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An Analysis of the Design-Build Delivery Method in Air Force Military Construction

James W. Rosner

AN ANALYSIS OF THE DESIGN-BUILD DELIVERY APPROACH IN AIR FORCE MILITARY CONSTRUCTION

THESIS

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AFIT/GEM/ENV/08-M16

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AN ANALYSIS OF THE DESIGN-BUILD DELIVERY APPROACH IN AIR FORCE MILITARY CONSTRUCTION

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Abstract

The design-build method for construction project delivery continues to grow in both the private and public sector. Several government agencies have observed, through experience with design-build, positive results which give “anecdotal” credibility to design-build methods. The objective of this study is to compare the performance of the design-build delivery method with traditional design-bid-build approaches for Air Force (AF) military construction (MILCON).

Data related to 835 (278 design-build, 557 traditional) MILCON projects were gathered from the Automated Civil Engineer System – Project Management Module (ACES-PM) for Fiscal Years 1996-2006. The design-build method had better performance for six of eight metrics with highly significant results for cost growth and number of modifications per million dollars. The traditional method experienced a highly significant advantage for the metrics of construction timeline and total project time. The historical analysis revealed that design-build MILCON has improved significantly for cost growth, modifications per million dollars, construction timeline, and total project time. The traditional method also improved for the cost growth and modifications per million dollars metrics. Finally, the facility type analysis revealed that the design-build method was best suited for seven of the nine facility types. This study provides empirical evidence of where the design-build delivery method provides an advantage to the traditional method for AF MILCON execution.

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James W. Rosner

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AN ANALYSIS OF THE DESIGN-BUILD DELIVERY APPROACH IN AIR FORCE MILITARY CONSTRUCTION

I. Introduction

The construction industry is continually trying to meet the demands of project cost, quality, and time (Chan, 2002). The construction industry has a large impact on the national economy with a 2005 Gross Domestic Product (GDP) for new non-residential construction of $441 billion dollars. Military spending greatly impacts the construction industry. The 2006 Military Construction (MILCON) and Veterans Affairs Appropriations contributed $82.5 billion in appropriations for military construction, military family housing, and veterans' affairs programs (Johnson, 2005). The FY06 MILCON budget was $16.26B (Kyle, 2006) of which the AF portion was $1.07B (Department of the Air Force, 2005). The Department of Defense, specifically the United States Air Force (USAF), faces several budgetary constraints in maintaining infrastructure and modernizing facilities: 1) funding major military operations in Afghanistan and Iraq for the Global War on Terrorism, 2) repositioning thousands of personnel and consolidating assets through Base Realignment and Closures (BRAC) 2005, and 3) implementing Program Budget Decision (PBD) 720 to recapitalize and modernize aircraft in the USAF inventory by retiring aircraft and reducing 40,000 active duty and 17,000 air reserve component member numbers (Eulberg, 2007). Each of these constraining factors highlights the need for a construction mechanism that can create quality products, on a rapid schedule, and within budget. This study will determine if the design-build delivery method for MILCON is such a mechanism.

Background

The Military Construction (MILCON) program provides the armed forces with new facilities and major renovations that cost $750,000 or more. These large projects typically take between four to five years to go from a user defined requirement to the completed project (Department of the Air Force, 2003). The Air Force (AF) manages and records the status of MILCON projects from planning through construction in the Automated Civil Engineer System – Project Management Module (ACES-PM). Data in ACES-PM is reported to and reviewed by Air Force Headquarters staff and Congress for insertion into the President's Budget. Funding for MILCON projects is strictly monitored and approved by Congress annually through the Military Construction Appropriations Act. Approved MILCON projects have five years to be completed before the appropriation expires (Department of the Air Force, 2003).

Design-Bid-Build

Historically, MILCON projects have been built using the design-bid-build (traditional) delivery method (Department of the Air Force, 2000). Design-bid-build is defined as:

> "the project delivery approach where the Owner commissions an architect or engineer to prepare drawings and specifications under a design services contract, and separately contracts for at-risk construction, by engaging a contractor through competitive bidding or negotiation." (DBIA, 2007a)

Federal laws and regulations mandated the use of the design-bid-build method for the public sector (Beard et al., 2001). The traditional method is a simple process to manage that is well understood by owners, designers, and builders (Department of the Air Force, 2000). This method appealed to owners due to its established track record, the complete control over project design, and the award given to the lowest bidder from competitive bidding (Webster, 1997; Department of the Air Force, 2000; Loulakis, 2003). However, the traditional method came under criticism in the 1970s due to increases in claims, disputes, and project delays (Cushman & Loulakis, 2001). The traditional method placed the owner as the arbitrator between the construction contractor and the designer. AF project managers in charge of MILCON projects were "managing by change order" when low bid contractors were searching for design errors and modifications to increase profits (Langley, 2007b).

Design-Build

Creation of alternative delivery methods resulted from the inefficiencies of the traditional methods (Beard et al., 2001; Cushman & Loulakis, 2001). The most popular alternative method is design-build which has steadily increased in popularity and performance (DBIA, 2007b). Design-build is defined as:

> "a system of contracting under which one entity performs both architecture-engineering and construction under one single contract." (DBIA, 2007a)

The design-build method removed the owner from acting as a middle man between the designer and builder. The responsibility for errors and omissions, faulty performance, and coordination of problems now rested with the design-build contractor (Cushman &

Loulakis, 2001; Link, 2006). This resulted in the reduction of claims and litigation, increased time and cost savings, reduced owner administrative burden, and higher quality (Konchar & Sanvido, 1998; Beard et al., 2001; Cushman & Loulakis, 2001; Link, 2006).

The use of the design-build method for federal construction required a change in procurement law. Only a few pilot projects were authorized to use design-build from 1986 to 1996 (Department of the Air Force, 2000). The rapid growth in the use of design-build did not occur until the Clinger-Cohen Act of 1996 authorized the unlimited use of design-build for federal use (Loulakis, 2003). As a result of observed successes and the approval for use, design-build looks to overtake design-bid-build as the premier project delivery method (DBIA, 2007b).

Motivation

Few formal, in-depth studies have been conducted to validate the claim that the design-build method is a significantly better project delivery process for military construction. Studies and reports have been qualitative and given anecdotal support for design-build methods (Mouritsen, 1993; Webster, 1997; Glardon, 2006). The quantitative MILCON design-build studies that were accomplished occurred at or prior to the approval of design-build for all projects. These studies are dated and are in need of validation and comparison to determine if the design-build process has improved over time (Webster, 1997; Konchar & Sanvido, 1998). Additionally, these studies were accomplished when the design-build process was new to most project managers so the learning curve was steep (Buckingham, 1989; Mouritsen, 1993).

The question arises as to whether design-build has improved over time. Is the process more efficient due to AF project manager's increased familiarity with the process? Or, now that it has become the delivery method of choice, has design-build become the status quo and no longer produces the advantages from its early days?

Problem Statement

The goal of this thesis is to use an empirical approach to assess if the design-build delivery method is better than the traditional design-bid-build method for Air Force MILCON projects. It will determine if the design-build method performs better for certain facility types. The results will be analyzed to determine if the success of the design-build method has improved through the years.

Research Questions

A thorough analysis of MILCON project data will focus on answering the following research questions:

1. Does the design-build delivery method for AF MILCON result in better cost performance characteristics than the traditional design-bid-build approach?
2. Does the design-build delivery method for AF MILCON result in better schedule performance characteristics than the traditional design-bid-build approach?
3. Does the design-build delivery method for AF MILCON result in fewer modifications than the traditional design-bid-build approach?

4. Has the design-build delivery method shown a statistically significant increased performance level over the traditional design-bid-build with regard to cost and schedule measures?
5. Using these measures of success, has the design-build delivery method improved over recent years at a statistically significant level?
6. What facility types make the design-build method a better option over the traditional design-bid-build approach?

Methodology

Project performance data will be collected from ACES-PM for Fiscal Year (FY) 1996 to FY 2006. Traditional and design-build projects will be selected from this data according to the following criteria: continental United States locations, minimum project value at the MILCON spending level, construction recorded at 100% complete, and exclusion of military family housing (MFH) projects.

An investigation of previous research will identify the performance metrics used to compare project delivery methods. Eight performance metrics will be used by this study and include: unit cost, cost growth, schedule growth, construction speed, modifications per million dollars, CWE/PA ratio, construction timeline, and total project time. The study will determine which performance metrics have shown a statistically significant difference between the design-bid-build and design-build delivery methods. For this study, a one-tailed test statistic that produces a p-value less than 0.05 will be considered statistically significant and highly significant if less than 0.01 (Webster, 1997).

The selected data will be grouped into two-year increments and compared within the study to determine if the design-build method has improved through time. Additionally, facilities will be grouped according to Category Codes in order to identify which delivery method has an advantage when applied to a particular facility type.

Assumptions and Limitations

This study compares the design-build and traditional delivery methods from MILCON data obtained from ACES-PM. This research was conducted with the assumption that, because of the oversight of ACES-PM data by MAJCOMs, HQ Air Force, and Congress, the data in ACES-PM is accurate and current. This study experienced limitations due to the scope of analysis and the use of ACES-PM data. The scope of this research was limited to conducting a strict empirical analysis and did not investigate causality of the results.

The use of ACES-PM data placed several unavoidable limitations on this research that must be identified. MILCON project timelines are documented from the notice to proceed (NTP) date to the beneficial occupancy date (BOD). The NTP to BOD field for design-build projects included design and construction time but only measure the construction time for traditional projects. As a result, this restriction on metrics using NTP to BOD skewed the results of in favor of traditional projects. The construction timeline and schedule growth metric results required the reader to interpret the findings with an understanding that NTP to BOD for design-build projects include design and construction whereas the NTP to BOD for traditional projects only include construction.

Additionally, ACES-PM does not document the cause of modifications. This study was limited by the assumption that all modifications were a result of a negative cause.

Implications

The results of this study could be used by Department of Defense project managers to enhance project management of MILCON projects. The results will quantitatively show where design-build provides an advantage to the design-bid-build method. This study will also provide project managers with the knowledge of which delivery method is historically more efficient for a certain facility type. The results will finally provide AF project managers the answer to the question of when or if to use the design-build method for MILCON projects.

Thesis Organization

Chapter 1 establishes the framework for the study by describing the impacts of federal spending on the construction industry and the budgetary challenges facing the Air Force. The MILCON program is described followed by the primary means to construct MILCON projects: the traditional design-bid-build and design-build delivery methods. The problem statement and research questions identify the focus of the study to determine if the design-build method performs better than the design-bid-build method. Chapter 2 examines the literature on MILCON, project procurement and delivery methods, and project performance measures. It establishes a foundation for the research methodology and identifies the gaps left in previous studies that will be filled by this study. Chapter 3 describes the methodology used to quantitatively compare the two delivery methods. It identifies the performance metrics used in this study and how the metrics were calculated. The performance metrics will be compared between the design-bid-build and design-build method to determine if the results are statistically significant. Chapter 4 outlines the results and analysis of the study over each performance metric. Chapter 5 provides the discussion and conclusions gained from the study along with recommendations for future research.

II. Literature Review

Chapter Overview

This chapter investigates the current literature and research regarding military construction (MILCON) project delivery methods. The purpose is to understand the key characteristics of the MILCON process, project delivery methods, and project success. This literature review is organized in the following manner: design-build history, history of MILCON design-build, MILCON overview, project delivery methods, project selection criteria, project delivery vs. procurement, project procurement methods, project success criteria, study performance metrics, and previous studies. Finally, a literature review summary will identify the gaps found in the literature that this study will address. The literature review serves as the foundation for the methodology used to compare delivery methods.

Design-Build History

Appointing a single entity in charge of all aspects of a project is not a new concept. The design-build concept has a rich history descending from the "master builders" or "master masons" of ancient Egypt, Greece, and Rome (Beard et al., 2001; Cushman & Loulakis, 2001). Master builders did not distinguish a project between its design and construction phases. They coordinated and controlled every aspect of a project including material procurement and selection, project design, supervising craftsmen, and project financing (Cushman & Loulakis, 2001).

The Renaissance brought about the first challenge to the idea of a master builder at the time of the most famous master builder Filippo Brunelleschi (1377-1446). Brunelleschi was commissioned to build the Gothic Cathedral of Florence in 1420 (Beard et al., 2001). The master builders were challenged by Leone Batista Alberti, who believed in the separation of design and construction, when he published the first architectural printed work *De re aedificatoria* (On Edifices) in 1485 (Cushman & Loulakis, 2001). The popular view of a master builder remained in the majority until the industrial revolution.

Industrial Revolution

The Industrial Revolution produced advances in technology, manufacturing, and productivity on a tremendous scale. The development of specialties arose during this time, thereby distinguishing designers from builders. Beard et al. attributed the principle changes in the organization of design and construction to the following five factors (2001; p.19):

1. Task specialization: the increase in complexity of industry drove the requirement for specialized engineer and architect expertise, but not builders.
2. Ability to communicate design intent: expanding design market created standardized systems of drawings and specifications which enabled the designers to work off site and not be tied to specific projects.
3. Division of labor: dividing work into individual tasks segregated the intellectual process of design from the physical act of construction.
4. Entrepreneurship: Builders routinely worked with contractual risk in order for business growth while designers were fundamentally risk averse.
5. Need for capital: Builders now required large capital from nonparticipating owners to support the new machinery and large labor force. Designers were

unable to partner with such stockholders due to the "ethic of individual professional responsibility" (Beard et al; 2001; p.20).

Professional Societies

The need for specialization, from increased industry complexity, formed professional societies that increased the separation of design from construction professions. The American Society of Civil Engineers and Architects (ASCE) were formed in 1852. The need for a separate architect society in 1857 lead to the American Institute of Architects (AIA) and the "and Architects" was removed from ASCE. Both societies saw the importance of separating the design professionals from the building contractor and material supplier (Beard et al., 2001).

Twentieth Century

The twentieth century brought about legal regulation of construction contracting practices. In order to increase accountability and reduce corruption, the courts passed legislation further separating design from construction. The Miller Act of 1935 protected the federal government from contractors that lacked the capital to finish a project (Beard et al., 2001). The 1947 Armed Services Procurement Act established procurement procedures for the military. The Federal Property and Administrative Procedures Act of 1949 followed for civilian agencies and federal public works. Both acts directed federal agencies to use negotiation procedures for architectural engineering (A-E) services and separate competitive bid procedures for construction (Loulakis, 2003). A-E services and construction acquisition was further regulated by the 1972 Brooks Act, 40 U.S.C. SS 541. Construction had to be bid competitively where A-E acquisition was focused on firm selection based on competence and qualification (Mouritsen, 1993; Loulakis, 2003).

The low bid regulation further separated the designer from the builder as described by Beard et al.: "Implied in these statutes is the role of the design professional as the agent of the owner, and the prohibition of the designer from having any financial relationship with the builder" (2001, p.22). Public agencies were required to hire a design firm to produce a 100% design, advertise the design and receive bids from construction contractors, and then hire the "lowest responsible bidder" to build to project. This project delivery method became known as the design-bid-build or "traditional" method and was the prevalent method for the twentieth century (Beard et al., 2001).

The traditional method came under intense scrutiny during the 1960s and 1970s (Cushman & Loulakis, 2001). Coordination between designers and builders was needed to complete the increasingly technically complex buildings of the late twentieth century. Public owners desired a single point of responsibility for design and construction. Public owners were responsible for coordination between the two and assumed all responsibility for the design (Beard et al., 2001). Increases in claims, disputes, and project delays were a result, driving public owners to search for a better delivery method for projects. The search for a new delivery method returned to the master builder concept and was called design-build (Cushman & Loulakis, 2001).

Emergence of Public Design-Build

The increased growth and use of the design-build method can be directly attributed to the expanding use in the public sector (Cushman & Loulakis, 2001). The federal agencies that significantly contribute to the construction industry include the Department of Defense (DOD), Veterans Affairs (VA), Department of State, General Services Administration (GSA), Environmental Protection Agency (EPA), National

Aeronautics and Space Administration (NASA), Federal Highway Administration, United States Postal Service (USPS), and the Department of Energy (DOE) (Mouritsen, 1993; Webster, 1997)

The DOD first began using the design-build method in 1967 for Military Family Housing (MFH) in an attempt to duplicate the private sector's success with design-build. Thirty MFH projects had been successfully completed by 1972, encouraging Congress to allow design-build methods to be used for each service's MFH program (Mouritsen, 1993). The early 1970s saw the first use of competitive public design-build procurement in the education arena for non-residential construction (Beard et al., 2001). The success of MFH led to experimentation using design-build for other construction projects, which will be explained in the next section.

Due to the increase of the design-build process, the AIA formed the 1975 Design-Build-Bid Task Force which made recommendations to clarify the roles of professionals for the new delivery system. The AIA used these recommendations to publish the first version of standard design-build contract documents in 1985 which were later re-published in 1996 (Beard et al., 2001). As with AIA and ASCE, a professional association was formed to facilitate standards for the new delivery industry. The Design-Build Institute of America (DBIA) was formed in 1993 as a result of the increased use and success of design-build (Cushman & Loulakis, 2001). Owners, designers, and contractors needed guidance and standard in order to use the design-build delivery method to its fullest potential. The goals of DBIA are to promote the growth of design-build and to disseminate the best design-build practices throughout the construction industry (DBIA, 2007c).

Military Construction (MILCON) Design-Build History

The use of design-build by public agencies has been controlled by legislation. Several key pieces of procurement law enabled the growth of design-build in MILCON (Loulakis, 2003). The Army and Air Force had little experience with design-build prior to 1986. The Army was the first to test the two-step turnkey method on three projects in 1982 (Fort Drum Headquarters, Fort Harrison Gym, Fort Stewart Fire House) and the one-step turnkey method on two projects in 1984 (Fort Bliss Gym, Fort Stewart Gym). The One-step and Two-step procurement methods will be described in the next section. The Army observed that both methods delivered the projects earlier than the traditional method and within budget. This success led to the limited approval of design-build for use by the branches of the military (Buckingham, 1989).

The Military Construction Authorization Act of 1986 authorized the use of design-build for MILCON, Military Family Housing, and Operations and Maintenance (O&M) programs (Department of the Air Force, 2000). Each branch of the military was allowed to use one-step procedures to execute a maximum of three design-build projects annually until 1990 (Buckingham, 1989). These pilot projects were used to determine if design-build was an effective and fair delivery method for MILCON. The restriction placed on the use of one-step design-build was then removed under Title 10 U.S.C., Section 2862 by the Congress in 1992 (Webster, 1997).

The Clinger-Cohen Act of 1996 opened up the use of design-build for federal use by authorizing the use of the two-step procurement procedures for any federal project whenever the situation merited design-build delivery (Beard et al., 2001; Loulakis, 2003). The Clinger-Cohen Act amended the Defense Authorization Act of 1996 and the 1996

Federal Acquisition Reform Act (FARA) (Beard et al., 2001). Design-build use by the federal government, specifically in MILCON, began to grow after 1996 since the services were no longer restricted to three projects per year (Beard et al., 2001; Loulakis, 2003).

MILCON Overview

The Military Construction program provides the armed forces with new facilities and major renovations. This section will define MILCON and describe the Air Force MILCON process. The overview will also identify the key milestones important to the analysis of the MILCON process with regard to project delivery methods.

MILCON Defined

Air Force Instruction (AFI) 32-1021 defines MILCON as:

> "any construction, development, conversion, or extension of any kind carried out with respect to a military installation. MILCON includes construction projects for all types of buildings, roads, airfield pavements, and utility systems costing $750,000 or more" (Department of the Air Force, 2003; p.21).

Prior to 2003, new construction projects costing more than $500,000 were considered as MILCON projects. Funds for MILCON projects are approved by Congress through the Military Construction Appropriations Act annually. Approved MILCON projects have five years to be completed before the appropriation expires (Department of the Air Force, 2003).

The MILCON Process

The MILCON process, as detailed in Figure 1, consists of four elements: planning, programming, design, and construction (Department of the Air Force, 2000). This process outlines the design-bid-build method and design-build method for MILCON

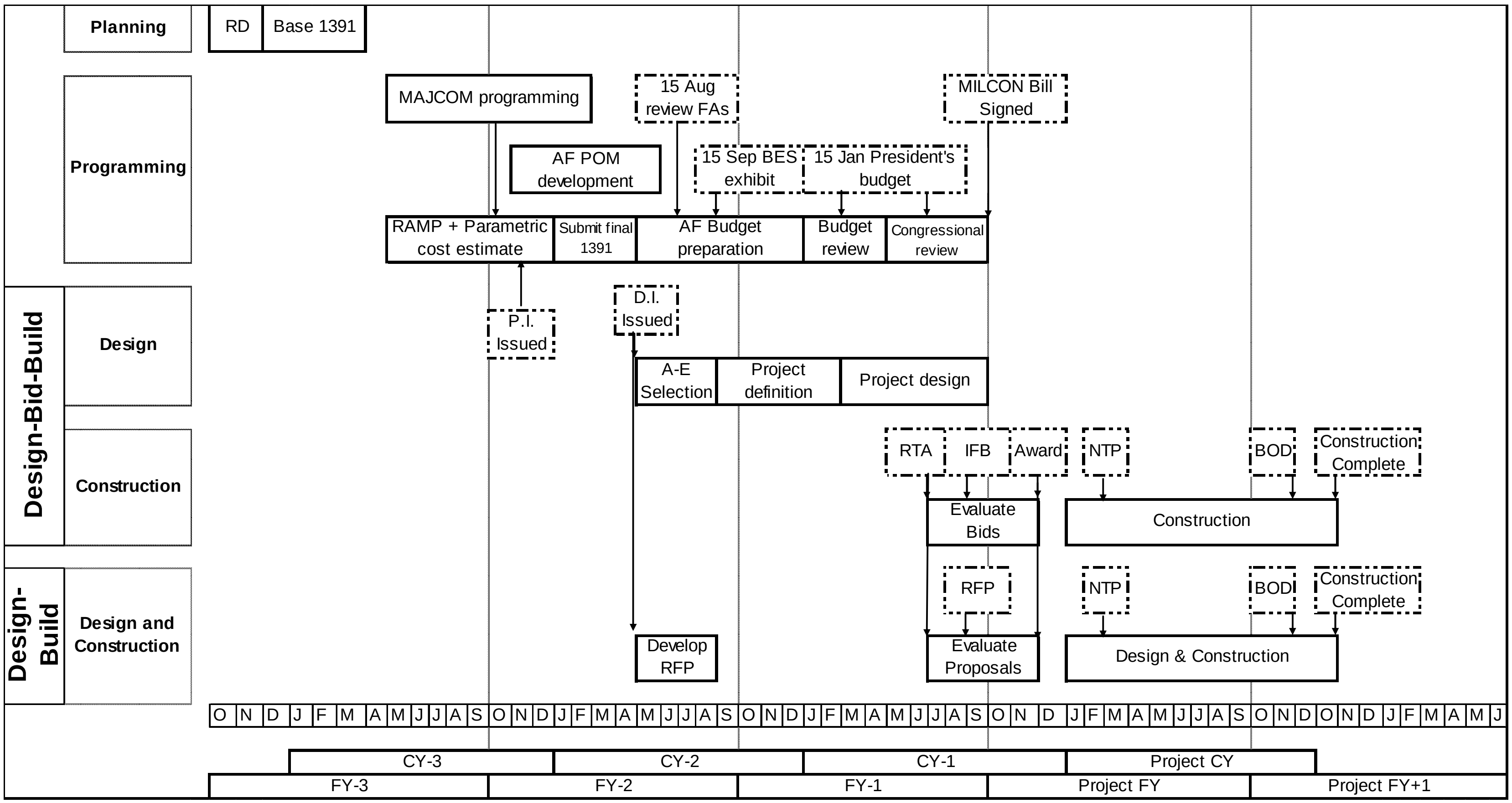

Figure 1. The MILCON Process (Adapted from Department of the Air Force, 2000; Figure 2-1)

projects. First the design-bid-build method will be outlined. The description of the design-build process is provided later in this chapter. Only the key products and milestones of each element will be discussed for brevity sake. Project managers should reference the *Project Managers Guide for Design and Construction* (Department of the Air Force, 2000), known as the Blue Book, for a comprehensive description of the Air Force MILCON process and policy.

Planning

The goals of MILCON planning are to identify critical facility requirements and decide the most effective and economical method to meet those requirements. Planning begins when a new requirement is identified by the user, major command (MAJCOM), or Headquarters AF Staff (Air Staff) to support a renovation, new mission, or unit relocation. The planning phase consists of three key actions: development of the Requirements Document (RD), preparation of the DD Form 1391, and the Certificate of Compliance (Department of the Air Force, 2003).

