ratings.

There was a difference between how each sub-group rated these aspects. Owners gave *Communication* (4.57) and *Collaboration* (4.43) the highest rating, and *Integration* (4.14) the lowest rating. Both Designers and Contractors gave a perfect score (5) to *Validation*. Building Commissioners also gave *Validation* and *Integrity* the highest rankings, followed by *Communication*, *Collaboration* and *Integration*, all with equal rating of 4.33. Designers gave *Communication* the lowest ranking (3.67).

Table 6. 2 - Results of Participants Rating the Importance of each Internal Performance Aspect

	All Respondents		Owners		Designers		Contractors		Commissioning Cor	
	Mean	d^2	Mean	d^2	Mean	d^2	Mean	d^2	Mean	d^2
PAi1: Communication	**4.38**	0.81	**4.57**	0.79	**3.67**	0.58	**4.67**	0.58	**4.33**	1.15
PAi2: Validation	**4.63**	0.62	**4.29**	0.76	**5.00**	0.00	**5.00**	0.00	**4.67**	0.58
PAi3: Collaboration	**4.50**	0.63	**4.43**	0.79	**4.67**	0.58	**4.67**	0.58	**4.33**	0.58
PAi4: Integration	**4.25**	0.68	**4.14**	0.69	**4.00**	1.00	**4.67**	0.58	**4.33**	0.58
PAi5: Integrity	**4.50**	0.52	**4.43**	0.53	**4.67**	0.58	**4.33**	0.58	**4.67**	0.58

Additional Performance Aspects:

As for additional performance aspects for the commissioning process, one of the respondents proposed *“Documentation.”* This performance aspect was identified as a product of commissioning process, which could in turn be considered as an External Performance Aspect and would be out of the scope of this study. Two other recommendations for performance aspects were *"Background and Experience"* and *"Defined Objective and Criteria."* Although these factors are notably important in any successful commissioning process, they were both recognized as essential requirements for the process and not performance aspects of the process itself. Another suggested aspect was *"Accountability."* This aspect was already identified in the literature review and was classified as a sub-aspect of PAi5 (*Integrity*). There were also other general or specific comments regarding each of the recommended aspects. These comments were taken into account in redefining the performance aspects for the second survey. A detailed list of these comments is provided in Appendix D. However, no additional PAi were added to the list and the initial five performance aspects were used in the second survey.

6.3.3.2. Survey 2: Performance evaluation of each commissioning delivery alternative

The objective of Survey 2 was to assess the performance of each commissioning delivery alternative, based on experts' knowledge. All five internal aspects were used as the basis of comparison, as all of them received high-importance scores in the previous survey. A second survey package was sent to participants, which included the summary results of the first survey, a commissioning process flow-chart provided in Guideline 0, as well as a link to the second survey. A copy of Survey 2 is provided in Appendix E.

Fifteen panelists responded to Survey 2, and one panelist opted to not participate, due to lack of time. Detailed results of the responses to Survey 2 are provided in Appendix F. These results are summarized in table 6.3. Also radar charts in figure 6.5 provide a visual comparison of expert performance ratings for alternatives under each project delivery system. The majority of panelists provided comments supporting their ratings; these comments are also provided in Appendix F.

Table 6. 3 – Survey 2: Summary of Responses

			Overall				Owners				Designers				Contractors				Commissioning Cons.			
			Mean	**SD**	**W**	**Sig.**	**Mean**	**SD**	**W**	**Sig.**	**Mean**	**SD**	**W**	**Sig.**	**Mean**	**SD**	**W**	**Sig.**	**Mean**	**SD**	**W**	**Sig.**
	DBB	***O-Led***	**11.53**	2.61			**12.83**	1.94			**10.33**	3.51			**10.67**	3.21			**11.00**	2.65		
	DBB	***D-Led***	**8.20**	2.54			**6.83**	1.94			**11.33**	1.53			**7.33**	2.52			**8.67**	2.31		
PAi1: Communication					**0.24**	0.01			**0.72**	0.00			**0.43**	0.28			**0.30**	0.44			**0.09**	0.84
	DB	***O-Led***	**11.00**	3.36			**11.17**	3.76			**12.00**	2.65			**10.00**	2.65			**10.67**	5.13		
	DB	***DB-Led***	**8.60**	3.27			**7.83**	3.87			**9.67**	2.52			**10.00**	2.65			**7.67**	4.04		
	DBB	***O-Led***	**11.53**	2.75			**12.83**	1.47			**10.67**	2.31			**10.67**	4.04			**10.67**	4.16		
	DBB	***D-Led***	**8.47**	3.07			**8.33**	2.94			**11.67**	2.52			**7.33**	1.15			**6.67**	3.79		
PAi2: Validation					**0.21**	0.03			**0.90**	0.00			**0.24**	0.54			**0.32**	0.41			**0.33**	0.39
	DB	***O-Led***	**11.40**	2.77			**12.67**	2.07			**11.33**	2.08			**10.00**	2.65			**10.33**	4.73		
	DB	***DB-Led***	**7.73**	3.35			**6.50**	3.15			**9.00**	4.58			**10.33**	2.08			**6.33**	2.89		
	DBB	***O-Led***	**11.67**	2.53			**13.17**	1.60			**9.33**	2.08			**10.00**	3.46			**12.67**	1.15		
	DBB	***D-Led***	**8.20**	2.93			**6.33**	1.63			**11.67**	2.08			**7.00**	3.61			**9.67**	1.53		
PAi3: Collaboration					**0.18**	0.04			**0.67**	0.00			**0.61**	0.14			**0.38**	0.33			**0.86**	0.05
	DB	***O-Led***	**10.67**	2.85			**11.33**	4.03			**10.00**	1.73			**10.67**	2.52			**10.00**	2.00		
	DB	***DB-Led***	**9.47**	2.45			**9.00**	2.45			**11.00**	3.00			**10.67**	2.52			**7.67**	0.58		
	DBB	***O-Led***	**10.27**	3.17			**11.67**	4.23			**8.67**	2.31			**8.67**	2.08			**10.67**	1.53		
	DBB	***D-Led***	**9.73**	2.46			**9.00**	2.61			**11.33**	2.31			**9.67**	3.21			**9.67**	2.08		
PAi4: Integration					**0.03**	0.71			**0.38**	0.07			**0.59**	0.16			**0.03**	0.96			**0.47**	0.24
	DB	***O-Led***	**10.27**	2.84			**11.33**	3.08			**9.33**	1.15			**9.33**	3.06			**10.00**	4.00		
	DB	***DB-Led***	**9.27**	2.91			**9.67**	2.66			**10.67**	3.06			**10.00**	2.65			**6.33**	2.89		
	DBB	***O-Led***	**12.67**	2.47			**13.33**	1.51			**12.67**	2.31			**11.33**	4.62			**12.67**	2.52		
	DBB	***D-Led***	**6.87**	3.04			**6.33**	3.14			**9.67**	1.53			**7.33**	2.31			**4.67**	3.51		
PAi5: Integrity					**0.57**	0.00			**0.75**	0.00			**0.57**	0.16			**0.19**	0.63			**0.91**	0.04
	DB	***O-Led***	**11.00**	3.07			**11.50**	3.51			**10.67**	2.31			**10.33**	4.62			**11.00**	2.65		
	DB	***DB-Led***	**8.67**	4.27			**8.67**	5.05			**9.67**	4.04			**10.67**	4.04			**5.67**	3.21		

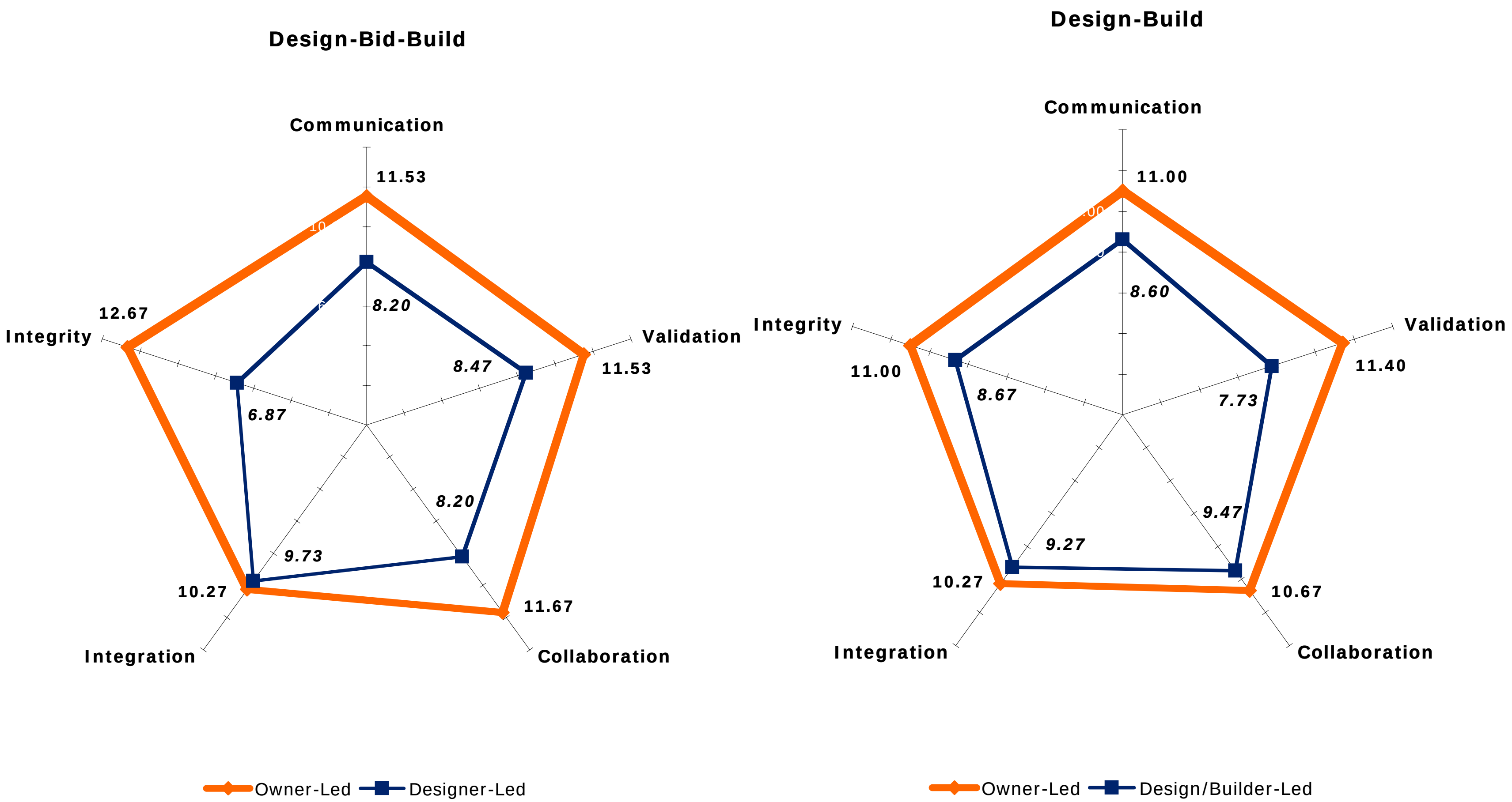

Figure 6. 5 - Survey 2: Overall group evaluations for commissioning alternatives in Design-Bid-Build and Design-Build Delivery Systems

Overall Results:

As shown in the table and accompanying graphs, the Owner-led Commissioning process received the highest overall performance ratings among all aspects in both delivery methods. In addition, the following points were discovered:

Design-Bid-Build:

- *Integration* received the closest performance rating for both commissioning delivery systems.
- The lowest performance evaluation was the *Integrity* of Designer-led Commissioning, which was evaluated as half the value of the *Integrity* of the Owner-led Commissioning.
- The other three performance aspects, *Communication*, *Validation* and *Collaboration* all maintained a consistent difference between Owner-led and Designer-led Commissioning.

Design-Build:

- Again, *Integration* of both Commissioning Delivery Systems received very close ratings.
- *Collaboration* of both CDS also received close ratings.

- *Integrity* of DB-led commissioning in the Design-Build delivery system received a higher value than the *Integrity* of the Designer-led Commissioning in the Design-Bid-Build delivery system.
- *Validation* of DB-led Commissioning received the lowest score.
- Overall, there was a lower performance difference between the commissioning alternatives in Design-Build delivery system than in Design-Bid-Build delivery system.

In order to obtain a measure of consistency in the responses, a statistical test was applied involving the calculation of *Kendall's Coefficient of Concordance (W).* Commonly used in most Delphi studies, Kendall's W can be interpreted as a coefficient of agreement among raters [Chan et al. 2001; Siegel and Catellan 1988]. This coefficient ranges between 0 to 1, with 1 indicating complete inter-rater agreement, and 0 indicating complete disagreement among experts[3].

Kendall's W was calculated using SPSS software. The W values and their significance are provided in Table 6.3. These values were compared with critical W values provided in table A.2, provided in Appendix A for analysis. Result of the analysis

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[3] A more detailed overview of Kendall's W, its interpretation and other non-parametric tests used in Delphi studies is provided in Appendix A.

showed moderate-to-average agreement among experts on four of the five performance aspects. The highest level of agreement was on *Integrity* (W=0.57 at *.00* significance). Results also indicated that experts had some agreement on *Communication*, *Validation* and *Collaboration*. However, there was no agreement among experts on rating of the *Integration* aspect.

Subgroup Results

In order to further explore the differences among experts, the result of the performance evaluations were calculated for each of the four categories. Figure 6.6 and 6.7 summarize these results.

Design-Bid-Build:

- *Owners*: As shown in these figures, in both project delivery systems, the Owners' performance rating was very close to the overall group average. This can be attributed to the fact that this group had the largest number of panel members (six members), as opposed to other sub-groups, which only had three members.

- *Designers*: Designers gave higher performance ratings to the Designer-led Commissioning than Owner-led Commissioning in nearly all of the aspects. The only performance aspect that this group rated higher in Owner-led was *Integrity*.

Also, as the graph shows, Designers ranked *Validation* and *Communication* of two different commissioning delivery systems very closely. But *Collaboration* and *Integration* were ranked noticeably higher for the Designer-led Commissioning.

- *Contractors*: Contractors gave noticeably higher performance ratings to Owner-led Commissioning for every aspect, except *Integration*. The *Integration* of Designer-led Commissioning ranked slightly higher than the Owner-led Commissioning.

- *Commissioners*: Commissioners ranked Owner-led Commissioning noticeably higher than Designer-led Commissioning. Although, performance scores for *Integration* was very close for both Commissioning Delivery Systems.

Design-Build

- *Owners:* Again, Owners ratings were very close to the overall results and Owner-led Commissioning received a higher rating on all performance aspects.
- *Designers:* Designers rated *Collaboration* and *Integration* slightly higher in DB-led Commissioning than in Owner-led Commissioning. At the same time,

Integrity, *Communication* and *Validation* were rated higher in Owner-led Commissioning.

- *Contractors:* Contractors gave both Owner-led Commissioning and Contractor-led Commissioning very similar performance scores. *Communication* and *Collaboration* of two Commissioning Delivery Systems received the exact same score. *Validation*, *Integration* and *Integrity* were rated slightly higher for the DB-led than for Owner-led.
- *Commissioners:* Similar to the Design-Bid-Build delivery system, Commissioners gave Owner-led Commissioning higher performance scores in every aspect. Again, *Integrity* of the DB-led Commissioning received the lowest performance score; although, the relative difference was smaller than the difference between Owner-led and Designer-led.

Agreement among group members in each sub-group:

Kendall's coefficient of agreement was calculated for each of the four sub-groups. Owners showed very high agreement in their ratings. They showed almost perfect agreement on rating *Validation* (W=0.90 at 0.00 significance). Owners also showed strong agreement in rating *Integrity* (W=0.75 at 0.00 significance), *Communication*

(W=0.72 at 0.01 significance), and *Collaboration* (W=0.67 at 0.00 significance). However, the results for *Integration* showed no agreement among Owners.

Commissioners also showed some agreement among their ratings. They showed strong agreement on *Integrity* (W=0.91 at .04 significance). Results also indicated a high agreement on *Collaboration* (W=0.86), although the significance was somewhat low (0.05). Designers and Contractors showed no agreement among their ratings. This is partly to the small number of raters (k=3) in each of these sub-groups.

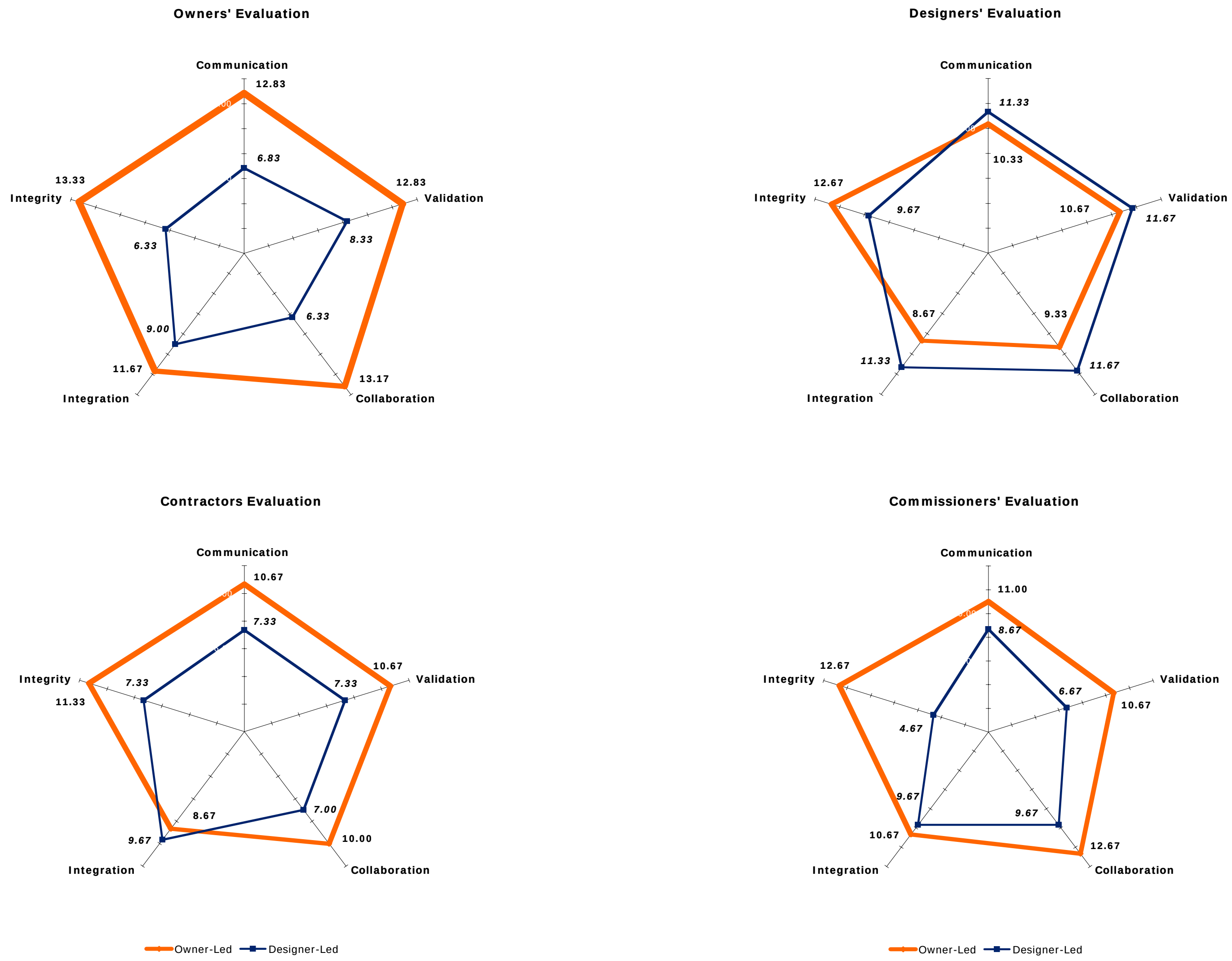

Figure 6.6 – Survey 2: Sub-group evaluations of commissioning alternatives in Design-Bid-Build delivery system

Figure 6.7 – Survey 2: Sub-group evaluations of commissioning alternatives in Design-Build Project Delivery System

6.3.3.3. Survey 3 – Re-evaluation of performance of commissioning delivery systems based on the results of Survey 2

The objective of Survey 3 was to give participants an opportunity to reconsider their previous ratings, in light of the average group responses and comments of the other panel members. The same structure used in Survey 2 was used for this survey. In addition, participants were provided with the average group ratings and comments for each performance aspect. In cases in which comments to the previous questions addressed more than one performance aspect, they were broken down and put under the proper aspect. A sample copy of Survey 3 is provided in Appendix G.

Fourteen panelists responded to Survey 3. One respondent opted to not participate, due to professional commitments and lack of time to respond to the survey. Detailed results of Survey 3 are provided in Appendix H. Table 6.4 and Figure 6.8 summarize these results. Comments provided by the participants are also provided in Appendix H, although the amount of feedback in this survey was less than the previous survey.

Table 6. 4 - Survey 3: Summary of the Results

			Overall				Owners				Designers				Contractors				Commissioning Cons.			
			Mean	SD	W	Sig.	Mean	SD	W	Sig.	Mean	SD	W	Sig.	Mean	SD	W	Sig.	Mean	SD	W	Sig.
	DBB	O-Led	10.93	2.87			12.40	1.82			8.33	4.16			11.00	2.65			11.00	2.65		
		D-Led	8.64	2.24			7.00	1.58			11.33	1.53			9.00	1.73			8.33	2.08		
PAi1: Communication					0.14	0.12			0.58	0.03			0.15	0.71			0.24	0.54			0.12	0.78
	DB	O-Led	10.57	2.98			10.40	3.65			10.67	2.08			10.33	2.31			11.00	4.58		
		DB-Led	8.93	3.22			8.20	3.03			10.67	4.04			10.00	2.65			7.33	3.79		
	DBB	O-Led	10.86	2.88			12.20	0.84			8.33	3.51			11.33	2.89			10.67	4.16		
		D-Led	8.57	2.74			8.00	1.58			11.67	2.52			8.67	2.08			6.33	3.21		
PAi2: Validation					0.29	0.01			0.95	0.00			0.29	0.46			0.26	0.51			0.41	0.30
	DB	O-Led	10.64	2.44			11.60	0.55			9.67	3.06			10.00	2.65			10.67	4.16		
		DB-Led	7.79	3.04			6.40	1.82			9.00	4.58			10.33	2.08			6.33	2.89		
	DBB	O-Led	10.93	2.43			12.00	0.71			8.33	2.31			10.00	3.46			12.67	1.15		
		D-Led	8.64	2.59			6.80	0.84			11.67	2.08			8.00	3.61			9.33	1.15		
PAi3: Collaboration					0.19	0.04			0.70	0.01			0.57	0.16			0.56	0.17			0.87	0.05
	DB	O-Led	10.50	2.41			10.60	2.70			8.67	2.08			12.67	1.53			10.00	2.00		
		DB-Led	9.64	2.44			9.40	2.51			11.00	3.00			10.67	2.52			7.67	0.58		
	DBB	O-Led	9.43	2.24			10.20	2.49			7.67	2.08			8.67	2.08			10.67	1.53		
		D-Led	9.71	2.27			9.00	2.00			11.33	2.31			10.00	3.61			9.00	1.00		
PAi4: Integration					0.01	0.94			0.23	0.33			0.57	0.16			0.03	0.96			0.33	0.39
	DB	O-Led	9.79	2.49			10.40	2.70			8.33	1.53			9.67	2.52			10.33	3.51		
		DB-Led	9.43	2.95			9.80	2.59			10.67	3.06			10.33	2.89			6.67	3.21		
	DBB	O-Led	12.14	2.60			13.00	1.41			11.33	2.31			11.33	4.62			12.33	3.06		
		D-Led	7.43	3.20			6.80	1.92			11.00	3.61			7.33	2.31			5.00	3.46		
PAi5: Integrity					0.51	0.00			0.94	0.00			0.33	0.39			0.33	0.39			0.95	0.04
	DB	O-Led	10.79	2.04			11.20	0.84			9.00	2.65			11.67	2.31			11.00	2.65		
		DB-Led	8.64	3.32			8.60	1.95			9.67	4.04			10.67	4.04			5.67	3.21		

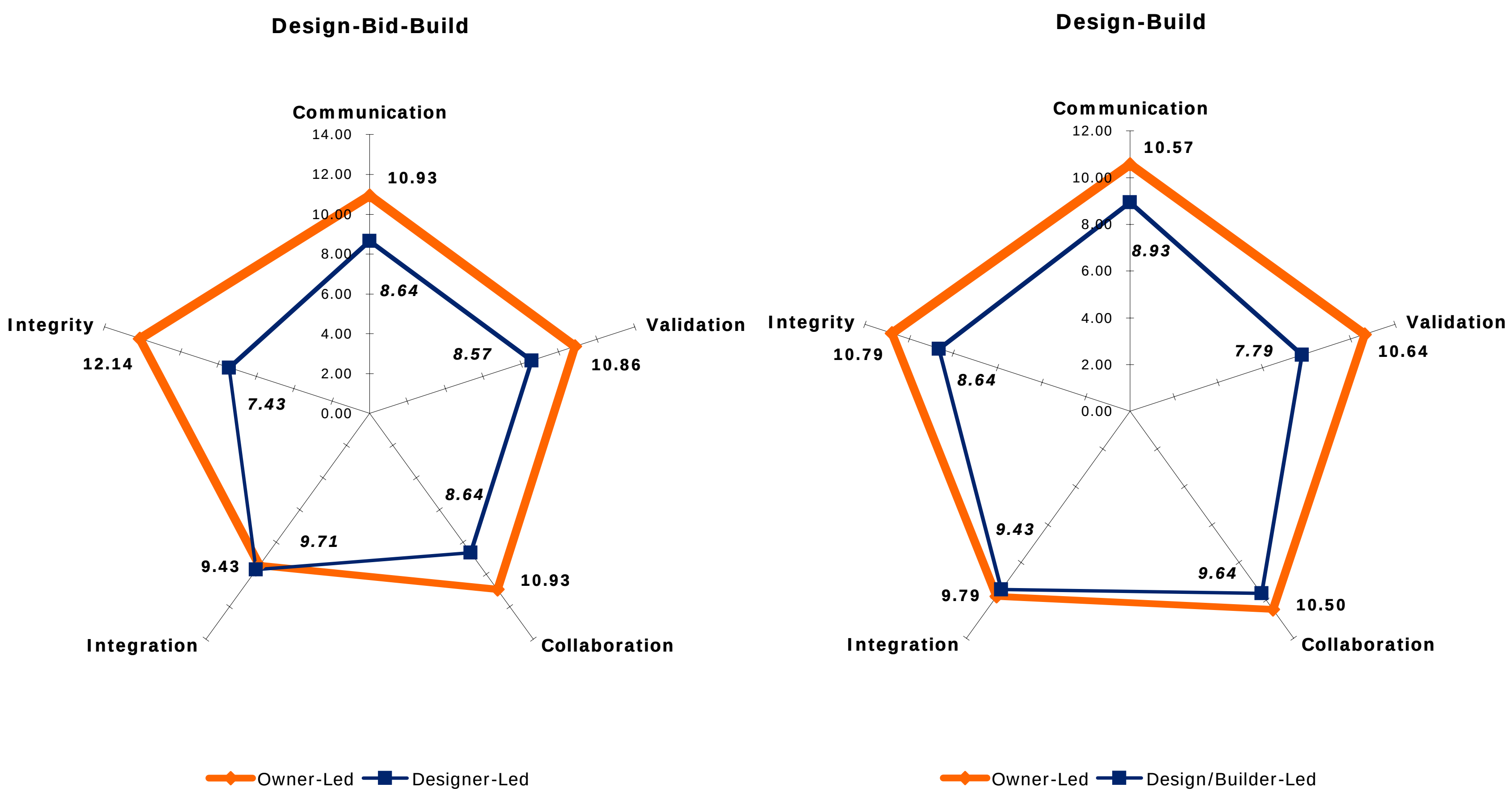

Figure 6.8 – Survey 3: Overall group evaluations for commissioning alternatives in Design-Bid-Build and Design-Build delivery systems

Overall Results:

Overall, the results of Survey 3 were very close to the results of the Survey 2. Owner-led Commissioning again received a higher performance rating than Designer-led (in Design-Bid-Build) and DB-led Commissioning (in Design-Build). However, this time the difference between performance ratings had been reduced. In other words, almost all of the performance scores for Owner-led Commissioning were reduced and performance scores for Designer-led Commissioning and DB-led Commissioning increased. As a result, *Integration* of Designer-led Commissioning jumped slightly above the *Integration* of Owner-led Commissioning. Also, in Design-Build delivery system, *Integration* of Owner-led and DB-led received nearly the same score. *Integrity* of both DB-led Commissioning and Owner-led Commissioning in Design-Build delivery system was reduced; however, the relative difference between these two was lower than the previous survey. Finally, the *Integrity* of Designer-led Commissioning still received the lowest performance score.