The Requirements Document (RD) contains the project description, functional, architectural, technical requirements, project site, and programmed amount (PA) (Department of the Air Force, 2000). The PA outlines the costs for completing the projects. The PA includes the government estimate for the facility, site work, utilities, demolition, communications, contingency, supervision, inspection, and overhead (SIOH). MILCON projects costing over $2 million must undergo an economic analysis to validate the project is the most effective way to meet the identified requirement. Once the project is found to meet the requirement, the DD Form 1391 will be developed (Department of the Air Force, 2003).

The Base Civil Engineer (BCE) will develop the DD Form 1391 (1391), the purpose of which is to ensure the project is aligned with the long term plans of the base. The full DD Form 1391 package contains the project PA, cost estimate breakdown, scope, description of work, justification (requirement, current situation, impact if not provided), deficiency detailed data (D^3) sheet, floor plan, site plan, location plan, and Certificate of Compliance (Frailie, 2004). The 1391 is then input into the Automated Civil Engineer System – Project Management Module (ACES-PM) and will be updated, approved, and verified at MAJCOM, Air Staff, and DoD before it is included in the President's Budget submittal for Congressional approval (Department of the Air Force, 2000).

Environmental planning is accomplished by completing a Certificate of Compliance. The Certificate of Compliance contains 32 items addressing environmental and cultural resources, environmental permits, project site conditions, and sustainable design considerations for the project. The installation commander signs the document certifying all actions have been completed before the project can be included in the Future Years Defense Program (FYDP) (Department of the Air Force, 2003).

Programming

"Programming is the process of developing and obtaining approval and funding for Military Construction (MILCON) projects" (Department of the Air Force, 2003; p.21). The MILCON project moves into the programming phase after the base 1391 has been input into ACES-PM and submitted to MAJCOM. Key products from the programming process are the Requirements and Management Plan (RAMP) and final DD Form 1391. The RAMP must be completed by the time the MAJCOM submits the 1391 to Air Staff for inclusion in the MILCON program (Department of the Air Force, 2000).

The RAMP consists of the RD and the Project Management Plan (PMP). The PMP includes the following key strategic decisions for the project (Department of the Air Force, 2000):

- Project delivery method (traditional, design-build, fast track, construction management)
- Project procurement type (firm fixed price, cost plus, letter contract)
- In-house vs. Architect-Engineer (A-E) design
- List of all project team member names and organizations
- Project risk, scheduling, and packaging

The completed RAMP and DD Form 1391 for each base's projects are prioritized and submitted by MAJCOM to Air Staff to be included in the MILCON budget. The AF Program Objective Memorandum (POM) outlines the planned AF budget and includes the FYDP. The FYDP is the six-year MILCON program. From the FYDP, the AF submits a two fiscal year MILCON budget to the Office of the Secretary of Defense (OSD) and Congress. The first year of this MILCON budget is included in the President's Budget (PB) submitted to Congress. Congress then approves the National Defense Authorization Act and the Military Construction Appropriations Act. The authorization and appropriations act become law after the President signs both.

Construction funding can then be arranged after the bill is signed by the President (Department of the Air Force, 2003).

Design

Much of the programming and design timelines overlap to ensure the MILCON project is ready for construction once the bill is signed. The Air Staff Planning Instruction (PI) directs the MAJCOM to change the project from programming status to design status. The Design Instruction (DI) is directed from the MAJCOM to the design agent to initiate design of the project in accordance with the RAMP and DD Form 1391. The Air Force is not its own design and construction agent. The AF is allowed to manage only 5% of MILCON projects at the Air Force Center for Engineering and the Environment (AFCEE). Typically, the US Army Corps of Engineers (USACE) or the Navy Facilities Engineering Command (NAVFAC) acts as the design and construction agent for the Air Force (Thornburn, 1994). Table 1 outlines the stages for MILCON design for the traditional delivery method. MILCON design produces the project drawings and specifications needed to construct the facility and refines the cost and scope of the project (Buckingham, 1989).

Table 1. Authority to Proceed Design Stages
(Department of the Air Force, 2000; p.2-7)

Design Stage	% Design	Activity
Selection of A-E	2%	▪ Activities up to award of design contract
Notice to Proceed (NTP)	3%	▪ Direct A-E to initiate design
Project Definition (PD)	15%	▪ Validate project requirements outlined in RD ▪ Resolves all scope, requirements, and cost differences
Early Preliminary Design	30%	▪ Design review including drawing and specification submittals
Preliminary Design	60%	▪ Design review including drawing and specification submittals
Pre-Final Design	90%	▪ Completion of design and preparation of invitation for bids (IFB) (traditional delivery) ▪ Completion of Request for Proposal (RFP) documents (design-build)

The time allowed for design is determined by the PA. The design phase begins with the issuing of the PI to when the project is ready to advertise (RTA). Table 2 shows the historic observed time required for key design milestones depending on project PA (Department of the Air Force, 2000).

Table 2. Historical Average Design Period
(Department of the Air Force, 2000; Table 2-1)

	Then time is from AF PI to...		
If PA is:	NTP	PD	RTA
<$5M	4 months	6 months	11 months
$5-10M	6 months	9 months	15 months
>$10M	7 months	10 months	17 months

Construction

The construction phase of the MILCON project includes the solicitation for bids from construction contractors, project management of construction, conducting pre-final and final inspections, facility acceptance/Beneficial Occupancy Date (BOD), and financial close out (Department of the Air Force, 2000). The authority to advertise a MILCON project by the MAJCOM is granted by Air Staff when all of the following criteria are accomplished (Department of the Air Force, 2000; p.6-5):

- Project included in bills signed by the President
- Project at least 95% designed as reported in ACES-PM
- Current Working Estimate (CWE)/PA ratio is not greater than 110%
- MAJCOM fiscal year MILCON program CWE/PA ratio below 100%
- Environmental Impact Analysis Process (EIAP) is completed and reported in ACES-PM

The contract is awarded in accordance with the selected procurement method criteria if the award CWE is within the authorization threshold. The contract CWE must not exceed the PA by 25% or $2.0 million. The project must be redesigned, re-bid, or reprogrammed if the CWE is above the threshold (Department of the Air Force, 2000).

The time for MILCON construction contracts has been based off of Dirtkicker Criteria. The Dirtkicker Award program was established to provide metrics to measure MILCON execution (Robbins, 2003). Further details of the Dirtkicker program will be discussed later in this study. As with design, MILCON construction timelines are dependent on PA (Table 3). The MILCON project is complete when all deficiencies have been corrected, project as-built drawings have been submitted, all costs are recorded, and the financial close-out has been accomplished (Department of the Air Force, 2000).

Table 3. Dirtkicker Construction Timeline (Fox, 2006)

If PA is:	Then time from NTP to… BOD
<$5M	365 days
$5-20M	540 days
>$20M	730 days

The MILCON process described above was developed from the vast experience using the traditional design-bid-build method for MILCON execution. The Air Force, and other branches, is no longer limited to solely using the traditional method for MILCON construction (Department of the Air Force, 2000; Beard et al., 2001). The next section describes the project delivery methods now available for construction projects.

Project Delivery Methods

Project delivery methods are the processes in which a project is planned, designed, and constructed (Beard et al., 2001). This section identifies the methods used by the construction industry to complete projects. First, the traditional design-bid-build method is described. A brief description of alternative methods will identify other options for construction execution. This section will be concluded by a comprehensive discussion of the design-build method and its application to MILCON.

Traditional Design-Bid-Build Method

The traditional delivery method used by the Air Force is design-bid-build. Broadly summarizing, the government hires an Architect-Engineer (A-E) firm to produce a 100% design of the project with all drawings, specifications, and contract documents. This design is then advertised through an Invitation for Bids (IFB) and receives bids from construction firms. Typically, the “low responsible and responsive bidder” (Department of the Air Force, 2000; C.8 p.5) is awarded the contract with a firm fixed price. The construction firm then completes the project with oversight from the owner (Department of the Air Force, 2000).

The traditional process has historically been the primary method for construction by the Department of Defense. The process is well understood by project managers because all the steps, processes, requirement, and roles have been codified by professional societies, the government, designers, and contractors (Department of the Air Force, 2000). Table 4 outlines the advantages of the traditional approach identified through previous studies, literature, and interviews.

Table 4. Advantages of Traditional Approach

Advantages	Description	Source
Established way of doing projects	Well-established legal and contractual precedents	2, 5
Appropriateness for competitive bidding	Competitive nature of bidding obtains lowest price for construction based on 100% design documents	2, 5, 7
Complete control over design	Owner holds meetings typically at 30%, 60% and 90% design complete stages to comment on all drawings and specifications	3, 4
Low price award	Owners award the project to the contractor who presented the lowest bid price	3, 4, 6
A/E working directly for the owner	A-E gives professional design advice to the owner in a not-at-risk relationship	5
No legal barriers to procurement and licensing	Established legal findings for allocating risk and responsibility. Established procedure for licensing A/Es and construction firms in all states.	5
Contractor assumes all construction risks	Absorbs weather costs, labor disputes, material cost increases, and external factors	2
Projects is fully defined	Design phase produces 100% complete drawings, specifications, and cost estimates	2, 6
Objective contract award	Sealed bid packages ensures contract award based on price and not subjective metrics	7

Key:

1	Mouritsen (1993)	5 Beard et al. (2001)
2	Fee (1996)	6 Cushman & Loulakis (2001)
3	Webster (1997)	7 Link (2006)
4	Department of the Air Force (2000)	8 Langley (2007b)

Several problems emerged though the years resulting from the separation of design and construction. As previously stated, increased claims and litigation along with rising costs and delayed project timelines drove owners to investigate alternative delivery methods. Table 5 identifies several of the disadvantages found in the traditional design-bid-build delivery method.

Table 5. Disadvantages of Traditional Approach

Disadvantages	Description	Source
Owner is the arbiter between designer and constructor	Owner bears the risk for adequacy of design. Designer and constructor disagreements must be solved by the owner	5, 6, 7
Owner pays for changes	Owner funds change orders to overcome design conflicts and change orders. Increase costs deplete contingency funds and could lead to litigation	6, 8
No shared vision or goals for between the owner, designer, and contractor	Neither party is totally focused on the ultimate goals of the project or owner. Designer goals focus on accuracy and quality of physical products. Constructor focuses on cost and schedule management	2, 5, 6
An initial low bid does not necessarily result in final best value	Preoccupation with low first cost ignores importance of past performance, good environmental practices, concern for life cycle performance, and other best-value selection criteria.	5, 6
Price not certain until construction bid is received	Bids over budget present problems for owners. Cost is unknown until the 100% design package is bid on. If bids are over the owner's budget the project must be redesigned or lowered in scope	5, 7
Constructor is not involved in the design	Separation of designer and builder is required by the traditional process. Constructability is lowered by lack of construction input in design.	2, 5, 6, 7
Design-Bid-Build is slower than other delivery systems	Linear structure includes time required to select an A-E, design to 100%, bid the design package, then build with no overlap	2, 5, 6
History of litigation	Increased disputes between the constructor and designer over design clarity, errors, omissions, in place construction quality, time delays, and other project related issues	2, 5
Change orders	Contractors can low bid and recover profits by generating change orders resulting from design omission and errors.	2, 8
Agency may need more technical staff	Architects, engineers, and construction inspectors typically required to review drawings, specifications, and inspect construction	7

Key:

1	Mouritsen (1993)	5	Beard et al. (2001)
2	Fee (1996)	6	Cushman & Loulakis (2001)
3	Webster (1997)	7	Link (2006)
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Alternative Delivery Methods

Various alternative approaches have been developed in order to meet the growing demands of owners for better quality, faster project delivery, lower cost, and less risk (Pocock, 1996). Most alternative project approaches center on the concept of merging the efforts of the A-E firm and construction firm together to increase communication, accountability, and improve the design. Other alternative procurement methods include:

- Bridging: Unlike true design-build, the owner develops initial designs and specifications, typically 30% to 50% complete (Webster, 1997), before contracting with a design-build firm. Bridging provides owners with more control over design but can limit the advantages of true design-build. Bridging is not recognized by the DBIA as a design-build method due to the level of design completed before the issuing to the RFP (Webster, 1997, Beard et al., 2001).
- Fast track: Fast-track is similar contractually to design-build. However, this method expedites construction by beginning construction before working drawings and specifications are completed (Webster, 1997; Department of the Air Force, 2000).
- Construction management (CM): The owner hires a designer under a separate contract. Before the final design is complete, a construction agent is hired to review the design for constructability. The construction agent is then hired to take the project into construction (CM at Risk). In CM at fee, the construction

agent serves solely in a consulting role and does not continue into construction (Webster, 1997; Konchar & Sanvido, 1998; Beard et al., 2001).

- Partnering: This method attempts to establish long-term relationships between owners, designers, contractors to meet mutually beneficial goals (Pocock, 1996; Webster, 1997).
- Constructability: This method emphasizes bringing in a construction expert to contribute at the early phases of planning. This concept can be used along with other delivery methods as well (Pocock, 1996).
- Turn-key: Owner develops a narrative project description and uses it in an RFP without drawings or specifications to hire a design-builder (Thornburn, 1994). The design-build firm performs additional services such as financing the project, land acquisition, obtaining permits, and maintaining the facility after completion (Webster, 1997; Department of the Air Force, 2000).

The differences between the traditional method and alternative delivery methods are displayed in Figure 2. A key differentiation between the delivery methods is the point at which a firm cost is known for the project. The design-build method benefits the owner by determining the known contract cost earlier in the project timeline. Therefore, the budget risk of the owners is transferred into the assumed cost risk of the design-build contractor. The contractor must work to stay within the budget set early in the timeline. The next section describes the alternative delivery method this study will focus on: design-build.

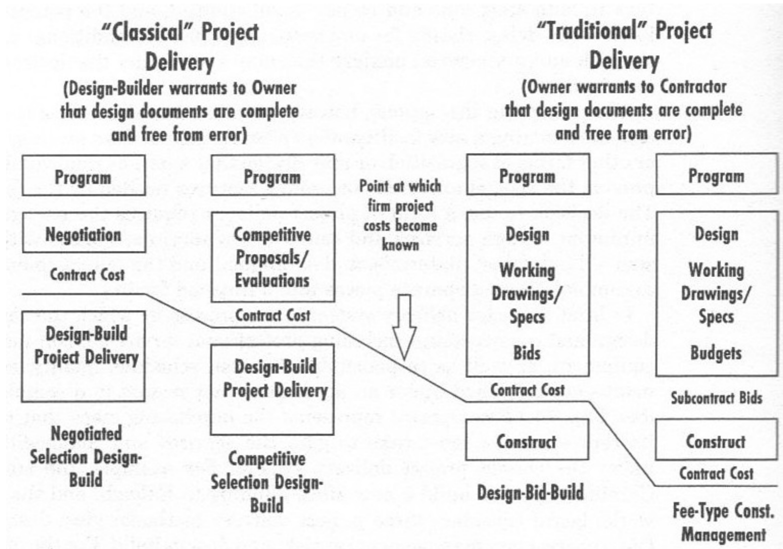

Figure 2. "Classical" vs. "Traditional" project delivery (Beard et al., 2001; Figure 9.1)

Design-Build

The Design-Build Institute of America defines design-build as: "a system of contracting under which one entity performs both architecture/engineering and construction under one single contract" (DBIA, 2007a). Design-build is now the second most used delivery method in the United States as seen in Figure 3 (Department of the Air Force, 2000, DBIA, 2007b). The previously skeptical public sector has dramatically increased its use of design-build since 1998 (Loulakis, 2003). The DBIA predicts the design-build method will overtake the traditional method in the next ten years.

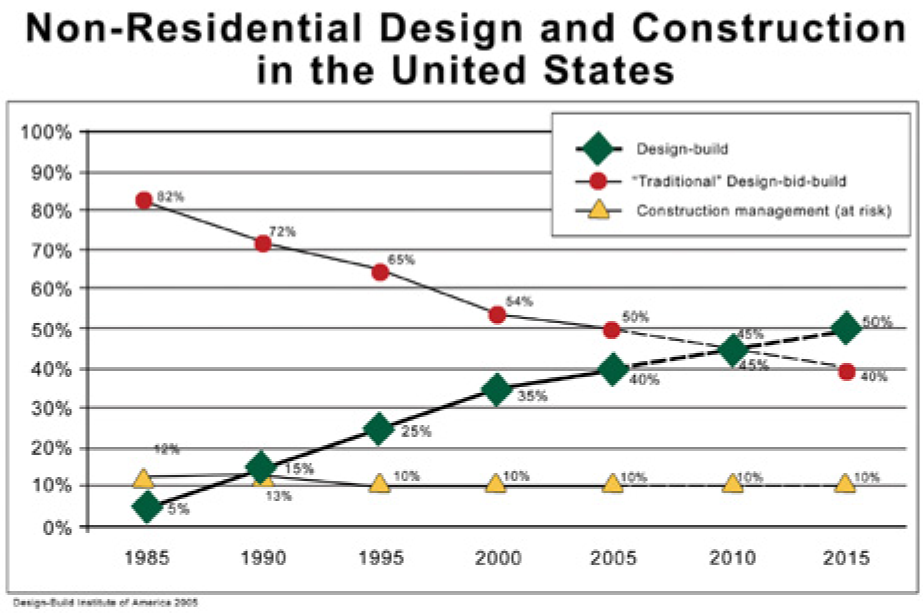

Figure 3. Market Saturation of Delivery Method (DBIA, 2007b)

The popularity for design-build stems from the advantages it has over the traditional design-bid-build method (Department of the Air Force, 2000). Table 6 displays the advantages observed in the literature. As previously mentioned, owners were searching for a delivery mechanism that would improve upon the problems experienced with design-bid-build. Owners were burdened by acting as an arbitrator between the construction contractor and the designer and being financially responsible for changes and errors (Cushman & Loulakis, 2001; Loulakis, 2003). The single contract for design and construction, and the resulting benefits, is what draws project managers towards design-build.

Table 6. Advantages of Design-Build

Advantages	Description	Source
Single source of responsibility for design and construction	Responsibility for errors and omissions, faulty performance, coordination of problems lies with the design-builder instead of the owner.	1, 2, 5, 6, 7, 8
Time savings	Design-build eliminates the bidding periods and redesign of the traditional method. Materials and equipment procurement, and site staging can begin before completed design documents.	1, 2, 5, 6, 7, 8
Early knowledge of firm costs	Guaranteed project costs are known at proposer selection. Additional costs savings result from one entity coordinating cost estimates for construction as designs are completed.	4, 5, 6, 7
Higher quality	The design-build contractor is responsible for the entire project. Construction input is given from the beginning of design from the builder. Design errors, omissions, and defects are identified and quickly solved from within.	2, 3, 5, 6, 7
Cost-effectiveness	Value engineering and constructability are ongoing throughout the whole process resulting in lower cost.	1, 4, 5, 6
Encourages innovation	Design-build is a performance based system instead of the specifications based traditional method. The RFP outlines the performance requirements of the owner and the proposers may use different solutions to meet the owner's goals.	1, 2, 4, 5, 7
Lower claims and litigation	Owners avoid the majority of claims and litigations due to the responsibility for the designs rests with the design-build contractor. The number of disputes is far fewer since the design-builder has no one to blame for errors but itself.	1, 4, 5, 7, 8
Reduced administrative burden	Does not require the many architects, engineers, and construction inspectors typically required for oversee the traditional method. Personnel required to administer conflicts between contractors has been reduced.	1, 4, 6, 7

Key:

1	Mouritsen (1993)	5	Beard et al. (2001)
2	Fee (1996)	6	Cushman & Loulakis (2001)
3	Webster (1997)	7	Link (2006)
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The increased popularity and observed successes of design-build have produced several issues. The disadvantages listed in Table 7 predominantly result from the misuse of the method by owners, agents, and firms (Cushman & Loulakis, 2001). Several owners feel that design-build can be used for any project and fail to consider other project characteristics that also contribute to project success. Additional issues arise when there is a lack of trust between the owner and the design-build contractor (Cushman & Loulakis, 2001). Some owners attempt to protect themselves by placing all project risk on the design-builders. Other owners are unwilling to release the creative control and over constrain the design-build team with detailed specifications based RFPs instead of performance based requirements (Beard et al., 2001; Cushman & Loulakis, 2001; Loulakis, 2003).

Table 7. Disadvantages of Design-Build

Disadvantages	Description	Source
Unfamiliarity with the process	Owners and practitioners might not have used design-build and are unaccustomed to the collaborative method.	5, 6
Experience of management team	Success increases as the team gains in experience. Inexperienced teams might need to hire and experienced professional owner's representative	4, 7, 8
Adequate owner staffing	An owner that does not have staff to adequately develop the RFP will have difficulty defining and presenting their needs to the design-build team	7
Communicating owner's needs in design-build is different	The owner's performance requirements must be outlined as criteria for design and not detailed specifications. Owners comfortable with the traditional method will struggle with the qualifications based proposals for the RFP instead of the low cost bid on complete design documents	5
Barriers in procurement and licensing laws	Some states still require the use of separate design and construction contracts	5
Availability of insurance and bonding products for design-build	Industry still wary of providing the same coverage to design-build firms as traditional construction firms resulting in higher premiums for insurance and bonding.	1, 2, 5
Trust and Control	Inexperienced owners continue to desire the same involved design review process or place all the project risk on the contractor. These owners do not possess the trust required reduce the effectiveness, increase cost, and delay the process.	6, 8
Loss of designer as the owner's advocate	Both the designer and constructor are in the business to generate profit. The designer's interests are no longer directly tied owner's needs as in the traditional method	1, 2, 7
Subjective contract award	The process may bypass the competitive bidding process, possibly not affording the owner the lowest price	7

Key:

1 Mouritsen (1993)
2 Fee (1996)
3 Webster (1997)
4 Department of the Air Force (2000)
5 Beard et al. (2001)
6 Cushman & Loulakis (2001)
7 Link (2006)
8 Langley (2007b)

One factor that determines whether design-build will be successful for a project is knowing the design-build process for one’s agency. The next section outlines the AF MILCON design-build process. The AF MILCON design-build process must be understood in order to know what type of MILCON project the design-build method should be used.

MILCON Design-Build Process

The MILCON design-build process, as displayed in Figure 1, can be summarized in the following six phases: planning, pre-design activities develop RFP, administer RFP, proposal evaluation and award, and design/construction (Thornburn, 1994).

1. Planning: The decision, by the responsible MAJCOM, to use the design-build method occurs during this phase. The products of this phase are the RD and draft PMP development for the RAMP and sent to the Design Agent (Thornburn, 1994).
2. Pre-Design Activities: This phase develops the project definition (PD) document which will guide the creation of the RFP. If the Design Agent is unable to develop the PD or RFP in-house due to inadequate staff or experience, an A-E will be selected to develop the RFP for the Agent (Thornburn, 1994).
3. Develop RFP: RFP development is the most critical and owner resource intensive phase of design-build and presents the greatest departure from the traditional design-bid-build project development process (Beard et al., 2001). The RFP "must clearly describe the technical requirements of the project, and the criteria for evaluating proposals, and the contractual relationship between the Government and Offeror" (Department of the Air Force, 2000; p.8-19). The owner must relate the performance requirements in clear and unambiguous language (Department of the Air Force, 2000) so that the proposers will have

consistently similar understandings of the owner's needs (Beard et al., 2001). A RFP typically contains "design criteria, program requirements, performance specifications, site information, contract requirements, selection procedures, and proposal requirements or deliverables" (Beard et al., 2001; p.7-8). Requirements and goals are the focus of the RFP instead of the detailed specification focus of the Invitation for Bid (IFB) phase in the traditional method (Cushman & Loulakis, 2001).

4. Administer RFP: The RFP is reproduced and issued for proposals. The RFP team manages proposers' inquiries. Answers to inquiries are made through amendments in the RFP and presented to all package holders. The team receives proposals and begins the evaluation process (Thornburn, 1994). The development of proposals is extremely costly for design-build firms. Proposers use extensive resources to develop design-build proposals (Cushman & Loulakis, 2001). A project that is too small will not offset the risk assumed by proposers to develop a design package. Some owners (not government agencies) have offered to pay a stipend to proposers who were not awarded the contract in order to honor the effort required to submit a proposal (Beard et al., 2001). Offering such a stipend will enhance relationships with design-build contractors (Pocock, 2007a) and give incentive for many proposers, especially "A-teams," to compete (Beard et al., 2001).
5. Proposal Evaluation and Award: The proposals received are evaluated according to the procurement method process and evaluation criteria decided on by RFP

development. The selection of the One-step or Two-step procurement method determines the steps in the process. The source selection evaluation board (SSEB) rank orders a range of proposals that have met the owner's requirements. The proposers in this range are allowed to submit a Best and Final Offer (BAFO) which clarifies any questions and clarifications of the SSEB (Thornburn, 1994). The One-step method will then select the proposal from this range that gives the best value to the government (Webster, 1997). The Two-step method will first select the proposals that meet the technical requirements without knowing proposal costs. The proposals that meet requirements will then be asked for a sealed cost bid out of which the lowest bid receives the award (Webster, 1997)

6. Design/Construction: The final phase of the process begins with the notice to proceed (NTP). The NTP instructs the contractor to begin the design phase of the project. Design and cost reviews will be conducted as specified in the RFP. The owner must approve the construction documents before work can begin on site (Beard et al., 2001). The NTP will then be issued for construction with the Design Agency supervising work for quality control and amount of completion. Work proceeds until the beneficial occupancy date (BOD) when the government accepts the facility (Thornburn, 1994). The decision for using fast-track methods must be made in the planning phase and not after contract award (Thornburn, 1994). If fast-track is to be used, the design will be broken into two phases. The first package will contain site work, exterior utilities, and foundations. The second package designs the rest of the project. The construction NTP will be

issued after each design phase has been approved. Fast-track methods require a larger staff for construction supervision and increases the risk of errors and problems due to the fast pace of work (Thornburn, 1994).

Project Delivery vs. Procurement

There is a distinct difference between project delivery methods and project procurement methods. Construction literature and previous studies have used the terms delivery (Pocock, 1996; Webster, 1997; Konchar & Sanvido, 1998; Department of Defense, 2000; Ling et al., 2004) and procurement (Mouritsen, 1993; Songer & Molenaar, 1997; Chan et al., 2002) synonymously when describing design-build methods. Delivery and procurement are two separate and important aspects of a project.

"A *project delivery system* is the process by which the components of design and construction-including professional services, labor, materials, and equipment, as well as responsibility for cost, schedule, quality, and management-are combined under an agreement that results in a complete facility" (Beard et al., 2001; p.169). Examples of delivery systems for construction are traditional (design-bid-build), design-build (classical), construction management, and partnering methods. Project delivery methods will be discussed later in this chapter.

"*Procurement* represents the purchasing steps that the owner or its representative must take to gain the services and commodities required under the chosen project delivery system" (Beard et al., 2001; p.169). Examples of procurement methods are sole source, qualifications-based, source selection, adjusted low bid, and low cost first methods (Beard et al., 2001). Procurement methods range from the relationship and qualitative base of sole source selection to the bottom line and quantitative driven approach of low cost.

Design-Bid-Build Procurement Method

Low cost first bidding has been the traditional way for design-bid-build construction procurement (Figure 4) (Beard et al., 2001). Prescriptive specifications are contained in a contracted A-E firm's drawings and specifications. An Invitation for Bids (IFB) is submitted by the owner and selects the bidder with the lowest cost. (Department of the Air Force, 2000).

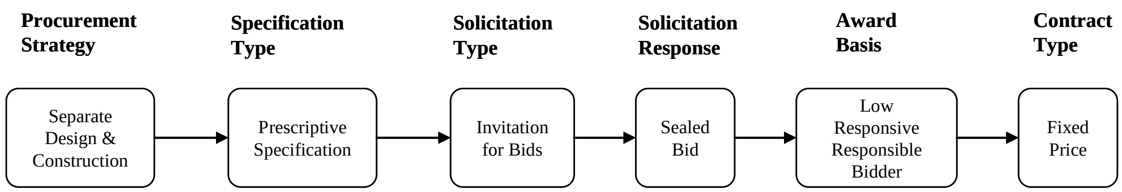


Figure 4. Traditional Procurement Process (Mouritsen, 1993; Figure 2.5)

Design-Build Procurement Methods

The three types of design-build procurement methods currently used by the DOD are the One-step, Two-step, and Newport design-build methods (Mouritsen, 1993; Webster, 1997; Department of the Air Force, 2000). The One-step and Two-step methods are used by the Army and Air Force while the Newport design-build method is used almost exclusively by the Navy.

One-Step Design-Build

Also known as the Source Selection method (Figure 5), this method is used by federal agencies and is regulated by the Federal Acquisition Regulations (FAR) Part 15 to provide the “best value” to the government (Beard et al., 2001; p.173). Technical and price proposals are submitted for projects from multiple bidders after the owner has advertised a request for proposals (RFP). Discussions will be held with proposers within “the competitive range” for the project (Beard et al., 2001; p.172). The contract award is selected from the proposers’ best and final offers.

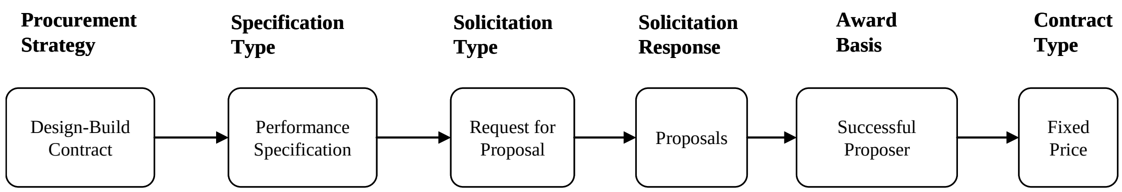


Figure 5. One-Step Design-Build Procurement Process (Mouritsen, 1993; Figure 2.6)

Two-Step Design-Build

The Two-step method (Figure 6) takes advantage of technical proposal review and low bidder award. Owners solicit proposals using a RFP that contains all project details. The first phase of the process withholds cost details and identifies the three to five most qualified proposers. The qualified proposers then submit sealed bids and the project is awarded based on the low bid (Department of the Air Force, 2000).

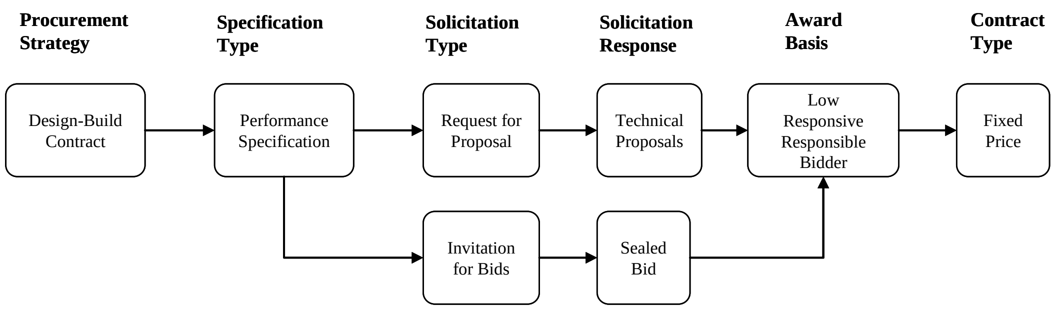


Figure 6. Two-Step Design-Build Procurement Process (Mouritsen, 1993; Figure 2.7)

Newport Design-Build

The Newport design-build method removes the costly initial technical proposals required for RFP preparation (Figure 7). This method "combines the single source of responsibility concept with lump sum competitive bidding, awarding the contract to the lowest bidder" (Mouritsen, 1993; p. 47).

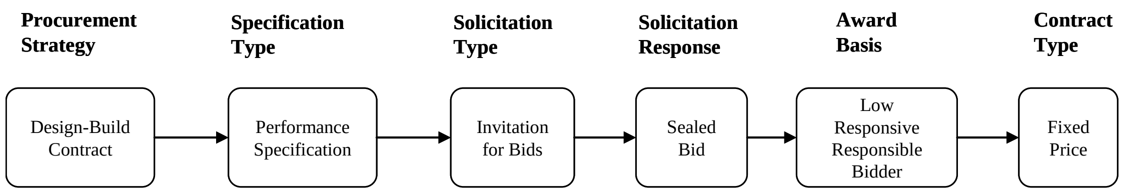


Figure 7. Newport Design-Build Procurement Process (Mouritsen, 1993; Figure 2.8)

An in-depth analysis of design-build procurement methods for MILCON is beyond the scope of this research. However, design-build procurement was analyzed in the previously mentioned study by El Wardani et al. (2006). The study built off the Sanvido and Konchar (1997) study that will be discussed later. El Wardani et al. collected data from 76 of the 155 Sanvido and Konchar design-build projects. Sole source, qualifications-based, best value, and low bid procurement methods were analyzed against the performance metrics in Figure 8 and facility type. Significant results of the study were: 1) the highest cost growth resulted from projects using the low bid procurement method and 2) the qualifications-based method resulted in the lowest cost growth. However, due to a small sample size, the study was unable to significantly determine the one procurement method best suited for design-build.

Project Selection Criteria

Professionals disagree on when design-build should be used as a project delivery system (Cushman & Loulakis, 2001). Early design-build studies reported that the design-build delivery method should only be used for simple, repetitive (such as housing) or non-technical projects (Buckingham, 1989). The unfamiliarity with the design-build process kept many project managers skeptical of the broad applicability of the new approach (Buckingham, 1989; Mouritsen, 1993; Molenaar & Songer, 1998). The pendulum has now shifted away from the early thoughts of limited use for design-build (Buckingham, 1989; Cushman & Loulakis, 2001). However, some feel that design-build can and should be used for any and all projects (Pocock, 1996; Webster, 1997; Langley, 2007b), while others have a more conservative viewpoint of using design-build for the right application (Songer & Molenaar, 1997; Konchar & Sanvido, 1998; Department of the Air Force, 2000; Ling et al., 2004). Additionally, owners and agents must realize that the choice of delivery methods is only one piece of the puzzle. Project success also depends on the correct consideration of procurement method, risk allocation, and owner's financing abilities (Cushman & Loulakis, 2001).

When to use design-build

Public projects have traditionally been selected for delivery via design-build on a subjective basis (Molenaar & Songer, 1998). Recently, key project characteristics have been identified and incorporated into models for delivery method selection. Additionally, facility type has emerged as a factor that influences the decision to use design-build.

Project characteristics for successful design-build have been extensively studied, thereby providing managers with multiple resources for delivery method decision making. Academic studies have identified the key characteristics for design-build consideration (Songer & Molenaar, 1997), produced models for public sector design-build selection (Molenaar & Songer, 1998), and predicting performance of design-build and traditional projects (Ling et al., 2004).

Identification of significant project characteristics enabled the construction of a project selection model. Public owners and project managers should consider using the Design-Build Selector (DBS) (http://www.colorado.edu/engineering/civil/db/) to rate a project's overall appropriateness for using the design-build method (Molenaar & Songer, 1998). However, to fully reap the benefits of the DBS selection tool, owners need to understand the significant project characteristics used to develop the tool. Characteristics that significantly predict project success are grouped into four categories: project, owner, market, and relationship characteristics (Molenaar & Songer, 1998).

Project Characteristics

The project characteristics that predict project success are scope definition, schedule definition, budget definition, and project complexity.

- Scope definition: A well defined scope and a shared understanding of scope are the two characteristics that have the most impact on project success (Songer & Molenaar, 1997). Success results from a clear RFP that conveys the owner's requirements and goals but is not constrained by initial design so as to leave room for contractor input (Molenaar & Songer, 1998).

- Schedule definition: Projects with established completion dates (Songer & Molenaar, 1997) and driven by schedule are appropriate for design-build. Such projects require owners to load their involvement in design on the front end of the project (Molenaar & Songer, 1998).
- Budget definition: An established budget (Songer & Molenaar, 1997) and the conveyance of budget through a constraint on scope will enhance project success (Molenaar & Songer, 1998).
- Project complexity: Technologically advanced and complex projects using design-build delivered less administrative burden and higher overall satisfaction (Songer & Molenaar, 1997; Molenaar & Songer, 1998). However, the owner must understand the project requirements in order to effectively communicate project complexity to proposers (Beard et al., 2001). Against earlier thought, simple and repetitive projects were not correlated with design-build success (Songer & Molenaar, 1997).
- Size of project: Project size, indicated by cost, must be sufficient enough to offset the proposer's expense to submit a proposal (Songer & Molenaar, 1997; Cushman & Loulakis, 2001; Beard et al., 2001; Pocock, 2007a).

Owner Characteristics

The owner characteristics that predict project success are owner/agency experience and owner/agency staffing.

- Owner/Agency experience: The owner's construction sophistication must be adequate to precisely define the scope (Songer & Molenaar, 1997). Performance increases as the owner gains experience. A typical project should be used for the owner's first design-build project (Molenaar & Songer, 1998). Inexperienced government agencies are advised against using design-build for the first time without experienced consultants (Department of the Air Force, 2000).

- Owner/Agency staffing: An allure of design-build is the ability to do more with less (Molenaar & Songer, 1998). However, owners must be able to dedicate adequate staff to the specific design-build project (Songer & Molenaar, 1997) to meet the demands of each project. Some projects (fast-track, schedule-driven) require additional staff to develop the RD and RFP, as well as meet the demands of the expedited schedule (Thornburn, 1994).

Market characteristics

The market characteristic that predict project success is design-builder experience.

- Design-builder experience: The availability of experienced design-builders can be an issue that impacts success (Songer & Molenaar, 1997; Department of the Air Force, 2000). Experienced design-builders enhance constructability and innovation leading to cost and schedule savings. Experienced contractors perform well with performance-based RFP processes and specifications (Molenaar & Songer, 1998).

Relationship Characteristics

The relationship characteristics that predict project success are design-builder selection and design-builder prequalification.

- Design-builder selection: Selection of design-builders through a combination of price and quality requirements best meets owner's expectations and influences administrative burden. Although difficult for the public sector, developing a short list of proven qualified bidders to choose from enhances performance (Molenaar & Songer, 1998).
- Design-builder prequalification: Prequalification, through past performance, keeps the best proposers in the field and reduces frivolous proposals. A limited number of quality proposals encourage competition (Molenaar & Songer, 1998).

Ling et al. (2004) also developed a comprehensive list of project characteristics that impact cost, quality, and schedule performance metrics. The 59 project, owner, consultant, and contractor characteristics were used to develop a model to predict design-build and design-bid-build performance across the performance metrics identified in Figure 8. The study produced two robust design-build and design-bid-build prediction models for time performance and two design-build quality prediction models (Ling et al., 2004).

Facility Type

Understanding and identifying the characteristics of the project and the attributes of the management team in order to determine what product delivery method to use can be complicated and time consuming. The type of facility an owner is trying to build is much easier to understand than the characteristics of the projects. The type of facility that lends itself to the design-build method has become of interest to the design-build community.

Two studies classified facilities as light industrial, multi-story dwelling, simple office, complex office, heavy manufacturing, and high technology to determine what delivery method (Konchar & Sanvido, 1998) and procurement method (El Wardani, 2006) are most effective. Significant results were obtained by Konchar & Sanvido (1998) when delivery method depending on facility type was analyzed for the performance metrics displayed in Figure 8. Design-build significantly out-performed design-bid-build in light industrial (unit cost, construction speed, delivery speed, system quality), multi-story dwelling (intensity), simple office (intensity), complex office (intensity, turnover quality), and high technology (cost growth, turnover quality, system quality) facility types (El Wardani, 2006). However, due to small sample size, the type of procurement method did not yield significant cost, time, or quality results depending on facility type (El Wardani, 2006).

The Blue Book (Department of the Air Force, 2000) directs AF project managers to consider facilities that use private sector standards, commercial standards, and AF design guides as appropriate MILCON projects for use with the design-build method (Table 8). Standard design specifications, similar to existing projects, have been identified as a characteristic for successful design-build (Songer & Molenaar, 1997). However, the rationale for selecting design-build for these facility types is that extensive guidance and standards exist that will aid project development when formal contract documents are not created. Although the AF recommends certain facilities for design-build, the most effective delivery method depending on facility type for AF MILCON projects has not been quantitatively evaluated.

Table 8. Facility Standards
(Department of the Air Force, 2000; Table 8-1)

Facility Type	Private Sector Standards	Commercial Standards	AF Design Guides
Housing	X	X	X
Hangars	X	X	
Admin/HQ	X	X	
Medical Clinics	X		
Maintenance Fac	X	X	
Dorms/TLFs			X
Child Dev Centers	X	X	X
Training Facilities		X	
Dining Facilities	X		X
Warehouse	X	X	
MWR Facilities	X	X	
Flightline Facilities	X		

Project Success Criteria

A thorough comparison between design-build and traditional delivery methods requires the identification of project success criteria that will be measured. This section reviewed the available literature on project success as it pertains to design-build construction. Additionally, the metrics used to measure successful MILCON projects were identified. Understanding the metrics used by the industry to measure project success will develop the metrics to be used by this study to compare delivery methods.

Project Success

Chan et al. defined project success as: “the degree to which project goals and expectations are met” (2002; p.121). Project performance indicators define the criteria used to measure the success of the project. Project performance has historically been measured using three key criteria: cost, time, and performance or quality (Meredith & Mantel, 2006; Chan et al.; 2002; Beard et al.; 2001; Konchar & Sanvido, 1998; Songer et al., 1997). The end product consists of goals for each criteria making up a target for the entire project.

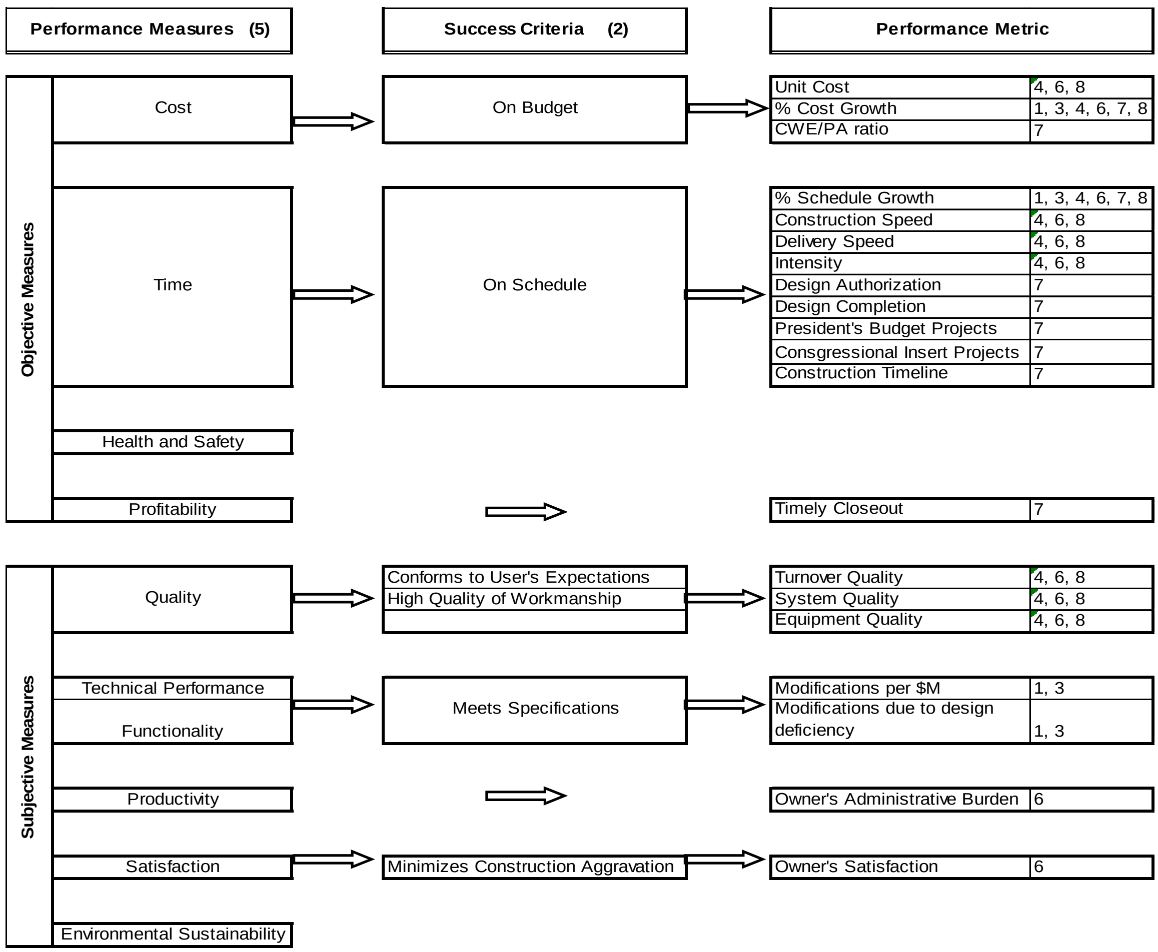
The generalized criteria of cost, time, and performance encompass many factors that define success differently for each project participant. Clients, owners, designers, and builders each have differing project success criteria (Mouritsen, 1993; Chan et al., 2002). Project success criteria also change as the project progresses through the three phases of construction: preconstruction, construction, and post construction phases (Chan et al., 2002).

Project Performance Measures

Chan et al. (2002) conducted a comprehensive study of construction literature in order to develop success criteria for the design-build delivery method. The results of the study grouped project performance measures into objective and subjective categories. Objective measures include time, cost, health and safety, and profitability. Subjective measures include quality, technical performance, functionality, productivity, satisfaction, and environmental sustainability. The framework developed by Chan et al. captured the success criteria and performance metrics used by researchers to measure design-build success.

Industry Performance Metrics

Objective and subjective performance measures are operationalized through success criteria categories (Songer & Molenaar, 1997) which are in turn broken down into performance metrics. Figure 8 summarizes the performance metrics used by the premier design-build studies to measure and compare the effectiveness of the design-build and traditional delivery methods.



Key:

1	Pocock (1996)	5	Chan et al (2002)
2	Songer & Molenaar (1997)	6	Ling et al. (2004)
3	Webster (1997)	7	Fox (2006)
4	Konchar & Sanvido (1998)	8	El Wardani et al. (2006)

Figure 8. Project Performance Measures

Dirtkicker Criteria

The Air Force Civil Engineer created Dirtkicker criteria to measure the successful execution and management of AF MILCON by the MAJCOMs. Project managers, MAJCOMs, and the Army Corps of Engineers use the Dirtkicker metrics to assess the progress and performance of AF MILCON projects. The best performing large and small MAJCOM would be awarded additional Operations and Maintenance (O&M) funds. Dirtkicker criteria provided metrics for project design, award, construction, and financial closure (Robbins, 2003). Table 9 outlines the goals set forward by the FY06 Dirtkicker Award criteria.

Table 9. FY06 Dirtkicker Award Criteria (Fox, 2006)

	Criteria	Goal
Design	Use of Old P&D Funds	All FY04 and prior year funds obligated. FY05 funds at least 80% obligated. Criteria are measured for the entire MAJCOM's program.
	Design Authorization	MAJCOMs Issue Field Design Instructions to agents within 30 days after ILEC issues Project Design Authorization
	Design Completion	FY07 President's Budget projects design complete (i.e., 100%) NLT 30 Sep 06
Award	President's Budget Projects	FY06 President's Budget projects awarded NLT 31 Mar 06.
	Congressional Insert Projects	FY06 Congressional Insert projects awarded NLT 30 Sep 06
	CWE/PA Ratio	The sum of the Award CWE (or Design CWE for unawarded projects) divided by the sum of the original PA (e.g., before any rescission, if applicable) for all FY06 projects, grouped by MAJCOM is less than or equal to 97% (.97).
Construction	Cost Growth	5% Cost Growth or less, which is when the ratio of current contract cost to original contract cost is 1.05 or less.
	Schedule Growth	10% Schedule Growth or less, which is when the performance days (i.e., NTP to BOD) divided by the original estimated performance days is 1.1 or less
	Construction Timeline	Construction Timeline is the frequency with which a MAJCOM constructs its projects at or below specified 'Target Days', which are determined by Programmed Amounts. (MILCON overview Table 3)
Financial Closure	Timely Closeout	Financial closeout within 12 Months (15 months for OCONUS).

Dirtkicker criteria provide the standards by which Army and AF leadership determines MILCON project success. Military leadership uses the project data in ACES-PM to calculate the Dirtkicker values. Therefore, these metrics provide a common basis to communicate the results of this study to AF program managers.

Previous Studies

The purpose of this section is to consolidate previous investigations into similar questions and suggest where this proposed inquiry may differ in terms of approach, data source, and subject matter focus. Table 10 displays the attributes of the previous studies researched that have impacted the direction of this thesis.