Kendall's W for the results of Survey 3 was calculated and compared to critical values provided in table A.2. Table 6.5, presents these values along with values calculated in Survey 2.

Table 6. 5 – Summary of Kendall Coefficient Values for Surveys 2 & 3

	Survey 2		Survey 3	
	W	Sig.	W	Sig.
PAi1: Communication	**0.24**	0.01	**0.14**	0.12
PAi2: Validation	**0.21**	0.03	**0.29**	0.01
PAi3: Collaboration	**0.18**	0.04	**0.19**	0.04
PAi4: Integration	**0.03**	0.71	**0.01**	0.94
PAi5: Integrity	**0.57**	0.00	**0.51**	0.00

The highest agreement remained on *Integrity*, although the W value was slightly lower (0.51) than in the previous survey (0.57). The agreement on *Validation* improved 0.08 points to 0.29. Agreement on the rating of *Collaboration* stayed the same. The agreement for *Communication* was reduced, and the results showed no significant agreement among participants on this aspect. Results also showed no agreement among experts on the performance rating of *Integration*.

Subgroup Results

Figures 6.9 and 6.10 summarize the results of sub-group responses. Overall, the following points were observed:

Design-Bid-Build

- *Owners:* Similar to the previous survey, Owners' ratings were very similar to the group response. The only noticeable difference was the fact that Owners gave a lower score to *Integration* of Designer-led Commissioning than Owner-led Commissioning.

- *Designers:* There was a noticeable difference between the Designers' response to Survey 3 and their previous responses to Survey 2. They gave the Designer-led Commissioning the exact same performance rating on four of the five performance aspects. The only change was for *Integrity*, in which their average response was higher than that of the previous survey. However, the Owner-led Commissioning was treated very differently. In this survey, Designers gave every performance aspect of the Owner-led Commissioning in Design-Bid-Build process a lower score.
- *Contractors:* Contractors' response to this survey was very similar to their previous survey. They gave Owner-led Commissioning a higher performance score for all the aspects except *Integration*, which was rated higher for the Designer-led Commissioning.
- *Commissioners:* Commissioners' ranking was also very similar to their previous ranking. Owner-led Commissioning received a higher performance score in all five performance aspects.

Design-Build:

- *Owners:* Owners' ratings was similar to the overall group response. Owner-led Commissioning received a higher score in all performance aspects.
- *Designers:* Designers had reduced their previous rating for Owner-led Commissioning. Owner-led Commissioning received a lower performance score in *Collaboration*, *Integration*, and *Integrity* than DB-led Commissioning. *Communication* of both commissioning delivery systems received the same performance score. Owner-led Commissioning received a higher performance score for *Validation*.
- *Contractors:* Similar to their responses to Survey 2, Contractors gave both alternatives very close performance scores. Still, *Integration* and *Validation* were slightly higher for DB-led Commissioning. *Integrity* and *Communication* were rated slightly higher for Owner-led Commissioning. *Collaboration* in Owner-led Commissioning received a noticeably higher score than DB-led Commissioning.
- *Commissioners:* Very similar to their previous response, Commissioners gave higher performance scores to Owner-led Commissioning than DB-led Commissioning.

Agreement among panelists in each sub-group

Coefficient of conformance was calculated for each sub-group. Table 6.6, summarized the calculation of these values for surveys 2 and 3.

Table 6. 6 - Comparison of Sub-group Kendall Coefficient Values in Surveys 2 & 3

	Owners				*Designers*				*Contractors*				*Commissioning Cons.*			
	Survey 2		Survey 3		Survey 2		Survey 3		Survey 2		Survey 3		Survey 2		Survey 3	
	W	Sig.	W	Sig.	W	Sig.	W	Sig.	W	Sig.	W	Sig.	W	Sig.	W	Sig.
PAi1: Communication	**0.72**	0.00	**0.58**	0.03	**0.43**	0.28	**0.15**	0.71	**0.30**	0.44	**0.24**	0.54	**0.09**	0.84	**0.12**	0.78
PAi2: Validation	**0.90**	0.00	**0.95**	0.00	**0.24**	0.54	**0.29**	0.46	**0.32**	0.41	**0.26**	0.51	**0.33**	0.39	**0.41**	0.30
PAi3: Collaboration	**0.67**	0.00	**0.70**	0.01	**0.61**	0.14	**0.57**	0.16	**0.38**	0.33	**0.56**	0.17	**0.86**	0.05	**0.87**	0.05
PAi4: Integration	**0.38**	0.07	**0.23**	0.33	**0.59**	0.16	**0.57**	0.16	**0.03**	0.96	**0.03**	0.96	**0.47**	0.24	**0.33**	0.39
PAi5: Integrity	**0.75**	0.00	**0.94**	0.00	**0.57**	0.16	**0.33**	0.39	**0.19**	0.63	**0.33**	0.39	**0.91**	0.04	**0.95**	0.04

Owners again showed the highest level of agreement in their ratings. Their highest level of agreement was on *Validation* (0.95) and *Integrity* (0.94), showing almost perfect agreement. Agreement level on *Collaboration* also improved slightly. However, the W value for *Communication* was reduced to 0.58 at 0.03 significance, indicating an average agreement level among this group.

Commissioners showed slightly higher agreement on *Integrity* (0.95); however, the agreement level on *Collaboration* stayed the same. Designers and Contractors showed no significant agreement on rating of any of the performance aspects.

Figure 6.9 – Survey 3: Sub-group evaluations of commissioning alternatives in Design-Bid-Build delivery system.

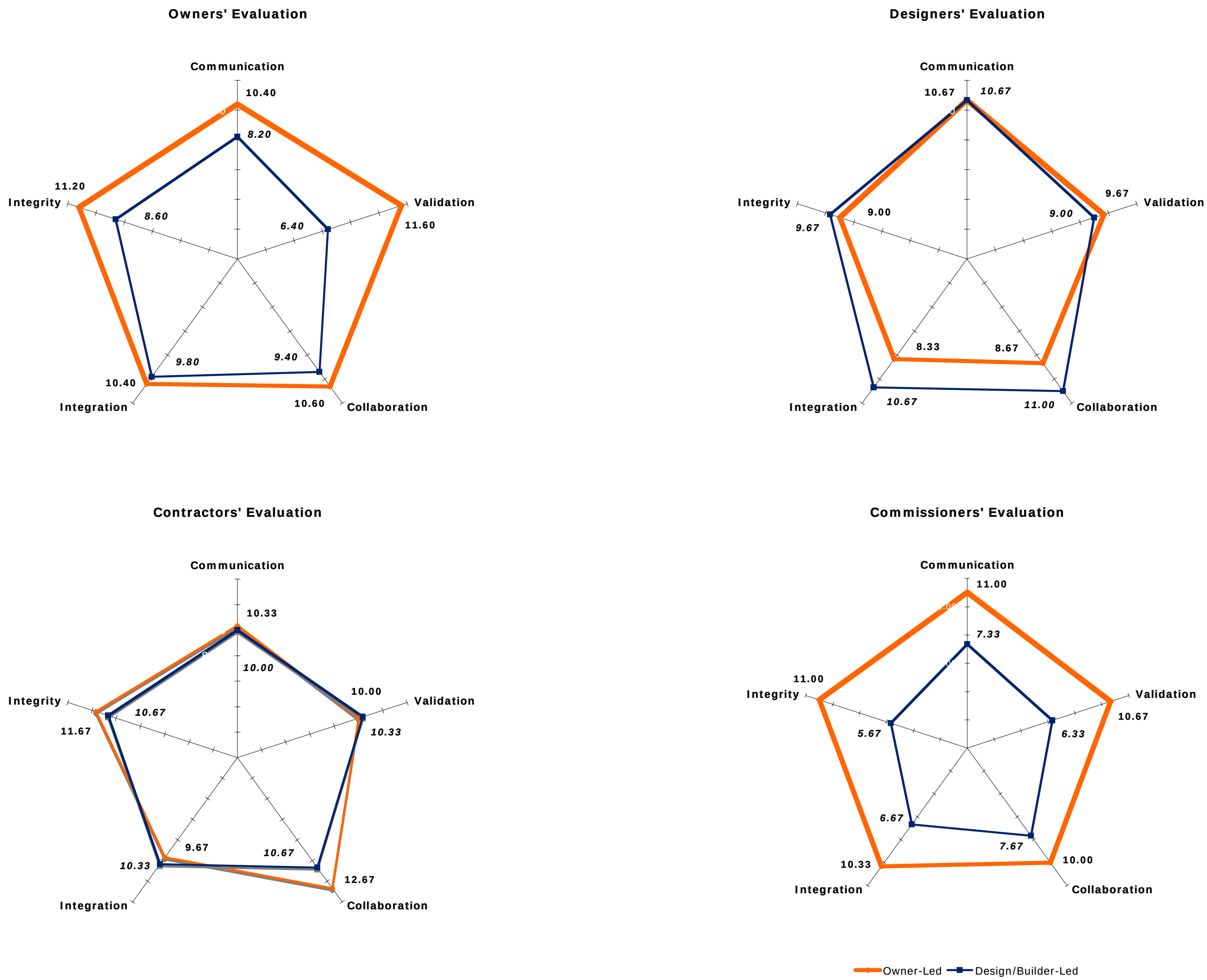

Figure 6.10 – Survey 3: Sub-group evaluations of commissioning alternatives in Design-Build delivery system

6.4. Summary of Findings and Discussion

This chapter presented the result of a Delphi study performed for performance assessment of commissioning delivery alternatives based on expert judgments. The Delphi included three surveys. The first survey asked participants to validate the internal performance indicators by rating their level of importance. The result of this survey showed all identified indicators are regarded as important aspects of the commissioning process.

In the second survey, the participants were asked to rate the performance of each Commissioning Delivery System, based on validated performance aspects. As a result of expert ratings, Owner-led Commissioning received higher performance ratings than AE-led Commissioning and DB-led Commissioning. An analysis of sub-group responses also revealed that Owners and Commissioners gave Owner-led Commissioning higher performance ratings in all aspects. Contractors also gave higher ratings to Owner-led commissioning in every performance aspect, except *Integration*. Designers, on the other hand, had a very different respond, giving AE-led Commissioning a higher performance rating in every aspect, except *Integrity*.

In the third survey, the respondents were provided with summary results of the second survey, and they were asked to reconsider their previous responses. The results were similar to Survey 2, and Owner-led Commissioning received higher performance ratings in all aspects except *Integration*, in which AE-led Commissioning received a higher performance rating. Analyses of sub-group responses did not reveal much difference between Survey 2 and Survey 3. The only noticeable change was the Designers' responses, which revealed lower performance ratings for Owner-led Commissioning.

In order to evaluate the reliability of responses, Kendall's coefficient of concordance was calculated. Results indicated an average agreement among experts on rating the *Integrity* of alternatives, and moderate agreement on rating the *Validation* and *Collaboration* of alternatives. At the same time, experts did not show any agreement on rating the *Communication* and *Integration* aspects. Calculation of Kendall's coefficient for different sub-groups, showed a very strong agreement among owners on their ratings for *Validation*, *Collaboration*, and *Integrity*. At the same time, they showed an average level of agreement on performance rating of *Communication* and no agreement on performance rating of *Integration.* Commissioners, showed strong agreement on their ratings for *Collaboration* and *Integrity*, and no agreement for their rating of other performance aspects. Designers and contractors showed no agreement on their performance ratings.

Based on the Kendall's coefficient calculations for the overall group response, the collected expert ratings for performance aspects of *Validation*, *Collaboration*, and *Integrity* are accepted and is used for comparing the different commissioning delivery systems. However, the performance ratings for *Communication* and *Integration* are not accepted and cannot be used as basis for comparing different commissioning delivery alternatives. At the same time, since both of these aspects were identified as important dimensions of a successful commissioning, an alternative approach was undertaken for their evaluation in each CDS. This alternative approach, as well as the result of the analysis, will be provided in the next chapter.

CHAPTER 7

PERFORMANCE ASSESSMENT BASED ON QUANTITATIVE ANALYSIS

7.1. Purpose

The result of the Delphi study, presented in previous chapter, showed no consensus among experts in rating the performance of different commissioning delivery systems in two aspects of *Communication* and *Integration*. At the same time, the literature review performed for developing performance measures (Chapter 5) revealed that both of these aspects are very important for the overall success of the commissioning process. In addition, results of responses to first questionnaire of the Delphi study indicated that experts regard these aspects as being "very important".

Therefore, in this chapter, these aspects of the commissioning process will be further investigated. This investigation will be based on quantitative analysis of process models developed and validated in Phase I of this study (chapter 5). The aim of these analyses is twofold. First, is to compare the performance of different Commissioning Delivery System. The second purpose is to investigate the underlying reasons that resulted in disagreement among experts. The scope of this investigation will be limited to commissioning delivery options under design-bid-build. Delivery options under design-build are not considered. This is due to the fact that this phase of the study focuses on quantitative analysis of the formal dependencies and interactions among entities as defined by the contract. At the same time, in a design-build project, these dependencies are highly affected by the structure of design-build entity itself, as it can take many different forms (e.g. joint venture, GC-led Design-Builder, AE-led Design-Builder, Integrated Design-Builder), and each of these forms present another layer of inter-organizational relationships that would require a more comprehensive study that is out of the scope of this investigation.

This chapter consists of two main sections. The first section will provide the analysis performed analyzing the *Communication* aspect of two alternatives. The focus of the second section will on be analyzing the *Integration* in each process.

7.2. Communication

The literature review, performed in Chapter 5, revealed that improved communication is one of the most important factors in the success of a commissioning process. Also, in the first survey of the Delphi study, *Communication* received an importance rating of 4.38 out of 5, demonstrating that respondents regarded communication as a 'very important' performance aspect of the commissioning process. However, the final results of the Delphi study showed no agreement among experts on comparing this performance aspect of commissioning delivery alternatives.

This section of this study focuses on analyzing the communication performance of each CDS, based on a quantitative analysis of the process models developed in Chapter 4. To accomplish this, a brief overview of communication theory will first be provided. This overview will be used to identify possible sources of communication problems within a process, and come up with performance indicators which can quantify some aspects of the process communication, based on the developed models. Next, the value of the indicators will be calculated for each CDS, and results will be used to compare these alternatives. Finally, the outcome of these quantitative analyses will be compared to the survey results and differences will be discussed in order to investigate the underlying reasons for experts' disagreement.

7.2.1. Communication Process

Communication is defined as "*the process of effecting an interchange of understanding between two or more people*" [Flippo and Musinger 1982]. Kramer & de Smit [1977] provide a model for the communication process (Figure 7.1). Based on this model, communication processes start with a *sender* using a *coding* device to transform a *message* into a set of *signals*. These *signals* will then be transmitted through a *channel*, until they reach the intended *receiver*. The *receiver* will use a *decoding* device to decode the transmitted signals to a message understandable by the *receiver*. The communication process ends when the transmitted *message* causes a reaction in the *receiver*.

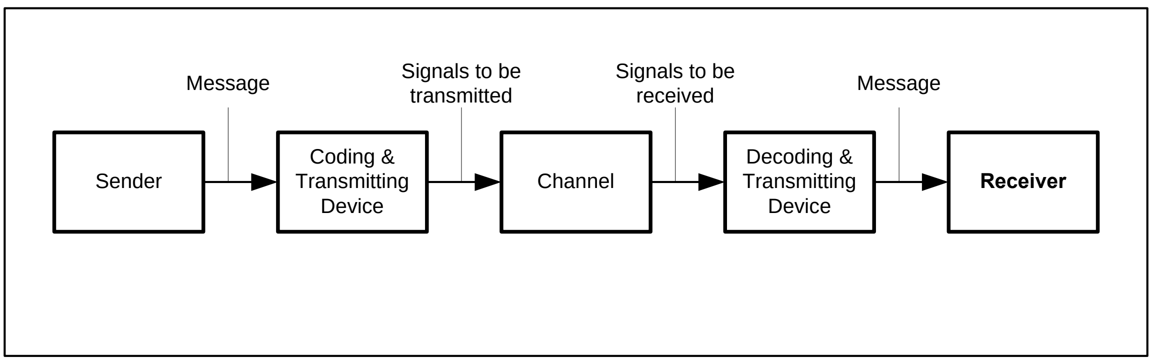

Figure 7. 1 - The Communication Process (Kramer & de Smit 1977)

Kramer & de Smit [1977] further describe communication as part of semiotic (general theory of signs), and distinguish three areas of study in semiotics:

1. **Syntax:** which is the study of formal theory of signs, the determination of signs, and the rules for combining signs.

2. **Semantics:** which focuses on the area of the meaning and content of signs with references to the reality.

3. **Pragmatics:** which is the study of the use and effect of signs on the receiver's behavior relative to a desired result.

Based on these three areas, Shannon and Weaver [1998], classifies the potential communication problems into three levels:

Level A – Technical Problems: which refers to the accuracy by which the symbols of communication are transmitted.

Level B – Semantic Problems: which refers to the ability of the transmitted symbols in conveying the desired meaning.

Level C – Effectiveness Problems: which refers to the effectiveness of received meaning in affecting the conduct in a desired way.

They further argue that all these three levels are inter-related and embrace all potential problems in a process.

In regard to the construction projects, Thomas et al. [1998] proposes a categorization, which focuses on the elements of the communication process in identifying the potential communication process. Based on this categorization, communication problems can be a result of sender/receiver characteristics (e.g.

interpersonal issues, such as biases and prejudice), coding/decoding inadequacies (e.g. poor training and lack of training), and, finally, attributes of the communication channels (e.g. layered organizations or excessively long channels).

7.2.2. Quantifying the Communication of Commissioning Delivery Systems

In Survey 2, respondents were asked to rate *Communication* in different commissioning delivery alternatives, based on three areas of *Clarity*, *Integrity*, and *Directness*. A further analysis of the experts' comments revealed that experts had focused on two dominant factors to assess the communication in each delivery alternative: (1) The skills of the entities involved in the process; and (2) the amount of direct interaction among the entities in the process.

The entities' skills can be categorized as part of sender/receiver and coding/decoding characteristics, as mentioned in the previous section. These characteristics are a function of the personalities involved, their knowledge and experience, interpersonal and communication skills of each entity, and, finally, the personal relationships between these entities. At the same time, these issues are very project-specific and cannot be measured at the process level.

Another factor used by experts was the amount of direct interaction among entities. Comments showed that experts believed layered communication would negatively affect communication, and it would hinder both *timeliness* and *completeness* of information. At the same time, the directness factor refers to the properties of the communication *channels* mentioned in the previous section, which can be analyzed at the process level. As a result, the quantitative analysis of the communication process was focused on measuring the channel properties and, specifically, the directness of communication in different alternatives.

7.2.2.1. PCi1: Communication Directness

The first measure developed for assessing the communication of the commissioning process was *PCi1: Communication Directness.* The main purpose of this indicator was to measure the amount of direct communication between entities in each commissioning alternative.

PCi1 values for each process were calculated by analyzing the process models developed in Chapter 4. The first step was to identify those dependencies, which resulted in a direct communication between two separate entities. In addition, certain events, such as commissioning meetings, which provided an opportunity for direct communication between entities, were identified. The number of direct entity-to-entity communications for each of the four phases of communication was calculated. Finally, the amounts of direct communication for all phases were added together, to develop a PCi1 value for each of the commissioning alternatives. Tables 7.1 and 7.2 summarize the results of these calculations, and Table 7.3 presents the values of PCi1 for each CDS.

Table 7. 1 – Direct Communication between CxA and others in CDS alternatives (a)

	Owner-CxA		*AE-CxA*		*CxA-GC*	
	O-LED	AE-LED	O-LED	AE-LED	O-LED	AE-LED
Pre-design	13	2	2	14	0	0
Design	13	3	6	15	2	2
Construction	10	0	3	11	3	3
Occupancy	6	0	1	6	4	4
Total	**42**	**5**	**12**	**46**	**9**	**9**

Table 7. 2 - Direct Communication between other entities in CDS alternatives (b)

	Owner-AE		*Owner-GC*		*AE-GC*	
	O-LED	AE-LED	O-LED	AE-LED	O-LED	AE-LED
Pre-design	3	14	0	0	0	0
Design	6	14	2	2	2	2
Construction	5	10	3	3	3	3
Occupancy	2	6	2	2	1	1
Total	**16**	**44**	**7**	**7**	**6**	**6**

Table 7. 3 - PCi1 values for each CDS (a+b)

	O-led	AE-led
PCi1 (a+b)	**92**	**117**

As shown in Table 7.3, based on these calculations, AE-led Commissioning received a higher value for PCi1 than Owner-led Commissioning. In other words, AE-led Commissioning provides a higher amount of direct communication among different entities, and, therefore, has a higher performance in that respect.

Apart from showing a higher degree of communication in AE-led Commissioning, the numbers provided in Tables 7.1 and 7.2 also reveal a significant difference in the distribution of direct communication lines in two CDS. Owner-led Commissioning provides a high degree of direct communication between Owner and CA, but limits the direct communication between the Project Designer and CA. In AE-led Commissioning, on the other hand, most of the direct communication takes place between AE-CA and AE-Owner, and the Owner has a very limited direct access to CA. At the same time, to have the most efficient communication process, it is crucial that the distribution of direct communication lines match the actual information requirements and interdependencies of the entities involved in the process. This led to the development of another performance indicator, PCi2, described in the next section.

7.2.2.2. PCi2: Communication Distribution

The other measure for assessing the communication in CDS alternatives was *PCi2: Communication Distribution*. The purpose of this indicator was to measure the distribution of direct communication lines in each CDS, as it corresponds to the actual information needs of the entities involved in the process.

The first step in calculating the PCi2 was to determine the information needs of the different parties during a commissioning process. To do this, the commissioning documentation provided in Guideline 0 was examined, and the relationship of each entity to each document was established. Four conditions of entity-document relationships were identified based on Guideline 0:

1. *Input*: When preparation of a document relies on the information provided by a certain entity.
2. *Write (Prepare):* The entity that is directly responsible for preparing a document.
3. *Approve (Review):* The entity responsible for approving a document before it can be used by the other members.
4. *Read (Use):* When an entity requires the information provided in the document for performing his/her commissioning activities.

Table 7.4 summarizes these relationships for each document. As shown in the table, several entities have more than one relationship with a document.

Table 7. 4 - Entity-Document Relationship Summary

		Owner				AE				CA				GC			
		I	W	A	R	I	W	A	R	I	W	A	R	I	W	A	R
	Owner's Project Requirement	1		1		1			1		1		1				
	Commissioning Plan	1		1	1	1			1	1	1		1				
	Systems Manual Outline	1		1					1	1	1						
	Training Requirements Outline	1		1		1			1	1	1						
	Pre-design Issues Log								1	1	1		1				
	Pre-design Issues Report			1	1				1	1	1						
PRE-DESIGN	Pre-Design Phase Cx Report			1	1					1	1						
	Basis of Design			1		1	1		1			1	1				
	Construction Specification for CX	1		1		1			1	1	1		1				1
	Systems Manual Outline - Expanded	1		1		1			1	1	1	1		1			1
	Training Requirements in Specifications	1		1		1			1	1	1						
	Design Review Comments			1					1	1	1						
	Design Issues Log								1	1	1		1				
	Design Issues Report			1	1				1	1	1						
DESIGN	Design Phase Cx Report			1	1					1	1						
	Construction Submittals				1			1	1				1	1	1		
	Submittal Review Comments						1	1		1							1
	System Coordination Plan					1		1				1	1	1	1		1
	Inspection Checklist					1		1		1	1	1		1			1
	Inspection Reports			1							1	1		1			1
	Construction Test Procedures					1		1		1	1	1		1			1
	Construction Test Data Reports			1							1	1		1			1
	Cx Meeting Agendas & Minutes			1	1			1	1	1	1	1	1			1	1
	Training Plans	1		1	1	1				1		1		1	1		1
	Systems Manual	1		1	1	1				1		1		1	1		
	Construction Issues Log								1	1	1		1				1
	Construction Issues Report			1	1			1	1	1	1						1
CONSTRUCTION	Construction Cx Report			1	1					1	1						
	Maintenance Program	1		1	1					1	1	1		1			
	Occupancy Test Procedures	1				1		1		1	1	1		1			1
	Occupancy Test Data Reports			1	1						1	1		1			1
	Occupancy Issues Log				1				1	1	1		1				1
	Occupancy Issues Report			1	1				1	1	1						1
OCCUPANCY	Final Cx Report			1	1					1	1						

After the entity-document relationships were established, the next step was to use these relationships to identify the inter-entity information dependencies. This was achieved through mapping the documentation process on a dependency matrix[4]. This matrix is provided in Figure 7.2.

[4] A detailed description of Dependency Matrix and its applications is provided in 7.3

		1	2	3	4	5	6	7	8	12	9	10	13	11	14	15	24	25	16	17	18	19	23	20	21	22	26	27	28	29	30	31	32	33	34		Owner - Input	AE - Input	GC - Input	CA - Input	Owner-CA	AE-CA	GC-CA
MATRIX IV: CA-Entity information Depen. — CA-GC	9																		1				1																				
MATRIX IV: CA-Entity information Depen. — CA-AE	18	1	1											1							1																						
MATRIX IV: CA-Entity information Depen. — CA-Owner	17	1	1											1																													
CA - Input		1	1			1	1		1				1	1					1		1		1				1						1										
MATRIX II: Information Provided by Entity — Owner - Output		1	1	1	1						1	1		1			1	1												1	1												
MATRIX II: Information Provided by Entity — AE- Output		1	1		1				1		1	1		1			1	1		1	1	1			1					1	1												
MATRIX II: Information Provided by Entity — GC - Output											1						1	1	1		1	1	1	1	1	1				1	1	1											
MATRIX I: Document-Document Dependencies		1	2	3	4	5	6	7	8	12	9	10	13	11	14	15	24	25	16	17	18	19	23	20	21	22	26	27	28	29	30	31	32	33	34	**MATRIX III: Information Used by Entity (Input)**					**MATRIX V: Entity-CxA Information Dependency** 23	38	25
Owner's Project Requirement	1	1																																		1		1		1		1	
Commissioning Plan	2	1	2																																	2	1	1		1	1	1	
Systems Manual Outline	3	1	1	3																																3		1		1		1	
Training Requirements Outline	4	1	1		4																															4		1		1		1	
Pre-design Issues Log	5	1	1			5																														5		1		1		1	
Pre-design Issues Report	6					1	6																													6		1		1		1	
Pre-Design Phase Cx Report	7	1	1	1	1		1	7																												7	1			1	1		
Basis of Design	8	1						1	8	1																										8		1					
Design Review Comments	12	1	1						1	12																										12		1		1		1	
Systems Manual Outline - Expanded	9			1					1		9																									9		1	1	1		1	1
Training Req. in Specifications	10				1				1			10																								10		1		1		1	
Design Issues Log	13									1			13																							13		1		1		1	
Construction Specification for CX	11	1	1						1		1	1		11																						11		1	1	1		1	1
Design Issues Report	14												1		14																					14	1	1		1	1	1	
Design Phase Cx Report	15								1	1	1	1		1	1	15																				15	1			1	1		
Training Plans	24											1		1			24																			24	1		1	1	1		1
Systems Manual	25										1			1				25																		25	1			1	1		
Construction Submittals	16															1	1	1	16	1																16	1	1					
Submittal Review Comments	17																		1	17																17			1	1			1
System Coordination Plan	18																		1		18															18			1				
Inspection Checklist	19																		1			19														19			1	1			1
Cx Meeting Agendas & Minutes	23																		1				23													23	1	1	1				
Inspection Reports	20																		1			1		20												20			1				
Construction Test Procedures	21																		1					1	21											21			1	1			1
Construction Test Data Reports	22																								1	22										22			1	1			1
Construction Issues Log	26																			1			1	1		1	26									26		1	1	1		1	1
Construction Issues Report	27																										1	27								27	1	1	1	1	1	1	1
Construction Cx Report	28																1	1	1	1	1	1	1	1	1	1		1	28							28	1			1	1		
Maintenance Program	29																												1	29						29	1						
Occupancy Test Procedures	30																												1		30					30			1	1			1
Occupancy Test Data Reports	31																														1	31				31	1		1	1	1		1
Occupancy Issues Log	32																															1	32			32	1	1	1	1	1	1	1
Occupancy Issues Report	33																																1	33		33	1	1	1	1	1	1	1
Final Cx Report	34							1								1													1	1	1	1		1	34	34	1			1	1		
Information Weights		8	6	2	2	1	1	2	5	3	3	3	1	3	1	2	2	2	7	3	1	2	2	3	2	2	1	1	3	1	2	2	1	1	1								

Figure 7. 2 - Document and Entity Information Dependencies

The main matrix (MATRIX I) shows the dependencies of different documents on each other, based on their information content. For example, as the matrix shows, *Inspection Reports (20)* relies on the information provided in *Inspection Checklist (19)* and *Construction Submittals (16)*. This helped to map the flow of information between different documents, and to develop a *relative importance weighting* for each document. This relative importance weight was calculated by adding the number of other documents, which depend on the information provided in that original document. As a result, *Owner's Project Requirements (1)* received the highest relative importance of 8, since it provided the information for eight of the documents.