Buckingham, 1989

Buckingham (1989) was one of the first studies conducted by the AF in analyzing the possible use of design-build as a solution to problems with traditional MILCON construction. The AF was new to design-build with only four projects completed at the time (one FY84, one FY85, two FY87). Private sector companies were interviewed for their opinions on the design-build method. The study then conducted a case study on the FY85 AF Communications Command HQ Facility at Scott AFB, IL and the FY87 Base Dining Facility at Robbins AFB, GA. The study suggested only small, simple MILCON projects should use design-build. An insufficient track record existed and AF personnel were too inexperienced to determine if design-build was more effective (Buckingham, 1989).

Table 10. Comparison of Previous Studies (adapted from Konchar & Sanvido, 1998)

Attribute	Project Delivery Study							
	Buckingham (1989)	Mouritsen (1993)	Pocock (1996)	Webster (1997)	Konchar & Sanvido (1998)	Allen (2001)	Hale (2005)	El Wardani et al. (2006)
(a) Data collecion Instment								
Objective data	-	X	X	X	X	X	X	X
Owner quality data	-	-	-	-	X	X	-	X
(b) Systems Compared								
Design-bid-build	-	X	X	X	X	X	X	-
Design-build	X	X	X	X	X	X	X	X
Construction management	-	-	-	-	X	-	-	-
Partnering	-	-	X	-	-	-	-	-
Combination	-	-	X	X	-	-	-	-
(c) Type of comparison								
Univariate analysis	-	X	X	X	X	X	X	X
Multivariate analysis	-	-	-	-	X	-	-	X
Number of variables	NA	5	4	4	13	4	5	13
(d) Survey research								
Project/respondend specific data collection	X	X	X	X	X	X	X	X
Nonresponse study	-	-	-	-	X	-	-	-
Case Study	X	X	-	-	-	-	-	-
Opinion poll	-	-	-	-	-	X	-	-
Empirical measures	-	X	X	X	X	X	X	X
Private sector	X	-	-		X	-	-	X
Public sector	X	X	X	X	X	X	X	X
MILCON	X	X	X	X	-	X	X	-
Facility classification	-	X	-	-	X	X	X	X
Number of projects	2	11	209	29*	351	110	77	76
Number of subjects	4	NA	NA	NA	NA	NA	NA	NA
NA= not applicable			* Plus 146 Pocock projects					

Mouritsen, 1993

One of the first quantitative MILCON studies of design-build was accomplished by Mouritsen in 1993 for the US Navy. The study analyzed 11 child care centers constructed in FY90 (five traditional, two One-step design-build, four Newport design-build). Results showed a design-build cost savings range of 15.5% for the one-step method to 21.9% using the Newport design-build method, but without a statistical analysis completed. Project delivery time was claimed to be cut in half, but without adequate methodological support. The observations of the study determined that the design-build method should be used for all projects. The study was limited by small sample size, lack of project data in the information system, and the Navy's inexperience with the process. As with the Buckingham (1989) study, the study analyzed the few existing pilot projects so a sufficient track record did not exist (Mouritsen, 1993).

Pocock, 1996

The research of Pocock (1996) was the first quantitative delivery method MILCON study found by this research to use statistical significance to validate findings. Pocock compared partnered, design-build, and combination alternative methods to design-bid-build projects using the performance indicators in Figure 8. Pocock gathered 209 (90 traditional, 63 partnering, 40 design-build, 16 combination) projects from FY88 to FY95 from the USACE Automated Management and Progress Reporting System (AMPRS). Combination projects used characteristics from traditional, design-build, and constructability delivery approaches. The study also defined and measured the degree of interaction (DOI), which is the amount of interaction between design and construction. Pocock developed a method to calculate the DOI for each project in order to compare the interaction levels for the different delivery methods (Pocock, 1996).

The results of the study showed that design-build was the best category for significantly less cost growth and design deficiencies of all delivery methods. The overall conclusion was that alternative approaches have a significantly better performance and degree of interaction than traditional projects (Pocock, 1996). Table 11 summarizes the results of the Pocock (1996) study along with the Webster (1997) study.

Webster, 1997

Webster's study was a continuation of Pocock's 1996 dissertation thesis. The research sought to verify Pocock's methods, determine if design-build improved over time, and investigate subjective success criteria. Webster compared 29 additional design-build FY91 to FY96 MILCON projects with Pocock's traditional, combination, and design-bid projects over the same four performance indicators. Interviews were conducted to gather the data for the subjective indicators of user satisfaction, project management satisfaction, and experience with the design build process.

Results showed (Table 11) design-build data was significantly ($p<0.05$) better than traditional projects for schedule growth, modifications per million dollars, modifications due to design deficiencies. However, only schedule growth showed a significant improvement over time for design-build projects. Additionally, the design-build projects failed to be statistically better than the combination projects for all categories. The subjective analysis of satisfaction only resulted in a brief discussion of two design-build projects. Therefore, the subjective analysis did not provide enough of a response for generalization for all design-build projects (Webster, 1997).

This study succeeded in validating the statistical analysis of MILCON projects proposed by Pocock (1996). However, the results of the study suffered due to a small sample size of new design-build projects and how recently it was conducted after the Pocock study. The MILCON process is slow to change, so it is not reasonable to expect much of a change in only one year.

Table 11: Average Project Performance (Webster, 1997; Table 4.1)

Performance Indicators	*Study* *Design-build*	Traditional	Pocock study Design-build	Combination
Cost Growth (%)	6.5	8.48	6.37	10.44
Variance	113	141	59	100
p(T,=t),one tail	0.20294	-	0.1135	0.2460
Schedule Growth (%)	15.04	27.76	26.23	18.76
Variance	906	1099	1285	541
p(T,=t),one tail	0.03982	-	0.4107	0.0978
Modifications per Million Dollars	5.43	8.3	6.8	4.95
Variance	10	37	36	7
p(T,=t),one tail	0.0007	-	0.1081	0.0004
Modifications due to Design Deficiencies (%)	24.4	41.84	9.39	15.18
Variance	459	344	157	329
p(T,=t),one tail	2.16E-04	-	6.93E-15	1.34E-05

Konchar & Sanvido (1998)

This work is considered as the industry benchmark and is cited in the leading guides (Cushman & Loulakis, 2001; Loulakis, 2003), textbooks (Beard et al., 2001; Link, 2006), and studies (Ling et al., 2004; El Wardani et al., 2006). Sponsored by the Construction Industry Institute (CII), the study analyzed 351 (traditional, design-build, construction management (CM)) private and public projects. The study compared the delivery methods against the performance metrics in Figure 8. Additionally, the performance of the delivery methods was compared over six facility types: light industrial, multi-story dwelling, simple office, complex office, heavy manufacturing, and high technology. Results showed that design-build was significantly better than CM at risk and traditional methods over cost, schedule, and quality categories. The study also identified which type of facility was best suited for each delivery method. El Wardani et al. (2006), as previously discussed, built off this study to analyze the effects of procurement types for design-build projects.

Allen, 2001

This study compared 36 design-build and 74 design-bid-build Navy Bachelor Enlisted Quarters (BEQ) MILCON projects from FY1996 to FY2000. Projects were further categorized as horizontal or vertical projects. The data was retrieved from the Navy Financial Information System (FIS). The results showed that design-build projects have less award growth, cost growth, and schedule growth with better construction placement than design-bid-build. The qualitative portion of this study revealed that the design-bid-build method outperformed design-build in turnover process quality and system performance quality. While the study compared performance metric means, the analysis lacked statistical analysis to determine significant difference levels. The study thoroughly analyzed one facility type with a larger sample size than previous studies. However, the study analyzed the first projects using design-build by the Southwest Division of the NAVFAC. Therefore, the project managers were new to the design-build process and it would be beneficial to analyze projects after a sufficient design-build track record has been established.

Hale, 2005

This more recent, yet unrelated to Allen (2001), study also investigated Navy BEQs with a smaller sample size of 38 design-build and 39 design-bid-build projects from FY 1995 to FY 2004. Project data was gathered from the FIS. A statistical analysis of variance (ANOVA) was used to determine if the comparison of the performance metrics was significant. Design-build showed to be significantly better for the metrics of total project duration (date of contract award to completion), project duration per bed, time growth, and cost growth. The cost per bed metric favored design-build, but not at a significant level. As with Allen (2001), one shortfall of this study was that it only analyzed one homogenous facility type with recommendations for the use of design-build for other facility types. Another shortcoming of this study was limiting the total project time metric to the contract period. The total project time for MILCON projects should look at the entire process including the planning, programming, and design portions of the projects and not just the construction portion.

Air Force Studies, 2006

The performance of design-build verses traditional delivery methods became of great interest among the AF civil engineer community in 2006.   A report from Air Staff in the Weekly Activity Report (WAR) showed that traditional projects had a higher probability of cost growth exceeding Dirtkicker goals and design-build was increasingly staying within or below cost (WAR, 2006). The WAR report contradicted an unpublished study by AF project managers at the Air Combat Command (ACC). The ACC study used Dirtkicker criteria performance metrics to compare the delivery method with facility type. The study determined that the traditional method outperformed the design-build method in every facility type category except child development centers and fire/crash facilities (Hunt, 2006). The confusion on the performance of MILCON design-build projects is represented by these studies, MAJCOM opinion, and anecdotal answers resulted in the call for a quantitative study of MILCON delivery methods (Glardon, 2006).

Summary

The design-build delivery method is no longer a new concept for MILCON execution. However, a consensus has not been reached by AF project managers as to the correct time, place, and application for using design-build. The private sector has embraced the design-build method based on academic studies (Beard et al., 2001). While the number of academic studies investigating design-build has increased (Pietroforte, 2004), few have focused on delivery methods for MILCON. The investigation of design-build literature identified the following gaps:

- All but one of the MILCON studies reviewed were conducted when a proven track record of projects did not exist and before the approval of design-build for widespread use.
- An in-depth study of Air Force MILCON delivery methods has not been conducted since 1989.
- The most recent MILCON studies only focused on Navy Bachelors Enlisted Quarters without addressing other facility types.
- MILCON design-build study sample size was limited due to few available projects.
- The inexperience of AF project managers with the design-build method hindered a qualitative study of delivery method as a predictor of project success.
- The performance of the design-build method over time has not been sufficiently analyzed in order to determine if the method has improved.

- The type of facility for using design-build has been recommended in the Blue Book, but an analysis of facility type for MILCON design-build has not been conducted.
- Dirtkicker criteria are used as the measure of success for MILCON projects. No formal study has used Dirtkicker criteria to compare design-build and traditional methods.
- An in-depth study has not been conducted to compare total project time for MILCON from the start of initial design to completion of construction.

This research will attempt to address the gaps identified in the previous research. The design-build and traditional design-bid-build methods will be compared for the MILCON application. The literature review identified how project success is measured. Eight performance metrics will be used by this study and include: unit cost, cost growth, schedule growth, construction speed, modifications per million dollars, CWE/PA ratio, construction timeline, and total project time. A complete description of the calculations used for the metrics discussed above and the methods used for this research will be included in Chapter 3, Methodology.

III. Methodology

Chapter Overview

This chapter describes the methodology used to compare the design-build delivery method to the traditional design-bid-build method for Air Force (AF) military construction (MILCON) projects. The procedures used by this study are organized into three sections: data source, data collection, and data analysis. Each section will explain the definitions, decisions, and criteria used for the study data analysis.

Data Source

The first step of data analysis was to identify a data source that contained consistent and accurate project information for traditional and design-build projects. Military construction projects provide researchers with consistent and accurate data due to Congressional oversight and established contracting and management procedures (Pocock, 1996). MILCON project information is documented by design agents in three main databases. Projects managed by the Army Corps of Engineers will be entered into the Automated Review and Management System (ARMS). Projects which use the NAVFAC as the design agent are tracked in the NAVFAC Construction Management Information System (CMIS). Regardless of design agent, every AF MILCON project is documented and managed in the Automated Civil Engineer System - Project Management (ACES-PM) database from the planning and programming stage through construction.

ACES tracks an enormous amount of project information in order to manage real property, housing, fire department, government provided furnishings, facility maintenance and scheduling, personnel and training, military construction, environmental impact, and energy utilization data (AFCESA, 2007). The ACES database replaced and captured the data from the Planning, Design, and Construction (PDC) system previously used to manage MILCON projects in FY00 (Department of the Air Force, 2000). AF regulation requires all AF MILCON projects be tracked and managed using the fields in ACES. Interviews with MILCON managers indicate that the MILCON ACES data is up to date and is accurately reflective of project costs as it represents the means by which funds are disbursed and contractors are paid (Gogel, 2007a; Langley, 2007b). The ACES-PM database will be used as the data source to retrieve project information for this study.

Data Collection

Project information was collected from ACES-PM through the help and guidance of the construction management branch of Air Combat Command and Air Force Material Command. Project information for all AF MILCON projects from FY 1990 to 2009 was retrieved via an Oracle Discoverer report. Managers use the Oracle Discoverer report-writing software to extract data from ACES-PM (PACAF, 2004). The data retrieved from the Discoverer report was placed in an excel spreadsheet for project selection and analysis (Wells, 2007). The data that would be used for this study required two additional steps. First, project selection criteria were established to select projects within the scope of the research. Second, the ACES-PM fields that contain project, cost, and schedule data were identified.

Project Selection Criteria

Projects were selected from ACES-PM using the following criteria:

1. Only continental United States (CONUS) projects were selected to avoid effects from overseas costs.
2. Project fiscal year (FY) ranging from FY 1996 to FY 2007 will be analyzed. This year range will enable the analysis of the design-build method after the Clinger-Cohen act of 1996 opened the two-phase method for use. Additionally, this year group will build on previous studies (Webster, 1997) that ended at FY 1996.
3. Projects meeting the minimum project value at the MILCON spending level will be included. This level was $500,000 for FY90 to FY02 and $750,000 for FY03 to FY07.
4. All projects must show a 100% construction completion level in ACES-PM.
5. This research will analyze MILCON projects in the 321 funding category. Emergency 341 MILCON projects are not included due to the unique timelines and methods of procurement.
6. Due to differences in funding and contracting policies, no military family housing projects will be included

ACES-PM Field Selection

The ACES-PM database is composed of many fields that contain a multitude of project details. The fields that contain project, cost, and schedule data were identified in order to retrieve the necessary information to perform a comparative analysis. The AFMC civil engineering construction contract (AFMC/A7CCC) staff aided in the selection of fields that were incorporated in the Discoverer report. The complete listing of all fields incorporated in the report is located in Appendix A. The sample size will further be refined by removing projects with a "null" or "other" listed design method, duplicate projects, projects at overseas locations that slipped through the criteria of the report, and projects with incomplete data fields.

Data Analysis

Now that the data source and project selection criteria have been established, the method in which the data will be analyzed must be defined. First, the performance metrics to be used by this study will be defined. Next, the method in which the data is separated into facility type and project size will be identified. The way in which the delivery methods are compared over time will be described. Finally, the statistical method that will be used to determine significance over the performance metrics, facility types, and timeline will be defined.

Performance Metrics

The literature identified performance metrics used by AF project managers and previous studies to compare project delivery methods. Eight performance metrics will be used by this study and include: unit cost, cost growth, schedule growth, construction speed, modifications per million dollars, CWE/PA ratio, construction timeline, and total project time. Equations were developed for the project data retrieved from ACES-PM to calculate the performance metrics. Each equation was reviewed and commented on by AF project managers.

Unit Cost

The unit cost indicates the dollar amount per unit of area of the project cost. Unit cost typically consists of the funds used to construct the physical building excluding supporting facilities, equipment, supervision, inspection, and overhead costs (SIOH) (UFC, 2007). This study will use the Total Current Working Estimate (CWE) amount when calculating unit cost. The CWE includes all of the costs associated with the project including modification, contingency, SIOH, design, and management reserve costs. The equation for unit cost for this study is:

$$\text{Unit Cost}\left(\frac{\$}{\text{m}^2}\right) = \frac{(\text{Total CWE Amt} * \text{Index})}{\text{Scope}} \qquad (1)$$

where

Total CWE Amt = Total Current Working Estimate Amount ($)

Index = time adjustment * location adjustment

Scope = quantity of units constructed (m^2)

The CWE indicates the final project cost since all projects in the analysis were 100% construction complete. An index factor was calculated in order to compare projects constructed in different locations and years. The time adjustment factor used the RSMeans (2006) National 30-city average historical escalation factor. The time factor was calculated by dividing the national average for 2006 by the national average for the year of the project. The MILCON Area Cost Factor (ACF) was used to account for project location as published in the DoD Facilities Pricing Guide (UFC, 2007).

Cost Growth

Cost growth indicates the percent difference between the original contract cost and the actual contract cost (Pocock, 1996). The AF MILCON Dirtkicker goal is to have the ratio of current contract cost to original contract cost be less than 5% (Fox, 2006). Increases to the original contract cost are documented in the contract modification amount field in ACES-PM. The equation for cost growth is:

$$\text{Cost Growth (\%)} = \left(\frac{\text{Contract Mod Amt}}{\text{Contract Orig Amt}}\right) * 100 \qquad (2)$$

where

Contract Mod Amt = contract modification amount ($)

Contract Orig Amt = contract original amount ($)

Contract modifications originate from many different sources. Modifications can indicate problems with the design or construction errors, environmental or unforeseen site conditions, or might not be problems at all and indicate additional benefits added to the project (Langley, 2007b). An in-depth analysis of modifications and change orders is beyond the scope of this thesis. A limitation of this study is that the cause of a modification is not indicated in ACES-PM; therefore, this study will assume that a modification is generated from a problem or negative cause.

Schedule Growth

The farther a project continues past its planned completion date, the greater the impact to the cost of the project and delays occupancy or use of the facility. Keeping schedule growth to a minimum is a goal of every project manager. The equation to calculate schedule growth from the ACES-PM data is:

$$\text{Schedule Growth (\%)} = \left[\left(\frac{\text{NTP to Act BOD}}{\text{NTP to Est BOD}}\right) - 1\right] * 100 \qquad (3)$$

where

NTP to Act BOD = notice to proceed to actual beneficial occupancy date

NTP to Est BOD = notice to proceed to estimated beneficial occupancy date

Negative values indicate an early project finish. The AF MILCON Dirtkicker goal is to keep schedule growth less than 10% (Fox, 2006). The ACES-PM data for NTP to BOD is the construction phase of traditional projects but is design and construction for design-build projects. The traditional design schedule growth is not documented in ACES-PM. Therefore, interpretation of the results of the schedule growth metric must be conducted with the understanding of this limitation.

Construction Speed

Construction speed is an indicator of how quickly the project team was able to deliver the facility (Konchar & Sanvido, 1998). The construction speed value indicates the amount of square footage per month that was constructed. The Konchar & Sanvido (1998) equation was adapted for ACES-PM MILCON data and is represented as:

$$\text{Construction Speed (m}^2\text{/month)} = \frac{\text{Scope}}{\left(\frac{\text{NTP to Act BOD}}{30}\right)} \qquad (4)$$

where

Scope = number of units constructed (m^2)

NTP to Act BOD = notice to proceed to actual beneficial occupancy date

Modifications per Million Dollars

The number of modifications per million dollars was used by Pocock (1996) and Webster (1997) as an indirect measure indicating how many problems the project experienced. This indicator is used to quantitatively compare the typically subjective quality performance of the design-build and traditional delivery methods. The limitations of using ACES-PM data previously discussed in the cost growth section also apply to this success metric. The equation to determine the modifications per million dollars was

$$\text{Modifications}\left(\frac{\#}{\$M}\right) = \frac{\text{Mod Count Qty}}{\left(\frac{\text{Contract Orig Amt + Eng Dsg Amt}}{\$1,000,000}\right)} \qquad (5)$$

where

Mod Count Qty = number of modifications

Contract Orig Amt = contract original amount ($)

Eng Dsg Amt = engineering design amount ($)

Project cost is calculated only using the cost for design and construction contracts for the MILCON project. Additional costs are withheld in order to determine modifications resulting from the delivery method costs. Dividing the number of modifications by the contract value normalizes the effects of project size (Pocock, 1996).

In addition to metrics identified by previous studies, several metrics were chosen for comparison of the delivery methods from the Dirtkicker criteria. Along with the previously mentioned cost and schedule growth, the CWE/PA ratio and construction timeline metrics will be investigated.

CWE/PA Ratio

The CWE/PA ratio is representative of the effectiveness of the delivery method in meeting the programmed amount of MILCON projects. The equation for the ratio is:

$$\text{CWE/PA} = \frac{\text{Total CWE Amt}}{PA} \qquad (6)$$

where PA is the programmed amount. The award CWE cannot exceed 25% or $2.0 million, whichever is greater, of the PA without being redesigned, re-bid, or reprogrammed (Department of the Air Force, 2000). The AF goal is to have a CWE/PA ratio less than or equal to 0.97 (Fox, 2006).

Construction Timeline

The Dirtkicker criteria defines construction timeline as “a measure of how often projects meet acceptable performance time targets based on the Programmed Amounts” (Fox, 2006). The equation used by this study to calculate this metric is:

$$\text{Construction Timeline (days)} = \left(\text{NTP to Act BOD}\right) - \text{Target Days} \qquad (7)$$

where target days are:

365 Days for PA < $5M

540 Days for PA ≥ $5M and PA < $20M

730 Days for PA ≥ $20M

Negative values indicate the project finishing earlier than the Dirtkicker goal. MAJCOMs are graded on the percentage of projects that meet the target day goal (Fox, 2006). Construction timeline was selected since the Dirtkicker requirement is used as the standard when writing RFP and IFB packages (Langley, 2007b). Again, the ACES-PM data places a limitation on the direct delivery method comparison of construction timeline. NTP to BOD is the construction phase of traditional projects but is design and construction for design-build projects. The traditional design timeline is documented in ACES-PM with a design start date but without a design completion date. Therefore, the study was unable to add design time to the duration of construction for traditional projects. Therefore, interpretation of the results of the construction timeline metric must be conducted with the understanding that the design-build construction timeline includes design and construction whereas traditional construction timeline results only include construction.

Total Project Time

The final performance metric results from the interest in total project time by AF project managers (Astin, 2007; Langley, 2007b; Pocock, 2007a). This metric has been avoided in research due to the uncertainty in AF MILCON programming and ACES-PM documentation (Astin, 2007; Langley, 2007b). Total project time refers to the moment design action begins on a project to when the occupants enter the building. The equation for total project time is:

$$\text{Total Project Time (days)} = \text{Actual BOD} - \text{Field DI Issued} \qquad (8)$$

where Field DI Issued is the date when the program managers at MAJCOM direct the agent (ACOE, NAVFAC, AFCEE) to begin design of the project. The Actual BOD date is when the user takes occupancy of the facility. The difference between these dates will provide project managers the answer to which delivery method is faster from start to finish. Figure 9 was developed in order to display the schedule performance metrics. It shows the MILCON project milestones and where those milestones correspond with the activities of each project delivery method. Figure 9 also displays the limitations placed on the schedule growth and construction timeline comparisons by the MILCON ACES-PM documentation for this study.

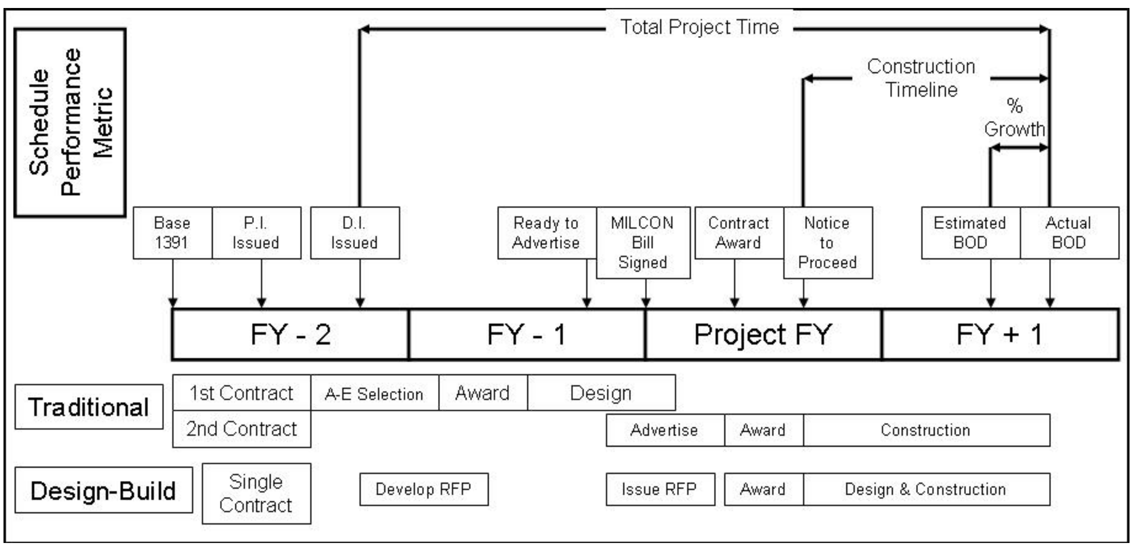


Figure 9. Schedule Performance Metric Diagram

Historical Delivery Method Performance

The data selected provides the ability to observe the historical trends of the design-bid-build and design-build delivery methods. Webster (1997) attempted to determine if the design-build method had improved from the study by Pocock (1996). However, a sufficient track record of projects was not available to either study due to the new use and approval of the delivery method and the lack of a centralized database like ACES-PM to track MILCON projects. This study will attempt to capture all AF MILCON projects since design-build was approved for widespread use in 1996 (Loulakis, 2003).