In addition to document dependencies, the entity-document relationships provided in Table 7.4 were also mapped in Matrices II & III. Matrix II shows the information provided by each entity (entity output) to each document, and Matrix III shows the information used by each entity (entity input) from a document.

After entity-document relationships were mapped, they were used to develop the *entity-entity* information dependencies. These dependencies are shown on the Matrices IV & V. Since the focus was to analyze the dependencies between CxA and other entities, only *CxA-Entity* and *Entity-CxA* relationships were mapped. Matrix IV shows the dependency of CxA on the information provided by other entities (CxA-Entity) and Matrix V shows the dependency of entities on information provided by CxA (Entity-CxA relationships). Finally, a dependency value for each relationship was calculated, which equaled the weighted sum of the number of entity dependencies. Table 7.5 summarizes the results of these calculations.

Table 7. 5 - Information dependencies among entities

	Entity-CxA Dependency	CxA-Entity Dependency	Total
Owner	23	17	**40**
AE	38	18	**56**
GC	25	9	**34**

After the entity information relationships were established, they were compared with values provided in Table 7.1, in order to measure the degree to which the distribution of communication in each CDS matches information needs. For each CDS, the direct communication values were divided by the value of total information dependencies, provided in Table 7.5, to calculate the value of *communication utilization* for each entity-entity relationship. Standard deviations of three entity-CxA utilization values were calculated for each CDS. PCi2 was defined as the reciprocal value of these standard deviations. As a result, the higher the PCi2 value, the lower the standard deviation between communication utilizations. This, in turn, would indicate that the distribution of the direct communications among entities matched the information dependencies among these entities. Table 6.6 summarizes the results of these calculations.

Table 7. 6 - Calculation of PCi2 for each CDS

	Information Dependencies (a)	Communication Distributions (b)		Communication Utilization (b / a)	
		O-led	AE-led	O-led	AE-led
Owner-CA	40	42	5	1.05	0.125
AE-CA	56	12	36	0.21	0.64
GC-CA	34	9	9	0.26	0.26
			SD	0.47	0.27
			PCi2	**2.13**	**3.73**

As shown in the table, AE-led Commissioning shows a slightly better communication distribution than Owner-led Commissioning. At the same time, both of these delivery systems have a very low PCi2 values. This can be seen as an indication that the current processes used for these delivery systems do not match the information needs of these processes and both CDS present a very poor communication performance. A second explanation is that the method used for developing PCi2 does not reveal much information about the real communication process in place. In other words, the documentation provided in the process might not be a good indicator of the actual information dependencies and communication needs among entities in the process. At the same time, considering the fact that experts could not come to an agreement about the performance assessment of Communication aspect, it seems that the first explanation has more validity. In other words, had any of CDS provided a significantly better communication for entities than the other alternative, it would be likely that experts would be able to come to an agreement in giving that alternative a better performance rating. Lack of agreement among experts may well point to the same result that was attained by the quantified analysis, which is an overall poor commissioning performance for both CDS.

7.2.3. Summary of Communication Measurement Results

The result of quantitative analysis on communication in each commissioning delivery alternative showed that the AE-led Commissioning provides a higher amount of direct communication among entities than the Owner-led Commissioning, However, both alternatives received very poor performance ratings in regard to the way the distribute the direct communication opportunities among entities as a function of their information needs. These results can further explain the underlying reasons lack of agreement among experts for rating the Communication aspect of commissioning delivery alternatives. For example, as shown in the sub-group responses provided in Figure 6.9 in Chapter 6, Owners and Commissioners both had ranked communication in AE-led Commissioning significantly lower than communication in Owner-led Commissioning. Results from the direct communication analysis, provided in Table 7.1 of this chapter also show that, in AE-led Commissioning, these two entities (Owner-CA) will have the minimum amount of direct communicaiton in the process (5), which is insufficient to the actual communication requirements of these two entities. The same explanation can describe the reasoning behind the Designer's low rating for Communication performance of the Owner-led Commissioning as it doesn't provide the required communication between AE and CA in regard to their information needs.

At the same time, it should be noted that the quantitative analysis performed in this section only focuses on those aspects of the communication performance, which can be measured based on the generic process models developed for each CDS. At the same time, the experts' comments in the surveys showed that they have used other measures (e.g. organizational issues, personal characteristics and skills, etc.) to rate the performance of the different commissioning delivery alternatives.

Overall it can be concluded that results of both qualitative performance assessment based on expert judgments and quantitative analyses based on process models, indicate to communication difficulties in the current commissioning practices. Therefore, a more rigorous investigation of communication process in order to improve the overall communication in commissioning process. Such investigation can be envisaged as basis for a follow up study in the future.

7.3. Integration

Integration was another aspect of the commissioning process that was found to be crucial to the success of this process, both according to the literature review and expert ratings in the first survey. However, the result of Surveys 2 & 3 showed no agreement among experts on rating the level of integration in each commissioning delivery alternative.

As a result, this section focuses on investigating the integration in each commissioning delivery system based on quantitative analysis of process models developed in Chapter 4. To accomplish this, a brief discussion of integration will first be provided, and its elements will be discussed. This discussion will be used as the basis to develop relevant performance indicators for quantifying integration in each delivery alternatives. Values of these performance indicators will be calculated for each CDS, and the results will be used to compare the alternatives. Finally, the outcome of these quantitative analyses will be compared to the results of the surveys, and differences will be discussed.

7.3.1. Process Integration

Process integration has been a major subject of study in process engineering and system analysis [Prasad 1999]. In these fields, an integrated process is defined as a process in which the flow of deliverables among different activities is well-defined and coordinated [Browning 2001]. In this process, sequencing among activities are defined in such a way that, at each stage, all the resources and information required for performing an activity will be present. At the same time, in modern process engineering practices, such as concurrent engineering, an attempt is made to perform design and manufacturing activities simultaneously, in order to reduce overall time and cost [Kusiak and Wang 1993]. This results in situations in which some activities rely on information that is provided by an activity later in the process. In such cases, the activity has to depend on an estimate for the required information, in order to produce its deliverables. This further results in iteration cycles, in which all of or part of the previous activities will be repeated until the deliverables meet the project requirements. Therefore, these iterative cycles can be a major source of coordination problems and inefficiencies within a process and will reduce process integration [Austin et al. 2000].

In addition to process iterations, integration of a process is also affected by the level of its complexity [Browning 2002]. Complex processes entail more interaction among the activities and, therefore, require higher levels of coordination. This, in turn, reduces the overall integration of the process. As a result, most of the efforts to improve process integration have been focused on reducing the process complexity and iterations.

7.3.2. Quantifying the Integration of Commissioning Delivery Systems

In this study, *Integration* was defined as the level by which commissioning activities are incorporated into the design and construction process. Experts were asked to evaluate the integration of each CDS based on three major elements of *Efficiency*, *Simplicity* and *Coordination*. These elements are very similar to the integration factors discussed in the previous section. All of these elements are affected by the amount of iterations in the process as well as complexity of the process.

As a result, a comparison of the level of integration of each commissioning delivery process, based on the amount of iterations in each process and their level of complexity was performed.

7.3.2.1. PIi1: Iterations

The objective of this performance measurement was to compare the amount of iterations in each commissioning delivery system. Iteration of each process was measured by using *Dependency Structure Matrix (DSM)*. Developed by Steward [1981], DSM is a widely used modeling technique for identifying and reducing the iterations in a process [Austin et al. 1997; Denker et al. 2001a; Denker et al. 2001b]. A DSM is simply a matrix with corresponding rows and columns. The diagonal cells in a DSM represent the activities within a process, in their chronological order. Off-diagonal cells show the dependencies among these activities. Based on this structure, any mark above the diagonal indicates that an early activity depends on a later activity. This can be either attributed to improper ordering of the activities in the matrix, or due to process iterations.

	Activity 1	Activity 2	Activity 3	Activity 4	Activity 5	Activity 6
Activity 1	1					
Activity 2	●	2	●			
Activity 3			3		●	
Activity 4		●	●	4		
Activity 5				●	5	
Activity 6					●	6

a.

	Activity 1	Activity 3	Activity 2	Activity 4	Activity 5	Activity 6
Activity 1	1					
Activity 3	●	3			●	
Activity 2		●	2			
Activity 4		●	●	4		
Activity 5				●	5	
Activity 6					●	6

b.

Figure 7. 3 - DSM for a Sample Process

Figure 7.3a shows a sample DSM process model. As shown in this model, based on original chronological order, Activities 2 and 3 both depend on later activities in the process. However, the dependency of Activity 2 on Activity 3 does not represent iteration; it is simply the result of the current chronological order. In other words, this process can be improved by re-arranging the chronological order of these two activities in the process (Figure 7.3b). But at the same time, the dependency of Activity 3 on Activity 5 represents iteration in the process. This is due to the fact that Activity 3 provides input to Activity 4, which, in turn, is the basis for Activity 5. Therefore, no rearrangement of these three activities in the matrix will remove the dependency from the upper diagonal order.

In practice, certain algorithms called *partitioning* algorithms are used to reorder the activities and eliminate the dependencies resulting from chronological errors. After a

DSM is partitioned, any remaining mark above the diagonal indicates an iterative cycle, which cannot be eliminated.

In order to measure the amount of iteration in each commissioning delivery system, the process models developed in Chapter 3 were used to develop DSM models for each alternative. For simplicity, each process was broken down to four phases (pre-design, design, construction, and occupancy). As a result, a total of eight DSM models (one for each of the four phases of each delivery system) were developed. These models were partitioned using an add-on macro in an Excel spreadsheet. The partitioned models are provided in Appendix I.

The number of iterations for each model was counted, and PIi1 was defined as the reciprocal of the total of iterations for each alternative. Therefore, higher values for PIi1 would indicate lower iterations in the process, and low values of PIi1 would indicate a high amount of iteration in the process. Table 7.7 summarizes the result of these calculations.

Table 7. 7 - Calculation of PIi1 for each CDS

Iterations	**Owner-led**	**A/E-led**
Pre-design	4	8
Design	3	5
Construction	3	4
Occupancy	2	3
Total (X)	12	20
PIi1 (1/X)	**0.08**	**0.05**

As shown in this table, Owner-led Commissioning received a higher PIi1 value. In other words, the Owner-led Commissioning process has lower iterations than AE-led

Commissioning. This is mostly due to the complicated approval process in AE-led Commissioning, in which most of the CA deliverables have to be approved both by owner and designer. This approval process results in more iterations in the process, which can negatively affect the overall process integration.

7.3.2.2. PIi2: Number of Activities

As mentioned before, process integration has a reverse relationship with process complexity. Therefore, measuring the complexity of each alternative can be another basis of comparing the integration of two processes.

Browning [2002] describes process complexity as a function of four factors: (1) the number of elements in a process; (2) the individual complexity of each element; (3) the number of relationships between the process elements; and (4) the individual complexity of each of those relationships. Process models developed for commissioning alternatives are compromised of very similar activities, which have the same level of the complexity. As a result, the number of activities was the focus in comparing the level of complexity in these processes.

As a result, the number of activities in each process model, developed in Chapter 3, was calculated. PIi2 was defined as the reciprocal of sum of activities in each process. These calculations and PIi2 values for each process are provided in Table 7.8.

Table 7. 8 - Calculation of PIi2 for each CDS

Number of Activities	**Owner-led**	**A/E-led**
Pre-design	22	28
Design	36	38
Construction	38	38
Occupancy	20	23
Total (x)	116	127
PIi2 (1/x)	**0.0086**	**0.0079**

As the table shows, Owner-led Commissioning again received a higher PIi2 value. In other words, AE-led Commissioning is compromised of more activities than the Owner-led Commissioning. This is based on the additional involvement of a project designer in pre-design and occupancy activities. A higher number of activities can result in more complexity, and reduce the integration in AE-led Commissioning. But, as the table shows, the overall difference between two processes is very small, and two processes do not seem to differ much in their level of complexity.

7.3.3. Summary of Integration Analysis

The result of the quantitative analysis performed in this section shows that Owner-led Commissioning is a more integrated process than AE-led Commissioning, as it has both a fewer number of iterations and fewer number of activities. At the same, based on these results the difference of Integration in two processes is very small. These results correspond to the collective performance assessments of experts for integration of CDS. Based on those results, even though experts did not come to an agreement about the performance ratings of different CDS, overall they gave both AE-led Commissioning and Owner-led Commissioning very similar performance ratings. The difference between quantitative analysis and expert judgments is the fact that in quantitative analysis, Owner-led Commissioning received a slightly higher value for integration, whereas in expert judgments AE-led Commissioning received a higher performance rating. This difference can be further explained by analyzing the comments provided by experts accompanying their performance ratings. Review of comments reveals that a number of experts referred to some soft aspects (such as the "knowledge" of AE and his "familiarity" with the design and construction process) as a positive aspect contributing to a higher level of integration in AE-led Commissioning. At the same time, these soft aspects were not captured in the quantitative analysis performed in this chapter as they only focused on structural differences that was introduced based on the process of each CDS.

Overall, it can be concluded that from a mere process point of view, the Owner-led Commissioning has better integration with the overall design and construction process than AE-led Commissioning. At the same, the difference between these two CDS is very small and in most cases negligible, considering the overall higher level of knowledge and familiarity of project designers with the overall design and construction process.

7.4. Summary

This chapter presented the result of quantitative analysis performed in further investigating the performance aspects of Communication and Integration for Commissioning Delivery Alternative. These investigations were performed based on generic processes models developed for each CDS in Chapter 4. For each performance aspect a review on the established theories about these concepts were provided. These theories were then used to develop appropriate performance indicators. The value of each of these performance indicators was calculated for each CDS and results were reported.

These results were further compared with the results of the expert's ratings for these performance aspects and differences were discussed. The next chapter will provide the overall summary this research, conclusions and recommendations for future research.

Chapter 8

Summary, Contributions, Conclusions, and Recommendations for Future Research

8.1. Purpose

This chapter provides a summary of the steps taken in this study, as well as research conclusions. A discussion of the methodology used in this investigation and its merits will also be provided. At the end, some areas of inquiry to follow-up on the findings of this research will be recommended.

8.2. Summary

As previously stated, the practice of Total Building Commissioning has gained a lot of attention in recent years. Owners and managers are requiring implementation of commissioning in construction projects to ensure the proper performance of facility as-a-whole, as well as the quality of individual building systems throughout the life cycle of the facility. With increased implementation of the commissioning process in construction projects, several delivery options for procuring commissioning services have emerged. Each of these options provides a unique set of contractual relationships, which, in turn, translates into different distributions of commissioning roles and responsibilities for the entities involved in the project. There is an ongoing debate in the construction industry about the selection of the most-appropriate Commissioning Delivery System for specific projects. However, no systematic study on the actual effect of each Commissioning Delivery System on the overall outcome of this process has been performed, and most of the decisions are based on the perceived advantages and disadvantages of each Commissioning Delivery System. Systematic evaluation of each Commissioning Delivery System requires a research methodology, which can assess the effect of procurement options on the outcome of a project. Therefore, the aim of the current study was to develop a research methodology that can be used to perform a comprehensive investigation of the effect of different construction procurement options on the project outcomes. This methodology was further applied to the specific problem of this research which is to evaluate the effect of each Commissioning Delivery System on the outcome of the commissioning process. This was accomplished through the following steps:

Background Study

In the first step of this study, provided in Chapter 2, a literature review on the practice of building commissioning was performed and its evolution as a quality-assurance process was studied. Different types of commissioning practices in the construction industry were identified, and Total Building Commissioning, the most comprehensive type of this practice, was chosen as the subject of this study. In addition, as the outcome of the commissioning process was to be defined in terms of performance aspects of this process, a literature review on the concept of performance measurement was performed. The result of this literature review revealed several performance frameworks that are applicable to measuring the outcome of construction projects.

Research Methodology

The literature review on the concept of building commissioning practice helped to develop a system-wide view of building commissioning practice. This system-wide view was provided in Chapter 3. In this view, both building commissioning practice and Commissioning Delivery Systems were identified as part of the larger system of project procurement. This system view was used to identify the common methodologies in construction management research that were applicable to the problem of this research. Two major methodologies were identified: (1) quantitative analysis, based on empirical data on performance aspects of a sample of existing projects; and, (2) qualitative analysis, based on interpretive investigation of procurement options from expert judgments. Advantages and disadvantages of each method were discussed, and their applicability to the specific problem of this research was examined. As a result, a methodology was designed for this investigation in which a qualitative analysis of the interpretive approach was coupled with quantitative analysis of contractual relationships in each commissioning method. This was done in order to perform a comprehensive analysis of the effect of each CDS on the outcome of the commissioning process. This methodology was compromised of five phases:

Phase I of the methodology, presented in Chapter 4, focused on analyzing the structural differences of each CDS. To do this, a framework for categorizing different Commissioning Delivery Systems for Total Building Commissioning was first developed. Based on this framework, four major commissioning delivery alternatives were identified: Owner-led Commissioning (which can be used under all three major Project Delivery Systems (PDS) of Design-Bid-Build, Design-Build, and CM @ Risk); AE-led Commissioning (which is only applicable to the Design-Bid-Build PDS); Design/Builder-led Commissioning (which is only applicable to Design-Build PDS); and, finally, CM-led Commissioning (which is only applicable to CM @ Risk PDS). Based on the scope of the study, the research only focused on performance assessments of CDS options under Design-Bid-Build and Design-Build Project Delivery Systems. Next, a generic process model for each Commissioning Delivery System was developed. The basis for developing these models was the flowchart of commissioning activities provided by ASHRAE's Guideline 0, in addition to different roles and responsibilities of entities based on each CDS. Since Guideline 0 defines the building commissioning process, and the roles and responsibilities of different entities, based on a Design-Bid-Build Project Delivery System, only two applicable CDS were modeled. These models were validated by commissioning experts and were used to analyze the structural differences between CDS options. As a result, three main differences between Owner-led Commissioning and AE-led Commissioning were discovered: (1) The level of involvement of AE in the commissioning process is significantly higher in AE-led Commissioning than in Owner-led Commissioning; (2) In AE-led Commissioning, the project Designer is the main interface between Owner and Commissioner (CA), and, therefore, becomes the repository of project information, whereas in Owner-led Commissioning, the Owner acts as the interface between AE and CA and is the repository of information; and (3) AE-led Commissioning presents a more-elaborate approval process for commissioning deliverables, in which most of deliverables need the approval of both AE and Owner. In Owner-led Commissioning, on the other hand, the Owner is the sole entity responsible for approving the commissioning deliverables.

Phase II of this investigation, presented in Chapter 5, focused on identifying the Internal Performance Aspects (PAi) for the commissioning process. The goal was to provide a framework for assessing the performance of each CDS that can be used by a group of commissioning experts to analyze the performance of each delivery alternative. This was achieved through performing a thorough investigation of the existing literature on building commissioning. As a result of this investigation, a comprehensive list of all cited factors for success of a commissioning process was generated. These success factors were further grouped into larger categories to develop the PAi. As a result, five major PAi were identified: *PAi1: Communication; PAi2: Validation; PAi3: Collaboration; PAi4: Integration;* and *PAi5: Integrity*. Each aspect was defined, and its significance was discussed based on the existing literature. In addition, for each PAi, evaluation criteria were proposed, which highlighted the important factors in that PAi. The purpose of these evaluation criteria was to provide a common ground for experts' evaluations of each performance aspect. Finally, to ensure the validity of these PAi, they were presented to experts. This validation process was performed as part of the Delphi study conducted in Phase III.

In Phase III of the study, presented in Chapter 6, the identified PAi were used as a basis for performance assessment of each CDS. This performance assessment was based on the judgment of a group of experts who had extensive knowledge and experience with the overall commissioning process, as well as different Commissioning Delivery Systems. Several knowledge-gathering techniques were studied and the Delphi method was identified as the most-appropriate technique for this study. A group of 16 experts, representing the different disciplines in the construction industry, were identified. Experts participated in a Delphi study, which comprised of three surveys. The first survey asked participants to validate the importance of PAi. As a result, all performance aspects were identified as being "very important." In the second survey, experts were asked to use the identified performance aspects and rate the relative performance of each Commissioning Delivery System, based on their knowledge and experience with the commissioning process. They were also encouraged to provide the underlying reasons behind their performance ratings. In the third survey, the comments and overall ratings were sent back to experts, and they were asked to reconsider their initial performance ratings in light of the group's response. The results of the third survey were collected and summarized. As a result, Owner-led Commissioning received a higher performance rating than AE-led Commissioning and DB-led Commissioning in almost every performance aspect. The only exception was the *Integration* aspect of AE-led Commissioning, which received a slightly higher performance rating (9.71) than in Owner-led Commissioning (9.43). In order to validate the expert ratings, a statistical test was used to measure the consensus among experts. The result of the statistical analysis showed that experts were not able to reach consensus on two performance aspects of: *Communication* and *Integration*. Therefore, the results of experts' ratings for these performance aspects were not considered for comparing different CDS.

In Phase IV of this study, presented in Chapter 7, *Communication* and *Integration* aspects of CDS were further analyzed, in order to investigate the performance of each CDS in these two aspects. This investigation was based on quantitative analysis of process models developed in Phase I. The fundamental theories behind each of these performance ratings were reviewed. This helped to develop applicable indicators for measuring these performance aspects based on generic process models. The value of these performance indicators for each CDS was calculated and findings were analyzed. The result of these analyses revealed a higher amount of direct communication between different entities in AE-led Commissioning than in Owner-led Commissioning. At the same time, it was found that both CDS provided a very poor distribution of direct communication lines among entities, in respect to their information dependencies. As for *Integration*, Owner-led Commissioning presented a better opportunity for integration than AE-led Commissioning. At the same time, the difference was marginal. The results of these analyses were compared to the results of the surveys and differences were discussed. Overall, it was found that experts had used more-comprehensive measures for rating each of these performance aspects, which included both soft and hard measures, whereas quantitative analysis could only capture the hard elements of each of these aspects.

8.3. Research Contributions

The choice of appropriate procurement options for construction projects has always been one of the most important questions in the construction research. At the same time, methodologies for performing such investigations are underdeveloped. Most of the existing methodologies in construction research focus on either quantitative or qualitative aspects of procurement and therefore, do not provide a comprehensive analysis of procurement options. In the face of this problem this research designed a hybrid methodology. In this methodology, qualitative analysis, based on gathering experts' knowledge about procurement options, were combined with quantitative analysis of formal contractual relationships among different entities in the project, in order to provide a comprehensive analysis of procurement options. This methodology was further tested through its application to the specific problem of this research, which was to compare the effect of different Commissioning Delivery Systems on the project outcome.

This methodology was comprised of several steps:

- The process of each Commissioning Delivery System was modeled to investigate their structural differences.
- A set of performance aspects for the commissioning process were developed through an in-depth review of the literature.
- Each performance aspect was defined in detail and important elements of each aspect were identified to eliminate perception differences among experts.
- A set experts were carefully identified through a purposive sampling process and thorough evaluation of their level of expertise and experience.
- Experts were asked to assess the performance of each CDS based on identified performance aspects.
- A systematic knowledge-gathering technique (Delphi) was used to take advantage of interaction among experts, but, at the same time, eliminating the negative aspects of face-to-face meetings that could threaten the integrity of individual judgments.
- Questionnaires used a case-study approach to provide a uniform context for experts' assessments and eliminate the systematic errors in their judgments.
- Experts were asked to compare the Commissioning Delivery Systems based on internal aspects of this process, which more directly correspond to their experience, rather than overall project measures such as time and cost.
- In rating each performance aspect, the extreme conditions were explained through examples, to ensure experts would use similar rating scales.

- In addition to overall group response, sub-group response was analyzed to investigate the group biases.

- A statistical test was used to validate the expert ratings through measuring the degree of consensus among experts.

- In cases where experts did not show an agreement, performance aspects were further investigated through quantitative analysis of generic process models.

The analysis of responses of different sub-groups, revealed some biases among different expert sub-groups in their performance ratings. In the face of these biases and judgment errors, the last two steps of the project proved tremendous value in analyzing the results. Kendall's coefficient helped to identify the amount of biases and judgment errors by measuring the degree of consensus among experts. This helped to identify the problematic areas, which required further investigations. A quantitative analysis of these problematic areas was performed based on process models, and provided a basis for better analyzing the experts' responses and providing a more-comprehensive analysis of the issues.

As a result the proposed methodology proved to be a valuable approach in providing a comprehensive analysis of the effect of different project procurement options on the outcome of a construction project. Therefore, it can be recommended for other studies that deal with complex problems regarding project procurement options, similar to the problem addressed in this research.

8.4 Conclusions

The developed methodology was further applied to the specific problem of this research to investigate the effect of each commissioning delivery system on the outcome of the commissioning process.

The results of the Delphi study performed in Chapter 5, as well as the quantitative analysis in Chapter 6, provide sufficient evidence for proof of the research hypothesis: there is strong evidence that the type of Commissioning Delivery System used in a project does affect the overall performance of this process.

The results of the first round of Delphi showed that experts regarded all five of the internal performance aspects as “highly important.” In addition, the results of the second and third rounds of the Delphi study revealed that experts showed moderate-to-average agreement that Owner-led Commissioning has a relatively better performance than AE-led Commissioning in the Design-Bid-Build delivery system, DB-led Commissioning in the Design-Build delivery system, in three aspects of *Collaboration*, *Validation* and *Integrity*. At the same time, experts did not show any agreement on the performance ratings of *Communication* and *Integration*.

Quantitative analysis of *Communication*, in two commissioning alternatives, revealed that AE-led Commissioning provides a higher amount of direct communication between entities than Owner-led Commissioning. At the same time, measuring the distribution of *Communication* among entities, showed a poor communication performance in both alternatives. This finding indicated the need for a more-comprehensive investigation of *Communication* in the commissioning process, which can be considered as a part of a future investigation to follow this study. The quantitative analysis of *Integration* aspect of each Commissioning Delivery System provided evidence of higher *Integration* in Owner-led Commissioning than in AE-led Commissioning. However, the difference was marginal. This finding corresponds to the experts' assessment of the *Integration* aspect of these two delivery systems, in which both CDS received very close performance ratings.

It can be concluded that Owner-led Commissioning is a more-appropriate Commissioning Delivery System for procuring commissioning services than AE-led Commissioning in a Design-Bid-Build Project Delivery System. This is based on the findings of the study, in which Owner-led Commissioning presented a performance advantage in four performance aspects of: *Validation*, *Collaboration*, *Integration* and *Integrity*. Designer-led Commissioning presented a higher *Communication* performance than Owner-led Commissioning. At the same time, *Communication* performance of both delivery options was very poor, which further indicates to the communication difficulties in current commissioning practices. Therefore, this study suggests a more-thorough investigation of the *Communication* aspect of commissioning process, as a follow-up investigation.

It also can be concluded that Owner-led Commissioning is a more-appropriate Commissioning Delivery System than DB-led Commissioning in a Design-Build Project Delivery System. This is due to the fact the Owner-led Commissioning presented a higher performance advantage in three aspects of: *Validation*, *Collaboration*, and *Integrity*. Overall survey results also showed higher performance ratings for *Communication* and *Integration* for Owner-led Commissioning than DB-led Commissioning. However, due to the high complexity of entity relationships in a Design-Build project, these results could not be further validated through quantitative analysis.

It should be noted that the conclusions derived from this study must be viewed within the context of the study's scope. This study focused on commissioning of institutional buildings, which account for the majority of current commissioning implementations. At the same time, findings of this research can provide some insight for commissioning other building types. However, their applicability to projects with a very different level of complexity requires further investigation.

8.5. Recommendations for Future Research

This research proposed a novel methodology in analyzing the effect of different procurement options on the outcome of a construction project. This methodology was used to perform a systematic analysis of the building commissioning practice. Preliminary findings of this study bring several issues into attention, which require follow-up investigation and can be good opportunities to further expand this work.

One of the major follow-ups on this study is to investigate the applicability of the developed methodology in investigation of other procurement options in the construction industry. Such investigations can assist to provide a comprehensive analysis of the effect of different procurement alternative on the outcome of a construction project and identify the appropriate options. Such studies will also help to further develop and improve the proposed methodology in this research.

The other major follow-up on this study is investigating the issue of *Communication* in the commissioning process. The literature review, performed in Chapter 5, pointed to communication as one of the major aspects of the commissioning practice. Results of the first Delphi survey also showed that experts regarded *Communication* as a very important aspect of the commissioning process. However, an analysis conducted in this study showed an overall poor communication performance for both Commissioning Delivery Systems. In this regard, an important follow-up investigation would be to focus on the issue of communication in a commissioning process. This would include developing communication models for the commissioning process, and using these models in order to perform an in-depth study of communication needs of different entities involved in the process. The result of such investigation can be used to further modify/improve the current commissioning practices.

Another follow-up opportunity would be the expansion of the process models developed in this research through real-life implementations. This would help to further fine-tune these models and provide a standard and best practice. The expanded models can also be used in conjunction with information models, proposed in previous research, to provide a basis for tools which could assist in a more-efficient management of the commissioning process.

Another research opportunity would be to use the performance framework, developed in this research, as a basis for gathering data on performance of commissioning projects. This data can be used to evaluate other aspects of managing the commissioning process, and develop a source of best practices. It can also be used to further validate the findings of this study based on real life examples.

Finally, as stated earlier, the amount of systematic research on the subject of building commissioning is still very limited. In that regard, this study hopes to provide a basis for further investigations on advantages of implementation of this process, as well as identifying the opportunities for improvement.

Amirali Shakoorian, Spring of 2006

APPENDIX A

OVERVIEW OF DELPHI TECHNIQUE

This section provides a detailed discussion of these methodologies. The discussion will begin with an overview on the validity of group judgment over individual judgments, and the underlying theories behind this concept. Common group techniques will then be reviewed, including the Delphi method, which is discussed in further detail, as it is the methodology used in this research. Finally, this section will end with a summary of the issues involved with implementing the Delphi methodology.

The source articles and publications used for this discussion were identified through a review of existing literature. The first step of the literature survey included a search of several databases, including *EBSCOHost* and *ProQuest*. Preliminary results identified the peer-reviewed journal, *Technological Forecasting and Social Change* as the major source of Delphi publications. Most of the related articles were then identified through this journal. In addition, citations from these articles were used to find additional articles related to this subject.

Group vs. Individual Judgments

Before beginning a discussion of the concept of group judgment, it is important to make a clear distinction between the term *Judgment*, and two other states of awareness, *Knowledge* and *Guess*. Sniezek and Henry [1989] define these three concepts based on differing levels of certainty. In this view, a Judgment task can be defined as the association of “some level of uncertainty” with the “accuracy of response,” as opposed to a Knowledge task, which is a result of “prefect certainty” about the “accuracy of response,” or a Guess, which is basically a response with “no certainty.”

Use of groups to make decisions and judgments has been an essential part of the modern era. Juries, councils, committees, task forces, and boards are all based on the widespread belief that N+1 heads are better than one [Hill 1982]. The underlying assumption is that the combination of individuals in a group setting brings different perspectives together, and provides a larger knowledge source for decision-making and, therefore, can produce more-accurate judgments and better solutions. This assumption is so strong that it has been at the foundation of all decision-making systems of modern society.

However, it wasn’t until the second half of the twentieth century that this assumption was tested based on scientific methodologies. Since the late 1940s and 1950s, numerous studies have focused on comparing the true performance of groups and individuals, in regard to decision-making tasks. The results have not been surprising. A number of studies provide evidence that committees or groups have an advantage over individual judgments in a variety of domains [Hill 1982; Nisbett and Ross 1980; Rowe et al. 1991]. Studies also showed that even a simple aggregation of individual judgments is more accurate than the judgment of a random individual [Woudenberg 1991].

The superior ability of groups over individuals in accurate decision-making can be explained based on the “theory of errors” [Dalkey 1975]. According to this theory, the median response of a group will always be at least as close to the true answer as one-half of the individuals in the group (Figure A.1a). In addition, if the group response range includes the true answer, the median group response will be more accurate than more than half of the group (Figure A.1b). As shown in the Figures, in both cases, there is always a group member whose response will be nearest to the true answer than the group mean. Empirical findings have confirmed this matter, showing the group performance to be inferior to the performance of the best individual [Davis 1969; Hill 1982]. However, it should be noted that groups are virtually always used in situations where no prior knowledge of the true answer exists. In such cases, identification of the best individual whose response is the closest to the true answer is impossible. And therefore, the group response becomes more accurate.

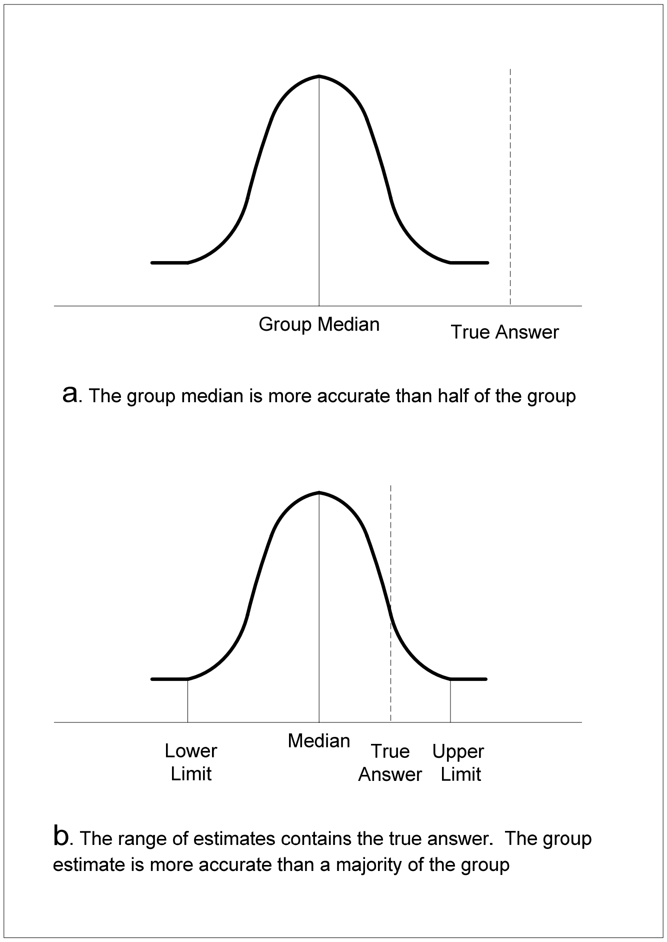

Figure A. 1 – 'Theory of Errors' in Explaining Superiority of Groups Response over Individuals (Dalkey 1975)

Group Techniques

Staticized Groups

The simplest form of obtaining a group judgment is through use of *Staticized Groups* [Rowe et al. 1991]. This method is basically a polling technique, in which the opinions of a group of individuals are gathered separately, and then summarized, based on common statistical methods, to form the group decision. Members of a staticized group are usually selected randomly to form a statistical sample of the target population.

Due to their simplicity and convenience of use, staticized groups have been very popular, and they have been employed in a number of domains. Opinion surveys, or any other kind of survey, in general, are good examples of staticized groups. Though studies have shown that staticized groups can produce better results over individuals, use of this group technique has been largely criticized. The main reason for this criticism is that, based on their nature, staticized groups don't provide an opportunity for interaction among individuals. At the same time, a great body of research shows that interaction among a set of individuals has some usefulness, and can produce better results in the construction of subjective judgments [Armstrong 1978].

Interacting Groups

Interacting Groups are the most-common group technique. In this method, individuals are brought together to form a refined opinion after deliberate discussions [Rowe et al. 1991]. Studies have shown that judgments from interacting groups are more accurate than a statistically aggregated judgment [Woudenberg 1991]. This can be explained based on the increased knowledge sources available to each group member, which equals at least the sum of information available to any particular individual within that set [Rowe et al. 1991]. In addition, it has been argued that being part of a group can have other advantages that will result in better performance, such as increased commitment of individuals, assistance in resolving ambiguous and conflicting knowledge, and facilitation of creativity [Lock 1987].

However, interacting groups are not without pitfalls. Lock [1987] summarizes the downsides of the group process into three categories:

1. Groupthink: This is the result of group members' access to the same knowledge base; groupthink emerges as a restriction on the range of ideas generated by a group. Groupthink can also be a result of individual's desires to conform to group norms.
2. Inhibition of contributions: This is caused by differences in the status of individuals. Most individuals are not willing to put forward ideas that are contrary to the ideas that have already been expressed in the group. It also may be caused by the presence of one dominant individual in the group.
3. Premature Closure: This results from the tendency to adopt the first alternative, which is satisfactory to all group members, rather than reaching the best alternative.

These and other additional factors, such as an individual group member's desire to "win" or avoid changing a position once they've taken it in front of the group, causes interacting groups to not perform up to their optimal level and potential [Rowe et al. 1991].

As a result, several other alternatives to interacting groups have been proposed. These alternatives attempt to reduce or totally eliminate the shortcomings of interacting groups, by changing the unstructured interaction among group members to a more structured process of feedback. In the following section, two main structured techniques (Nominal Group Techniques (NGT) and Delphi) are discussed.

Nominal Group Technique (NGT)

The *Nominal Group Technique* (NGT) is the most widely known structured group technique that provides direct interaction among individuals [Woudenberg 1991]. NGT was developed by Andre L Delbecq and Andrew H. Van de Ven in 1968, as a result of their social-psychological studies in a number of different fields, including industrial engineering, and studies of NASA program design problems and of citizen participation in program-planning [Delbecq et al. 1975; Van_De_Ven and Delbecq 1974].

A NGT study starts with individuals seated around a table writing down ideas related to a problem on a pad paper. Each individual then presents one of the ideas to the group. Ideas are recorded and discussion does not start until all of the ideas are presented. After all ideas are presented, the group begins to discuss them one-by-one. After the discussion, each individual writes down his/her own evaluation of the ideas separately. The final stage is to aggregate all the individual evaluations to come up with a group decision.

NGT attempts to eliminate some of the negative aspects of interacting groups by separating out the processes of independent idea generation, structured feedback, and evaluation and aggregation of opinions [Lock 1987].

Delphi Technique

Delphi Technique is a structured process which utilizes a series of questionnaires or rounds to gather and to provide information [Keeney et al. 2001]. A Delphi can be seen as a virtual group meeting, which aims to make use of the positive aspects of interacting groups, while removing the negative aspects largely attributed to the social difficulties within such groups [Okoli and Pawlowski 2004; Rowe et al. 1991].

History

Delphi Technique was developed by Dalkey and Kaplan and their associates at the RAND Corporation [Van_De_Ven and Delbecq 1974]. Kaplan headed a research effort directed at improving the use of expert predictions in policy-making [Dalkey 1968]. He found that unstructured, direct interaction did not provide more accurate predictions than aggregation of individual predictions [Kaplan et al. 1949; Woudenberg 1991]. They associated this low performance with the negative aspects of face-to-face meetings and developed Delphi as a way to reduce these negative aspects. Kaplan coined the name "Delphi" after the site of the ancient Greek oracle at Delphi where necromancers foretold the future [Dalkey 1968; Gordon 1994].

Methodology

Dalkey and Helmer [1963] describe Delphi as a procedure to *"obtain the most reliable consensus of opinion of a group of experts… by a series of intensive questionnaires interspersed with controlled opinion feedback."* In a Delphi study, the participants are asked individually, through a questionnaire, to provide their estimates for a variable in question. Then, the feedbacks are collected and summarized in a way to conceal the origin of original estimates. The results are then circulated, and participants are asked if they wish to refine their previous answers based on the summary results. This iteration process continues until estimates stabilize [Lock 1987]. A Delphi study has three major characteristics: anonymity; iteration with controlled feedback; and statistical aggregation [Dickey and Watts 1978]:

1. Anonymity: In a Delphi study, the identity of respondents stays concealed throughout all the rounds. This anonymity and isolation helps to largely eliminate most of the social pressures to conform that arise in interacting groups, such as domination of a single individual, or avoiding change of a position once one is made [Van_De_Ven and Delbecq 1974].
2. Iteration with Controlled Feedback: This takes place between different rounds, and allows members to review and change their response in light of additional information and opinions provided by other group members [Rowe and Wright 1999].
3. Statistical Aggregation: In the final stage of a Delphi study, the group response is obtained through statistical aggregation of the final individual responses. Statistical techniques may also be used to provide the level of consensus strength [Rowe and Wright 1999].

<u>Theory</u>

Like other group techniques, the underlying mechanics of Delphi can be explained based on the "theory of errors," which was described earlier in this chapter. In addition, Dalkey [1975] hypothesized that a Delphi will have a superior performance to unstructured group techniques as a result of the iteration process. According to Dalkey, the iteration and feedback built into the Delphi process, provides an opportunity for the less-knowledgeable panelists (whom he called "swingers") to move towards more-accurate panelists (known as "hold outs") and, therefore, results in a more-accurate response for the whole group (figure A.2). This is based on the assumption that experts on a subject are less likely to change their response during the iteration and feedback process than people who have less knowledge on the subject. Some empirical evidence has supported this assumption. For example, Rowe and Wright [1996] found that the most-accurate Delphi panelists in the first rounds changed their estimates less frequently over rounds than those who were initially less accurate.

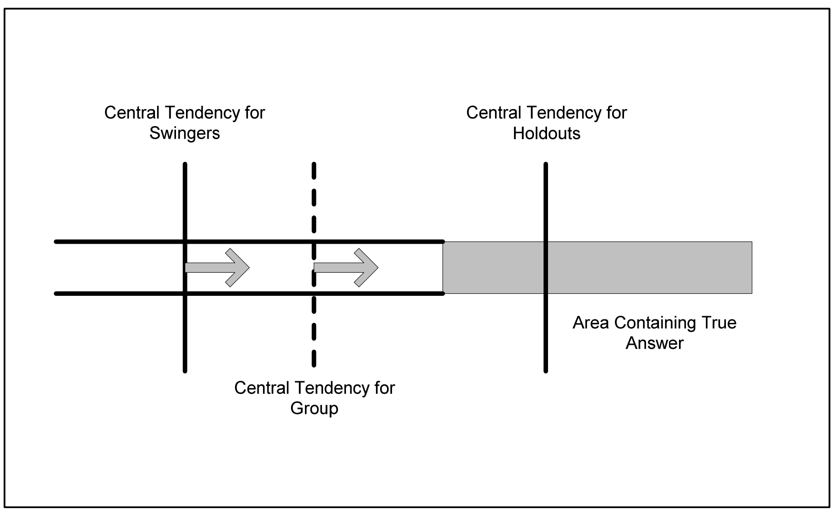

Figure A. 2 - Shift of Average Group Response during Iteration and Feedback Process (Dalkey 1975)

Delphi and Inquiry Systems

Inquiry systems (IS) are philosophical systems, which underlie different methods used for analyzing a phenomenon [Lock 1987]. According to Mitroff and Turoff [1975], an inquiry process is compromised of four major steps. First, an individual is faced with some assumed "external event" or "raw data set" which is considered to be a characteristic property of the "real world." Second, this individual transforms or filters this "raw data" into the "right form," so it can be inputted into a model. Next, the model transforms the "input data" to "output information." Finally, this "output information" can be passed to another filter, so it can be used by the "decision-maker." Mitroff and Turoff describe five main inquiry systems, which can be used as the philosophical basis for the Delphi technique:

- Lockean IS: This states that truth is *experimental*. Based on this inquiry system, the truth of a model is measured in terms of its ability to: 1) Reduce every complex proposition down to its simplest referents; and, 2) Ensure the validity of simple referents, by means of widespread, freely obtained agreements between different observers.
- Leibnizian IS: Truth is *analytic*. Based on this IS, the truth of a model is measured in terms of: 1) Its ability to offer a theoretical explanation of a wide range of general phenomena; and, 2) Our ability to state clearly the formal conditions under which the model holds.
- Kantian IS: This has a *synthetic* view of the truth. In other words, in a Kantian IS, truth has both empirical and theoretical natures. Truth of a model is measured in terms of the model's ability to: 1) Associate every theoretical

term of the model with some empirical referent; and, 2) Show how underlying every empirical observation is a theoretical referent.

- Hegelian IS: Truth is *conflictual*. In other words, truth of is a result of a complicated process, which depends on the existence of a plan and a counter plan.
- Singerian IS: Truth is *pragmatic*. Truth of a system is relative to the overall goals and objectives of the inquiry, and is measured with respect to its ability to: 1) Define certain objectives; 2) Propose several alternative means for securing these objectives; and, 3) Specify new goals to be accomplished by some future inquiry.

Delphi is a classic example of Lockean IS, since its main purpose is to get consensus from expert judgments [Mitroff and Turoff 1975; Parente and Anderson-Parente 1987]. However, Mitroff and Turoff argue that some applications of Delphi are based on a different inquiry basis. For example, policy Delphis, which function as a result of causing experts to debate on mostly unstructured issues, can be best described from a Hegelian viewpoint. Or in problems, in which the purpose is to elicit different alternatives, a Kantian Delphi can be more appropriate than pure Lockean or Leibnizian approaches [Mitroff and Turoff 1975].

As a result, we can conclude that, for a researcher who is intending to perform a study, knowledge of the inquiry base used in the method is very important, because it defines the merits and boundaries of the studies, and can help identify the limitations of the technique.

Applications

The first application of Delphi was used in 1948 to improve the betting scores at horse races [Woudenberg 1991]. However, the first major application of this method did not occur until the 1950s, when it was used on a U.S. Air Force-sponsored project. The goal of the project was to gather expert opinions on the selection of an optimal U.S. industrial target system, from the point-of-view of a Soviet strategic planner [Rowe and Wright 1999]. Application of Delphi during the 1950s was, however, limited to the army-sponsored projects in the Rand Corporation. Use of the Delphi technique became popularized in the 1960s, after it was first described in a published article in 1963 [Gupta and Clarke 1996].

Since its development, one of the major applications of the Delphi has been in technological forecasting. Today, it is estimated that 90% of all technological forecasts studies are based on Delphi [Yuxiang et al. 1990]. In addition to forecasting, Delphi has been used extensively for other applications, such as policy formation and decision-making [Rowe and Wright 1999]. Currently, Delphi is applied to a number of different problems, such as project evaluation, short- and long-range forecasting, science and technology planning, policy formulation, energy generation, urban analysis, bank automation, risk management, market research, curriculum development, and others. [Gupta and Clarke 1996]. Delphi studies are used in various areas, such as education, business, health care, information systems, engineering and transportation [Rowe and Wright 1999]. Interest in Delphi has grown from non-profit organizations and government, as well as industry and academia [Linstone and Turoff 1975].

In the construction industry, Delphi has been applied to a number of professional and academic problems including: development of residential areas [Anatharajan and Anataraman 1982]; bridge condition rating and effects of improvements [Saito and Sinha 1991]; construction process quality [Arditi and Gunaydin 1999]; procurement selection [Chan et al. 2001]; project risk management [Cano and Cruz 2002]; identifying factors affecting international construction [Gunhan and Arditi 2005]; and determining the standard of care for structural engineers [Kardon et al. 2005].

Delphi Critique

Despite its extensive use in both industry and academia, application of Delphi technique has not been without criticism. The first major criticism of the Delphi technique was proposed by Sackman [1974]. Referring to a number of studies that were conducted based on the Delphi method, Sackman strongly criticized the use of Delphi to obtain any scientific results. In response, several authors questioned Sackman's findings. Linstone [1978] argued that most of Sackman's criticism is pointed toward poor executions of Delphi, rather than the method itself, and he had ignored significant supportive evidence. Coates [1975] argued that the criteria in evaluating a Delphi is not so much that it is *right*, but that it is *useful*: "*If one believes that the Delphi technique is of value not in the search for public knowledge, but in the search for public wisdom, not in the search for individual data, but in the search for deliberative judgment, one can only conclude that Sackman missed the point.*" Furthermore, Mitroff and Turoff [1975] noted that much of the accusation that the Delphi technique is nonscientific, arises from the misconception in equating what is "scientific" to what is "Leibnizian."

In recent years, as a result of growing application of Delphi, especially in the scientific field, a number of studies have been performed on the validity of this technique. Following is a summary of the Delphi method's major shortcomings, as cited in these studies:

- Accuracy: Accuracy of a Delphi study can be expressed in terms of the correspondence between the obtained group judgment and the true value [Woudenberg 1991]. Since most of Delphi studies are on unknown issues, such as forecasting an event in the far future, accuracy of Delphi studies is hard to measure. Strauss and Ziegler [1975] argue that the claim that Delphi represents valid expert opinion is scientifically untenable and overstated. In response, Goodman [1987] argues that, if the panel members in the study are representative of a group or area of knowledge, then content validity can be assumed. In addition, there have been studies that show the result of Delphi have been accurate in terms of forecasting [Ono and Wedemeyer 1994]. A study by Rowe et al [2004] shows that the accuracy of judgmental probability forecasts increases over Delphi rounds.
- Reliability: Reliability is defined as the certainty with which an instrument produces the same results over time [Woudenberg 1991]. The Delphi technique has been heavily criticized as having no evidence of reliability; meaning, there is no guarantee that the same results will be obtained if the same Delphi study is repeated with another panel [Keeney et al. 2001].
- Anonymity: Another criticism of Delphi has been the issue of anonymity. It has been argued that complete anonymity may lead to lack of accountability,

and will encourage ill-considered judgments [Goodman 1987]. It has also been argued that anonymity of Delphi will hinder the positive effects of unstructured group interactions, such as flexibility and richness of non-verbal communication [Woudenberg 1991]. In addition, Dijk [1990] claims that this anonymity prevents a meaningful discussion.

- Consensus: Consensus resulting from a Delphi study has also been a subject of criticism. Keeney notes that the existence of consensus from a Delphi process does not mean that the correct answer has been found [Keeney et al. 2001]. Also, the Delphi technique has been criticized as a method which forces consensus [Goodman 1987]. Some study findings suggest that the consensus gained over several rounds may be a result of panelists simply altering their estimates, in order to conform to the group without actually changing their opinion [Rowe and Wright 1999; Woudenberg 1991]. Empirical evidence supports this argument by showing that a majority opinion exerts a strong pull on minority opinion, even when the majority favors an incorrect answer [Rowe et al. 2004]. It is also argued that social pressures, such as the impact of a dominant individual, are still felt even though they are not as immediate and threatening as in an unstructured group [Rowe et al. 1991].

In considering the varying criticism of the Delphi method, it should be emphasized that it is a technique of "last resort," to be used when no adequate models exist upon which some statistical predictions or judgment might be based [Coates 1975]. Although criticism of the Delphi method have been countered by studies in the favor of the technique, consideration of its criticism is useful in recognizing this method's shortcomings as a valid research methodology and in recognizing opportunities for improvement. Therefore, the "Delphi Method" has largely escaped examination [Rowe et al. 1991]. Delphi is not a procedure intended to challenge statistical or model-based procedures, against which human judgment is generally shown to be inferior; rather, it is intended to be used in judgment and forecasting situations in which pure, model-based statistical methods are not practical or possible. This is due to a lack of appropriate data, and, thus, some form of human judgment input is necessary [Rowe and Wright 1999]. The Delphi method is especially effective in difficult areas that can benefit from subjective judgments on a collective basis, but for which there may be no definitive answer [Lindeman 1975]. As Rowe et al. [1991] conclude, Delphi is a valuable technique in judgment-aiding, but improvements are needed.

Delphi vs. Nominal Group Techniques

Delphi and NGT are both well-known structural techniques, and each has their own characteristics. The prime difference between them goes back to the level of anonymity, specifically at the feedback stage. NGT provides an opportunity for direct communication among participants at the feedback stage. Although this direct communication has been cited as an advantage of NGT over Delphi, it also gives NGT the normal drawbacks cited for interactive groups [Lock 1987].

A number of studies have made an attempt to compare the results of Delphi and NGT group techniques. Most of these studies have compared these two methods on three main dimensions: accuracy of the technique; quantity of the ideas generated; and participant satisfaction.

The results of studies that have compared the accuracy of Delphi and NGT have not been consistent. Gustafson et al. [1973] and Miner [1979] found NGT to be more accurate than Delphi. On the other hand, Fischer [1981] Boje and Murnigham [1982] found the two techniques to be equally accurate. In addition, another study [Erffmeyer and Lane 1984], found Delphi results to have a higher quality (in terms of comparison of rankings to “correct rank”).

As for the quantity of ideas, Van De Ven and Delbecq [1974], found NGT to produce more ideas than Delphi. At the same time, a study by Hill [1982] showed that NGT and the Delphi procedure did not differ in quantity of unique ideas.

In terms of satisfaction of the participants, studies by Van de Ven and Delbecq [1974] and Hill [1982] showed a higher satisfaction among participants of NGT than Delphi. First study explained the lower satisfaction with Delphi process as a result of the lack of social-emotional rewards in the problem-solving process and unresolved conflicting or incomplete ideas. But at the same time, a more recent study [Hornsby et al. 1994] showed participants in a Delphi study to have higher satisfaction with the process than NGT.

As discussed, the results of comparisons between these two techniques have been very different. This disparity can be explained based on the fact that each study has used a different evaluation method, and each study has used a different variation of Delphi, which may account for these discrepancies.

Based on these contrasting findings, it is difficult to draw a conclusion as to which method is superior. Selection of a method can then be based purely on the specific research requirements (i.e. geographical, time, cost, etc.) and the qualitative differences of these two methods. Table A.1 summarizes these qualitative differences based on Van De Ven and Delbecq [1974].

Based on these differences, Delphi is selected as the appropriate knowledge gathering technique for this study. This technique is chosen due to its ability to provide an environment of discussion among a panel of experts and gain a level of consensus among them, while minimizing the difficulties involved with face-to-face meetings such as the limited amount of time and availability of experts and geographical considerations. Delphi also helps to remove the negative impacts of the face-to-face meetings and keep the independency of individuals in analyzing the situation.