The selected data will be grouped into five two-year categories and compared within the study to determine if the design-build method has improved through time. The first group will include data from FY 1996 to FY 1997. These projects occurred after the Clinger-Cohen act of 1996 authorized the Two-step design-build method for all MILCON projects (Loulakis, 2003). The remaining projects will be grouped into year groups FY 1998 to FY 1999, FY 2000 to FY 2001, FY 2002 to FY 2003, and FY 2004 to FY 2005. The time study will end with FY 2005 projects because at the time of this study, few FY 2006 and even fewer FY 2007 MILCON projects would be 100% construction complete.

Facility Type

The Blue Book (Department of the Air Force, 2000) suggested certain facility types for use with the design-build method due to available private sector standards, commercial standards, and AF design guides (Table 8). The facility type will be determined from the retrieved ACES-PM data from the Category Code (CATCODE). The CATCODE is a six-digit number that represents the function of the facility or area of the project (Department of the Air Force, 1996). The first two numbers of the

CATCODE identify the main facility type for the project. The CATCODE for each facility type is displayed in Table 12.

Table 12. Facility Category Code Prefix (Department of the Air Force, 1996)

CATCODE	Description
11	Airfield Pavements
12	Petroleum Dispensing and Operating Facilities
13	Communications, Navigation Aids & Airfield Lighting
14	Land Operations Facilities
17	Training Facilities
21	Maintenance Facilities
41	Liquid Fuel Storage
42	Explosives Facilities
44 & 45	Storage Facilities Covered, Open, Special Purpose
61	Admin Facilities
72	Dorms, Officer Quarters, Dining Halls
73	Personnel Support
81	Electricity
82 & 83 & 84	Heat, Sewage & Waste, Water
85	Roadway Facilities
86	Railroad Trackage
87	Ground Improvement Structures
88	Fire and Other Alarm Systems
89	Miscellaneous Utilities

It was arbitrarily determined that at least 10 projects, 5 design-build and 5 design-bid-build, must be retrieved from ACES-PM for each facility type in order to compare the delivery method according to the performance metrics. The best delivery method for a facility will be determined by the majority of significant findings by a particular delivery method for that facility type.

Statistical Analysis

This study will use statistics to test if the design-build sample performance metrics are significantly different than the design-bid-build performance metrics. This study will use the *t*-test for samples with unequal variances method to compare two population means (Pocock, 1996; Webster, 1997; McClave, 2005). Two conditions must be met in order for the two sample t-test to be valid. First, the samples must be independent and random samples from each population. Secondly, the sample populations must have distributions that are approximately normal (McClave, 2005). Once these conditions are met, the t-test will determine what the p-value for that comparison. The Microsoft Excel Data Analysis package will be used to compute the p-values for analysis.

Study Hypothesis

For the performance metrics defined, the facility types identified, and the design-build method improvement over time:

- The null hypothesis for this study is: There will be no significant difference between the between the average performance of the design-bid-build and the design-build delivery method.
- The alternative hypothesis is: The average performance of the design-build method will be significantly better than the design-bid-build approach.

Study Significance Level

The level of significance, α, represents a Type I error where the null hypothesis is rejected when in fact the null hypothesis was true. The hypothesis test statistic (t value) produces an observed significance level for the sample, or p-value, that is compared to the determined α level. A p-value less than α for a one-tailed test reduces the likelihood that the null hypothesis was rejected in error (Pocock, 1996; McClave, 2005). For this study, a one-tailed test statistic that produces a p-value less than 0.05 will be considered statistically significant and highly significant if less than 0.01 (Webster, 1997).

Summary

Chapter 3, Methodology, described the data source, data collection, and data analysis methods that will be used to compare the delivery methods used for MILCON. The design-build delivery method will be compared with the design-bid-build method over eight performance metrics, over time, and according to facility type. Chapter 4, Results, will now present, analyze, and discuss the data in order to test the study hypotheses and answer the research questions.

IV. Analysis and Results

Chapter Overview

This chapter provides the raw results of the study based on the methodology developed in Chapter 3.   The results are presented graphically and in tables with discussions limited to the statistical analysis. Additional interpretation, explanation, and speculation of the results will be addressed in Chapter 5, Conclusions.

The first section describes the data retrieved from the Automated Civil Engineer System – Project Management Module (ACES-PM) used in this analysis. The second section compares the performance of design-build and design-bid-build MILCON projects, using all the data collected, across eight performance metrics: unit cost, cost growth, schedule growth, construction speed, modifications per million dollars, CWE/PA ratio, construction timeline, and total project time. The performance over time for each metric is then analyzed. Finally, the data is grouped according to facility type and analyzed across the eight performance metrics. A summary of the total analysis results is provided in Table 14 on page 95.

Results

The initial data retrieved from ACES-PM was used to observe the percentage of the AF MILCON program that utilized the design-build delivery method. All AF MILCON projects were gathered from FY 1990 to FY 2009, including overseas projects. Figure 10 displays the results of this initial observation.   The use of the design-build method began to increase after the Clinger-Cohen Act of 1996 allowed the unrestricted

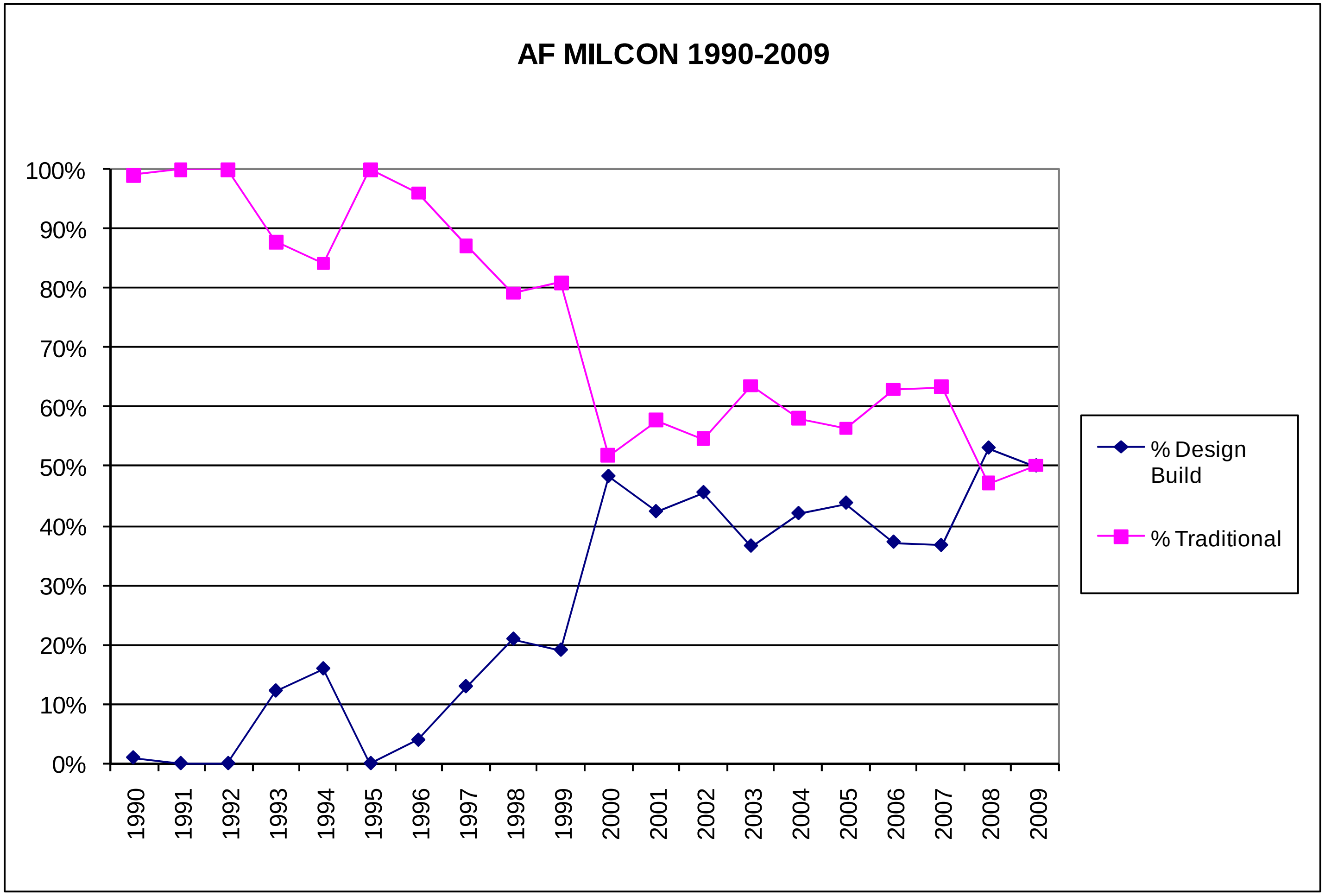


Figure 10. MILCON Delivery Method Use

use of design-build for MILCON. The most notable increase observed was the 18% use in FY1999 rising to 48% for FY2000. The actual use of design-build for MILCON generally matches the predictions made by the DBIA for the industry shown in Figure 3. Design-build is expected to overtake the traditional method for FY2008 projects at 53%, when the DBIA predicted this to occur in 2010. The future AF MILCON design-build use is expected to increase. MILCON project management was transferred from the MAJCOMs to the Air Force Center for Engineering and the Environment (AFCEE) in October 2007 (AFCEE, 2007b). AFCEE will now use the design-build delivery method as the default method for MILCON execution for new construction. The traditional method will be used primarily for MILCON renovation projects (Morrison, 2007a). Therefore, the use of design-build by the Air Force will continue to grow and follow the predictions made by the DBIA.

Data Description

After the observation of MILCON delivery method use, the project data was filtered in order to meet the project selection criteria outlined in the methodology. The data retrieved needed additional refinement in order to remove overseas projects that were incorrectly coded and projects with insufficient field population. 835 projects met the required analysis criteria consisting of 557 (67%) traditional design-bid-build and 278 (33%) design-build projects.

In order to proceed with the statistical analysis, the conditions required to ensure a valid t-test had to be met. The first requirement was that the data must be selected independently and randomly. The data used in this study met these criteria because every possible data point was retrieved without a preference to any particular project type and without choosing particular projects for analysis. Additionally, every project in the sample was independent of each other with regards to the performance metrics chosen. Secondly, the sampled populations needed to have a distribution that was approximately normal. The design-build and traditional results for each performance metric was plotted on a histogram located in Appendix K. The results of these histograms show that the design-build and traditional distributions for the performance metric were approximately normal and satisfy the second requirement for performing a two-sample t-test with unequal variances.

Performance Metric Analysis

The performance metric analysis compared the entire sample of 835 projects across eight performance metrics. Table 13 displays the overall results of the one tailed t-test for the comparison between design-build and design-bid-build projects. The mean, variance, number of observations, and p-value was calculated for design-build and traditional delivery methods for each metric. As outlined in the methodology, a p-value of less than 0.05 indicates statistical significance and less than 0.01 is highly significant. The p-value indicates the level at which the null hypothesis is rejected in error. Each performance metric will now be discussed including the historic performance characteristics of the design-build delivery method. The explanatory results, provided by Air Force project managers, of the historical analysis will be reserved for the discussion located in Chapter 5: Conclusions.

Table 13. Overall Analysis Results

Performance Metric		Mean		Variance		Observations		P(T<=t)
		DB	*T*	*DB*	*T*	*DB*	*T*	one-tail
Unit Cost ($/SM)		3041.0872	2706.5277	6403431.1	4179979.2	177	356	0.0637538
Cost Growth(%)		4.5145524	6.4186242	38.104292	233.67265	277	553	0.0055705
Schedule Growth (%)		17.341071	18.819136	1135.8948	1604.5974	271	507	0.2929871
Construction Speed (SM/Month)		422.97993	683.17434	1518378	10927894	176	351	0.0962699
Modifications Per $M (#/$M)		2.0999542	4.7975433	8.3208965	49.418071	276	557	7.98E-15
CWE/PA		0.9904743	0.9907844	0.0130928	0.0521008	278	557	0.4895706
Construction Timeline (# days over target)	PA < $5M	195.05797	155.44523	55568.467	43357.73	69	283	0.1019087
	$5M < PA < $20M	161.59794	98.665807	64792.387	50821.261	194	243	0.0036144
	PA > $20M	202.75	56.375	72454.386	20856.517	12	16	0.0534474
Total Project Time (Years)		3.2820922	3.0530874	1.4117642	1.8354118	275	546	0.0066169

Unit Cost

The traditional average unit cost was better than design-build at $2,706.53/m^2 and $3,041.09/m^2, respectively. However, the p-value of 0.0637 failed to reject the null hypothesis and the difference is not significant. The sample size used to compare unit cost consisted of 177 design-build and 356 traditional projects. Project removal resulted from dormitory projects listing scope in number of rooms or people, other projects not measured in square meters, and unpopulated ACES-PM CWE and scope fields. A unit cost analysis was conducted later in the facility type analysis using the number of rooms as the scope.

Figure 11 displays the unit cost performance of design-build and traditional AF MILCON projects over time. The only significant difference in delivery methods occurred in the FY00-01 year group. The traditional ($2,166.77/m^2) method outperformed design-build ($2,932.06/m^2) with a highly significant p-value of 0.0028. The unit cost performance for design-build worsened over time. The FY02-03 unit cost was worse than the previous year group FY00-01 at a significant level of p=0.041 and when compared to the starting year group FY96-97 at a significant level of p=0.011. The complete t-test results for the time comparison of unit cost are provided in Appendix B.

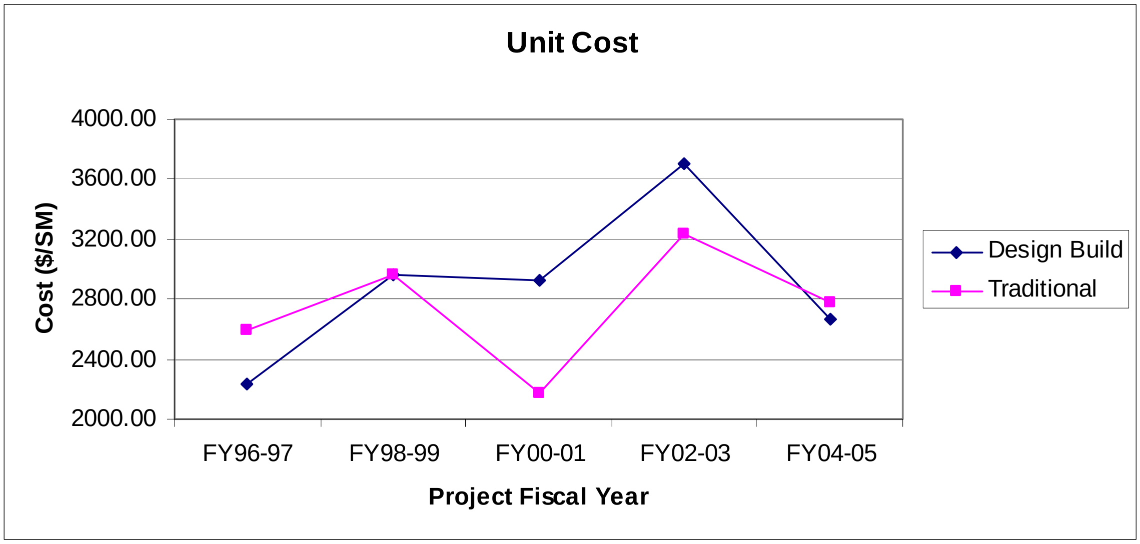


Figure 11. Unit Cost Performance over Time

Firm conclusions cannot be drawn from the unit cost analysis until facility type has been accounted for. The previous analysis included project from every facility type. The facilities ranged from airfield pavement projects to fitness centers to maintenance hangars and research and development labs, all of which have significantly different costs per square meter. Additionally, the unit cost variation over time may result from many projects of a certain type of facility being constructed for a particular year. For example, the FY00-01 group had 12 traditional pavement projects compared to three that used design-build. Conclusive results for unit cost will arise from the facility type analysis described later in this chapter.

Cost Growth

The cost growth analysis showed that the design-build delivery method outperformed the traditional method with a p-value of $p=0.0056$, indicating a difference between the two delivery methods at a highly significant level. The design-build mean cost growth was 4.51% while the traditional average was higher at 6.41%. The sample size used for the cost growth analysis contained 277 design-build and 553 traditional projects. Projects were removed from the analysis that did not have values in the original contract amount field of ACES-PM.

The historical analysis of cost growth yielded several notable results. Figure 12 displays the cost growth performance of design-build and traditional AF MILCON projects over time. Although not statistically significant, design-build consistently outperformed the traditional method for every year group. The design-build delivery method itself improved over time. The FY04-05 (2.79%) design-build cost growth improved from FY02-03 (4.84%) at a significant level of p=0.022 and from FY96-97 (8.21%) at a highly significant level of p=0.0024.

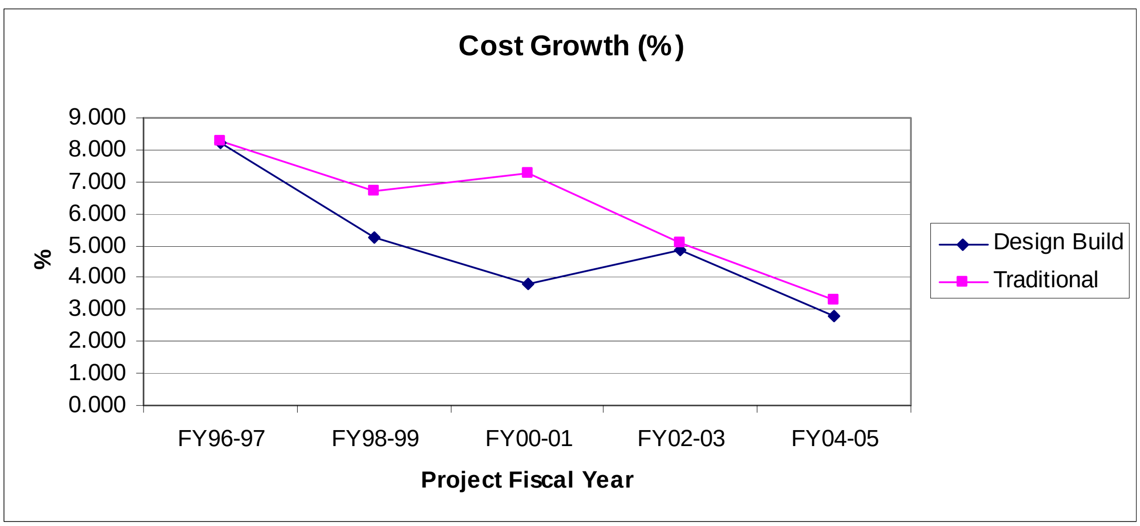


Figure 12. Cost Growth Performance over Time

The traditional delivery method performance also improved over time. The FY04-05 (3.25%) traditional cost growth improved at a highly significant level of $p=6.6 \times 10^{-5}$ when compared to the FY96-97 (8.26%) year group. Meanwhile, the traditional comparisons between each year group did not result in any statistically significant results. The t-test results for the time comparison of cost growth are provided in Appendix C.   The cost growth study showed that the design-build delivery method outperforms the traditional design-bid-build method and has improved over time at a statistically high significant level.

Schedule Growth

The schedule growth analysis determined that the mean schedule growth was 17.3% for design-build projects and 18.8% for traditional projects. While the design-build method had lower schedule growth, the results of the t-test were not nearly significant due to a p-value of 0.29. The sample size for the analysis of schedule growth consisted of 271 design-build and 507 traditional projects. The sample size was reduced by removing projects with missing data in the notice to proceed (NTP) and beneficial occupancy date (BOD) fields in ACES-PM. In several cases, the revised BOD field was used instead of the estimated BOD field when the duration of NTP to estimated BOD was a zero or negative number.

The historical analysis shown in Figure 13 shows a trend of increasing schedule growth for both design-build and traditional delivery method. The Dirtkicker goal for schedule growth is to have projects below 10% growth. The design-build schedule growth increased from FY96-97 to FY00-01 at a significant level with p=0.023. While the overall comparison between design-build and traditional methods was not significant, there was a significant difference in the FY02-03 group. The FY02-03 schedule growth for design-build (17.37%) was better than traditional (33.69%) at a highly significant p-value of 0.002.   The t-test results for the time comparison of schedule growth are provided in Appendix D.

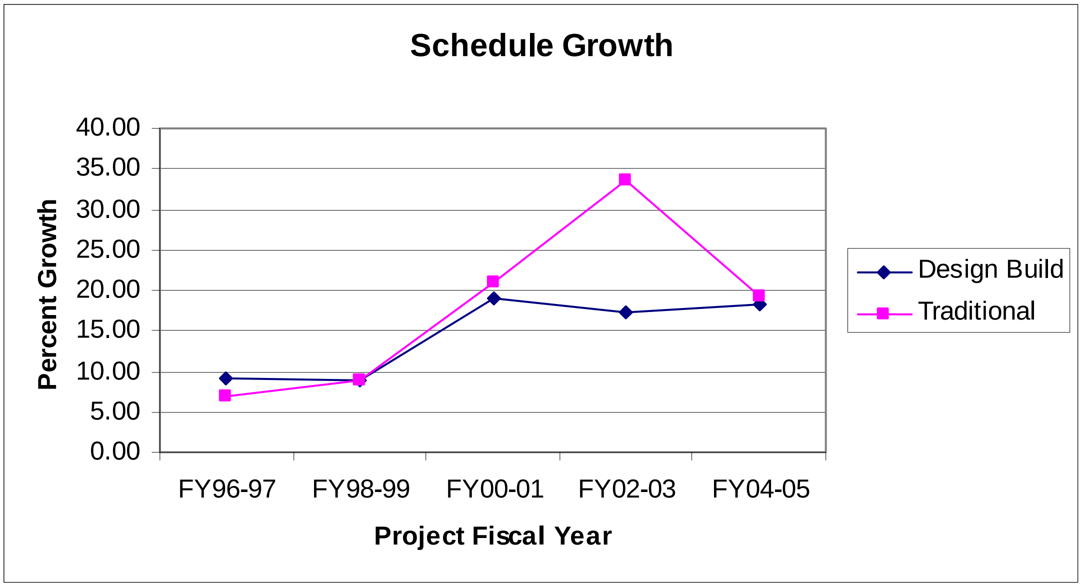


Figure 13. Schedule Growth Performance over Time

A limitation for the schedule growth analysis is based on the project documentation in ACES-PM. The only fields that lend themselves to schedule analysis are the NTP and BOD milestones. NTP to BOD only accounts for the construction portion of traditional projects while NTP to BOD for design-build includes both design and construction phases. The results already show that design-build had a lower schedule growth than the traditional method. Although not investigated by this study, it can be expected that the schedule growth for traditional projects would increase once the design schedule was included.

Construction Speed

The traditional construction speed was faster than design-build at 683.2 m^2/month and 422.9 m^2/month, respectively. However, the p-value of 0.096 failed to reject the null hypothesis and the difference is not significant. The sample size used to compare unit cost consisted of 176 design-build and 351 traditional projects. As with the unit cost metric, all dormitory projects were removed from this analysis due to the listing scope in number of rooms or people instead of square meters. Additional projects were removed due to the project scope not being measured in square meters and unpopulated ACES-PM NTP, BOD, and scope fields.

Figure 14 displays the construction speed performance of design-build and traditional AF MILCON projects over time. The complete t-test results for the time comparison of unit cost are provided in Appendix E.   The construction speed over time analysis did not yield any statistically significant results. The comparison within design-build over time was not significant, neither was the comparison between design-build and traditional for each two year group.