Table A. 1 – Qualitative Differences between Delphi and Nominal Group Technique (Van De Ven and Delbecq 1974)

Dimension	Nominal Groups	Delphi Technique
Overall Methodology	Structured face-to-face group meeting Low flexibility Low variability in behavior of groups	Structured series of questionnaires & feedback reports Low variability respondent behavior
Role of orientation of groups	Balanced focus on social maintenance and task role	Task-instrumental focus
Relative quantity of ideas	Higher: independent writing & hitch-hiking round-robin	High: isolated writing of ideas
Search Behavior	Proactive search Extended problem focus High task centeredness New social & task knowledge	Proactive search Controlled problem focus High task centeredness New task knowledge
Normative Behavior	Tolerance for non-conformity through independent search and choice activity	Freedom not to conform through isolated anonymity
Equality of participants	Member equality in search & Choice phases	Respondent equality in pooling of independent judgment
Method of problem solving	Problem-centered Confrontation and problem solving	Problem-centered Majority rule of pooled independent judgments
Closure decision process	Lower lack of closure High felt accomplishment	Low lack of closure Medium felt accomplishment
Resources utilized	Medium administrative time, cost, preparation High participant time and cost	High administrative
Time to obtain group ideas	1.5 hours	5 calendar months

Delphi Execution

Despite the extended use of the Delphi method over the past four decades, a standard procedure for implementation still does not exist. Delphi studies differ from each other in many ways, and the number of variations of Delphi is almost as many as the number of the Delphi studies that have been conducted. In this section, a more detailed discussion of the important elements of a Delphi procedure is provided. The goal is to find a more scientific base for implementation of this technique, based on a comprehensive review of the literature relating to this topic.

Unstructured vs. Structured Delphi

In conventional Delphis, the first round is always unstructured, meaning that the participants are allowed to identify and elaborate on those issues they consider as important [Rowe and Wright 1999]. However, some recent applications of Delphi have used structured first rounds, in which an inventory is provided to save time and make the process simpler for the monitor and panelists. This information is established by interviewing key experts [Woudenberg 1991]. This is specially useful in an industrial context, in which the experts are technical specialists who may not be aware of all the dynamics of an issue [Parente and Anderson-Parente 1987].

However, it has been argued that use of a structured first round in a Delphi study will prevent involvement of experts in expressing their beliefs as to what may be important in relation to the issues of interest. Therefore, this may deny the construction of coherent scenarios for assessment [Rowe et al. 1991]. Also, Keeney et al. [Keeney et al. 2001] argue that providing information in the first round may introduce some bias in the panelists' judgment.

Number of Rounds

One of the main differences between variations of Delphi implementation has been in the number of the rounds (Rowe et al. 1991). The original Delphis used by the Rand Coporation consisted of four rounds [Keeney et al. 2001]. However, different Delphi studies have been implemented from as low as 2 to as many as 10 rounds [Woudenberg 1991].

Selecting the number of rounds in a Delphi study is an important issue, as studies have shown that the accuracy of judgmental probability forecasts increases over Delphi rounds [Rowe et al. 2004]. It has been stated that most of the change in panelists' responses occurs after one or two iterations [Rowe and Wright 1999], and consensus is almost always maximized after the second estimation round [Woudenberg 1991]. Results from the Erffmeyer et al. [1984] study showed that the quality of responses increased up to fourth round, but not thereafter.

By the same token, the issue of time is also of considerable importance, as there is a higher tendency for participants to drop out during later rounds [McKenna 1994]. Implementation of three Delphi rounds can take anywhere from three to four months [Gordon 1994]. As a result, it seems the best outcome of the Delphi will be achieved with three or four rounds, in order to maximize the accuracy of results and minimize participation drop-outs.

Size of Expert Panel

There is little agreement about the ideal size of the expert panel in a Delphi study [Keeney et al. 2001]. Most studies have used between 15 and 35 panelists [Gordon 1994]. Parente and Anderson-Parente [1987] suggested a minimum number of 10 panelists after drop-out. Okoli and Pawlowski [2004] suggested that Delphi group size does not depend on statistical power, but rather on group dynamics for arriving at consensus among experts.

Rowe et al. [1991] proposed that a Delphi can be interpreted as a two-stage process. The focus of the first stage is to limit the bias of individuals through structured interaction, while the second stage is aimed at obtaining a group opinion by using statistical methods. They argue that, as the second stage of a Delphi study is similar to a statistical group, factors that affect the performance of statistical groups (such as the number of the participants) must play an important role within the Delphi process. The impact of the number of panelists has been considered by Brockhoff [1975] (with groups of 5, 7, 9, and 11) and Boje and Murnighan [1982] (with groups of 3, 7, and 11). None of these studies found a consistent relationship between panel size and effectiveness criteria.

Hogarth [1978] proposed an analytical model which yields group validity as a function of the number of experts, their mean individual validity and the mean correlation among their judgments. Based on this model, he explains that the validity of the group is an increasing function of the number of experts and their mean validity, and a decreasing function of the average inter-correlation among the experts' opinion. Based on this, he concludes that, in the case of expert groups (such as Delphi) where there is some correlation between panelists' judgments, the maximum validity of the group is reached with 8-12 panelists under a wide range of circumstances (in certain conditions the maximum is reached with only 6 panelists). This further reinforces the findings of the Brockhoff and Boje and Murnighan studies. In addition, Ashton [1986] performed an empirical study to evaluate Hogarth's model and his findings, which further confirmed the results of Hogarth's model.

Expert Selection

Unlike statistical group techniques, a Delphi study is not based on a random sample which is a statistical representative of the target population [Keeney et al. 2001]. In contrast, Delphi is aimed at obtaining a judgment/forecast from a panel of experts. Studies have shown expertise of members does have an impact on performance within interacting groups [Bonner and Baumann 2002]. Therefore, the selection of panel experts is central to the success of the Delphi method [Robinson 1991]. However, this topic has been one of the most neglected aspects in Delphi studies [Okoli and Pawlowski 2004].

An expert panel has been defined as: a group of "informed individuals" [McKenna 1994] who can be "specialists" in their field [Goodman 1987], have knowledge about a specific subject [Davidson et al. 1997; Green et al. 1999; Lemmer 1998] or are recognized by others in the field [Harman and Press 1975]. At the same time, literature has warned about the drawbacks of illusory expertise [Goodman 1987], and it has been stated that simply having knowledge of a particular topic does not necessarily mean that someone is an expert [Keeney et al. 2001]. Based on this, one of the main problems of Delphi studies has been the issue of lack of criteria for distinguishing experts from laymen [Gupta and Clarke 1996].

Dalkey [1969] showed that self-rated experts provide more accurate estimates than self-rated non-experts. Based on this a number of studies used self-rating as a basis for the expert identification. At the same time, the result of a study performed by Larreche and Moinpur [1983] showed that, although self-rated confidence does appear to discriminate between experts and non-experts, experts identified in this fashion are not likely to provide significantly better estimates than the average of the group's initial judgments, or than non-experts. Rowe et al. [2004] support this view by showing that confidence is not a good predictor of expertise.

Another technique suggested for identifying experts is the use of external measures [Rowe et al. 1991]. A study by Larreche and Moinpur [1983] showed that use of a simple external measure of expertise appeared to provide significantly better estimates than non-experts identified by the same measure. Based on this, and based on guidelines provided by Delbecq et al. [1975], Okoli and Pawlowski [2004] suggested a five-step procedure for selecting the experts. This process is shown in Figure A.3

Finally, the issue of expert backgrounds will be discussed. According to Rowe et al. [1991], a key aspect of the selection process is choosing "*experts from varied backgrounds to guarantee a wise base of knowledge.*" Selection of a heterogeneous sample for the Delphi has been mentioned in many studies [Keeney et al. 2001]. This view is also supported by Hogarth's Model (described in the previous section), which shows that group validity has a negative relation with the mean inter-correlation of expert judgments [Hogarth 1978].

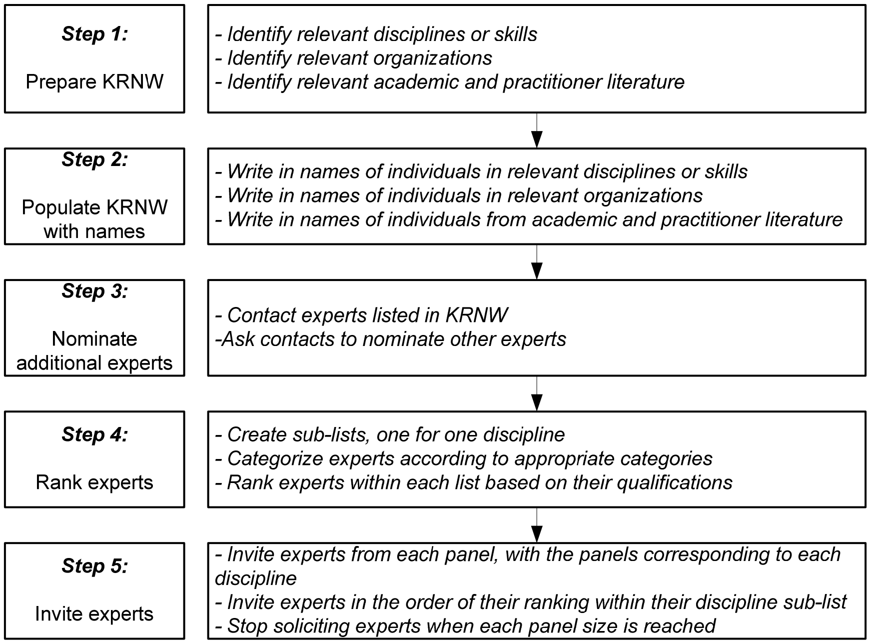

Figure A. 3 – Five-Step Procedure for Selection of Experts (Okoli and Pawlowski 2004)

Questions

One of the criticisms of Delphi studies has been in use of crudely designed questionnaires [Gupta and Clarke 1996]. The process of writing responses to the questions forces respondents to think through the complexity of the problem, and to submit high-quality ideas [Van_De_Ven and Delbecq 1974]. Therefore, an effort should be made to describe the potential event so that all respondents interpret it in exactly the same way [Salancik et al. 1971]. Several studies have given general guidelines for designing Delphi questionnaires [Gordon 1994; Okoli and Pawlowski 2004; Robinson 1991].

Salancik et al [1971] performed a study to determine the appropriate number of the words in event statements. The results of the study showed a curvilinear relationship between the amount of information one receives from respondents, and the number of the words used to describe them events Based on this, authors suggest that for the best response, wording of the questions should be between 20 to 25 words.

Feedback

Generally, it is assumed that a Delphi study provides richer data because of multiple iterations and response revisions due to feedback [Okoli and Pawlowski 2004; Rowe et al. 2004]

Studies performed by Parente et al. [1984] and Boje and Murnighan [1982] suggest the main influence leading to improved accuracy of the Delphi studies is iteration, not feedback. At the same time, Rowe and Wright [1996] argued that the feedback used in these studies has been somewhat superficial, and more informative feedback is likely to be more influential. Furthermore, in their study, Rowe and Wright [1996] compared three feedback conditions of "iteration," "statistical" and "reasons" feedback. They found that, although subjects were less likely to change their forecasts as a result of receiving "reasons" feedback, when they did change their forecasts, this change tended to be for the better, leading to a reduction in error. This results support the findings of the Best study [1974], which showed that a Delphi group that was given "reason" feedback, in addition to median and range of estimates, was more accurate than a Delphi group that was provided with feedback that excluded reasons.

As a result, it can be concluded that Delphi works partially because of the iteration, which allows participants to reflect on their previous answers, and partially because of the feedback [Rowe et al. 2004]. Additionally, in order to take advantage of the benefits of the iteration process in the Delphi study, one must make sure that the feedback is informative and provides a wide range of information, including statistical results, in addition to all the reasons participants provided for their responses.

Aggregation

The last step in a Delphi study is the aggregation of the individual response in the final round of the Delphi, in order to obtain the group judgment/forecast. To accomplish this, statistical aggregation methods, such as the mean or median of response, are employed [Gordon 1994; Larreche and Moinpur 1983].

Use of mean and median gives an equal weight to all the individuals involved in the study. An alternative to this method has been proposed in the form of using differential weights in aggregating the answers. One of the major difficulties with using differential weights is requiring prior knowledge of accuracy of responses [Lock 1987]. Dalkey [1975] has suggested the use of self-ratings as a source for weights. In addition, De Groot [1974] considered processes of revision of individual judgments, in light of others' judgment. At the same time, several studies have argued that equal weighting avoids arguments about relative weighting and performs remarkably well, compared with differential weighting [Ashton and Ashton 1985; Winkler and Makridakis 1983]. Overall, they conclude, "*if all the judges have positive validity and reasonably similar variability, then equal weighting will work well.*"

In concluding this section, we should mention another statistical measure that has been widely used in Delphi studies. This statistical measure is Kendall's W coefficient of concordance [Siegel and Catellan 1988]. Kendall is a measure that determines the relation between several rankings of N objects or individuals. This measure is widely recognized as the best metric for measuring non-parametric rankings [Okoli and

Pawlowski 2004]. This metric has been used in Delphi studies as an indicator of strength of agreement among panel experts on results.

The value of a Kendall's Coefficient W value ranges from 0 to 1, with 1 indicating complete 'inter-rater' agreement, and 0 indicating complete disagreement among experts. Kendall [1970] provides a table (A.2) for critical W values based on k (number of rankers) and N (number of ranked objects). For example, if 3 rankers (k=3) ranked 6 proposals (N=6), and their agreement was W=.16, based on the table we can see the value of W is not significant at the $\alpha = .05$ level. For the concordance to have been significant at the $\alpha = .05$ level, the observed W would have to be .660 or larger.

Table A. 2 – Critical W Values Based on Different Values for k (Number of Raters) and N (Number of Objects) (Kendall 1970)

	N = 4		N = 5		N = 6		N = 7	
k α	**.05**	**.01**	**.05**	**.01**	**.05**	**.01**	**.05**	**.01**
3	-	-	.716	.840	.660	.780	.624	.737
4	.619	.768	.552	.683	.512	.629	.484	.592
5	.501	.644	.449	.571	.417	.524	.395	.491
6	.421	.553	.378	.489	.351	.488	.333	.419
8	.318	.429	.287	379	.267	.347	.253	.324
10	.256	.351	.231	.309	.215	.282	.204	.263
15	.171	.240	.155	.211	.145	.193	.137	.179
20	.129	.182	.117	.160	.109	.146	.103	.136

APPENDIX B

DELPHI INVITATION LETTER

INVITATION TO PARTICIPATE IN A DELPHI STUDY

Dear _________________,

Once again, I wanted to thank you for taking the time out of your busy schedule and meeting with me regarding my Ph.D. dissertation: *Performance Assessment of Building Commissioning Process as a Quality Control System.*

As a recognized expert in the field of Building Commissioning, I believe that your knowledge and experience will provide invaluable information for a critical phase of my doctoral research.

During this phase of my work, a group of 16 experts and experienced professionals will participate in a series of three surveys to identify the effects of a type of a *Commissioning Delivery System* on the overall performance of this process. The surveys are described below:

Survey 1: Appraise a list of performance attributes for the building commissioning process and recommend other attributes that maybe appropriate. [Approximately 45 minutes. Due November 21]

Survey 2: Evaluate the performance of each commissioning delivery system based on the identified attributes for the commissioning process. [Approximately 1 hour. Due December 5]

Survey 3: Participate in a second round on Survey 2 to gain some level of consensus [Approximately 30 minutes. Due December 19]

I have attached a detailed description of the research and its criteria for your reference. I STRONGLY RECOMMEND THAT YOU STUDY THIS DOCUMENT BEFORE TAKING THE FIRST SURVEY. To take the survey, please click on the following link:

XXXXXXXX

THANK YOU, in advance, for assisting in my research. I look forward to working with you and will provide you with any additional information about this project at your request. Also, I will be happy to send you a PDF of the results of this phase of my study, or my entire dissertation when completed, if you so desire. Please feel free to call me if you have any questions about this study.

Sincerely,

Ali Shakoorian

Cell: XXX-XXX-XXXX

APPENDIX C

SURVEY 1

Survey 1: Evaluation of Commissioning Process Performance Indicators **Exit this survey >>**

Introduction

Thanks for participating in this Delphi survey. This is the first round of a three part survey aimed at assessment of performance of different Commissioning Delivery Systems. WE STRONGLY RECOMMEND THAT YOU REVIEW THE SURVEY PACKAGE (ATTACHED TO THE INVITATION E-MAIL) BEFORE STARTING THIS SURVEY. Based on the nature of the Delphi Study, the identity of participants will be kept anonymous and only summary of the group responses will be communicated with participants.

This first survey is consisted of two main sections. In the first section, you will be asked general questions about your experience with Construction Industry and the Building Commissioning Process. The second section will provide you with a set of Internal Performance Attributes of the Commissioning Process and you will be asked to rate the appropriateness of each indicator.

Also before you proceed, Georgia Tech regulations require that you read and accept a consent letter (provided in the next page). If you have any questions feel free to contact me at 404-449-4068 (cell) or ali@arch.gatech.edu.

Sincerely,

Ali Shakoorian,
Ph.D. Candidate
Building Construction Program
College of Architecture
Georgia Insistute of Technology

Next >>

Survey 1: Evaluation of Commissioning Process Performance Indicators Exit this survey >>

Consent Form

Georgia Institute of Technology
Project Title: Performance Assessment of Building Commissioning Process as a Total Quality Control Program
Investigators: Saeid Sadri, Ph.D.; Amirali Shakoorian
Consent title: Main 10/10/05v1

Research Consent Form

You are being asked to be a volunteer in a research study. You are encouraged to take your time in making your decision.

Purpose:
The purpose of this study is to compare different types of Commissioning Delivery Systems based on a set of developed performance aspects of this process. This comparison will be based on an expert judgment study. The expert judgment will be acquired through three anonymous surveys. A total of 16 experts have been identified to participate in this survey.

Procedures:
If you decide to be in this study, your part will involve participating in 3 online surveys over the course of 1.5 months. Each survey will require 45-60 minutes. And you will have 7 days to respond to each survey.

Risks/Discomforts
The following risks/discomforts may occur as a result of your participation in this study:
You may face some risks or discomforts due to being part of this study. The risks involved are no greater than those involved in daily activities such as filling up an online survey.

Benefits
The following benefits to you are possible as a result of being in this study:
• You will be provided with the results of the study, and at your request a copy of the dissertation will be sent to you in PDF format.

Compensation to You
There won't be any monetary compensation for participants in this study. However, findings of this study will be shared with participants.

Confidentiality
The following procedures will be followed to keep your personal information confidential in this study: The data that is collected about you will be kept private to the extent allowed by law. To protect your privacy, your records will be kept under a code number rather than by name. Your records will be kept in locked files and only study staff will be allowed to look at them. Your name and any other fact that might point to you will not appear when results of this study are presented or published.

You should be aware, however, that the experiment is not being run from a "secure" https server of the kind typically used to handle credit card transactions, so there is a small possibility that responses could be viewed by unauthorized third parties (e.g., computer hackers).

Also, in general the web page software will log as header lines the IP address of the machine you use to access this page, e.g.,102.403.506.807, but otherwise no other information will be stored unless you explicitly enter it.

To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology IRB may review study records. The Office of Human Research Protections may also look at study records.

Costs to You
There are no costs to you for participating in this study, other than the time requirements for filling out the surveys.

In Case of Injury/Harm
If you are injured as a result of being in this study, please contact Dr. Saeid Sadri at telephone (404) 894-4616. Neither the Principal Investigator nor Georgia Institute of Technology have made provision for payment of costs associated with any injury resulting form participation in this study.

Subject Rights

• Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.
• You have the right to change your mind and leave the study at any time without giving any reason, and without penalty.
• Any new information that may make you change your mind about being in this study will be given to you.
• You will be given a copy of this consent form to keep.
• You do not waive any of your legal rights by signing this consent form.

Questions about the Study or Your Rights as a Research Subject

• If you have any questions about the study, you may contact Dr. Saeid Sadri at telephone (404) 894-4616.
• If you have any questions about your rights as a research subject, you may contact Ms. Melanie Clark, Georgia Institute of Technology at (404) 894-6942.

Clicking on NEXT means that you have read the information given in this consent form, and you would like to be a volunteer in this study.

<< Prev **Next >>**

Survey 1: Evaluation of Commissioning Process Performance Indicators

Exit this survey >>

Survey 1 - Section 1

Background Information

*** Please indicate your level of experience with the construction industry in terms of years**

- 1-5 years
- 6-10 years
- 11-20 years
- more than 20 years

*** What roles have you presented during your career in the construction industry (select as many as applicable)?**

- Owner
- Architect/Engineer
- Contractor
- Project Manager
- Building Commissioner
- Other (please specify)

*** Please indicate your level of experience with the commissioning process in terms of number of the projects you have been involved in**

- 1-2
- 3-5
- 6-10
- more than 10

*** What was your primary role in the commissioning projects you have been involved in (Select as many as applicable)?**

- Owner
- Project Designer
- Contractor
- Commissioning Agent
- Other (please specify)

<< Prev Next >>

Survey 1: Evaluation of Commissioning Process Performance Indicators

Exit this survey >>

Survey 1 - Section 2: Performance Indicators for Commissioning Process

Following is a list of Internal Performance Aspects for the Total Building Commissioning Process. These aspects were identified based on an in-depth review of the exisitng literature on the subject of building commissioning. On a scale of 1-5 please identify the importance of each aspect. Also if you rate any performance aspect a rating less than 3, please provide a brief explanation.

At the end of this section you are asked to provide any other Internal Aspects that you find appropriate.

* **PAe1: Communication One of the most cited factors for a successful commissioning process is improved communication. Most of the problems in a project arise from the breakdown in communication lines among different entities and building commissioning is focused to eliminate these communication breakdowns through enhanced interaction among stakeholders. Communication has such a high importance in the building commissioning process that it had been cited as the main purpose of this process. As a result, the more effective and the more efficient the communication among entities, the more successful the commissioning process will be.**

1 (Not Important)	2	3 (Moderately Important)	4	5 (Extremely Important)

Comments:

* **PAi2: Validation A large part of the commissioning activities focus on validation and verification of project deliverables. This includes reviewing the building design and providing feedbacks on the ability of the designed systems to carry the owner requirements as well as verification and testing of the installed building systems. Therefore, the ability of the commissioning team to review the design and test the systems is one of the very important aspects of the building commissioning process and plays a major role in achieving its objectives. It should be noted that here, ability of the commissioning team in performing effective verification is viewed as a function of entities involved in the commissioning process and their relations, not the level of their technical capabilities. It is assumed that each type of commissioning delivery systems will bring in all the required technical capabilities required for performing commissioning activities.**

1 (Not Important)	2	3 (Moderately Important)	4	5 (Extremely Important)

Commments

* **PAi3: Collaboration Although, the commissioning authority is the entity responsible for managing the commissioning process, most of the activities in the commissioning process are performed through collaboration among different entities in the commissioning team. Several authors emphasize the importance of teamwork and collaboration among different entities. It has been stated that a constructive atmosphere in which the political barriers are eliminated will help to make the commissioning process more efficient. This efficiency comes from the fact that entities would more freely provide feedback on the work of the others and they will also be more open in implementing the feedbacks of the others.**

1 (Not Important)	2	3 (Moderately Important)	4	5 (Extremely Important)

Comments

* **PAi4: Integration Building commissioning is not a delivery system but a quality process that sits on top of the project delivery system. A successful commissioning process will not add to the complexity of the delivery system but will help to further streamline the whole project. Therefore, a seamless integration of commissioning activities into the delivery system is essential. This integration can be achieved through proper division of commissioning roles and responsibilities between different entities and coordination between entities in charge of these responsibilities. Responsibilities should be assigned in a way that takes advantage of existing capabilities of service providers and their current knowledge of the project and eliminates any double work. Also assigning commissioning authorities and accountabilities should be based on the existing lines of authorities and responsibilities that are already defined based on the project delivery system and any conflicts and ambiguity should be avoided.**

1 (Not Important)	2	3 (Moderately Important)	4	5 (Extremely Important)

Comments

* **PAi5: Integrity One of the key features of the building commissioning process is that the same entity representing the project intent from beginning through one or more years of use Therefore, the process should be designed in a way that this entity in collaboration with the commissioning team can perform all activities of the building commissioning without any conflict of interest. Integrity aspect of the commissioning process is in direct relation to the verification responsibilities of the commissioning authority and therefore a very important aspect of this process.**

1 (Not Important)	2	3 (Moderately Important)	4	5 (Extremely Important)

Comments

Please add any other Internal Performance Aspect for the Total Building Commissioning Process, that you may find appropriate. Note that the focus of this research is Internal Aspects of the Commissioning Process, NOT the External Aspects (such as time, cost, etc.) that focus on the outcomes of this process.
Also to avoid any confusion, please provide a short discription for each of the aspects that you propose.

<< Prev **Next >>**

Survey 1: Evaluation of Commissioning Process Performance Indicators

Exit this survey >>

Thanks!

I appreciate your feedback. You will receive the link for the second survey on Tuesday November 29th.

Thanks again!

Ali Shakoorian

<< Prev Done >>

APPENDIX D

SURVEY 1 RESULTS

Table D. 1- Survey 1: Participants Experience in the Construction Industry (in Years)

Experience in Construction				
	1-5	6-10	11-20	20+
Owner 1				1
Owner 2			1	
Owner 3		1		
Owner 4				1
Owner 5				1
Owner 6				1
Owner 7			1	
AE 1				1
AE 2				1
AE 3				1
GC 1				1
GC 2				1
GC 3				1
CA 1		1		
CA 2				1
CA 3			1	
Total	-	2	3	11

Table D. 2 - Survey 1: Participants Roles in the Construction Industry

Roles in the Construction Industry					
	Owner	Designer	Contractor	PM	CxA
Owner 1	1	1		1	
Owner 2					1
Owner 3	1				
Owner 4	1			1	1
Owner 5	1	1	1	1	1
Owner 6	1				
Owner 7	1			1	
AE 1		1			
AE 2	1	1		1	1
AE 3	1	1	1	1	1
GC 1		1	1	1	1
GC 2	1	1	1	1	1
GC 3	1	1	1	1	1
CA 1				1	1
CA 2		1		1	1
CA 3	1		1	1	1
Total	11	9	6	12	11

Table D. 3 - Survey 1: Participants Experience with Building Commissioning (in number of projects)

Experience in Commissioning				
	1-2	3-5	6-10	10+
Owner 1			1	
Owner 2	1			
Owner 3		1		
Owner 4				1
Owner 5				1
Owner 6	1			
Owner 7			1	
AE 1				1
AE 2		1		
AE 3				1
GC 1				1
GC 2				1
GC 3				1
CA 1				1
CA 2				1
CA 3				1
Total	2	2	2	10

Table D. 4 - Survey 1: Participants Roles in the Commissioning Projects

Roles in the Commissioning Projects				
	Owner	Designer	Contractor	CxA
Owner 1	1			
Owner 2				1
Owner 3	1			
Owner 4	1			1
Owner 5	1			
Owner 6	1			
Owner 7	1			
AE 1		1		
AE 2		1		
AE 3				1
GC 1		1	1	1
GC 2			1	1
GC 3		1	1	1
CA 1				1
CA 2				1
CA 3				1
Total	6	4	3	9

Table D. 5 - Survey 1: Owners' Evaluation of each Performance Aspect (1=not important, 5=extremely important)

	Communication	Validation	Collaboration	Integration	Integrity
Owner 1	5	5	5	5	5
Owner 2	5	3	5	4	4
Owner 3	5	4	5	5	5
Owner 4	5	4	5	4	4
Owner 5	5	5	3	3	5
Owner 6	4	4	4	4	4
Owner 7	3	5	4	4	4
Median	**5.00**	**4.00**	**5.00**	**4.00**	**4.00**
Average	**4.57**	**4.29**	**4.43**	**4.14**	**4.43**
ST Dev	**0.79**	**0.76**	**0.79**	**0.69**	**0.53**

Table D. 6 - Survey 1: Designers' Evaluation of each Performance Aspect (1=not important, 5=extremely important)

	Communication	Validation	Collaboration	Integration	Integrity
A/E 1	4	5	5	4	5
A/E 2	4	5	4	3	4
A/E 3	3	5	5	5	5
Median	**4.00**	**5.00**	**5.00**	**4.00**	**5.00**
Average	**3.67**	**5.00**	**4.67**	**4.00**	**4.67**
ST Dev	**0.58**	**0.00**	**0.58**	**1.00**	**0.58**

Table D. 7 - Survey 1: Contractors' Evaluation of each Performance Aspect (1=not important, 5=extremely important)

	Communication	Validation	Collaboration	Integration	Integrity
GC 1	5	5	5	5	5
GC 2	4	5	5	4	4
GC 3	5	5	4	5	4
Median	**5.00**	**5.00**	**5.00**	**5.00**	**4.00**
Average	**4.67**	**5.00**	**4.67**	**4.67**	**4.33**
ST Dev	**0.58**	**0.00**	**0.58**	**0.58**	**0.58**

Table D. 8 – Survey 1: Building Commissioners'' Evaluation of each Performance Aspect (1=not important, 5=extremely important)

	Communication	Validation	Collaboration	Integration	Integrity
CA 1	5	5	5	4	4
CA 2	3	5	4	4	5
CA 3	5	4	4	5	5
Median	**5.00**	**5.00**	**4.00**	**4.00**	**5.00**
Average	**4.33**	**4.67**	**4.33**	**4.33**	**4.67**
ST Dev	**1.15**	**0.58**	**0.58**	**0.58**	**0.58**

Table D. 9 - Survey 1: Overall Group Evaluation of each Performance Aspect (1=not important, 5=extremely important)

	Communication	Validation	Collaboration	Integration	Integrity
Median	**5**	**5**	**5**	**4**	**5**
Average	**4.38**	**4.63**	**4.50**	**4.25**	**4.50**
ST Dev	**0.81**	**0.62**	**0.63**	**0.68**	**0.52**

Table D. 10 – Survey 1: Comments

Communication	Communication of the commissioning process, the areas on which the process will focus and the expected results (project deliverables) must be communicated to everyone who is involved in the construction of the project as early as possible in order to minimize conflict as the process proceeds. During the commissioning process, there must be effective communication of the findings and results (in "real time")to everyone involved in the construction process. The main objective of good communications is to manage everone's expectations and avoid surprises where someone says, "I did not know that, why didn't you tell me." Then they add, "You did not
	While improved communications ARE an important aspect of the commissioning process, the insertion of a Commissioning Authority into the normal construction chain can have the effect of complicating normal communications. I would not rate "improved communications" as a major goal of the commissioning process.
Validation	A major aspect of the verification process is that the commissioning team have a realistic view of the expected deluiverables to insure that they are looking for results that were actually bought and are reasonable within the construction contract and not results that are "ideal" no matter what the costs or some vague "common practice' claims. In many cases, this involves managing the owner's expectations as well as those of the construction team, otherwise major conflicts will occur.If the owner bought "second rate" systems, fine, that is his/her perogative, but don't
	While I agree with the statement in general, I do not think that downplaying the technical ability of the commissioning authority is valid. While the CA does not have to be an expert in all aspects of a system - he can hire that talent - it IS important that the CA be a technically competent
Collaboration	results of the construction team and in many cases, the hard fact is that money and abilitiies are the problems, and not "political issues". Often the condition exists that one trade may have done an outstanding job and then another trade has done sub-standard work that does not deliver the results "bought' and both trades have to spend money to correct the situation and this produces conflict. Life safety and various control systems and their interaction with other trades is a common area of this type conflict.
Integration	I believe that the responsibility of the commissioning team is make the members of the construction team aware of what tests will be ultimately run and what results are expected and the construction team are the people who will insure that their work is performed correctly or pay the consequences. Also, if they are told up front what results are expected in a calm and reasonable way, then they have the opportunity to object if they feel the desired results are out of the scope of their work. Again, I believe that the main ingrediant is managing expectations.
	I disagree that a successful commissioning process "sits on top of the project delivery system." As the rest of the statment implies, a good Cx program will be integrated into the project delivery - requiring the minimum disruption and/or addition to the "normal" construction process.
	I dont agree with the second part of the first sentence, "...a quality process that sits on top of the project delivery system." I believe that commissioning, if done correctly, and if TRULY integrated, wont be an "add-on" service but one that is "business as usual". Obviously, when done the first time, this is a major challenge to achieve. However, owners should strive to making it just the way they've determined to procure their buildings. So, for the first sentence, I would agree that commissioning is a "quality process that is available for integration into the

Table D. 10 – (Continued)

Integrity	There must not be few or no past major personal or professional conflicts between the teams to insure that the integrity of both "sides" (the commissioning and the construction teams)is not even perceived to be violated.
Other	Documentation. Systematic, methodical, planned documentation is what sets Cx apart from a mere attempt at quality assurance by a dilettante. Documentation is proof that Cx has occurred. All credible definitions or descriptions of Cx point to it aspect of documentation. Better Cx has better documentation, as a rule.
	Background and Experience - The professionals who are performing the commissioning process must be people who have the education, qulifications, and real life experience for the work they are validating to allow them to judge with authority and in a practical manner the results that they observe, and to insure they are believable.
	In our organization the project manager is the lead person. AEs, Contractor, CMs, and Commissioning Agent all support the project mangaer. The term "commissioning team" is a part of the project manager's support and can be influence by the process.
	One of the biggest challenges to effective commissioning is to clearly identify the "defined objectives and criteria" that serve as the target for the commissioning efforts.
	ACCOUNTABILITY: The commssioning entity that shepherds the commissioning process should be answerable for their scope of work. Because the implementation of the process is relatively new to the industry and there is seen as a "hot" area for investment in the construction industry, more and more entities are emerging that are not experienced. Therefore, current commissioning delivery systems, to be successful, should have rigorous accountability measures put in place by owners to "commission" the "commissioning entity" so to speak.

APPENDIX E

SURVEY 2

Survey 2: Performance evaluation of four Commissioning Delivery Systems

Exit this survey >>

Introduction

Thanks for your response to the first survey. The result of the first survey helped us to identify the relative importance of developed performance attributes for the commissioning process. This is the SECOND round of the three-part survey, aimed at assessing the performance of different Commissioning Delivery Systems. We would like to remind you that based on the nature of the Delphi method, the identity of participants will be kept anonymous and only summary of the group responses will be communicated with participants.

This second survey includes two main sections. In the first section, you will be introduced to a construction project that is procured based on a DESIGN-BID-BUILD delivery method. Then you will be asked to rate the performance of each COMMISSIONING DELIVERY SYSTEM based on the performance attributes introduced to you in the first survey.

In the second section of the survey, you will be introduced to the same construction project, however, this time the procurement method will be DESIGN-BUILD. Again, you will be asked to rate the performance of two different COMISSIONING DELIVERY SYSTEMS.

If you have any questions feel free to contact me at 404-449-4068 (cell) or ali@arch.gatech.edu.

Sincerely,

Ali Shakoorian,
Ph.D. Candidate
Building Construction Program
College of Architecture
Georgia Insistute of Technology

Next >>

Survey 2: Performance evaluation of four Commissioning Delivery Systems

Exit this survey >>

Case

A large educational facility is planned on a university campus in Atlanta, GA. With a total of 200,000 square foot in 4 levels, this facility will house several functions such as classrooms, Auditorium, electronic and computer laboratories, common areas, faculty offices, general support spaces and parking.

To ensure the overall quality of the building the owner wants to implement a Total Building Commissioning process into the project. This commissioning process will start at pre-design stage and will continue through the 1st year of occupancy. Due to the nature of the project, owner is requiring a comprehensive commissioning process, which will cover:

- Mechanical and Energy Systems
- Structural Systems
- Exterior Building Envelope
- Roofing Systems
- Elevator Systems
- Plumbing Systems
- Electrical Systems
- Fire Protection Systems
- Telecommunications Systems

<< Prev Next >>

Survey 2: Performance evaluation of four Commissioning Delivery Systems

Exit this survey >>

Section 1: Design-Bid-Build Scenario

Scenario 1:
Owner has decided to procure this project through a DESIGN-BID-BUILD delivery system. He also has identified a competent A/E firm as the project designer. Based on this delivery system, there are two contractual options for obtaining the commissioning services:

OPTION 1 (OWNER-LED COMMISSIONING):
In this option the Owner will assume the responsibility for the Commissioning Process. Therefore, either a staff member of the owner's organization will be selected as the commissioning authority OR owner will use services of a THIRD-PARTY commissioning consultant.

OPTION 2 (DESIGNER-LED COMMISSIONING):
In this option the owner passes the commissioning responsibility to the project designer through a SEPARATE commissioning contract. Under this option, the designer can choose to perform the commissioning activities himself OR use services of an external consultant. In either case, the Designer will hold the commissioning contract and will be responsible for this process.

To make an informed decision the owner has asked you as an industry expert to evaluate each option based on the performance attributes presented to you on the first part of the survey. For your convenience, for each indicator three keywords are provided in parenthesis. These keywords are identified based on the definitions of each indicator (provided in the first survey) and participants' feedbacks.

Also please note that this performance comparison is purely based on CONTRACTUAL relationships between the entities, and any other determining characteristics such as technical and managerial capabilities are assumed to be the SAME.

*** How do you rank the COMMUNICATION (Clarity, Integrity, Directness) among entities?**

Examples of EXCELLENT Communication:
- Absolute dissemination of Information among all parties
- Direct and clear communication lines between parties
- Direct and clear Feedback lines between parties

Examples of POOR Communication:
- Information is piecemeal
- Message must run through several entities till finally reach the recipient
- Communication lines are constantly broken
- No direct feedback lines exist among entities

	(Very Poor) 1	2	3	4	5	6	7	(Average) 8	9	10	11	12	13	14	(Excellent) 15
Owner-led Commissioning															
Designer-led Commissioning															

Comments

* **How do you rank the quality of VALIDATION (Thoroughness, Accuracy, Explicity)?**

Examples of EXCELLENT Validation:
- Comprehensive Knowledge about the project and Owner Requirements
- Thorough validation of all related systems during design and construction stages
- Validation is realistic and based on stated owner requirements
- Ability to recommend practical solutions to existing problems

Examples of POOR Validation:
- Validation is based on assumptions and guesses instead of actual knowledge about the project
- Systems are validated individually and the overall performance of the project is not taken into account.
- Validation stays at the problem finding level and no solutions are proposed.

	(Very Poor) 1	2	3	4	5	6	7	(Average) 8	9	10	11	12	13	14	(Excellent) 15
Owner-led Commissioning															
Designer-led Commissioning															

Comments

* **How do you rank the COLLABORATION (Cooperation, Interaction, Teamwork) among different entities?**

Examples of EXCELLENT Collaboration:
- Maximum interaction among different entities on the project
- A constructive atmosphere with no political barriers
- All entities have a positive attitude and take a partnering approach to resolve the issues

Examples of POOR Collaboration:
- There is minimum interaction among parties.

- Entities are looking after their own interests in the project and try to pass the responsibility to the next party.
- Parties are constantly blaming each other for the identified problems.
- Parties are reluctant to implement the recommendations.

	(Very Poor) 1	2	3	4	5	6	7	(Average) 8	9	10	11	12	13	14	(Excellent) 15
Owner-led Commissioning															
Designer-led Commissioning															

Comments

* **How do you rank the INTEGRATION (Efficiency, Simplicity, Coordination) of the commissioning process into the Design and Construction process?**

Examples of EXCELLENT Integration:
- There is a seamless integration between the commissioning activities and design/construction process
- High degree of coordination between different activities.
- Maximum use of existing knowledge and expertise of the existing project members and elimination of any double work

Examples of POOR Integration:
- As a result of commissioning the project administration has become very complex
- Commissioning activities constantly interrupt the course of the project
- Different entities end up doing the same tasks and there is an extensive amount of double work.

	(Very Poor) 1	2	3	4	5	6	7	(Average) 8	9	10	11	12	13	14	(Excellent) 15
Owner-led Commissioning															
Designer-led Commissioning															

Comments

* How do you rate the INTEGRITY (Authority, Accountability, Ethicality) of the commissioning process?

Examples of EXCELLENT Integrity:
- Commissioning entity has clear Authority in implementing the commissioning tasks.
- Each party has clear responsibilities and therefore, can easily be hold accountable.
- There's no concern for unethical activity

POOR Integrity means:
- Parties constantly challenge the authority of the commissioning agent.
- Responsibilities are dispersed among different entities, and therefore there is no accountability.
- There is little trust in the commissioning activities

	(Very Poor) 1	2	3	4	5	6	7	(Average) 8	9	10	11	12	13	14	(Excellent) 15
Owner-led Commissioning															
Designer-led Commissioning															

Comments

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Survey 2: Performance evaluation of four Commissioning Delivery Systems

Exit this survey >>

Section 2: Design-Build Scenario

Scenario 2:
Owner has decided to procure this project through a DESIGN-BUILD delivery system. He also has identified a competent DESIGN/BUILD firm for the project. Based on this delivery system, there are two contractual options for obtaining the commissioning services:

OPTION 1 (OWNER-LED COMMISSIONING):
In this option the Owner will assume the responsibility for the Commissioning Process. Therefore, either a staff member of the owner's organization will be selected as the commissioning authority OR owner will use the services of a THIRD-PARTY commissioning consultant.

OPTION 2 (DESIGN/BUILDER-LED COMMISSIONING):
In this option the owner passes the commissioning responsibility to the project design/builder through a SEPARATE commissioning contract. Under this option, the design/builder can choose to perform the commissioning activities himself OR use services of an external consultant. In either case, the designer/builder will hold the commissioning contract and will be responsible for this process.

To make an informed decision the owner has asked you as an industry expert to evaluate each option based on the performance attributes presented to you on the first part of the survey. For your convenience, for each indicator three keywords are provided in parenthesis. These keywords are identified based on the definitions of each indicator (provided in the first survey) and participants' feedbacks.

Also please note that this performance comparison is purely based on CONTRACTUAL relationships between the entities, and any other determining characteristics such as technical and managerial capabilities are assumed to be the SAME.

*** How do you rank the COMMUNICATION (Clarity, Integrity, Directness) among entities?**

Examples of EXCELLENT Communication:
- Absolute dissemination of Information among all parties
- Direct and clear communication lines between parties
- Direct and clear Feedback lines between parties

Examples of POOR Communication:
- Information is piecemeal
- Message must run through several entities till finally reach the recipient
- Communication lines are constantly broken
- No direct feedback lines exist among entities

	(Very Poor) 1	2	3	4	5	6	7	(Average) 8	9	10	11	12	13	14	(Excellent) 15
Owner-led Commissioning															
DB-led Commissioning															

Comments

* **How do you rank the quality of VALIDATION (Thoroughness, Accuracy, Explicity)?**

Examples of EXCELLENT Validation:
- Comprehensive Knowledge about the project and Owner Requirements
- Thorough validation of all related systems during design and construction stages
- Validation is realistic and based on stated owner requirements
- Ability to recommend practical solutions to existing problems

Examples of POOR Validation:
- Validation is based on assumptions and guesses instead of actual knowledge about the project
- Systems are validated individually and the overall performance of the project is not taken into account.
- Validation stays at the problem finding level and no solutions are proposed.

	(Very Poor) 1	2	3	4	5	6	7	(Average) 8	9	10	11	12	13	14	(Excellent) 15
Owner-led Commissioning															
DB-led Commissioning															

Comments

* **How do you rank the COLLABORATION (Cooperation, Interaction, Teamwork) among different entities?**

Examples of EXCELLENT Collaboration:
- Maximum interaction among different entities on the project
- A constructive atmosphere with no political barriers
- All entities have a positive attitude and take a partnering approach to resolve the issues

Examples of POOR Collaboration:
- There is minimum interaction among parties.

- Entities are looking after their own interests in the project and try to pass the responsibility to the next party.
- Parties are constantly blaming each other for the identified problems.
- Parties are reluctant to implement the recommendations.

	(Very Poor) 1	2	3	4	5	6	7	(Average) 8	9	10	11	12	13	14	(Excellent) 15
Owner-led Commissioning															
DB-led Commissioning															

Comments

* **How do you rank the INTEGRATION (Efficiency, Simplicity, Coordination) of the commissioning process into the Design and Construction process?**

Examples of EXCELLENT Integration:
- There is a seamless integration between the commissioning activities and design/construction process
- High degree of coordination between different activities.
- Maximum use of existing knowledge and expertise of the existing project members and elimination of any double work

Examples of POOR Integration:
- As a result of commissioning the project administration has become very complex
- Commissioning activities constantly interrupt the course of the project
- Different entities end up doing the same tasks and there is an extensive amount of double work.

	(Very Poor) 1	2	3	4	5	6	7	(Average) 8	9	10	11	12	13	14	(Excellent) 15
Owner-led Commissioning															
DB-led Commissioning															

Comments

* **How do you rate the INTEGRITY (Authority, Accountability, Ethicality) of the commissioning process?**

Examples of EXCELLENT Integrity:
- Commissioning entity has clear Authority in implementing the commissioning tasks.
- Each party has clear responsibilities and therefore, can easily be hold accountable.
- There's no concern for unethical activity

POOR Integrity means:
- Parties constantly challenge the authority of the commissioning agent.
- Responsibilities are dispersed among different entities, and therefore there is no accountability.
- There is little trust in the commissioning activities

	(Very Poor) 1	2	3	4	5	6	7	(Average) 8	9	10	11	12	13	14	(Excellent) 15
Owner-led Commissioning															
DB-led Commissioning															

Comments

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Survey 2: Performance evaluation of four Commissioning Delivery Systems

Exit this survey >>

Thanks!

I appreciate your feedback. You will receive the link for the final survey on Tuesday December 13th.

Thanks again!

Ali Shakoorian

<< Prev Done >>

APPENDIX F

SURVEY 2 RESULTS

Table F. 1 – Survey 2: Owners' Assessment of CDS Alternatives under Design-Bid-Build Delivery System

Design-Bid-Build										
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
Owner 1	15	8	13	13	15	8	15	11	15	12
Owner 2	15	8	15	9	15	8	15	12	15	7
Owner 3	10	5	11	4	11	4	10	7	12	4
Owner 4	12	9	14	8	13	5	14	6	12	4
Owner 5	13	4	12	9	13	6	4	11	14	4
Owner 6	12	7	12	7	12	7	12	7	12	7
Median	**12.50**	**7.50**	**12.50**	**8.50**	**13.00**	**6.50**	**13.00**	**9.00**	**13.00**	**5.50**
AVERAGE	**12.83**	**6.83**	**12.83**	**8.33**	**13.17**	**6.33**	**11.67**	**9.00**	**13.33**	**6.33**
SD	**1.94**	**1.94**	**1.47**	**2.94**	**1.60**	**1.63**	**4.23**	**2.61**	**1.51**	**3.14**

Table F. 2 - Survey 2: Designers' Assessment of CDS Alternatives under Design-Bid-Build Delivery System

	Design-Bid-Build									
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
AE1	10	13	12	14	10	14	10	14	14	10
AE2	14	11	12	9	11	11	10	10	14	11
AE3	7	10	8	12	7	10	6	10	10	8
Median	10.00	11.00	12.00	12.00	10.00	11.00	10.00	10.00	14.00	10.00
AVERAGE	10.33	11.33	10.67	11.67	9.33	11.67	8.67	11.33	12.67	9.67
SD	3.51	1.53	2.31	2.52	2.08	2.08	2.31	2.31	2.31	1.53

Table F. 3 - Survey 2: Contractors' Assessment of CDS Alternatives under Design-Bid-Build Delivery System

	Design-Bid-Build									
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
GC 1	7	7	6	6	6	4	7	6	6	6
GC 2	13	10	13	8	12	11	11	11	14	10
GC 3	12	5	13	8	12	6	8	12	14	6
Median	12.00	7.00	13.00	8.00	12.00	6.00	8.00	11.00	14.00	6.00
AVERAGE	10.67	7.33	10.67	7.33	10.00	7.00	8.67	9.67	11.33	7.33
SD	3.21	2.52	4.04	1.15	3.46	3.61	2.08	3.21	4.62	2.31

Table F. 4 - Survey 2: Building Commissioners' Assessment of CDS Alternatives under Design-Bid-Build Delivery System

Design-Bid-Build										
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
CA1	14	6	14	4	14	8	12	8	15	1
CA2	9	10	12	11	12	11	11	12	13	8
CA3	10	10	6	5	12	10	9	9	10	5
Median	10.00	10.00	12.00	5.00	12.00	10.00	11.00	9.00	13.00	5.00
AVERAGE	11.00	8.67	10.67	6.67	12.67	9.67	10.67	9.67	12.67	4.67
SD	2.65	2.31	4.16	3.79	1.15	1.53	1.53	2.08	2.52	3.51

Table F. 5 - Survey 2: Overall Assessment Results of CDS Alternatives under Design-Bid-Build Delivery System

Design-Bid-Build										
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
Median	12.00	8.00	12.00	8.00	12.00	8.00	10.00	10.00	14.00	7.00
Average	11.53	8.20	11.53	8.47	11.67	8.20	10.27	9.73	12.67	6.87
SD	2.61	2.54	2.75	3.07	2.53	2.93	3.17	2.46	2.47	3.04

Table F. 6 - Survey 2: Owners Assessment of CDS Alternatives under Design-Build Delivery System

	Design-Build									
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
Owner 1	15	11	15	11	15	11	13	13	15	15
Owner 2	15	8	15	8	15	8	15	8	15	8
Owner 3	10	2	11	2	11	8	10	8	12	2
Owner 4	10	6	10	7	11	7	12	9	9	4
Owner 5	5	13	13	4	4	13	6	13	6	13
Owner 6	12	7	12	7	12	7	12	7	12	10
Median	**11.00**	**7.50**	**12.50**	**7.00**	**11.50**	**8.00**	**12.00**	**8.50**	**12.00**	**9.00**
AVERAGE	**11.17**	**7.83**	**12.67**	**6.50**	**11.33**	**9.00**	**11.33**	**9.67**	**11.50**	**8.67**
SD	**3.76**	**3.87**	**2.07**	**3.15**	**4.03**	**2.45**	**3.08**	**2.66**	**3.51**	**5.05**

Table F. 7 - Survey 2: Designers' Assessment of CDS Alternatives under Design-Build Delivery System

	Design-Build									
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
AE1	14	12	12	14	11	14	10	14	12	14
AE2	13	10	13	8	11	11	10	10	12	9
AE3	9	7	9	5	8	8	8	8	8	6
Median	**13.00**	**10.00**	**12.00**	**8.00**	**11.00**	**11.00**	**10.00**	**10.00**	**12.00**	**9.00**
AVERAGE	**12.00**	**9.67**	**11.33**	**9.00**	**10.00**	**11.00**	**9.33**	**10.67**	**10.67**	**9.67**
SD	**2.65**	**2.52**	**2.08**	**4.58**	**1.73**	**3.00**	**1.15**	**3.06**	**2.31**	**4.04**

Table F. 8 - Survey 2: Contractors' Assessment of CDS Alternatives under Design-Build Delivery System

	Design-Build									
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
GC 1	9	12	9	12	11	13	10	12	13	13
GC 2	13	7	13	8	13	8	12	7	13	6
GC 3	8	11	8	11	8	11	6	11	5	13
Median	9.00	11.00	9.00	11.00	11.00	11.00	10.00	11.00	13.00	13.00
AVERAGE	10.00	10.00	10.00	10.33	10.67	10.67	9.33	10.00	10.33	10.67
SD	2.65	2.65	2.65	2.08	2.52	2.52	3.06	2.65	4.62	4.04

Table F. 9 - Survey 2: Building Commissioners' Assessment of CDS Alternatives under Design-Build Delivery System

	Design-Build									
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
CA1	15	3	14	3	12	7	14	3	14	2
CA2	12	10	12	8	10	8	10	8	10	7
CA3	5	10	5	8	8	8	6	8	9	8
Median	12.00	10.00	12.00	8.00	10.00	8.00	10.00	8.00	10.00	7.00
AVERAGE	10.67	7.67	10.33	6.33	10.00	7.67	10.00	6.33	11.00	5.67
SD	5.13	4.04	4.73	2.89	2.00	0.58	4.00	2.89	2.65	3.21

Table F. 10 - Survey 2: Overall Assessment Results of CDS Alternatives under Design-Build Delivery System

Design-Build										
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
Median	12.00	10.00	12.00	8.00	11.00	8.00	10.00	8.00	12.00	8.00
Average	11.00	8.60	11.40	7.73	10.67	9.47	10.27	9.27	11.00	8.67
SD	3.36	3.27	2.77	3.35	2.85	2.45	2.84	2.91	3.07	4.27

Table F. 11 – Survey 2: Comments on Performance Assessment of Commissioning Alternatives under Design-Bid-Build Delivery System

Communication	We don't know the personalities involved, but the social skills of the commissioning provider are key. There is no guarantee that the owner-led CxP will perform his role with good social skills. My choices represent a conservative expectation.
	We have found it necessary to directly manage this process rather than leaving it up to one of the consultants being evaluated - never allow someone to rate theirselves as to value to you if you are the owner and are paying the bills
	The designer does not have a direct contractural relationship with all parties for his design work and people will be confused as to whethjer he is talking as the project designer or as the commissioning agent and there may be conflict between the two. Communications will never be perfect and that is why I did not give it a 15.
	Cx under the owner control is a direct communication as compaired to disigner led. The communication will have an add layer thru disigner.
	The OLC communication is ususally limits the ability of the AE to get the full information directly and expeidiously.
	The designer led approach could lead to some conflicts of interest and hinder the speed at which information is communicated since they have to protect their interests. The owner led approach could lead to issues of conflict within the team (usually about scope of work issues)but communication should not be negatively impacted.
	Both approaches have merits - designers tend to be more knowledgeable and involved in the contractural and technical aspects of a project. Owners will have a better idea of what they want - but may tend to confuse the contractural obligations of the various particiapants due to lack of knowledge of the construction process. Both parties tend to be locked in to their respective obligations and may be miss the "big picture" because of their other obligations to the project.
	To give a fair judgement (and using a controlled mental experiment) of this and the following questions in an attempt to eliminate the obvious difference between whether the owner chooses to go with a 3rd party or do it himself and whether the designer chooses to go with a 3rd party or do it himself, I took the perspective of how the SAME 3rd party firm hired by the owner OR the designer, would perform under either circumstances.
	I rated designer-led Cx a little higher than owner-led because persons in the same A/E firm may be involved in design and Cx, thus reducing one line of communication in the process.
Validation	Who is the Owner? Typically, the owner comprises several parties as stakeholders. Is the funder the owner? Or the users? Are the O&M staff owners? If the "owner" is of multiple minds, the CxP has a difficult task validating the project requirements. Is tough when owner-led. Is extra tough when designer-led.
	here it is necessary for the owner to have written requirements for the process to be of maximum value. We have written standards AND require the devwelopment of a formal DESIGN INTENT DOCUMENT
	No one knows what the Owner wants or needs (or better yet expects) than the owner. the designer will probably be in a better position to offer solutions to problems than the owner.
	In my experience, Owners do not spend the time necessary to understand the details of the project or do not share completely their idea of operational intent.
	same comment as above..
	Designers tend to have a better grasp of the syustemes and their relationships then do owners.