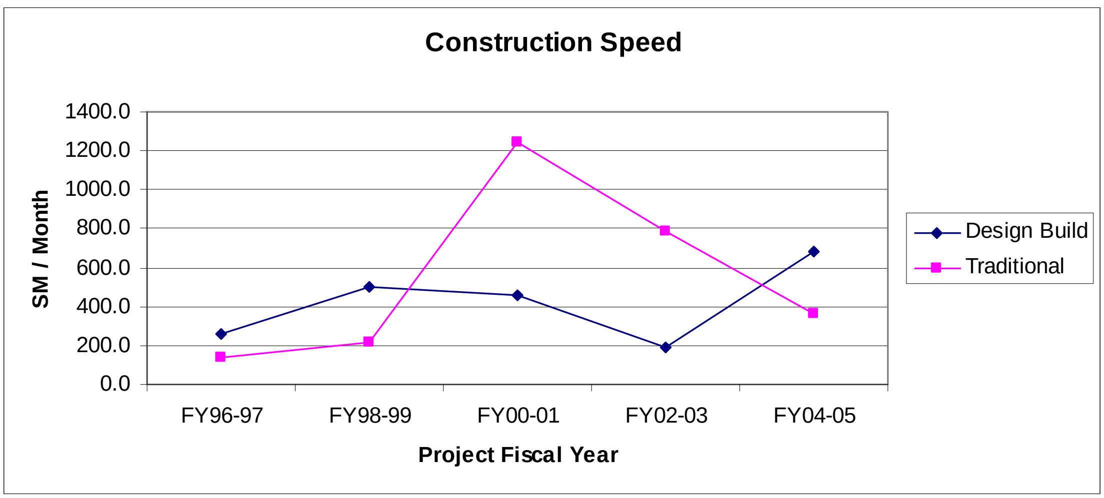


Figure 14. Construction Speed Performance over Time

As with the unit cost metric, firm conclusions cannot be drawn from the construction speed analysis until facility type has been accounted for. The impact of pavement projects was even greater for construction speed. The large spike in the FY00-01 traditional group construction speed was a direct result of a FY2000 94,500 m^2 airfield upgrade project for Tyndall AFB with a construction speed of 8,031.16 m^2/month and a FY2001 220,244 m^2 auxiliary airfield project for Charleston AFB with a construction speed of 40,288.54 m^2/month. These large airfield projects were the cause for the lack of significance with the traditional method construction speed. Pavement projects are included in the facility analysis and will be discussed later.

Modifications per Million Dollars

The design-build delivery method outperformed the traditional method with 2.7 less modifications per million dollars (Mods/$M) at a highly significant level of p = $8x10^{-15}$. The design-build mean Mods/$M was only 2.09 while the traditional average was higher at 4.79. The sample size used for the cost growth analysis contained 276 design-build and 557 traditional projects. Projects were removed from the analysis that did not have values in the modification number, original contract amount, or engineering design amount fields of ACES-PM.

The historical analysis of Mods/$M produced highly significant findings. Figure 15 displays the Mods/$M performance of design-build and traditional methods over time. The design-build method showed significant improvement from 2.96 Mods/$M in FY96-97 to 2.11 Mods/$M in FY00-01 and highly significant improvement at 1.79 Mods/$M in FY02-03 and 1.18 Mods/$M in FY04-05. The design-build method outperformed the traditional method at a significant level for FY00-01 and at a highly significant level for all other year groups. While the design-build method had better performance, the traditional delivery method displayed more improvement over time. The FY04-05 (2.23) traditional Mods/$M improved at a highly significant level of $p=1.4x10^{-8}$ when compared to the starting FY96-97 (5.7) year group and a significant level p=0.0109 when compared to FY02-03 (3.7). The t-test results for the time comparison of modifications per million dollars are provided in Appendix F. The modification per million dollar analysis showed that the design-build delivery method outperforms the traditional design-bid-build method and has improved over time at a highly statistically significant level.

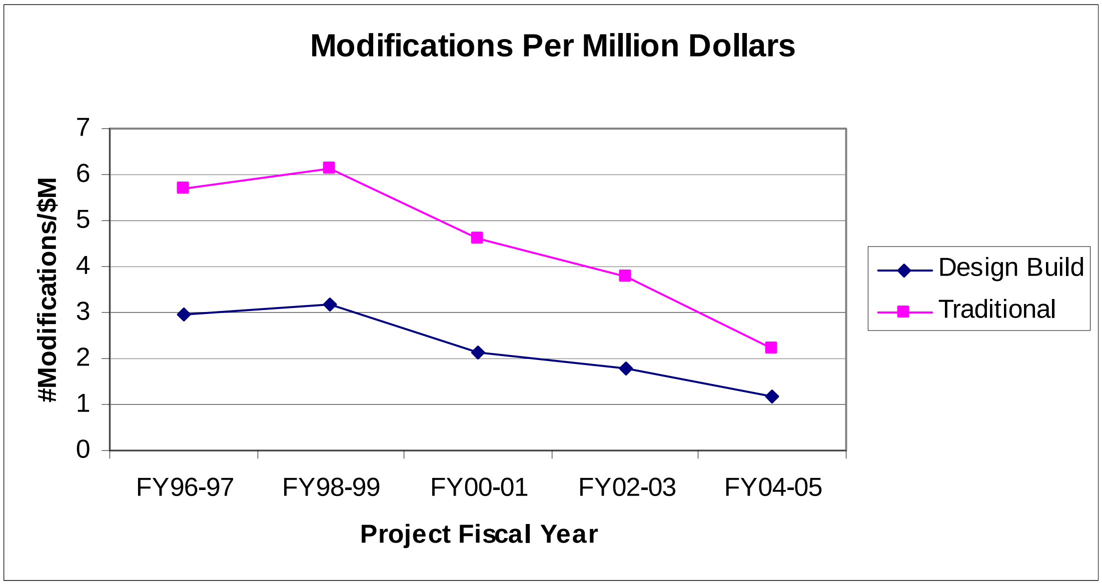


Figure 15. Modifications per $M Performance over Time

CWE/PA Ratio

The current working estimate (CWE) to programmed amount (PA) ratio analysis showed that there is practically no difference in the performance of either delivery method for this metric. The p-value of p=0.489 confirms that there is no difference between the CWE/PA ratio for design-build (0.9904) and traditional (0.9907). The sample size for CWE/PA contained 278 design-build and 557 traditional MILCON projects. Projects were removed for this analysis that did not contain values in the CWE or PA fields of ACES-PM. This metric contained the largest sample size after the filtering of projects according to the methodology. All other metric analysis used this sample as a baseline of projects in order to have as many projects with complete project data as possible.

The analysis of CWE/PA over time did not produce any consistent trend in the performance of design-build or traditional delivery methods. Figure 16 shows the performance of each delivery method alternating for each year group. The only comparison that yielded a significant result was the design-build FY02-03 comparison with the initial FY96-97 year group. No comparison between the two delivery methods was significant. The t-test results for the time comparison of CWE/PA are provided in Appendix G. Therefore, the design-build method has not improved over time when compared to itself and the traditional method for the CWE/PA metric.

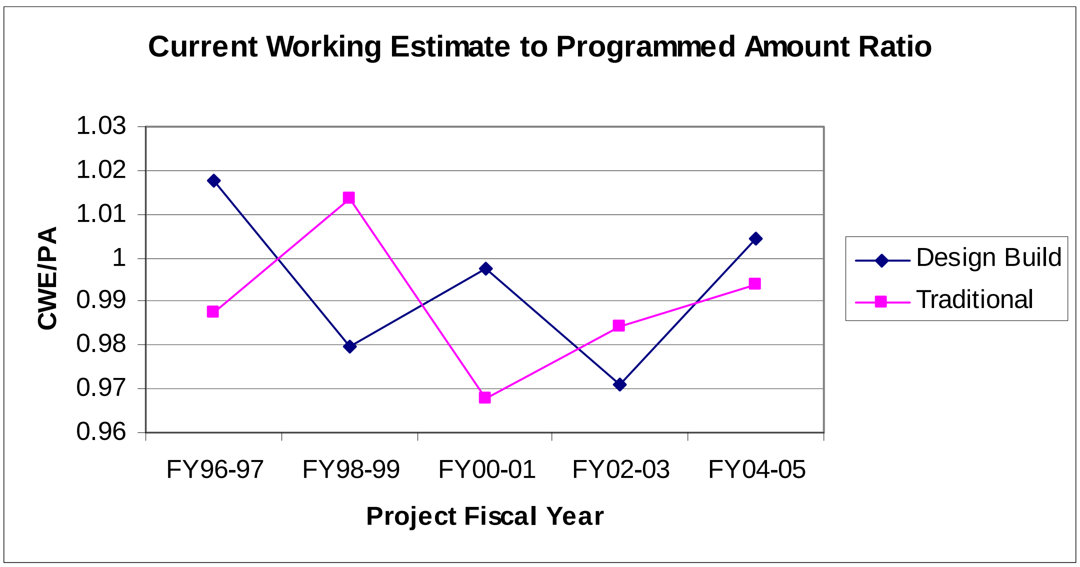


Figure 16. CWE/PA Performance over Time

Construction Timeline

The construction timeline is a Dirtkicker metric solely used to measure AF MILCON project success. This Dirtkicker metric measures the NTP to BOD for a project. The issues associated with using the NTP to BOD dates in ACES-PM previously discussed for schedule growth also affect the construction timeline analysis. The NTP to BOD for design-build includes both the design and construction of the facility whereas the traditional method only included the construction duration. It is difficult to directly compare the two delivery methods for this metric using ACES-PM because the design duration is not captured for traditional projects. Therefore, this analysis will proceed, using NTP to BOD and comparing that duration to the target days, with an understanding that the construction timeline includes design time for design-build projects. The results for each programmed amount (PA) grouping will now be presented.

PA < $5M

The target day duration for MILCON projects below five million dollars is 365 days from NTP to BOD. The traditional delivery method had fewer days over the target than design-build with a mean of 155.4 days and 195.1 days respectively. However, the p-value of 0.101 failed to reject the null hypothesis and the difference is not significant. The sample size used to compare construction timeline consisted of 69 design-build and 283 traditional projects. Projects were removed due to unpopulated ACES-PM NTP and BOD fields.

The historical analysis for construction timeline of projects less than $5M yielded significant design-build delivery results. Figure 17 displays the trend of design-build projects improving over time and overtaking the traditional method. The FY00-01 (166.7 days) and FY02-03 (172.3 days) groups improved at a significant level of p=0.023 and p=0.035, respectively, and the FY04-05 (56.07 days) group improved at a highly significant level of p=0.0028 when compared to the 369.3 days for the initial FY96-97 year group. While not statistically significant, the FY02-03 and FY04-05 design-build group performed better than the traditional projects in these groups. This is an interesting finding since the project durations included design time.

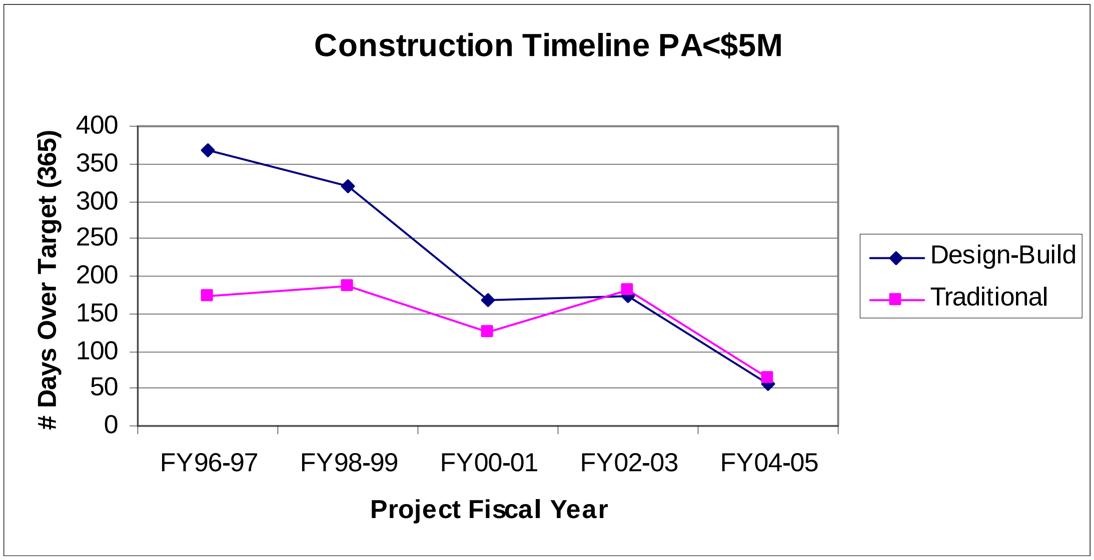


Figure 17. Construction Timeline PA<$5M over Time

The historical analysis showed the traditional method improved over time. The FY04-05 (63.6) traditional days over the construction timeline target of 365 days improved at a highly significant level of p=0.003 when compared to the starting FY96-97 (172.5) year group and at p=0.004 when compared to FY02-03 (182.4). The t-test results for the time comparison of construction timeline of projects less than $5M are provided in Appendix H.

While the entire sample for this PA category showed the traditional method to have better results, the historical analysis shows the design-build method has improved and out-performed the traditional method. The design-build delivery method is able to design and construct the project with fewer days over the 365 day target, while the traditional method only constructs the project in this time. This finding shows that design-build now produces facilities faster than the traditional method for programmed amounts less than $5M.

$5M < PA < $20M

The construction timeline analysis for this PA range resulted in several significant results. The target day duration for MILCON projects between five and twenty million dollars is 540 days from NTP to BOD. The traditional delivery method had fewer days over the target with a mean of 98.6 days while the design-build average was 161.6 days over. This comparison showed a highly significant level with a p-value of p=0.003. The sample size used to compare construction timeline consisted of 194 design-build and 243 traditional projects. Projects were removed due to unpopulated ACES-PM NTP and BOD fields.

The historical analysis identified the FY00-01 year group as having the most impact on the overall results for the construction timeline analysis. The FY00-01 comparison was highly significant ($p=2.2x10^{-5}$) in favor of the traditional method as displayed in Figure 18. However, the FY00-01 group was the only significant difference between the design-build and traditional methods. The design-build construction timeline performance has improved over time. The 47.9 day mean for FY04-05 design-build projects is significantly better than the 137.1 day mean for FY02-03 (p=0.023) and highly significant when compared to the initial 185.1 day mean for FY96-97 (p=0.003). The gap between traditional and design-build decreased from a difference of 19.1 days for FY02-03 to 10.3 days for FY04-05.

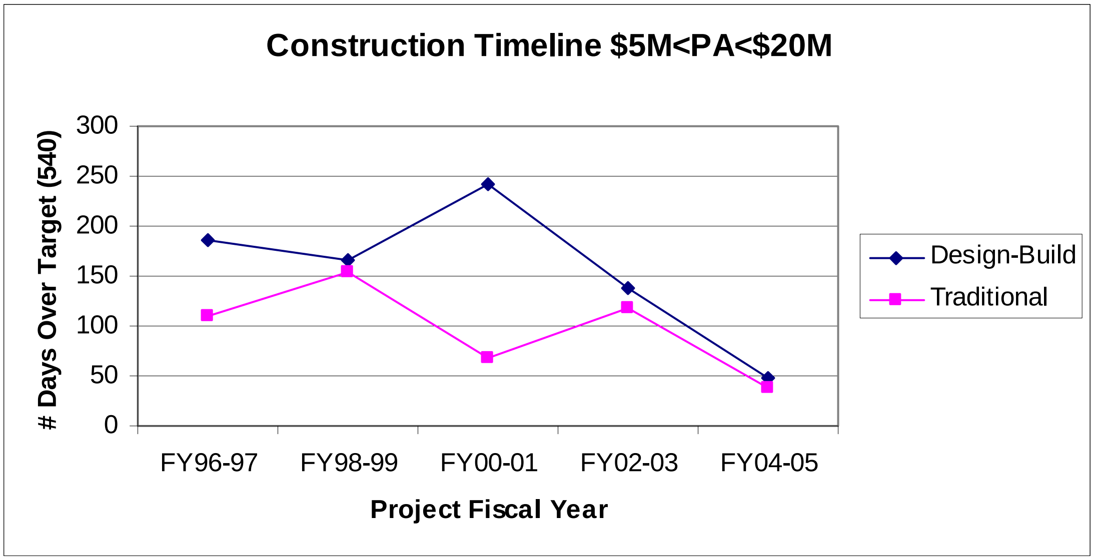


Figure 18. Construction Timeline $5M<PA<$20M over Time

The historical analysis showed the traditional method improved over time. However, the only significant improvement of p=0.012 was the comparison between the FY04-05 (37.6) and FY02-03 (118.03) year groups. As previously discussed in the PA<$5M section, the design-build method designs and constructs projects with similar days over the 540 target as the traditional method, which only completes the construction portion. The t-test results for the time comparison of this construction timeline are provided in Appendix I.

PA > $20M

The target day duration for MILCON projects above twenty million dollars is 730 days from NTP to BOD. The traditional delivery method had fewer days over the target than design-build with a mean of 56.4 days and 202.8 days, respectively. However, the p-value of 0.053 failed to reject the null hypothesis and the difference is not significant. The sample size used to compare this PA level for construction timeline was relatively small, consisting of 12 design-build and 16 traditional projects. Projects were removed due to unpopulated ACES-PM NTP and BOD fields. The small sample size for projects greater than $20M did not allow for a historical analysis to be conducted.

Total Project Time

This metric will attempt to measure which delivery method is the fastest in terms of total project time. This total project time was calculated using the date the field design instruction (DI) was issued from the MAJCOM to the design agents to the beneficial occupancy date (BOD). An example for this metric is the time it takes from when the customer (wing commander, user, base engineer) identifies the need for a facility to when that customer can take occupancy of it.

The mean traditional total project time was 3.05 years while the mean design-build total project time was 3.28 years. This 3.3 month difference was highly significant because the p-value of p=0.0066 rejected the null hypothesis that there was no difference between the two delivery methods. The sample size used to compare total project time consisted of 275 design-build and 546 traditional projects. Project removal resulted from unpopulated ACES-PM field DI issue date and actual BOD fields.

The finding that the traditional method has a highly significant shorter total project time was not a surprise to AF project managers. The cause of this finding is not a result of poor design-build time performance, but of the bureaucratic MILCON process. The key milestone in the MILCON process is the signing of the defense bill by the President that funds the MILCON projects for that fiscal year. At this milestone, a traditional project has a 95-100% design complete project that is ready for construction. The design-build project has only an RFP and will need to be designed and constructed after the funding arrives. The project time advantage typically seen by the private sector design-build with a single contract for design and construction is hindered by the MILCON process funding the project through construction dollars.

While the entire sample for total project time showed the traditional method to have better results, the historical analysis shows the design-build method has improved. Figure 19 displays the historical analysis for total project time. The traditional method was significantly better than design-build for only two time groups, FY96-97 (p=0.018) and FY00-01 (p=0.0005). The trend in the design-build performance has improved at a highly significant level (p=0.0016) when the FY04-05 group was compared with the initial FY96-97 group. The design-build total project time showed significant improvement for FY02-03 (p=0.035) and FY04-05 (p=0.013) when compared to their previous respective year groups.

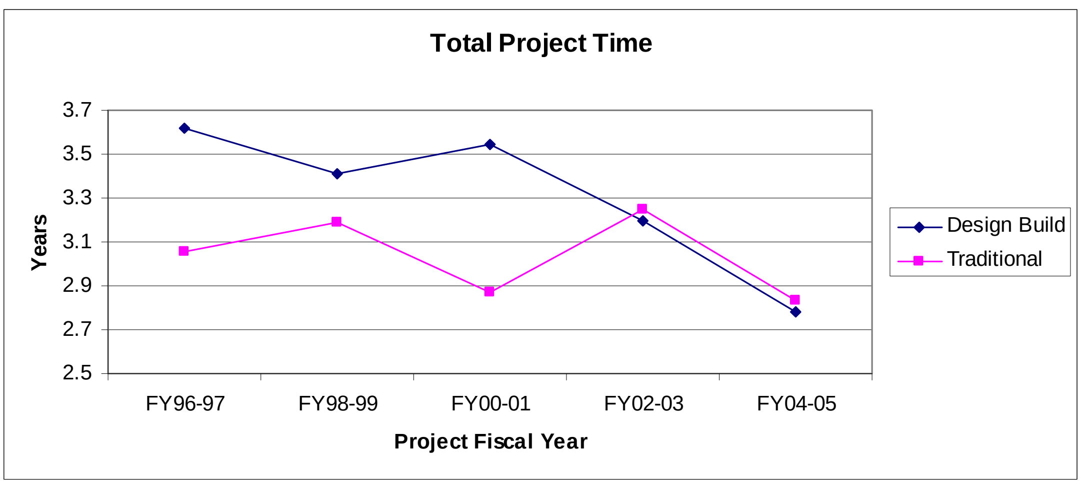


Figure 19. Total Project Time Performance over Time

The historical analysis did not show a consistent trend with the total project time performance of the traditional method. Although the FY04-05 year group (2.83 years) had better performance than the starting FY96-97 year group (3.05 years), the improvement was not significant. The traditional method showed significant p=0.041 worse performance for the FY02-03 year group from the previous FY00-01 year group. Therefore, the recovery for the FY04-05 year group was significant (p=0.022) from the FY02-03 performance. The t-test results for the time comparison of total project time are provided in Appendix J.

The most interesting result showed the FY02-03 and FY04-05 design-build year groups (126 projects) outperformed the performance of the traditional method (165 projects), though not at a significant level. The total project time is affected by the previously discussed construction timeline. The design-build construction timeline outperformed the traditional method and directly resulted in improving the total project time. The historical analysis shows that the design-build method is now able to start and complete MILCON projects in shorter total project time.

Facility Type Analysis

The final analysis of this study will attempt to answer if the design-build delivery method is better suited for a particular facility type. Nine facility types emerged from the sample of 835 projects: airfield pavements, operations, maintenance, corrosion control, storage, administration, dormitory, fitness center, and child development center. Table 14 presents the delivery method that had the better performance for the corresponding metric and facility type. Results that showed a NA lack a sufficient sample size to conduct an analysis. Before the results are presented, a brief explanation of how the nine facility types were chosen is required.

Table 14. Analysis Result Summary (Method with better metric performance shown)

		Performance Metric									
								Construction Timeline			Total Project Time
		Unit Cost	Cost Growth	Schedule Growth	Construction Speed	Modifications Per $M	CWE/PA	PA<$5M	$5M<PA<$20M	PA>$20M	
Overall Results		DB***	**DB ****	DB	DB***	**DB ****	DB	T	**T ****	T	**T ****
Facility Type (CAT CODE)	Airfield Pavements (11XXXX)	**DB ***	T	DB	DB	**DB ****	T	NA	T	NA	DB
	Operations (141XXX)	T	**DB ****	T	T	**DB ****	T	DB	T	NA	T
	Maintenance (21XXXX)	T	DB	DB	T	**DB ****	DB	T	**T ****	NA	T
	Corrosion Control (211159)	DB	**DB ***	T	DB	**DB ****	DB	NA	DB	NA	**T ***
	Storage (442758)	DB	DB	T	DB	DB	DB	T	T	NA	DB
	Administration (6102XX)	DB	DB	DB	**DB ***	**DB ***	DB	NA	T	NA	T
	Dormitory (721312)	T	**DB ***	DB	**T****	**DB ***	DB	NA	T	NA	T
	Fitness Center (740674)	**DB ***	DB	DB	DB	**DB ***	T	DB	T	NA	T
	Child Development Center (740884)	DB	**DB ****	**DB ***	DB	DB	DB	DB	T	NA	T

DB = Design Build
T = Traditional
NA = Not Applicable
*** = Significant (p<=0.05 one-tail)**
**** = Highly Significant (p<=0.01 one-tail)**
*** = After consideration of facility type

Facilities were chosen for analysis according to the minimum sample size of five projects per delivery method as outlined in the methodology. Facility categorization depended on the primary Category Code (Cat Code) determined by the first two numerals in the six digit code. Facility type was further refined if there were sufficient samples to test a specific building type. For example, although within the maintenance Cat Code, corrosion control facilities were analyzed separately due to a sufficient sample size and the project characteristics of additional HVAC and environmental requirements observed in corrosion control facilities. The facilities chosen cover the majority of the recommended facilities for design-build use recommended by the Blue Book shown in Table 8.