Table F.11 (Continued)

Collaboration	Positive, constructive relationships will depend upon personalities, of course, but also upon how informed the constructor was about roles and responsibilities at the time of placing his bid under D-B-B within the context of Cx as an element in the project.
	The owner is the only one that can require full cooperation between ALL entities A consultant will make himself look good aat the expence of the owner when possible - do not do this
	Once the "honeymoon" period is over, the designer and the contractor will begin the battle that exists on most projects about intent, clarity and mistakes.
	Whenever there are separate contracts there there is conflict. The best collaboration comes from a single source CM contract with a reputable team.
Integration	While owner-led Cx should be still somewhat stronger in this regard, designer-led Cx fares better than in other categories, I think.
	It wil be integrated only if the owner requires it to be. It requires full written standards and total involvment of the owner with the working knowledge of how this process works
	The designer will be more knowledgable as to who is really doing what on the job than the owner will be so he/she will be better at integrating the commissioning with the design work.
	DLC approach puts the responsibility to not only commission the building but solve any problems that come up.
	same as above, integration should not be affected by the contract structure , it's driven by the people.
	Again, design team members tend to have a better understanding of the construction process and relationships.
Integrity	Most common criticism of designer-led Cx and integrity is expressed in the "fox watching the henhouse" analogy. Here, the henhouse is knowledge about the project that must be distributed among the parties. Under designer-led Cx, there is much concern that the owner's project requirements will morph into something else undetected and unpoliced.
	Commissioning provider has authority ONLY if supported by the owner Without the support of the owner there is NO authority of the commissioning provider
	The owner can dictate integrity into the process whereas the designer's "dictates" will be suspect by everyone as being self serving.
	DLC method usually has the "shops" part of the owner less than helpful in making for a successful result.
	Once again , I see the inherent conflict when the designer will have to protect his interest instead of a totally objective 3rd party performing the commissioning. The 3rd party approach eliminates the potential conflicts of interest , but it does introduce another member of the team that must be dealt with
	"protect" their design rather than be as independent and objective as would sometimes be desired.

Table F. 12 - Survey 2: Comments of Performance Assessment of Commissioning Alternatives under Design-Build Delivery System

Communication	DBLC often leaves the owner out of the information.
	The DB delivery method crys out for independent Cx. There is too much incentive to hold information close to the DB.
	While design-build simplifies construction for the owner - it removes a level of controll
	The Owner is in no position to know who is responsible for what whereas the design-builder knows exactly and everyone works for him/her.
	The CxA has an obligation to the owner different than the Design Builder.
	the DB led team has much more at risk and you would have to question their thoroughness/accuracy because now we are looking at a single entity to "fix" the problem , much more is at stake.
	My experience with design-build led commissioning is that it tends to exagerate the worst features of design led commissioning as the design build team has a strong incentive to "cover" for any problems or mistakes made in the process. Owner led, in this scenario, has the same problems - general lack of knowledge of the technical aspects and often limited knowledge of the construction process - but in this scenario MAY be the best answer.
	Owner starts out will good intentions but then falls off as other competing events ocuur and take away focus.
Validation	DBLC has a contract to deliver and has a fiduciary responsibility to deliver a completely functioning project
	The incentive is to validate the DB decisions under DB-led Cx, not the OPR outcomes.
	The owner knows what he needs and wants and this is his chance to see if the design/builder understood and is getting it right.
	As mentioned above, design-build led commissioning tends to cover and compensate for problems and field deficiencies. Owner led, by virtue of being directed at protecting the Owner's interests and being done by/for the owner, tends to work better.
	our experience finds that the owner is just interested in the forms and does not understand the impact of the process.
Collaboration	DBLC team wants the project to work right as soon as possible since profitablity and repeat work depend on it.
	Collaboration is less an issue for quality under DB-led Cx
	Relationship between designer and contractor reduces the ability of the owner to controll the process
	Everyone works for the designer/builder, not the owner. He/she can drive effective collaboration wheas the Owner will be into someone else's relationships and won't have a clear understanding as to who is exactly responsible for what.
	For this, neither side has nay inherent advantqages or disadvantages, While the design build team SHOULD be better integrated, my experience has been that they are often as disjointed as any other design-bid-build team. The Owner, while knowing more from his side of the project, often does not have the construction ability to interact well with the construction team - and their being contractually bound to the design side of the project can result in objectivity and communication problems to the Owner - the actual consumer of the commissioning service.
	Whenever there are separte contracts, Cx Authority and Designers are at odds. Each protecting their interests.

Table F. 12 – (Continued)

Integration	Similar to collaboration. Again, integration and collaboration are no guarantees of the realization of the OPR under DB.
	The design/builder knows who is responsible for what and can integrate the commissioning work based on detailed knowlege of the process and contracts that are in place.
	Same comment - both have obstacles in the integration in a design-build process. Not to say it could not work well - just that my experience has been that it works no better than average.
Integrity	OLC is often not an intergral part of the team effort.
	Too much incentive to act in ways not on the positive behalf of the owner under DB-led Cx.
	Just not as good
	Again, the owner is not a participant in the delivery process but is the ultimate recipient of the product and as such is in no position to hold various participants "accountable" for their work. There may be gaps that the owner can not account for, but for which the designer/builder must and can.
	CxA A/E's and other professionals, hopefully, are more ethical.
	There is an inherent conflict of interest that is VERY hard to manage when the construction team is also esponsible for the commissioning process.

APPENDIX G

SURVEY 3

Introduction

Exit this survey >>

Thanks for your response to the second survey. The results of the second survey helped us to identify the relative performance value of each commissioning delivery system. This is the FINAL round of the three-part survey, aimed at validating the results of the previous survey.

In this survey, the summary results of the previous survey (your previous answer, the average of group response and also comments on each performance aspect) will be presented to you. You will be asked to reconsider your previous answers based on these summary results. If you wish to keep your previous answer, you can choose that answer from the menu.

We would like to remind you that based on the nature of the Delphi method, the identity of participants will be kept anonymous.

If you have any questions feel free to contact me at 404-449-4068 (cell) or ali@arch.gatech.edu.

Sincerely,

Ali Shakoorian,
Ph.D. Candidate
Building Construction Program
College of Architecture
Georgia Institute of Technology

Next >>

Section 1: Design-Bid-Build

Exit this survey >>

DESIGN-BID-BUILD PROJECT DELIVERY SYSTEM:

OPTION 1 (OWNER-LED COMMISSIONING):
In this option the Owner will assume the responsibility for the Commissioning Process. Therefore, either a staff member of the owner's organization will be selected as the commissioning authority OR owner will use services of a THIRD-PARTY commissioning consultant.

OPTION 2 (DESIGNER-LED COMMISSIONING):
In this option the owner passes the commissioning responsibility to the project designer through a SEPARATE commissioning contract. Under this option, the designer can choose to perform the commissioning activities himself OR use services of an external consultant. In either case, the Designer will hold the commissioning contract and will be responsible for this process.

*** How do you rank the COMMUNICATION (Clarity, Integrity, Directness) among entities?**

Comments:
- The Owner-led commissioning usually limits the ability of the AE to get the full information directly and expeditiously. There is a tendency to limit the information between parties.

- I rated designer-led Cx a little higher than owner-led because persons in the same A/E firm may be involved in design and Cx, thus reducing one line of communication in the process.

- We don't know the personalities involved, but the social skills of the commissioning provider are key.

- Cx under the owner control is a direct communication as compared to designer-led. The communication will have an added layer thru designer.

- The designer-led approach could lead to some conflicts of interest and hinder the speed at which information is communicated since they have to protect their interests. In the communication should not be negatively impacted.

Owner-Led: Group Average=**11.53** Your Answer=**15** Reconsidered Answer=

Designer-Led: Group Average=**8.20** Your Answer=**8** Reconsidered Answer=

Comments

* How do you rank the quality of VALIDATION (Thoroughness, Accuracy, Explicity)?

Comments:

- Both approaches have merits; Designers tend to be more knowledgeable and involved in the contractual and technical aspects of a project. Owners will have a better idea of what they want.

- Designer-led approach puts the responsibility to not only commission the building, but also solve any problems that come up.

- In my experience, Owners do not spend the time necessary to understand the details of the project or do not share completely their idea of operational intent.

- Designers tend to have a better grasp of the systems and their relationships then do owners.

- No one knows what the Owner wants or needs (or better yet expects) than the owner. The designer will probably be in a better position to offer solutions to problems than the owner.

- Who is the Owner? Typically, the owner comprises several parties as stakeholders. Is the founder the owner? Or the users? Are the O&M staff owners? If the "owner" is of multiple minds, the CxP has a difficult task validating the project requirements. Is tough when owner-led. Is extra tough when designer-led.

- It is necessary for the owner to have written requirements for the process to be of maximum value.

Owner-Led: Group Average=**11.53** Your Answer=**13** Reconsidered Answer=

Designer-Led: Group Average=**8.47** Your Answer=**13** Reconsidered Answer=

Comments

* **How do you rank the COLLABORATION (Cooperation, Interaction, Teamwork) among different entities?**

Comments:

- Positive, constructive relationships will depend upon personalities, of course, but also upon how informed the constructor was about roles and responsibilities at the time of placing his bid under D-B-B within the context of Cx as an element in the project.

- This is a tie between the 2 approaches, collaboration is usually not affected by the methodology of the procurement process, and it's about the individuals doing the work.

- Whenever there are separate contracts there is conflict. The best collaboration comes from a single source CM contract with a reputable team.

- Once the "honeymoon" period is over, the designer and the contractor will begin the battle that exists on most projects about intent, clarity and mistakes.

- Owner-led approach could lead to issues of conflict within the team (usually about scope of work issues).

- The owner is the only one that can require full cooperation between ALL entities. A consultant will make himself look good at the expense of the owner when possible.

Owner-Led: Group Average=**11.67** Your Answer=**15** Reconsidered Answer=

Designer-Led: Group Average=**8.20** Your Answer=**8** Reconsidered Answer=

Comments

*** How do you rank the INTEGRATION (Efficiency, Simplicity, Coordination) of the commissioning process into the Design and Construction process?**

Comments:

- Integration should not be affected by the contract structure; it's driven by the people.

- While owner-led Cx should be still somewhat stronger in this regard, designer-led Cx fares better than in other categories.

- Design team members tend to have a better understanding of the construction process and relationships.

- Designers tend to understand and be comfortable with the construction process and the usual contractual relationships.

- The designer will be more knowledgeable as to who is really doing what on the job than the owner will be so he/she will be better at integrating the commissioning with the design work.

- Third-part commissioning introduces another member of the team that must be dealt with.

- Owners may tend to confuse the contractual obligations of the various participants due to lack of knowledge of the construction process.

- The designer does not have a direct contractual relationship with all parties for his design work and people will be confused as to whether he is talking as the project designer or as the commissioning agent and there may be conflict between the two.

- It will be integrated only if the owner requires it to be. It requires full written standards and total involvement of the owner with the working knowledge of how this process works

- Both parties tend to be locked into their respective obligations and may miss the "big picture" because of their other obligations to the project.

Owner-Led: Group Average=**10.27** Your Answer=**15** Reconsidered Answer=

Designer-Led: Group Average=**9.73** Your Answer=**11** Reconsidered Answer=

Comments

* **How do you rate the INTEGRITY (Authority, Accountability, Ethicality) of the commissioning process?**

Comments:
- Most common criticism of designer-led Cx and integrity is expressed in the "fox watching the henhouse" analogy. Here, the henhouse is knowledge about the project that must be distributed among the parties. Under designer-led Cx, there is much concern that the owner's project requirements will morph into something else undetected and unpoliced.

- Once again, I see the inherent conflict when the designer will have to protect his interest instead of a totally objective 3rd party performing the commissioning. The 3rd party approach eliminates the potential conflicts of interest,

- We have found it necessary to directly manage this process rather than leaving it up to one of the consultants being evaluated - never allow someone to rate themselves as to value to you if you are the owner and are paying the bills

- Owner-led will tend to be more "independent" than does a design team. Designers will often tend to "protect" their design rather than be as independent and objective as would sometimes be desired.

- The owner can dictate integrity into the process whereas the designer's "dictates" will be suspect by everyone as being self-serving.

- Commissioning provider has authority ONLY if supported by the owner. Without the support of the owner there is NO authority of the commissioning provider.

- Designer-Led method usually has the "shops" part of the owner less than helpful in making for a successful result.

Owner-Led: Group Average=**12.67** Your Answer=**15** Reconsidered Answer=

Designer-Led: Group Average=**6.87** Your Answer=**12** Reconsidered Answer=

Comments

Section 2: Design-Build

Exit this survey >>

Design-Build Delivery System

OPTION 1 (OWNER-LED COMMISSIONING):
In this option the Owner will assume the responsibility for the Commissioning Process. Therefore, either a staff member of the owner's organization will be selected as the commissioning authority OR owner will use the services of a THIRD-PARTY commissioning consultant.

OPTION 2 (DESIGN/BUILDER-LED COMMISSIONING):
In this option the owner passes the commissioning responsibility to the project design/builder through a SEPARATE commissioning contract. Under this option, the design/builder can choose to perform the commissioning activities himself OR use services of an external consultant. In either case, the designer/builder will hold the commissioning contract and will be responsible for this process.

*** How do you rank the COMMUNICATION (Clarity, Integrity, Directness) among entities?**

Comments:
- DB-led Commissioning often leaves the owner out of the information.

- The DB delivery method cries out for independent Cx. There is too much incentive to hold information close to the DB.

- Owner starts out with good intentions but then falls off as other competing events occur and take away focus.

Owner-Led: Group Average=**11.00** Your Answer=**15** Reconsidered Answer=

Design/Builder-Led: Group Average=**8.60** Your Answer=**11** Reconsidered Answer=

Comments

*** How do you rank the quality of VALIDATION (Thoroughness, Accuracy, Explicity)?**

Comments:
- DB-led Commissioning has a contract to deliver and has a fiduciary responsibility to deliver a completely functioning project.

- The owner knows what he needs and wants and this is his chance to see if the design/builder understood and is getting it right.

- The DB-led team has much more at risk and you would have to question their thoroughness/accuracy because now we are looking at a single entity to "fix" the problem, much more is at stake.

- The incentive is to validate the DB decisions under DB-led Cx, not the OPR outcomes.

- Design-build led commissioning tends to cover and compensate for problems and field deficiencies. Owner led, by virtue of being directed at protecting the Owner's interests and being done by/for the owner, tends to work better.

Owner-Led: Group Average=**11.40** Your Answer=**15** Reconsidered Answer=

Design/Builder-Led: Group Average=**7.73** Your Answer=**11** Reconsidered Answer=

Comments

* **How do you rank the COLLABORATION (Cooperation, Interaction, Teamwork) among different entities?**

Comments:
- DB-led Commissioning team wants the project to work right as soon as possible since profitability and repeat work depend on it.

- Everyone works for the designer/builder, not the owner. He/she can drive effective collaboration whereas the Owner will be into someone else's relationships and won't have a clear understanding as to who is exactly responsible for what.

- Whenever there are separate contracts, Cx Authority and Designers are at odds, each protecting their interests.

- Owner-led Commissioning is often not an integral part of the team effort.

- Collaboration is less an issue for quality under DB-led Cx.

Owner-Led: Group Average=**10.67** Your Answer=**15** Reconsidered Answer=

Design/Builder-Led: Group Average=**9.47** Your Answer=**11** Reconsidered Answer=

Comments

* **How do you rank the INTEGRATION (Efficiency, Simplicity, Coordination) of the commissioning process into the Design and Construction process?**

Comments:
- For this, neither side has any inherent advantages or disadvantages, while the design-build team SHOULD be better integrated, my experience has been that they are often as disjointed as any other design-bid-build team. The Owner, while knowing more from his side of the project, often does not have the construction ability to interact well with the construction team - and their being contractually bound to the design side of the project can result in objectivity and communication problems to the Owner - the actual consumer of the commissioning service.

- Both have obstacles in the integration in a design-build process. Not to say it could not work well - just that my experience has been that it works no better than average.

- The design/builder knows who is responsible for what and can integrate the commissioning work based on detailed knowledge of the process and contracts that are in place.

- Owner-led, in this scenario, has the same problems - general lack of knowledge of the technical aspects and often limited knowledge of the construction process

- The Owner is in no position to know who is responsible for what whereas the design-builder knows exactly and everyone works for him/her.

- Our experience finds that the owner is just interested in the forms and does not

understand the impact of the process.

- While design-build simplifies construction for the owner - it removes a level of control

- Similar to collaboration. Again, integration and collaboration are no guarantees of the realization of the OPR under DB.

Owner-Led: Group Average=**10.27** Your Answer=**13** Reconsidered Answer=

Design/Builder-Led: Group Average=**9.27** Your Answer=**13** Reconsidered Answer=

Comments

* **How do you rate the INTEGRITY (Authority, Accountability, Ethicality) of the commissioning process?**

Comments:
- Too much incentive to act in ways not on the positive behalf of the owner under DB-led Cx.

- There is an inherent conflict of interest that is VERY hard to manage when the construction team is also responsible for the commissioning process.

- Relationship between designer and contractor reduces the ability of the owner to control the process

- My experience with design-build led commissioning is that it tends to exaggerate the worst features of design-led commissioning as the design build team has a strong incentive to "cover" for any problems or mistakes made in the process.

- The CxA has an obligation to the owner different than the Design Builder.

- Again, the owner is not a participant in the delivery process but is the ultimate recipient of the product and as such is in no position to hold various participants "accountable" for their work. There may be gaps that the owner cannot account for, but for which the designer/builder must and can.

- CxA A/E's and other professionals, hopefully, are more ethical.

Owner-Led: Group Average=**11.00** Your Answer=**15** Reconsidered Answer=

Design/Builder-Led: Group Average=**8.67** Your Answer=**15** Reconsidered Answer=

Comments

<< Prev **Next >>**

Thanks! **Exit this survey >>**

I appreciate your feedback. I will contact you in the coming months to share the results of the study. Meanwhile, if you have any questions, please don't hesitate to contact me at 404-449-4068.

Thanks again!

Ali Shakoorian

<< Prev **Done >>**

APPENDIX H

SURVEY 3 RESULTS

Table H. 1 – Survey 3: Owners' Assessment of CDS Alternatives under Design-Bid-Build Delivery System

Design-Bid-Build										
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
Owner 1	15	8	13	10	12	8	11	11	15	10
Owner 2	-	-	-	-	-	-	-	-	-	-
Owner 3	10	5	11	6	11	6	10	7	12	5
Owner 4	12	9	13	8	12	7	12	9	12	6
Owner 5	13	6	12	9	13	6	6	11	14	6
Owner 6	12	7	12	7	12	7	12	7	12	7
Median	**12.00**	**7.00**	**12.00**	**8.00**	**12.00**	**7.00**	**11.00**	**9.00**	**12.00**	**6.00**
AVERAGE	**12.40**	**7.00**	**12.20**	**8.00**	**12.00**	**6.80**	**10.20**	**9.00**	**13.00**	**6.80**
SD	**1.82**	**1.58**	**0.84**	**1.58**	**0.71**	**0.84**	**2.49**	**2.00**	**1.41**	**1.92**

Table H. 2 – Survey 3: Designers' Assessment of CDS Alternatives under Design-Bid-Build Delivery System

	Design-Bid-Build									
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
AE1	5	13	5	14	7	14	7	14	10	15
AE2	13	11	12	9	11	11	10	10	14	10
AE3	7	10	8	12	7	10	6	10	10	8
Median	7.00	11.00	8.00	12.00	7.00	11.00	7.00	10.00	10.00	10.00
AVERAGE	8.33	11.33	8.33	11.67	8.33	11.67	7.67	11.33	11.33	11.00
SD	4.16	1.53	3.51	2.52	2.31	2.08	2.08	2.31	2.31	3.61

Table H. 3 – Survey 3: Contractors' Assessment of CDS Alternatives under Design-Bid-Build Delivery System

	Design-Bid-Build									
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
GC 1	8	7	8	7	6	4	7	6	6	6
GC 2	13	10	13	8	12	11	11	11	14	10
GC 3	12	10	13	11	12	9	8	13	14	6
Median	12.00	10.00	13.00	8.00	12.00	9.00	8.00	11.00	14.00	6.00
AVERAGE	11.00	9.00	11.33	8.67	10.00	8.00	8.67	10.00	11.33	7.33
SD	2.65	1.73	2.89	2.08	3.46	3.61	2.08	3.61	4.62	2.31

Table H. 4 – Survey 3: Building Commissioners' Assessment of CDS Alternatives under Design-Bid-Build Delivery System

	Design-Bid-Build									
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
CA1	14	6	14	4	14	8	12	8	15	1
CA2	9	10	12	10	12	10	11	10	13	7
CA3	10	9	6	5	12	10	9	9	9	7
Median	10.00	9.00	12.00	5.00	12.00	10.00	11.00	9.00	13.00	7.00
AVERAGE	11.00	8.33	10.67	6.33	12.67	9.33	10.67	9.00	12.33	5.00
SD	2.65	2.08	4.16	3.21	1.15	1.15	1.53	1.00	3.06	3.46

Table H. 5 – Survey 3: Overall Assessment of CDS Alternatives under Design-Bid-Build Delivery System

	Design-Bid-Build									
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
Median	12.00	9.00	12.00	8.50	12.00	8.50	10.00	10.00	12.50	7.00
Average	10.93	8.64	10.86	8.57	10.93	8.64	9.43	9.71	12.14	7.43
SD	2.87	2.24	2.88	2.74	2.43	2.59	2.24	2.27	2.60	3.20

Table H. 6 - Survey 3: Owners' Assessment of CDS Alternatives under Design -Build Delivery System

	Design-Build									
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
Owner 1	15	9	12	8	13	11	13	13	11	11
Owner 2										
Owner 3	10	5	11	5	11	8	10	8	12	6
Owner 4	10	7	11	8	11	8	11	9	10	8
Owner 5	5	13	12	4	6	13	6	12	11	8
Owner 6	12	7	12	7	12	7	12	7	12	10
Median	10.00	7.00	12.00	7.00	11.00	8.00	11.00	9.00	11.00	8.00
AVERAGE	10.40	8.20	11.60	6.40	10.60	9.40	10.40	9.80	11.20	8.60
SD	3.65	3.03	0.55	1.82	2.70	2.51	2.70	2.59	0.84	1.95

Table H. 7- Survey 3: Designers' Assessment of CDS Alternatives under Design -Build Delivery System

	Design-Build									
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
AE1	10	15	7	14	7	14	7	14	7	14
AE2	13	10	13	8	11	11	10	10	12	9
AE3	9	7	9	5	8	8	8	8	8	6
Median	10.00	10.00	9.00	8.00	8.00	11.00	8.00	10.00	8.00	9.00
AVERAGE	10.67	10.67	9.67	9.00	8.67	11.00	8.33	10.67	9.00	9.67
SD	2.08	4.04	3.06	4.58	2.08	3.00	1.53	3.06	2.65	4.04

Table H. 8 - Survey 3: Contractors' Assessment of CDS Alternatives under Design -Build Delivery System

	Design-Build									
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
GC 1	9	12	9	12	11	13	10	12	13	13
GC 2	13	7	13	8	13	8	12	7	13	6
GC 3	9	11	8	11	14	11	7	12	9	13
Median	9.00	11.00	9.00	11.00	13.00	11.00	10.00	12.00	13.00	13.00
AVERAGE	10.33	10.00	10.00	10.33	12.67	10.67	9.67	10.33	11.67	10.67
SD	2.31	2.65	2.65	2.08	1.53	2.52	2.52	2.89	2.31	4.04

Table H. 9 - Survey 3: Building Commissioners' Assessment of CDS Alternatives under Design -Build Delivery System

	Design-Build									
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
CA1	15	3	14	3	12	7	14	3	14	2
CA2	12	10	12	8	10	8	10	8	10	7
CA3	6	9	6	8	8	8	7	9	9	8
Median	12.00	9.00	12.00	8.00	10.00	8.00	10.00	8.00	10.00	7.00
AVERAGE	11.00	7.33	10.67	6.33	10.00	7.67	10.33	6.67	11.00	5.67
SD	4.58	3.79	4.16	2.89	2.00	0.58	3.51	3.21	2.65	3.21

Table H. 10 - Survey 3: Overall Assessment of CDS Alternatives under Design-Build Delivery System

	Design-Build									
	Communication		Validation		Collaboration		Integration		Integrity	
	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led	O-Led	D-Led
Median	10.00	9.00	11.50	8.00	11.00	8.00	10.00	9.00	11.00	8.00
Average	10.57	8.93	10.64	7.79	10.50	9.64	9.79	9.43	10.79	8.64
SD	2.98	3.22	2.44	3.04	2.41	2.44	2.49	2.95	2.04	3.32

Table H. 11 – Survey 3: Comments on Performance Assessments of Commissioning Alternatives under Design-Bid-Build Delivery System

Communication	I remain skeptical of designer-led Cx and think the gap between the two leadership methods is better reflected in my original rankings.
	Communicationis difficult but something we can control with effort
	I have changed my answer for the designer-led commissioning as I believe that the personalities are much more inportant than I was giving credit to. However, I see that the answers of the group agree with me as to the relative effectiveness of the two, the owner-led being more effectiove than the designer-led as I believe that the designer-led has a built-in self-interest factor that renders it much less objective than that of an owner-led effort.
	Communication is first between the CxA and the TAB who is normally under the Constractor then between the CxA and the Architect or Engineer. The Owner gets in the loop after the building is commissioned and ready for training, demonstration and setting up specific Owner set points. To always have to go through the Owner is problemattic.
	Involvement of the owner during the Cx process is more important than satisfing a design engineers curiosity. However,if a third party is used to lead the effort the benefit to the actual
	It depends on the skill level of the provider. Clearly, it is in the best interest of the Owner to self perform. However, rarely does the owner have the resources and time committtment to make it happen. To often a owner does not understand the process and concentrates on just filling out forms. Designer led commissioning if self performed runs into the issue of a broken communication chain das commissioning can be seen as a conflict of intrest.
Validation	I'll be a bit more generous with designer-led Cx validation, agreeing that designers might know systems well enough to merit more credit than I gave them originally.
	We think we are on the right track
	I agree with some of the statements made, but not all. I feel that the critism of the Owners is not realistic as there are both excellant and terrible owners and all the critisms about the owner-led efforts are based on the assumption that owners are not willing to make the effort or do not have the experience to lead a commissioning effort. The same assumption can be made about the designers, and my view is based on the assumption that both have the desire and skills to perform, but I believe that the desiners have a built in bias concerning their mistakes that will work to the detriment of the effort. I therefore still agree with my original conclusion.
	The Designer has the responsiblity to bring the project into alignment with the operational intent. If the operational intent was originally documented, the Desginer-led approach more thoroughly brings the final building to that state.
	Typically, the designer team doesn't really know how the systems are suppose to work and default to the controls installer. Unless this is a very technical project, neither the owner or designer understands the complexities of the system, hence the facilities operators should lead this effort with the support of the contractor, designer and perhaps a third part organizer.
Collaboration	I remain more skeptical of designer-led collaboration under D-B-B than our group average, but I concede toward the mean a bit.
	We will continue to work to improve this process
	I still agree with my original evaluation. I disagree that the methodology of the procurement process process will not have an effect on the commissioning process. People are human and if they made a mistake that could be costly to correct, I do not care how well-meaning they are, it will adversely affect the collaboration of the commissioning process.
	I always assume that people get up in the morning to do a great job, the one they are contracted to do. The Owner who hires a CxA in the first place is usually dependent on the Design team for input. There must be collaboration between the Deigners and the Constructors or the desired results will not be met. The Owner is a second tier collaborator.
	Collaboration is the result of a good team, good leadership and a single contract via a Constuction Manager.
	Owners tend to listen to internal staff more closely than designer led commissioning

Table H.11 (Continued)

Integration	We do have written standards that we use
	I believe that I was too hard on the Owner-led process concerning integration, but I still feel that integration will be better accomplished by the designer-led effort because they will be more familiar with the relative strengths and weaknesses of the members of the team and should have an outstanding understanding of the systems within the building.. However, I now realize that there is a flaw in the comments as they are based on the overriding assumption by some of the respondants that an owner does not have the desire or the capability to lead such an effort. This is a bias that reflects the experience of the participants and the survey may have been better served if there had been a discussion as to the relative capabilities of owners and designers and if possibly an assumption was made that we were dealing with a qualified owner, as my experience tells me that there are many such owners and perhaps we need to investigate ways
	It is critical to have the Designer, Constructor and Owner in the process to be fully effective. The Owner does command more attention but the Designer-led approach puts the responsiblity for integration on the two parties that can integrate things.
	A third party tends to confuse the team when trying to show their value.
Integrity	We do only third party commissioning
	I agree with the comments made and with my initial evaluation of the Owners, but I believe that I may have been too hard on the integrity of the designers. I still believe however, that the designers are being put in a position that is almost unfair to think that their integrity will not suffer because of their position between delivery of the project and commissioning. I have always believed that it is wrong to establish a condition that will tempt honest men and that is what you are doing when you initiate a designer-led commissioning process unless they made no mistakes,
	I would hope all parties would be interested in getting the correctly operational building as soon as possible. The professionalism of each party will determine that. Both the designer and the constructor are under contract to do their job well and correctly without a conflict of interest.
	The integrity is contingent on the people, Professional Engineers are some of the most Ethical people in the world. Choose the people well.
	In my experience, accountability of the CxA themselves (with their many deliverables) has much to be desired of in the Owner-led commissioning delivery method. This typically is due to the Cx Process being new to many owners. If this is the case for Owner-led, the Designer-led commissioning delivery method is far worse.

Table H. 12 – Survey 3: Comments on Performance Assessments of Commissioning Alternatives under Design -Build Delivery System

Communication	Obviously, I pulled down the average, perhaps being too harsh on DB-led Cx. I maintain that there is a severe gap likely relative to communication with DB-led Cx on the poorer side of the equation.
	I believe that the Owner has relinquished control of the development to the design-build team except for relative broad parameters and the details are controlled by the design-build team. Therefore, the design-build team are best for doing the commissioning as they are responsible for delivering the project to meet the specific criteria set out in the design-build RFP and that the owner will check, but usually there is a lot more that is verified during the commissioning process that the design-build team will verify.
	If the performance specification accurately respresents the operational intent, the results will be the responsiblity of the DB anyway.
	A single contract and strong design build team will provide the best value to the owner. The contractor knows the schedule and integrates the team for success.
	DB tends to concentrate more on cost than quality in either case. In other 15 cases with DOE DB tends to giver you 70% of what the client actually needs at 80% of the cost as compared to Design Bid Build
Validation	I'm an outlier, again, on DB-led Cx. I moderate my score but maintain the severe gap regarding validation.
	The owner has issued more of a performance RFI and the design-build team is best suited to insure that the various componants are capable of delivering the proper performance of the building to meet the performance criteria set by the owner.
	Total building commissioning requires the team approach. The DB-led approach puts the responsiblity for accuracy on the correct party.
	The design bulder wants to complete the project within the intent of the owners needs to reduce call backs and be hired for the next project.
Collaboration	Comfortable with original ratings.
	Relationships will already exist within the DB team and therefore clear relationships will already exist and be understood by everyone, so collaboration will be more natural than if led by the owner.
	DB-led commissioning puts the leadership on the party that is responsible for and can achieve the final operational intent.
	Collaboration is a result of a single contract where everyone is working towards a single end result.
Integration	Comfortable with original ratings.
	Integration within the DB led team will be supoerior to that of an owner led effort because the team has had to integrate their effort fto complete construction whereas the owner has little experience with the relationships that hve already been established and the process in place..
	The DB team can call on the CxA to do a progressive commissioning at the appropriate time as the project progresses.
Integrity	As an outlier, again, on DB-led Cx, I moderate but continue to assert a severe gap.
	After being involved in a project over the last few months, I now agree that even though I expected that the integrity of professionals would be strong within a DB team during commisioning, I am now convinced that this is not necessarily so, and integrity within an owner led commissioning team will probably be better.
	The DB is responsible for the complte result and must be held accountable for that. No building works perfectly until the Cx process is complete. Owners should require the results, not manage the process.
	I see no reason to change my answer to this, or any of the other questions. I note that I do tend to be a bit different from the "norm" of this sample, but that is one of the reasons for seeking the input from a number of people. Good luck with your project - I look forward to the final results.
	In today's market the reputable design builder is as ethical as any engineer, the key is selection of a strong honest team.

APPENDIX I

DSM MODELS

		O_P_1_Select C 1	O_P_2_Select A 2	C_P_1_Form Co 3	C_P_2_Set up (4	C_P_3_Develop 5	O_P_3_Review (6	O_P_4_Accept (7	C_P_4_Determir 8	O_P_5_Review (9	O_P_6_Accept S 10	C_P_5_Develop 11	O_P_7_Review (12	O_P_8_Accept (13	C_P_6_Develop 14	C_P_7_Develop 15	C_P_8_Develop 16	O_P_9_Submit (18	C_P_9_Develop 17	O_P_10_Review 19	O_P_11_Accept 20	A_P_1_Review (21	C_D_1_Set up P 22	A_D_1_Start De 23
O_P_1_Select CxA	1	1																						
O_P_2_Select AE	2		2																					
C_P_1_Form Commissioning Team	3	1		3																				
C_P_2_Set up OPR Meeting	4			1	4																			
C_P_3_Develop OPR	5				1	5		1																
O_P_3_Review OPR	6					1	6																	
O_P_4_Accept OPR	7						1	7																
C_P_4_Determine Cx Scope & Budget	8							1	8		1													
O_P_5_Review Cx Scope & Budget	9								1	9														
O_P_6_Accept Scope & Budget	10									1	10													
C_P_5_Develop Initial Cx Plan	11										1	11		1										
O_P_7_Review Cx Plan	12											1	12											
O_P_8_Accept Cx Plan	13												1	13										
C_P_6_Develop Training Requirement O	14											1		1	14									
C_P_7_Develop Initial Format for Issues	15											1		1		15								
C_P_8_Develop Scope & Format for Proj	16											1		1			16							
O_P_9_Submit OPR and Cx Plan for AE	18		1											1				18						
C_P_9_Develop Pre-Design Cx Report	17																1		17		1			
O_P_10_Review Pre-Design Cx Report	19																		1	19				
O_P_11_Accept Pre-Design Cx Report	20																			1	20			
A_P_1_Review OPR and Cx Plan	21																	1				21		
C_D_1_Set up Pre-Design Cx Meeting	22																		1		1	1	22	
A_D_1_Start Design	23																						1	23

Figure I. 1 - DSM Model for Pre-Design Phase of Owner-led Commissioning

		O_P_1_Select A	A_P_1_Select C	C_P_1_Form Co	C_P_2_Set up C	C_P_3_Develop	A_P_2_Review (	A_P_3_Accept C	O_P_2_Review (	O_P_3_Accept (	C_P_4_Determir	A_P_4_Review (	A_P_5_Accept C	O_P_4_Review (	O_P_5_Accept (	C_P_5_Develop	A_P_6_Review (	A_P_7_Accept C	O_P_6_Review (	O_P_7_Accept (	C_P_6_Develop	C_P_7_Develop	C_P_8_Develop	C_P_9_Develop	A_P_8_Review F	A_P_9_Accept F	O_P_8_Review I	O_P_9_Accept F	C_D_1_Set up P	A_D_1_Start De
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
O_P_1_Select AE	1	1																												
A_P_1_Select CxA	2	1	2																											
C_P_1_Form Commissioning Team	3		1	3																										
C_P_2_Set up OPR Meeting	4			1	4																									
C_P_3_Develop OPR	5				1	5		1																						
A_P_2_Review OPR	6					1	6																							
A_P_3_Accept OPR	7						1	7		1																				
O_P_2_Review OPR	8							1	8																					
O_P_3_Accept OPR	9								1	9																				
C_P_4_Determine Cx Scope and Budget	10									1	10		1																	
A_P_4_Review Cx Scope & Budget	11										1	11																		
A_P_5_Accept Cx Scope & Budget	12											1	12		1															
O_P_4_Review Cx Scope & Budget	13												1	13																
O_P_5_Accept Cx Scope & Budget	14													1	14															
C_P_5_Develop Initial Cx Plan	15														1	15		1												
A_P_6_Review Cx Plan	16															1	16													
A_P_7_Accept Cx Plan	17																1	17		1										
O_P_6_Review Cx Plan	18																	1	18											
O_P_7_Accept Cx Plan	19																		1	19										
C_P_6_Develop Training Requirement O	20															1		1		1	20									
C_P_7_Develop Initial Format for Issues	21															1		1		1		21								
C_P_8_Develop Scope & Format for Proj	22															1		1		1			22							
C_P_9_Develop Pre-Design Cx Report	23																						1	23		1				
A_P_8_Review Pre-Design Cx Report	24																							1	24					
A_P_9_Accept Pre-Design Cx Report	25																								1	25		1		
O_P_8_Review Pre-Design Cx Report	26																									1	26			
O_P_9_Accept Pre-Design Cx Report	27																										1	27		
C_D_1_Set up Pre-Design Cx Meeting	28																							1		1		1	28	
A_D_1_Start Design	29																												1	29

Figure I. 2 - DSM Model for Pre-Design Phase of AE-led Commissioning

		C_D_1_Set up P 1	A_D_1_Start De 2	A_D_2_Design 3	A_D_3_Prepare 4	A_D_4_Submit D 5	O_D_1_Review I 6	O_D_2_Submit D 7	C_D_7_Review O 8	C_D_2_Review D 9	C_D_8_Verify OI 14	C_D_10_Update 16	O_D_4_Review I 17	O_D_5_Accept U 18	O_D_6_Submit U 19	A_D_5_Update O 20	C_D_3_Determir 10	C_D_4_Determir 11	C_D_5_Develop 12	C_D_6_Determir 13	C_D_9_OK Desi 15	O_D_3_Accept D 21	C_D_11_Develo 22	O_D_7_Review C 23	A_D_6_Review C 24	O_D_8_Review A 25	O_D_9_Accept C 26	A_D_7_Prepare 27	A_D_8_Incorpora 28	C_D_12_Set up 29	O_D_10_Bid the 30	C_D_13_Prepare 32	O_D_12_Review 33	A_D_9_Review D 34	O_D_13_Review 35	O_D_14_Accept 36	O_D_11_Select 31	C_D_14_Update 37	C_D_15_Set up 38	G_C_1_Start Co 39
C_D_1_Set up Pre-Design Meeting	1	1																																						
A_D_1_Start Design	2	1	2																																					
A_D_2_Design	3		1	3	1											1																								
A_D_3_Prepare Basis of Design	4		1	1	4																																			
A_D_4_Submit Design & BOD for Reviev	5			1	1	5																																		
O_D_1_Review Design & BOD	6					1	6																																	
O_D_2_Submit Design & BOD Comment	7						1	7																																
C_D_7_Review Owner Comments	8							1	8																															
C_D_2_Review Design & BOD	9					1				9																														
C_D_8_Verify OPR & BOD	14								1	1	14																													
C_D_10_Update OPR & BOD	16										1	16		1																										
O_D_4_Review Updated OPR & BOD	17											1	17																											
O_D_5_Accept Updated OPR & BOD	18												1	18																										
O_D_6_Submit Updated OPR & BOD for	19													1	19																									
A_D_5_Update OPR & BOD	20														1	20																								
C_D_3_Determine System Manual Struct	10					1											10																							
C_D_4_Determine Construction Checklis	11					1												11																						
C_D_5_Develop Construction and O&M T	12					1													12																					
C_D_6_Determine Training Requirement	13					1														13																				
C_D_9_OK Design	15										1										15																			
O_D_3_Accept Design	21																				1	21																		
C_D_11_Develop Cx Requirements for C	22											1		1			1	1	1	1	1		22				1													
O_D_7_Review Cx Requirements for Cor	23																						1	23																
A_D_6_Review Cx Requirements for Cor	24																						1		24															
O_D_8_Review AE Comments on Cx Re	25																								1	25														
O_D_9_Accept Cx Requirements for Con	26																							1		1	26													
A_D_7_Prepare Contract Documents	27					1																1						27												
A_D_8_Incorporate Cx Requirements in (	28																						1				1	1	28											
C_D_12_Set up Pre-bid Meeting	29																												1	29										
O_D_10_Bid the Project	30																													1	30									
C_D_13_Prepare Design Phase Cx Repo	32																													1		32				1				
O_D_12_Review Design Phase Cx Repo	33																															1	33							
A_D_9_Review Design Phase Cx Report	34																															1		34						
O_D_13_Review AE Comments on Cx R	35																																	1	35					
O_D_14_Accept Design Phase Cx Repor	36																																1		1	36				
O_D_11_Select the Contractor	31																														1						31			
C_D_14_Update Cx Team	37																																				1	37		
C_D_15_Set up Pre-construction Meeting	38																															1				1		1	38	
G_C_1_Start Construction	39																																						1	39

Figure I. 3 - DSM Model for Design Phase of Owner-led Commissioning

		C_D_1_Set up P 1	A_D_1_Start De 2	A_D_2_Design 3	A_D_3_Prepare 4	A_D_4_Submit D 5	O_D_1_Review I 6	O_D_2_Submit D 7	C_D_7_Review (8	C_D_2_Review I 9	C_D_8_Verify O 14	C_D_10_Update 16	O_D_4_Review 17	O_D_5_Accept 18	O_D_6_Submit 19	A_D_5_Update (20	C_D_3_Determi 10	C_D_4_Determi 11	C_D_5_Develop 12	C_D_6_Determi 13	C_D_9_OK Desi 15	O_D_3_Accept D 21	C_D_11_Develo 22	O_D_7_Review 23	A_D_6_Review 24	O_D_8_Review 25	O_D_9_Accept 26	A_D_7_Prepare 27	A_D_8_Incorpor 28	C_D_12_Set up 29	O_D_10_Bid the 30	C_D_13_Prepar 32	O_D_12_Review 33	A_D_9_Review I 34	O_D_13_Review 35	O_D_14_Accept 36	O_D_11_Select 31	C_D_14_Update 37	C_D_15_Set up 38	G_C_1_Start Co 39
C_D_1_Set up Pre-Design Meeting	1	1																																						
A_D_1_Start Design	2	1	2																																					
A_D_2_Design	3		1	3	1											1																								
A_D_3_Prepare Basis of Design	4		1	1	4																																			
A_D_4_Submit Design & BOD for Reviev	5			1	1	5																																		
O_D_1_Review Design & BOD	6					1	6																																	
O_D_2_Submit Design & BOD Comment	7						1	7																																
C_D_7_Review Owner Comments	8							1	8																															
C_D_2_Review Design & BOD	9					1				9																														
C_D_8_Verify OPR & BOD	14								1	1	14																													
C_D_10_Update OPR & BOD	16										1	16		1																										
O_D_4_Review Updated OPR & BOD	17											1	17																											
O_D_5_Accept Updated OPR & BOD	18												1	18																										
O_D_6_Submit Updated OPR & BOD for	19													1	19																									
A_D_5_Update OPR & BOD	20														1	20																								
C_D_3_Determine System Manual Struct	10					1											10																							
C_D_4_Determine Construction Checklis	11					1												11																						
C_D_5_Develop Construction and O&M T	12					1													12																					
C_D_6_Determine Training Requirement	13					1														13																				
C_D_9_OK Design	15										1										15																			
O_D_3_Accept Design	21																				1	21																		
C_D_11_Develop Cx Requirements for C	22											1		1			1	1	1	1	1		22				1													
O_D_7_Review Cx Requirements for Cor	23																						1	23																
A_D_6_Review Cx Requirements for Cor	24																						1		24															
O_D_8_Review AE Comments on Cx Re	25																								1	25														
O_D_9_Accept Cx Requirements for Con	26																							1		1	26													
A_D_7_Prepare Contract Documents	27					1																1						27												
A_D_8_Incorporate Cx Requirements in (	28																						1				1	1	28											
C_D_12_Set up Pre-bid Meeting	29																												1	29										
O_D_10_Bid the Project	30																													1	30									
C_D_13_Prepare Design Phase Cx Repo	32																													1		32				1				
O_D_12_Review Design Phase Cx Repoı	33																															1	33							
A_D_9_Review Design Phase Cx Report	34																															1		34						
O_D_13_Review AE Comments on Cx R	35																																	1	35					
O_D_14_Accept Design Phase Cx Repor	36																																1		1	36				
O_D_11_Select the Contractor	31																														1						31			
C_D_14_Update Cx Team	37																																				1	37		
C_D_15_Set up Pre-construction Meeting	38																															1				1		1	38	
G_C_1_Start Construction	39																																						1	39

Figure I. 4 - DSM Model for Design Phase of AE-led Commissioning

		G_C_1_Start Co (1)	G_C_2_Construc (2)	G_C_3_Prepare (3)	G_C_4_Perform (4)	G_C_5_Submit S (5)	C_C_1_Review & (6)	O_C_2_Review C (7)	O_C_1_Review & (8)	O_C_3_Submit O (9)	A_C_1_Review S (10)	A_C_2_Review O (11)	A_C_3_Approve (12)	G_C_6_Resolve (13)	C_C_2_Verify Co (14)	C_C_3_Develop (15)	C_C_4_Direct & (16)	G_C_7_Perform (17)	C_C_5_Review T (18)	A_C_4_Review & (19)	O_C_5_Review A (20)	O_C_4_Review T (21)	O_C_6_Submit O (22)	C_C_6_Review O (23)	C_C_8_Update O (25)	O_C_7_Review U (26)	A_C_6_Review & (27)	O_C_8_Review D (28)	O_C_9_Accept U (29)	C_C_9_Recomm (30)	O_C_11_Review (31)	G_C_8_Resolve (32)	C_C_7_OK Syst (24)	A_C_5_Recomm (33)	O_C_10_Accept (34)	C_C_10_Prepar (35)	O_C_13_Review (36)	A_C_7_Review & (37)	O_C_12_Review (38)	O_C_14_Accept (39)	O_O_1_Occupan (40)
G_C_1_Start Construction	1	1																																							
G_C_2_Construction	2	1	2																																						
G_C_3_Prepare System Manual	3	1		3																																					
G_C_4_Perform Training	4	1			4																																				
G_C_5_Submit Submittals	5		1	1	1	5								1																											
C_C_1_Review & Comment on Submittal	6					1	6																																		
O_C_2_Review CxA Comments on Subm	7						1	7																																	
O_C_1_Review & Comment on Submitta	8					1			8																																
O_C_3_Submit Owner & CxA Submittal (	9							1	1	9																															
A_C_1_Review Submittals	10					1					10																														
A_C_2_Review Owner & CxA Submittal (	11									1		11																													
A_C_3_Approve Submittals	12										1	1	12																												
G_C_6_Resolve Sumittal Issues	13												1	13																											
C_C_2_Verify Construction Checklist	14						1						1		14																										
C_C_3_Develop Test Requirements	15						1						1			15																									
C_C_4_Direct & Verify Tests	16														1	1	16																								
G_C_7_Perform Tests	17																1	17														1									
C_C_5_Review Test Results	18																	1	18																						
A_C_4_Review & Comment on Test Resu	19																	1		19																					
O_C_5_Review AE Comments on Test R	20																			1	20																				
O_C_4_Review Test Results	21																	1				21																			
O_C_6_Submit Owner & AE Test Comme	22																				1	1	22																		
C_C_6_Review Owner & AE Test Comme	23																						1	23																	
C_C_8_Update OPR & BOD	25																		1					1	25				1												
O_C_7_Review Updated OPR & BOD	26																								1	26															
A_C_6_Review & Comment on Updated (	27																								1		27														
O_C_8_Review Designer Comments on U	28																										1	28													
O_C_9_Accept Updated OPR & BOD	29																									1		1	29												
C_C_9_Recommend Modifications	30																		1					1	1				1	30											
O_C_11_Review and Require Modificatio	31																													1	31										
G_C_8_Resolve Issues	32																														1	32									
C_C_7_OK Systems	24																		1					1	1				1				24								
A_C_5_Recommend Final Acceptance	33																			1														33							
O_C_10_Accept Construction	34																							1										1	34						
C_C_10_Prepare Construction Cx Report	35																																1			35				1	
O_C_13_Review Construction Cx Report	36																																			1	36				
A_C_7_Review & Comment on Construct	37																																			1		37			
O_C_12_Review AE Comments on Cons	38																																					1	38		
O_C_14_Accept Construction Cx Report	39																																				1		1	39	
O_O_1_Occupancy	40																																		1	1				1	40

Figure I. 5 - DSM Model for Construction Phase of Owner-led Commissioning

		G_C_1_Start Co 1	G_C_2_Construc 2	G_C_3_Prepare 3	G_C_4_Perform 4	G_C_5_Submit S 5	O_C_1_Review & 6	A_C_1_Review S 7	C_C_1_Review & 8	A_C_2_Review O 9	A_C_3_Review C 10	A_C_4_Approve 11	G_C_6_Resolve 12	C_C_2_Verify Co 13	C_C_3_Develop 14	C_C_4_Direct & 15	G_C_7_Perform 16	O_C_2_Review & 17	A_C_6_Review O 18	A_C_5_Review & 19	A_C_7_Submit O 20	C_C_5_Review T 21	C_C_6_Review A 22	C_C_8_Update O 24	A_C_9_Review U 25	A_C_10_Accept 26	O_C_4_Review U 27	O_C_5_Accept U 28	C_C_9_Recomm 29	A_C_11_Review 30	O_C_6_Review a 31	G_C_8_Resolve 32	C_C_7_Ok Syste 23	A_C_8_Recomm 33	C_C_10_Prepare 35	A_C_12_Review 36	A_C_13_Accept 37	O_C_7_Review C 38	O_C_8_Accept C 39	O_C_3_Accept C 34	O_C_9_Occupan 40
G_C_1_Start Construction	1 |1|																																							
G_C_2_Construction	2	1	2																																						
G_C_3_Prepare System Manuals	3	1		3																																					
G_C_4_Perform Training	4	1			4																																				
G_C_5_Submit Submittals	5		1	1	1	5						1																													
O_C_1_Review & Comment on Submitta	6					1	6																																			
A_C_1_Review Submittals	7					1		7																																		
C_C_1_Review & Comment on Submittal	8					1			8																																	
A_C_2_Review Owner's Submittal Comm	9						1			9																																
A_C_3_Review CxA Submittals Commer	10								1		10																															
A_C_4_Approve Submittals	11							1		1	1	11																														
G_C_6_Resolve Submittal Issues	12											1	12																													
C_C_2_Verify Construction Checklist	13								1			1		13																												
C_C_3_Develop Test Procedures	14								1			1			14																											
C_C_4_Direct & Verify Tests	15													1	1	15																										
G_C_7_Perform Tests	16															1	16															1										
O_C_2_Review & Comment on Test Res	17																1	17																								
A_C_6_Review Owner's Test Comments	18																	1	18																							
A_C_5_Review & Comment on Test Resı	19																1			19																						
A_C_7_Submit Owner & AE Test Comme	20																		1	1	20																					
C_C_5_Review Test Results	21																1					21																				
C_C_6_Review AE & Owner Comments	22																				1		22																			
C_C_8_Update OPR & BOD	24																					1	1	24		1																
A_C_9_Review Updated OPR & BOD	25																							1	25																	
A_C_10_Accept Updated OPR & BOD	26																								1	26		1															
O_C_4_Review Updated OPR & BOD	27																									1	27															
O_C_5_Accept Updated OPR & BOD	28																										1	28														
C_C_9_Recomment Modifications	29																					1	1	1				1	29													
A_C_11_Review & Submit CxA Recomm	30																												1	30												
O_C_6_Review and Require Modification	31																													1	31											
G_C_8_Resolve Issues	32																														1	32										
C_C_7_Ok Systems	23																					1	1	1				1					23									
A_C_8_Recommend Final Acceptance	33																				1												1	33								
C_C_10_Prepare Construction Cx Report	35																																1		35		1				
A_C_12_Review Construction Cx Report	36																																		1	36					
A_C_13_Accept Construction Cx Report	37																																			1	37		1		
O_C_7_Review Construction Cx Report	38																																				1	38			
O_C_8_Accept Construction Cx Report	39																																					1	39		
O_C_3_Accept Construction	34																																	1						34	
O_C_9_Occupancy	40																																		1				1	1	40

Figure I. 6 - DSM Model for Construction Phase of AE-led Commissioning

		O_O_1_Occupa	C_O_1_Coordia	C_O_2_Coordin	C_O_3_Direct &	G_O_1_Resolve	G_O_2_Perform	A_O_1_Review	O_O_2_Review	O_O_3_Review	O_O_4_Submit	C_O_5_Review	C_O_4_Review	C_O_7_Recomm	O_O_6_Review	C_O_6_OK Syst	O_O_5_Final Ac	C_O_8_Conven	C_O_9_Prepare	A_O_2_Review	O_O_7_Review	O_O_8_Review	O_O_9_Accept F	C_O_10_End of
		1	2	3	4	5	6	7	8	9	10	11	12	14	15	13	16	17	18	19	20	21	22	23
O_O_1_Occupancy	1	1																						
C_O_1_Coordiante Contractor Call Backs	2	1	2																					
C_O_2_Coordinate Warranty Reviews	3	1		3																				
C_O_3_Direct & Verify Seasonal Tests	4	1			4																			
G_O_1_Resolve Issues	5		1	1		5									1									
G_O_2_Perform Required Tests	6				1	1	6																	
A_O_1_Review & Comment on Test Res	7						1	7																
O_O_2_Review Test Results	8						1		8															
O_O_3_Review AE Comments	9							1		9														
O_O_4_Submit AE & Owner Test Comm	10								1	1	10													
C_O_5_Review Owner & AE Test Comm	11										1	11												
C_O_4_Review Test Results	12						1						12											
C_O_7_Recommend Modifications	14											1	1	14										
O_O_6_Review and Require Modificatior	15													1	15									
C_O_6_OK Systems	13											1	1			13								
O_O_5_Final Acceptance	16															1	16							
C_O_8_Convene Lessons Learned Meeti	17															1		17						
C_O_9_Prepare Final Cx Report	18																	1	18				1	
A_O_2_Review & Comment on Final Cx	19																		1	19				
O_O_7_Review Final Cx Report	20																		1		20			
O_O_8_Review AE Comments on Final (	21																			1		21		
O_O_9_Accept Final Cx Report	22																				1	1	22	
C_O_10_End of Cx	23																1		1				1	23

Figure I. 7 - DSM Model for Occupancy Phase of Owner-led Commissioning

		O_O_1_Occupa 1	C_O_1_Direct & 2	C_O_2_Coordina 3	C_O_3_Coordina 4	G_O_1_Resolve 5	G_O_2_Perform 6	O_O_2_Review 7	A_O_1_Review 8	A_O_2_Review 9	A_O_3_Submit 10	C_O_5_Review 11	C_O_4_Review 12	C_O_7_Recomm 14	A_O_4_Review 15	O_O_3_Require 16	C_O_6_OK Syst 13	C_O_8_Conven 17	A_O_5_Recomm 23	C_O_9_Prepare 18	A_O_6_Review 19	A_O_7_Accept F 20	O_O_5_Review 21	O_O_6_Accept 22	O_O_4_Final Ac 24	C_O_10_End of 25
O_O_1_Occupancy	1	1																								
C_O_1_Direct & Verify Seasonal Tests	2	1	2																							
C_O_2_Coordinate Contractor Call Backs	3	1		3																						
C_O_3_Coordinate Warranty Reviews	4	1			4																					
G_O_1_Resolve Issues	5			1	1	5										1										
G_O_2_Perform Required Tests	6		1			1	6																			
O_O_2_Review Test Results	7						1	7																		
A_O_1_Review Test Results	8						1		8																	
A_O_2_Review Owner Comments	9							1		9																
A_O_3_Submit Owner & AE Comments t	10								1	1	10															
C_O_5_Review Owner & AE Comments	11										1	11														
C_O_4_Review Test Results	12						1						12													
C_O_7_Recommend Modifications	14											1	1	14												
A_O_4_Review Recommendations & Sul	15													1	15											
O_O_3_Require Modifications	16														1	16										
C_O_6_OK Systems	13											1	1				13									
C_O_8_Convene Lessons Learned Meeti	17																1	17								
A_O_5_Recommend Final Acceptance	23										1						1		23							
C_O_9_Prepare Final Commissioning Re	18																	1		18		1				
A_O_6_Review Final Cx Report	19																			1	19					
A_O_7_Accept Final Cx Report	20																				1	20		1		
O_O_5_Review Final Cx Report	21																					1	21			
O_O_6_Accept Final Cx Report	22																						1	22		
O_O_4_Final Acceptance	24																		1						24	
C_O_10_End of Cx	25																			1		1		1	1	25

Figure I. 8 - DSM Model for Occupancy Phase of AE-led Commissioning

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