Two metrics, unit cost and construction speed, were previously analyzed using all facility types and produced inconclusive results. The difficulty stemmed from comparing these metrics with varying facility types. The facility type analysis successfully analyzed unit cost and construction speed metrics, identifying design-build as the method with the best performance for these metrics. The unit cost comparison resulted in six of nine facility types favoring design-build. The significant results of design-build were for airfield pavement and fitness center facilities. Construction speed also showed design-build as better for six of the nine facility types. Design-build had significant results for administration buildings while the traditional method had highly significant results for dormitory projects. With design-build having better unit cost and construction speed performance for the majority of facilities, it can be speculated that design-build is better than traditional for these metrics. The significant findings for each of the nine facility types will now be discussed.

Airfield Pavements (11XXXX)

Airfield pavements include runways, taxiways, parking ramps, and cargo pads. Table 15 displays the airfield pavement design-build and traditional results for all performance metrics. The method with the best airfield pavement performance is design-build. Five out of eight performance metrics had better design-build performance with significant (p=0.031) unit cost and highly significant (p=0.004) Mods/$M. Airfield pavements were only one of two facility types where design-build had better total project time. The traditional method only had better cost growth, CWE/PA, and construction timeline but not at a significant level. Airfield pavements were the only facility type in which either method was below the construction timeline goal.

Table 15. Airfield Pavement Facility Analysis

Performance Metric		**Mean**		**Variance**		**Observations**		**P(T<=t)**
		DB	*T*	*DB*	*T*	*DB*	*T*	**one-tail**
Unit Cost ($/SM)		139.32495	230.87844	2210.0211	46470.333	5	26	0.0313169
Cost Growth(%)		5.6189186	4.0051904	76.246093	34.255572	8	40	0.3150306
Schedule Growth (%)		10.332994	28.625669	586.3347	4547.3104	9	39	0.0915185
Construction Speed (SM/Month)		6390.0237	6213.8585	6762561.8	96331310	5	26	0.4690931
Modifications Per $M (#/$M)		1.0584273	3.3531247	1.5101549	20.80633	8	40	0.0046627
CWE/PA		0.9435221	0.8908499	0.0180473	0.0413035	9	40	0.1763216
Construction Timeline (# days over target)	PA < $5M	NA						
	$5M < PA < $20M	-49.833333	-77.666667	38995.767	73323.433	6	21	0.392912
	PA > $20M	NA						
Total Project Time (Years)		2.3208904	2.8009589	0.6112118	1.5993951	8	40	0.0898772

Operations (141XXX)

The operations facilities analyzed consisted of base operations and squadron operations facilities. The design-build delivery method showed to have the best performance for operations facilities. Design-build had a better performance at a highly significant level for cost growth (p=0.006) and Mods/$M (p=0.0003). Although the traditional method had better performance for six out of nine metrics, none of the traditional performance results were significant. Table 16 outlines the operations facilities delivery method results for all performance metrics.

Table 16. Operations Facility Analysis

Performance Metric		**Mean**		**Variance**		**Observations**		**P(T<=t)**
		DB	*T*	*DB*	*T*	*DB*	*T*	**one-tail**
Unit Cost ($/SM)		2883.9348	2461.0581	1022902.7	707755.89	14	49	0.0849918
Cost Growth(%)		2.327506	5.2201591	11.696428	23.965746	15	54	0.006747
Schedule Growth (%)		17.29903	13.523083	756.8929	1197.8378	15	52	0.3314962
Construction Speed (SM/Month)		150.97182	168.3225	4864.6346	6170.7828	14	49	0.2166755
Modifications Per $M (#/$M)		2.4137192	5.3940911	4.9734443	17.889993	15	57	0.0002953
CWE/PA		1.0138376	0.9553369	0.0138806	0.0177626	15	57	0.0546267
Construction Timeline (# days over target)	PA < $5M	189.25	190.52381	62004.917	46539.662	4	21	0.4964114
	$5M < PA < $20M	209.63636	102.02941	53136.855	58413.605	11	34	0.1001066
	PA > $20M	NA						
Total Project Time (Years)		3.3623744	3.1173276	0.6935136	1.1013913	15	57	0.1735139

Maintenance (21XXXX)

The maintenance facility Cat Code includes aircraft maintenance hangars, munitions maintenance, missile maintenance, aerospace ground equipment (AGE) facilities, and civil engineer complexes. Table 17 displays the results for the analysis of maintenance facilities for all performance metrics. Neither delivery method emerged as the best method to use for maintenance facilities. The traditional method had a significant advantage (p=0.016) for construction timeline with five of nine metrics in favor of traditional. The design-build had a highly significant advantage ($p=4.7x10^{-5}$) for Mods/$M. The delivery methods were evenly matched for both cost and schedule metrics.

Table 17. Maintenance Facility Analysis

Performance Metric		Mean		Variance		Observations		P(T<=t)
		DB	*T*	*DB*	*T*	*DB*	*T*	one-tail
Unit Cost ($/SM)		3004.2297	2492.6018	1981022.2	2181257.2	27	72	0.0592417
Cost Growth(%)		4.2015111	6.0623967	42.824887	66.685865	32	88	0.1015177
Schedule Growth (%)		14.261267	15.112741	468.12097	801.12423	31	84	0.4321463
Construction Speed (SM/Month)		207.79207	512.74172	27031.168	7542839.4	26	72	0.1758116
Modifications Per $M (#/$M)		1.7359121	4.6090279	4.7971254	31.179345	32	88	4.689E-05
CWE/PA		0.9657319	0.9942665	0.011919	0.0279118	32	88	0.1401677
Construction Timeline	PA < $5M	219.875	138.94	69540.411	19927.69	8	50	0.2103203
(# days over	$5M < PA < $20M	249.42857	128.02778	36157.757	46599.399	21	36	0.0160418
target)	PA > $20M	NA						
Total Project Time (Years)		3.4272205	3.1872864	1.5896911	2.0787518	31	89	0.1916874

Corrosion Control (211159)

Corrosion control facilities are typically the paint shops for aircraft and equipment. The design-build delivery method was identified as the best method for constructing corrosion control facilities. The design-build method outperformed traditional in six of eight metrics including a significant result (p=0.038) for cost growth and a highly significant result (p=0.0063) for Mods/$M. The traditional method did report a significant, almost highly, result (p=0.0103) for total project time. The results for corrosion control facilities are shown in Table 18.

Table 18. Corrosion Control Facility Analysis

Performance Metric		Mean		Variance		Observations		P(T<=t)
		DB	*T*	*DB*	*T*	*DB*	*T*	one-tail
Unit Cost ($/SM)		3182.0401	3672.0032	1638199.9	4289100.3	8	9	0.2811299
Cost Growth(%)		3.852818	14.220042	15.154935	225.04865	8	9	0.0383452
Schedule Growth (%)		12.063306	0.3709418	968.18766	96.405544	8	7	0.1701015
Construction Speed (SM/Month)		229.38628	161.86725	3004.1391	10225.875	8	9	0.0530427
Modifications Per $M (#/$M)		1.2793511	5.7254119	0.8245366	17.59159	8	9	0.0063668
CWE/PA		1.0030469	1.0591324	0.0029169	0.0152497	8	9	0.1211001
Construction Timeline	PA < $5M	NA						
(# days over	$5M < PA < $20M	154.33333	172.5	70446.267	11867	6	4	0.442575
target)	PA > $20M	NA						
Total Project Time (Years)		3.7027397	2.6885845	0.7578951	0.4830981	8	9	0.0103447

Storage (442758)

Storage facilities include base supply, logistics, and aircraft parts warehouses. Table 19 shows the results for the storage facility analysis. Neither the traditional or design-build method proved to be better for building storage facilities. Neither method produced statistically significant results. One notable fact was that storage facilities were second out of two facility types where the design-build method had a faster total project time.

Table 19. Storage Facility Analysis

Performance Metric		**Mean**		**Variance**		**Observations**		**P(T<=t) one-tail**
		DB	*T*	*DB*	*T*	*DB*	*T*	
Unit Cost ($/SM)		1722.411	1993.6895	721629.03	862513.79	11	7	0.272059
Cost Growth(%)		3.5547324	4.4827889	17.797769	52.192262	11	9	0.3695856
Schedule Growth (%)		28.005109	13.948306	1318.6033	1048.227	10	8	0.1993889
Construction Speed (SM/Month)		864.30045	249.79005	4735088.6	31857.49	11	7	0.1867185
Modifications Per $M (#/$M)		2.4671865	3.0861676	3.8765671	5.8789354	11	9	0.2731644
CWE/PA		0.9915245	0.9917386	0.0092843	0.0307953	11	9	0.4987193
Construction Timeline (# days over target)	PA < $5M	302.8	146.28571	96789.2	17881.905	5	7	0.1693738
	$5M < PA < $20M	158.16667	33.5	24593.367	924.5	6	2	0.0572175
	PA > $20M	NA						
Total Project Time (Years)		2.7668742	2.8753425	0.6338637	0.8736069	11	10	0.389499

Administration (6102XX)

Administration facilities consist of headquarters and mission support buildings. The design-build delivery method was identified as the best method for constructing administration facilities. The design-build method outperformed traditional in six of eight metrics with two significant results for construction speed (p=0.105) and Mods/$M (p=0.026). The traditional method only outperformed design-build in construction timeline and total project time but not at a significant level. The results for administration facilities are shown in Table 20.

Table 20. Administration Facility Analysis

Performance Metric		Mean		Variance		Observations		P(T<=t)
		DB	*T*	*DB*	*T*	*DB*	*T*	one-tail
Unit Cost ($/SM)		2142.4217	2692.3414	1009936.3	1804155.6	11	20	0.1043814
Cost Growth(%)		9.4653069	11.198354	100.59537	157.54746	13	23	0.3266387
Schedule Growth (%)		8.1122765	17.577922	202.78299	1433.1791	13	22	0.1504258
Construction Speed (SM/Month)		344.10709	190.40431	30302.127	17202.293	11	20	0.0105631
Modifications Per $M (#/$M)		3.086033	7.8382245	7.3799829	114.32712	13	23	0.0267426
CWE/PA		0.9795442	1.0114323	0.0153172	0.0212294	13	23	0.2460941
Construction Timeline (# days over target)	PA < $5M	NA						
	$5M < PA < $20M	197.18182	134.53846	62827.364	46444.103	11	13	0.2615021
	PA > $20M	NA						
Total Project Time (Years)		3.6638567	3.0986301	1.6809387	1.4915935	13	23	0.1059119

Dormitory (721312)

The analysis of delivery method performance for dormitories revealed the design-build method out-performed the traditional method. The design-build method had two significant results for cost growth (p=0.023) and Mods/$M (p=0.034) while the traditional method only had one significant result. Traditional projects performed at a highly significant (p=0.0021) level for construction speed. The dormitory analysis used the number of rooms as the scope for the unit cost and construction speed metrics. Table 21 shows the results for the dormitory facility analysis.

Table 21. Dormitory Facility Analysis

Performance Metric		Mean		Variance		Observations		P(T<=t)
		DB	*T*	*DB*	*T*	*DB*	*T*	one-tail
Unit Cost ($/Room)		93595.204	90128.321	1.317E+09	1.083E+09	31	39	0.3403111
Cost Growth(%)		3.0037286	6.3382485	7.635004	103.26691	36	42	0.0234171
Schedule Growth (%)		13.698112	20.881137	538.50341	1135.3679	36	37	0.1458431
Construction Speed		5.6231229	7.893082	4.151523	17.456074	31	39	0.0021224
Modifications Per $M (#/$M)		2.096505	3.0727112	5.6856014	4.8556201	35	42	0.0341728
CWE/PA		1.003325	1.0155387	0.0095174	0.0175088	36	42	0.3205994
Construction Timeline (# days over target)	PA < $5M	NA						
	$5M < PA < $20M	161.22857	116.08458	53827.476	37153.102	35	33	0.1924834
	PA > $20M	NA						
Total Project Time (Years)		3.6539335	3.3767986	1.1717492	1.1847483	35	41	0.135421

Fitness Center (740674)

Table 22 displays the results for the analysis of fitness centers. The analysis identified the design-build method as best suited for fitness centers. Design-build outperformed the traditional method in six out of nine metrics with significant results for unit cost (p=0.035) and Mods/$M (p=0.0109).

Table 22. Fitness Center Facility Analysis

Performance Metric		Mean		Variance		Observations		P(T<=t)
		DB	*T*	*DB*	*T*	*DB*	*T*	one-tail
Unit Cost ($/SM)		2354.8515	2990.1525	628453.6	1195255.1	13	18	0.0354141
Cost Growth(%)		4.2945129	4.3558831	15.575598	18.986006	13	18	0.4838434
Schedule Growth (%)		9.916603	19.82723	642.00091	1432.6726	13	17	0.1992958
Construction Speed (SM/Month)		215.01477	165.07767	5568.2199	14777.821	13	18	0.0843641
Modifications Per $M (#/$M)		1.9426814	3.855718	1.1169509	9.2826648	13	18	0.0109572
CWE/PA		1.0235286	1.0037189	0.010777	0.0413937	13	18	0.3629852
Construction Timeline (# days over target)	PA < $5M	101.5	109.5	2244.5	7701.1	2	6	0.4391728
	$5M < PA < $20M	134.45455	118.25	30861.473	18381.477	11	12	0.404141
	PA > $20M	NA						
Total Project Time (Years)		3.1774499	3.0456621	0.657662	0.7210491	13	18	0.3325353

Child Development Center (740884)

The child development center facility type demonstrated the most success by the design-build method out of all facilities studied. Seven out of nine metrics resulted with the design-build method outperforming traditional with a highly significant level (p=0.0073) for cost growth and a significant level (p=0.04) for schedule growth. The results for the child development center analysis are shown in Table 23.

Table 23. Child Development Center Analysis

Performance Metric		Mean		Variance		Observations		P(T<=t)
		DB	*T*	*DB*	*T*	*DB*	*T*	**one-tail**
Unit Cost ($/SM)		2890.9641	3231.2856	380515.26	279828.72	5	11	0.1604834
Cost Growth(%)		3.3564487	6.8573174	3.1376262	10.151813	5	11	0.00735
Schedule Growth (%)		4.5672122	15.366163	3.453981	376.96338	4	12	0.0408063
Construction Speed (SM/Month)		134.4259	105.3184	2645.692	2181.2128	5	11	0.1581336
Modifications Per $M (#/$M)		3.3064026	8.2833807	3.5401642	91.884632	5	12	0.0544918
CWE/PA		1.0660252	1.1348042	0.0065795	0.0052878	5	12	0.072394
Construction Timeline (# days over target)	PA < $5M	178.5	229.66667	21012.5	11203.5	2	9	0.3596243
	$5M < PA < $20M	81.333333	0	6608.3333	18657	3	3	0.2203744
	PA > $20M	NA						
Total Project Time (Years)		3.2515068	2.8614155	2.2702586	0.2147992	5	12	0.3002533

Summary

This study gathered 835 (557 traditional, 278 design-build) military construction projects from ACES-PM to quantitatively determine the best delivery method. Projects were compared over eight performance metrics. The design-build method out-performed design-bid-build for six metrics: unit cost, cost growth, schedule growth, construction speed, modifications per million dollars, and CWE/PA. The design-build method yielded highly significant results for cost growth and number of modifications per million dollars. The traditional method out-performed the design-build method for the remaining two metrics: construction timeline and total project time at a highly significant level. The historical analysis revealed that the design-build method has improved significantly for cost growth, modifications per million dollars, construction timeline, and total project time. The traditional method also experienced significant improvement for the cost growth and modifications per million dollars metrics. Additionally, design-build has overtaken the traditional method in construction timeline and total project time. Finally, the facility type analysis revealed that the design-build method was best suited for seven of the nine facility types: airfield pavements, operations, corrosion control, administration, dormitories, fitness centers, and child development centers. Discussion and conclusions based on of the results of this analysis are contained in the next chapter.

V. Conclusions and Recommendations

Chapter Overview

This chapter summarizes the results and answers the research questions of this thesis. Where Chapter 4 provided the results of the raw data, this chapter will provide insights and observations made from comparing the AF MILCON design-build performance with design-bid-build. First, the conclusions made from this research will be given by answering the research questions. The significance and limitations of this study will then be identified. Next, recommendations for further action will be suggested. Finally, the recommendations for future research that were produced from this study will be listed.

Problem Statement

The goal of this thesis is to use an empirical approach to assess if the design-build delivery method is better than the traditional design-bid-build method for Air Force MILCON projects. It will determine if the design-build method performs better for certain facility types. The results will be analyzed to determine if the success of the design-build method has improved through the years.

Research Questions

1. **Does the design-build delivery method for MILCON result in better cost performance characteristics than the traditional design-bid-build approach?**

The cost characteristics compared by this study included unit cost, cost growth, and CWE/PA ratio metrics. The design-build method out-performed the traditional method in all three performance metrics using all the projects in the sample. The cost growth of design-build was better, at a highly significant level, than the cost growth of traditional projects. The Air Force FY06 Dirtkicker goal is to keep MILCON projects under 5% cost growth (Fox, 2006). The design-build method met this goal while traditional projects did not. Although closely matched and not statistically significant, the CWE/PA for design-build was better than the traditional method. Since the CWE/PA comparison did not reveal any difference, it may be "a metric that's done its job and needs to be retired now" (MAJCOM MILCON manager).

Initially, the unit cost of the traditional method outperformed design-build. The unit cost results were inconclusive until the facility type was considered for the unit cost metric. Once facility type was taken into account, the design-build delivery method resulted with better unit cost in six of nine facilities with a significant level for airfield pavements and fitness centers. With design-build having better unit cost performance for the majority of facilities, it can be speculated that design-build has better unit cost performance than traditional.

The cost results, specifically the cost growth metric, show the benefits built into the design-build process. Once MAJCOMs started using the design-build process, the traditional method problem of change orders was no longer an issue. "With traditional, we used to manage by change order. Not positive change orders that are getting you more facility. They are things the contractors finds such as design errors and misinterpretations in drawings that the government bears the cost for" (MAJCOM MILCON manager). Having a single entity responsible for the design and construction of a MILCON projects has removed the incentive and ability of contractors to seek out change orders and helps reduce cost growth.

2. **Does the design-build delivery method for MILCON result in better schedule performance characteristics than the traditional design-bid-build approach?**

The schedule performance metrics studied were schedule growth, construction speed, three construction timeline categories based on PA, and total project time. The design-build delivery method yielded better results for only two of the six metrics for the entire sample size. Design-build outperformed design-bid-build with less schedule growth, but was not significant. As with unit cost, the construction speed metric was influenced by the type of facility. When projects were compared according to facility type, design-build had a faster construction speed for six of the nine facility types with a significant level for administration facilities. With design-build having better construction timeline performance for the majority of facilities, it can be speculated that design-build has better performance than traditional for the construction timeline metric.

The traditional delivery method yielded a shorter construction timeline for all three PA categories and shorter total project time than design-build. The construction timeline comparison for projects valued at $5M < PA < $20M resulted in the traditional method outperforming design-build at a highly significant level. Additionally, the traditional method had a highly significant shorter total project time than the performance of design-build.

The results, that the traditional delivery method had better timeline characteristics than design-build, were not surprising to AF project managers. Although design-build

RFP only takes four months to finish, the project sits on the shelf until award while the traditional method is being designed. The possible explanation is based on the AF MILCON bureaucratic process which holds the schedule benefits of design-build back. “It’s because of the nature of how our process muddles along its way with awarding construction money. If we were able to get construction money as soon as we were ready to award, design-build would be better. Because both (methods) reach October, then we wait till the money comes, design-bid-build catches up” (MAJCOM MILCON manager). As stated in Chapter 4, the key milestone in the MILCON process is the signing of the defense bill by the President that funds the MILCON projects for that fiscal year. The defense bill provides the MILCON construction funds that enable projects to be awarded. “Once you award the contract, if you have got traditional, the guy just starts building. If you’ve got a design-build, you take anywhere from two to six months up front to get it designed to the point where you’re ready to start building and then you still have to build the project” (MAJCOM MILCON manager). Although the results for the entire study sample size showed the traditional method to have a shorter construction timeline and total project time, the historical analysis conducted to answer the fifth research question yielded significant findings for these performance metrics.

3. **Does the design-build delivery method for MILCON result in fewer modifications than the traditional design-bid-build approach?**

This study showed that the design-build delivery method had less project modifications per million dollars (Mods/$M) than the traditional method at a highly significant level. This made sense to AF program managers because design-build does not see the change orders from design omission, errors, or interpretations common to the traditional method. However, modifications have different meanings depending on what delivery method is being used. "For design-build projects, modifications are used to add value to the project. Traditional projects are managed by change order where modifications are used to fix problems with the project" stated a MAJCOM senior executive involved in MILCON execution. Modifications are directly tied to cost and schedule growth. It makes sense that the design-build delivery method had better modification performance, thus having better cost and schedule growth performance.

4. **Has the design-build delivery method shown a statistically significant increased performance level over the traditional design-bid-build with regard to cost and schedule measures?**

T-test results with a p-value of less than 0.05 were considered significant and highly significant with a p-value of less than 0.01. The significant findings have already been described in the performance metric discussion. The overall data analysis resulted in design-build outperforming traditional projects at a highly significant level for cost growth and modifications per million dollars. While traditional projects outperformed design-build at a highly significant level for the $5M < PA < $20M construction timeline and total project time metrics. The significant results discovered in the historical and facility type analysis will be discussed in respective sections that follow.

5. **Using these measures of success, has the design-build delivery method improved over recent years at a statistically significant level?**

The historical analysis revealed that the design-build method has improved significantly for cost growth, modifications per million dollars, construction timeline, and total project time performance metrics. Additionally, the design-build method has recently outperformed the traditional method in construction timeline and total project time. Two reasons have been identified as the possible causes for the improvement in the design-build method for AF MILCON. First, the AF gained experience using the design build delivery method. Secondly, the institutionalizing of the Dirtkicker criteria set goals for the performance of design-build and traditional MILCON projects.

Air Force Design-Build Experience

The literature review identified that design-build performance increases as the learning curve progress is achieved (Mouritsen, 1993; Thornburn, 1994) and as the project team gains experience (Beard et al., 2001; Cushman & Loulakis, 2001, Link 2006). The use of design-build by the AF increased from 18% use in FY1999 rising to 48% for FY2000. Figure 20 displays the percentage of design-build used by the MAJCOMs for FY1990 and FY2000. Prior to FY2000, six of the nine MAJCOMs used design-build for less than 10% of their projects. The increase in use coincided with an increase in the design-build construction timeline and total project time for the FY00-01 year group. The worsening of these metrics for FY00-01 could have resulted from the large learning curve for new MAJCOMs using design-build. The improvement in design-build construction timeline and total project time observed after FY2002 could be attributed to AF program managers gaining design-build experience after progress was achieved on the initial learning curve.

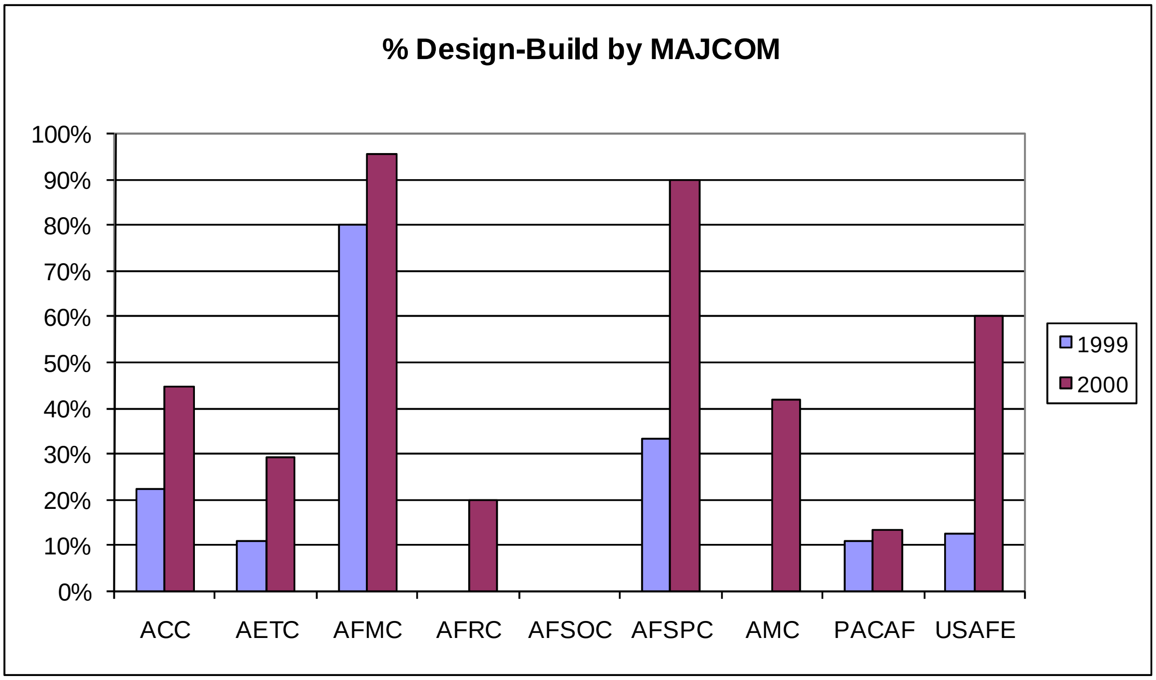


Figure 20. FY99 and FY00 Design-Build use by MAJCOM

Effects from Dirtkicker Criteria

Project managers feel that the institutionalizing of the Dirtkicker criteria improved the performance of design-build and traditional MILCON projects. The FY02-03 and FY04-05 year groups saw consistent improvement for the design-build method in the cost growth, construction timeline, and total time performance metrics. It was in 2003 that Dirtkicker goals were initiated by Major General Robbins and then carried on by Major General Fox during their tours as The Air Force Civil Engineer. "The improvement (in design-build) is because of Dirtkicker goals. They are now fairly institutionalized…and we are trying very hard to meet Dirtkicker goals" (MAJCOM MILCON manager).

One possible reason for the improvement observed for construction timeline stems from the target days set forward by Dirtkicker. Prior to FY2002, there was not a timeline goal that MILCON projects had to reach. To meet Dirtkicker goals, the target days established for the construction timeline are now written into design-build RFP and traditional IFB packages (Langley, 2007c). This change could explain how close the design-build and traditional construction timeline performance is for FY02-03 and FY04-05 year groups. The total project time performance metric subsequently benefited from this improvement in construction timelines.

The cost growth metric also significantly improved over time for design-build and traditional methods. The FY02-03 and FY04-05 year groups showed a very close cost growth performance between the two delivery methods. Again, this occurred at the time of the initiation and acceptance of Dirtkicker. Because both delivery methods were being graded by the same cost growth standard, MAJCOM MILCON managers feel it would make sense that the possible cause for this improvement over time was the reaction to Dirtkicker goals.

The historical analysis also discovered the modifications per million dollars (Mods/$M) metric significantly improved over time for design-build and traditional delivery methods. Modifications are the primary cause of cost and schedule growth. The first observation for this metric was that the design-build method had significantly less Mods/$M than the traditional method. The second observation was that both delivery method Mods/$M improved at a significant level. MAJCOM project managers again feel that institution of Dirtkicker in 2003 was the possible cause. The primary way to meet the Dirtkicker cost and schedule growth goals was to reduce the number of modifications and change orders that impact MILCON projects. The design-build and traditional FY04-05 year group experienced significant Mods/$M improvement from the previous FY02-03 year group.

6. **What facility types make the design-build method a better option over the traditional design-bid-build approach?**

The facility type analysis revealed that the design-build method was best suited for six of the nine facility types: airfield pavements, operations, corrosion control, administration, fitness centers, and child development centers. Neither delivery method showed an overwhelming advantage for the remaining three facility types: maintenance, storage, and dormitories. The Blue Book (Department of the Air Force, 2000) directs AF project managers to consider facilities that use private sector standards, commercial standards, and AF design guides as appropriate MILCON projects for use with the design-build method. The facility analysis confirmed the recommendation made by the Blue Book to use design-build for flightline facilities, administration, MWR facilities, and child development centers. However, the Blue Book suggested using design-build for hangars, maintenance, dormitories, and warehouses in which the study did not show a distinct advantage between the two delivery methods.

Significance of Research

This thesis provided an in-depth empirical analysis of AF MILCON after the design-build method was approved for widespread use and a sufficient design-build track record had been established. The research was conducted using one of the largest sample sizes used to compare the design-build (278) and traditional (557) delivery methods. This study was the first to analyze the performance of AF MILCON projects over time, using Dirtkicker metrics, and according to facility type. This study provides empirical evidence of where the design-build delivery method provides an advantage to the traditional method for AF MILCON execution.

Limitations of Research

There are specific limitations associated with this research. There are several limitations that stem from the reliance on project data from ACES-PM. Additional limitations resulted from the restrictions placed on the scope of the study.

First, ACES-PM replaced the Planning, Design, and Construction (PDC) system used to manage project information in FY 2000 (Department of the Air Force, 2000). Data retrieved from ACES-PM for projects prior to FY00 had to be transferred between the two databases. This transfer could limit the available information of projects originally stored in PDC. Because data could have been lost in the transfer, some project information could have been altered.

Secondly, ACES-PM was designed to manage project information for design-bid-build projects. Fields are not available to directly compare design-build to traditional projects. Therefore, design-build project milestones were forced into the fields available for design-bid-build projects. The NTP to BOD field for design-build included design and construction time. ACES-PM did not capture the dates that the design was completed and construction began. For traditional projects, the NTP to BOD field only captured the construction portion of the project. The design milestones only documented a design start date was captured and a design completion date was not documented. As a result, this restriction on metrics using NTP to BOD skewed the results of in favor of traditional projects. The construction timeline and schedule growth metric results required the reader to interpret the findings with an understanding that NTP to BOD for design-build projects include design and construction whereas the NTP to BOD for traditional projects only include construction.

Thirdly, ACES-PM MILCON data lacked two specific details that would have benefited this study. ACES-PM did not document the causes of modifications. This study was limited by the assumption that all modifications were a result of a negative cause. Additionally, the ACES-PM database does not distinguish between design-build variations. Projects that are by definition design-build, fast-track, or bridging are all documented in ACES-PM as using the design-build delivery method.

Finally, the scope of this research was limited to conducting a strict empirical analysis that did not investigate causality. This research focused on the quantitative questions of delivery method performance without the investigation as to why the results behaved as they did. Several experts were asked to give his or her anecdotal opinion as to the cause of the results. These expert opinions were only intended to gauge the reactions of AF project managers to the results of the study.

Recommendations for Action

Three recommendations for action by the AF civil engineer community involve the use of design-build, ACES-PM documentation, and Dirtkicker criteria. The first recommendation is to increase the use of design-build for AF MILCON, which is already being implemented. However, the development of a faster award process for design-build procurement is needed to remove the shelf time design-build projects experience waiting for the MILCON appropriations bill to be signed. Second, the ACES-PM project fields need to be updated to better document and manage each MILCON delivery method. Design-build is becoming the default delivery method for AF MILCON execution (Morrison, 2007a). ACES-PM should document the milestones specific to the method being used for each MILCON project. This would provide for accurate management of the delivery methods and allow for a valid comparison between the traditional and design-build method. Finally, the CE community needs to clearly define how the Dirtkicker criteria are calculated. The current criteria leave the definition of each metric vague so that each MAJCOM calculates the metrics differently. A concise equation to calculate Dirtkicker criteria will ensure an accurate assessment of MILCON performance for AF managers. Also, determine which Dirtkicker metrics are really worth tracking. For example, current metrics such as the CWE/PA ratio might be no longer relevant.

Recommendations for Future Research

Several topics have emerged from the study of this research that would benefit the Air Force Civil Engineer community.

1. An analysis of procurement method for AF MILCON design-build projects. The cited study by El Wardini et al. (2006) could be reproduced and investigated for AF MILCON projects. El Wardini et al. called for additional research in this area

due to the study's small sample size. This topic was of interest for this research; however, researching procurement method (low bid, best-value, qualifications based) would have been too large of a scope to include in this study.

2. An analysis of the PIPS performance contracting process for AF MILCON. AFMC is testing this process on two FY08 BRAC pilot projects at Kirtland AFB with an estimated completion date of December 2009. The performance information procurement system (PIPS) process was developed by Dr. Dean Kashiwagi at Arizona State University (dean.kashiwagi@asu.edu) as a new delivery method for construction projects that diverges from traditional and design-build practices. The manager and advocate at AFMC is Mr. Douglas Langley AFMC/A7CCC.
3. An analysis of overseas and forward deployed project delivery methods for MILCON. This and previous MILCON studies have investigated CONUS projects. A study of overseas MILCON has not yet been accomplished. An investigation in overseas (PACAF, USAFE) and contingency (Iraq, Afghanistan) locations would be extremely interesting and beneficial to the military engineering community.
4. A comparison between private and government design-build processes. Standard policies, practices, contracts, and guides have been published by the DBIA, AIA, and ASCE for the design-build process. These standards are what private industry and design-build firms use. Additionally, each government design agencies (ACoE, NAVFAC, AFCEE) and AF MAJCOM manage design-build

differently with their own guides and opinions. Investigating why each agency has differing opinions and developing a process that aligns itself with standard practices would be a major, yet rewarding, undertaking.

5. A Decision Analysis/Value Focused Thinking (VFT) analysis of design-build MILCON. Determining what selection criteria or performance criteria AF leaders, project managers, and customers value would be beneficial in order to analyze the decision to use design-build or traditional delivery for MILCON. VFT is a method for making selection decisions that has not been looked at for use with MILCON.
6. Investigate subjective performance criteria for design-build vs. design-bid-build MILCON projects. This study focused on the objective (time, cost) criteria while the subjective (quality, technical performance, functionality, productivity, satisfaction, and environmental sustainability) criteria are just as important to project success (Chan et al., 2002). Data for subjective criteria is not as available in ACES as objective information.
7. Environmental sustainability and LEED performance of design-build MILCON projects. Does the design-build process meet more LEED criteria and produce more innovative solutions to environmental concerns than design-bid-build? LEED topics are appearing in more design-build publications and could be investigated for MILCON.
8. An investigation of design agency project performance over time. A study could be conducted using Dirtkicker criteria to investigate which design agencies

(NAVFAC, USACE, AFCEE) have better MILCON performance. The analysis could investigate which districts have the best performance. Additionally, a study could be conducted to measure how MILCON performance has changed over time comparing AFCEE management with previous MAJCOM management. This could be conducted once AFCEE has established a track record for managing all of the AF MILCON execution.

Summary

This chapter described the conclusions made from this research as a result of answering the research questions. The limitations facing this study were identified along with the significance of this research. As a result of this research, recommendations were made for future research and actions that could be taken to improve the management of MILCON projects. This study provides empirical evidence of where the design-build delivery method provides an advantage to the traditional method for AF MILCON execution.

Appendix A: ACES-PM Project Fields

ACES-PM Project Description Fields

FIELD NAME	DESCRIPTION
FY	Fiscal year of project
Command Req	MAJCOM requesting project
Installation	Name of installation
Project Nbr	Project number identification
TITLE	Title of project
Project Dsg Method	Traditional or Design-build design method
Cat Nbr	Category Code of facility
Scope Of Project	Scope of the project
Unit Of Measure	Unit of measure for the project scope
DSG %	% design complete
CNS %	% construction complete

ACES-PM Project Cost Fields

FIELD NAME	DESCRIPTION
PA	Programmed Amount
Total Cwe Am	Total Current Working Estimate for Project
Mod Count Qy	Number of modifications to the project
Contract Mod Am	Cost of Modifications
Contract Orig Am	Original awarded contract amount
Contingency Am	Contingency funds amount
Eng Dsg Am	Project design cost (traditional) RPF cost (DB)
Mgmt Reserve Am	Management and reserve amount
Sioh Am	Supervision, Inspection, and Overhead amount
Other Cost No Sioh Am	Other Cost amount
Other Cost Am	Other Cost amount

ACES-PM Project Description Fields

FIELD NAME	DESCRIPTION
Act Ramp Dt	Requirements and Management Plan (RAMP) completion date
Field Di Issued	Field Design Instruction Issue date
Dsg Start Act	Actual design start date
Act Proj Def Approved Dt	Project Definition (PD) approval date
Ready To Advertise Act	Ready to Advertise date
Di Hq Usaf Auth Advertise Dt	HQ USAF Authorization to Advertise date
Bid Opening Act	Bidding opening date
Di Auth To Award Dt	Authorized to award date
Contract Award Act	Contract Award date
NTP	Notice to Proceed date
NTP to ACT BOD	Number of Days between NTP and actual BOD
EST BOD	Estimated Beneficial Occupancy Date
ACT BOD	Actual Beneficial Occupancy Date
EST CNS COMPL	Estimated construction complete date
ACT CNS COMPL	Actual construction complete date
ACT FC	Actual financial closeout date

Appendix B: Unit Cost Performance over Time t-tests

Design-Build unit cost comparison to FY96-97 year group

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	FY98-99	FY00-01	FY02-03	FY04-05
	Variable 1	*Variable 2*	*Variable 2*	*Variable 2*	*Variable 2*
Mean	2237.973	2964.186	2932.062	3705.406	2661.744
Variance	1957556	12523705	2296017	11505942	1764085
Observations	13	29	51	48	36
Hypothesized Mean Difference	0	0	0	0	0
df		40	20	49	20
t Stat		-0.95157	-1.569384	-2.348905	-0.948569
P(T<=t) one-tail		0.173515	0.066123	0.011453	0.177081
t Critical one-tail		1.683851	1.724718	1.676551	1.724718

Design-Build unit cost comparison between year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	FY98-99	FY98-99	FY00-01	FY00-01	FY02-03	FY02-03	FY04-05
Mean	2237.973	2964.186	2964.186	2932.062	2677.58	3705.406	3705.406	2661.744
Variance	1957556	12523705	12523705	2296017	2709243	11505942	11505942	1764085
Observations	13	29	29	51	27	48	48	36
Hypothesized Mean Difference	0		0		0		0	
df	40		34		72		65	
t Stat	-0.95157		0.046519		-1.762578		1.942358	
P(T<=t) one-tail	0.173515		0.481584		0.041108		0.028214	
t Critical one-tail	1.683851		1.690924		1.666294		1.668636	

Design-Build vs. traditional unit cost comparison within year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97		FY98-99		FY00-01		FY02-03		FY04-05	
	DB	*T*	*DB*	*T*	*DB*	*T*	*DB*	*T*	*DB*	*T*
Mean	2237.97	2593.97	2964.19	2963.40	2932.06	2166.77	3705.41	3240.72	2661.74	2772.96
Variance	1957556	2737960	12523705	6129025	2296017	1833119	11505942	4131705	1764085	5286012
Observations	13	84	29	101	51	65	48	58	36	41
Hypothesized Mean Difference	0		0		0		0		0	
df	18		36		101		74		65	
t Stat	-0.8318		0.0011		2.8282		0.8333		-0.2636	
P(T<=t) one-tail	0.2082		0.4996		0.0028		0.2037		0.3964	
t Critical one-tail	1.7341		1.6883		1.6601		1.6657		1.6686	
P(T<=t) two-tail	0.4164		0.9991		0.0056		0.4073		0.7929	
t Critical two-tail	2.1009		2.0281		1.9837		1.9925		1.9971	

Appendix C: Cost Growth Performance over Time t-tests

Design-Build cost growth comparison to FY96-97 year group

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	FY98-99	FY00-01	FY02-03	FY04-05
	Variable 1	*Variable 2*	*Variable 2*	*Variable 2*	*Variable 2*
Mean	8.210679	5.267267	3.8238	4.848114	2.792385
Variance	65.38475	53.57534	19.76772	44.31088	22.92917
Observations	24	46	78	77	50
Hypothesized Mean Difference		0	0	0	0
df		43	27	33	31
t Stat		1.492552	2.542191	1.851078	3.037021
P(T<=t) one-tail		0.071428	0.008532	0.036563	0.002407
t Critical one-tail		1.681071	1.703288	1.69236	1.695519

Design-Build cost growth comparison between year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	FY98-99	FY98-99	FY00-01	FY00-01	FY02-03	FY02-03	FY04-05
Mean	8.210679	5.267267	5.267267	3.8238	3.8238	4.848114	4.848114	2.792385
Variance	65.38475	53.57534	53.57534	19.76772	19.76772	44.31088	44.31088	22.92917
Observations	24	46	46	78	78	77	77	50
Hypothesized Mean Difference	0		0		0		0	
df	43		65		132		124	
t Stat	1.492552		1.212137		-1.125078		2.0216	
P(T<=t) one-tail	0.071428		0.114924		0.131299		0.022685	
t Critical one-tail	1.681071		1.668636		1.656479		1.657235	

Design-Build vs. traditional cost growth comparison within year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97		FY98-99		FY00-01		FY02-03		FY04-05	
	DB	*T*	*DB*	*T*	*DB*	*T*	*DB*	*T*	*DB*	*T*
Mean	8.211	8.264	5.267	6.706	3.824	7.267	4.848	5.087	2.792	3.286
Variance	65.385	129.199	53.575	55.623	19.768	1022.672	44.311	56.963	22.929	48.678
Observations	24	145	46	143	78	91	77	99	50	66
Hypothesized Mean Difference	0		0		0		0		0	
df	40		77		94		171		113	
t Stat	-0.028		-1.154		-1.016		-0.223		-0.451	
P(T<=t) one-tail	0.489		0.126		0.156		0.412		0.326	
t Critical one-tail	1.684		1.665		1.661		1.654		1.658	
P(T<=t) two-tail	0.978		0.252		0.312		0.824		0.653	
t Critical two-tail	2.021		1.991		1.986		1.974		1.981	

Traditional cost growth comparison between year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	*FY04-05*	*FY00-01*	*FY02-03*	*FY02-03*	*FY04-05*
Mean	8.2638171	3.285774	7.266727	5.086972	5.086972	3.285774
Variance	129.19915	48.67806	1022.672	56.96294	56.96294	48.67806
Observations	145	66	91	99	99	66
Hypothesized Mean Differenc	0		0		0	
df	191		99		147	
t Stat	3.9008094		0.634188		1.571957	
P(T<=t) one-tail	6.637E-05		0.263711		0.059055	
t Critical one-tail	1.6528705		1.660391		1.655285	
P(T<=t) two-tail	0.0001327		0.527421		0.11811	
t Critical two-tail	1.9724619		1.984217		1.976233	

Appendix D: Schedule Growth Performance over Time t-tests

Design-Build schedule growth comparison to FY96-97 year group

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	FY98-99	FY00-01	FY02-03	FY04-05
	Variable 1	*Variable 2*	*Variable 2*	*Variable 2*	*Variable 2*
Mean	9.108851	8.989413	18.93575	17.37141	18.19836
Variance	342.0955	749.2848	718.708	1003.431	1570.508
Observations	24	43	77	76	49
Hypothesized Mean Difference		0	0	0	0
df		62	56	68	71
t Stat		0.021221	-2.023356	-1.57684	-1.335752
P(T<=t) one-tail		0.491569	0.02391	0.059737	0.092948
t Critical one-tail		1.669804	1.672522	1.667572	1.6666

Design-Build schedule growth comparison between year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	FY98-99	FY98-99	FY00-01	FY00-01	FY02-03	FY02-03	FY04-05
Mean	9.108851	8.989413	8.989413	18.93575	18.93575	17.37141	17.37141	18.19836
Variance	342.0955	749.2848	749.2848	718.708	718.708	1003.431	1003.431	1570.508
Observations	24	43	43	77	77	76	76	49
Hypothesized Mean Difference	0		0		0		0	
df	62		85		146		86	
t Stat	0.021221		-1.922771		0.329523		-0.122929	
P(T<=t) one-tail	0.491569		0.028929		0.371116		0.451225	
t Critical one-tail	1.669804		1.662979		1.655357		1.662765	

Design-Build vs. traditional schedule growth comparison within year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97		FY98-99		FY00-01		FY02-03		FY04-05	
	DB	*T*	*DB*	*T*	*DB*	*T*	*DB*	*T*	*DB*	*T*
Mean	9.11	6.87	8.99	8.87	18.94	21.02	17.37	33.69	18.20	19.23
Variance	342.10	556.33	749.28	592.73	718.71	1685.67	1003.43	1627.98	1570.51	1052.16
Observations	24	121	43	129	77	88	76	99	49	62
Hypothesized Mean Difference	0		0		0		0		0	
df	39		66		151		173		92	
t Stat	0.516		0.025		-0.390		-2.996		-0.147	
P(T<=t) one-tail	0.304		0.490		0.349		0.002		0.442	
t Critical one-tail	1.685		1.668		1.655		1.654		1.662	
P(T<=t) two-tail	0.609		0.980		0.697		0.003		0.884	
t Critical two-tail	2.023		1.997		1.976		1.974		1.986	

Appendix E: Construction Speed Performance over Time t-tests

Design-Build construction speed comparison to FY96-97 year group

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	FY98-99	FY00-01	FY02-03	FY04-05
	Variable 1	*Variable 2*	*Variable 2*	*Variable 2*	*Variable 2*
Mean	259.2114	501.0464	457.3444	193.7201	683.4642
Variance	44361.24	2589962	1422670	11688.63	3397020
Observations	13	29	51	48	35
Hypothesized Mean Difference		0	0	0	0
df		30	59	14	36
t Stat		-0.794198	-1.119773	1.083143	-1.338463
P(T<=t) one-tail		0.216659	0.133674	0.148524	0.094569
t Critical one-tail		1.697261	1.671093	1.76131	1.688298

Design-Build construction speed comparison between year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	FY98-99	FY98-99	FY00-01	FY00-01	FY02-03	FY02-03	FY04-05
Mean	259.2114	501.0464	501.0464	457.3444	457.3444	193.7201	193.7201	683.4642
Variance	44361.24	2589962	2589962	1422670	1422670	11688.63	11688.63	3397020
Observations	13	29	29	51	51	48	48	35
Hypothesized Mean Difference	0		0		0		0	
df	30		46		51		34	
t Stat	-0.794198		0.127652		1.571561		-1.570038	
P(T<=t) one-tail	0.216659		0.44949		0.061118		0.062834	
t Critical one-tail	1.697261		1.67866		1.675285		1.690924	

Design-Build vs. traditional construction speed comparison within year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97		FY98-99		FY00-01		FY02-03		FY04-05	
	DB	*T*	*DB*	*T*	*DB*	*T*	*DB*	*T*	*DB*	*T*
Mean	259.2	140.5	501.0	214.3	457.3	1242.3	193.7	783.0	683.5	367.2
Variance	44361.2	41807.4	2589962.2	151531.5	1422669.5	26182500.0	11688.6	10397217.3	3397020.5	506008.3
Observations	13	80	29	100	51	65	48	58	35	41
Hypothesized Mean Difference	0		0		0		0		0	
df	16		29		73		57		43	
t Stat	1.893		0.951		-1.196		-1.391		0.956	
P(T<=t) one-tail	0.038		0.175		0.118		0.085		0.172	
t Critical one-tail	1.746		1.699		1.666		1.672		1.681	
P(T<=t) two-tail	0.077		0.349		0.236		0.170		0.344	
t Critical two-tail	2.120		2.045		1.993		2.002		2.017	

Appendix F: Modifications per $M Performance over Time t-tests

Design-Build modifications per $M comparison to FY96-97 year group

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	FY98-99	FY00-01	FY02-03	FY04-05
	Variable 1	*Variable 2*	*Variable 2*	*Variable 2*	*Variable 2*
Mean	2.96536	3.17173	2.116389	1.798117	1.183972
Variance	4.161619	30.93135	4.247715	2.77546	2.807132
Observations	24	46	78	77	50
Hypothesized Mean Difference		0	0	0	0
df		63	39	33	38
t Stat		-0.224393	1.778525	2.550501	3.718143
P(T<=t) one-tail		0.411589	0.041557	0.007791	0.000323
t Critical one-tail		1.669402	1.684875	1.69236	1.685954

Design-Build modifications per $M comparison between year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	FY98-99	FY98-99	FY00-01	FY00-01	FY02-03	FY02-03	FY04-05
	Variable 1	*Variable 2*	*Variable 1*	*Variable 2*	*Variable 1*	*Variable 2*	*Variable 1*	*Variable 2*
Mean	2.96536	3.17173	3.17173	2.116389	2.116389	1.798117	1.798117	1.183972
Variance	4.161619	30.93135	30.93135	4.247715	4.247715	2.77546	2.77546	2.807132
Observations	24	46	46	78	78	77	77	50
Hypothesized Mean Difference	0		0		0		0	
df	63		52		147		104	
t Stat	-0.224393		1.237833		1.057957		2.022715	
P(T<=t) one-tail	0.411589		0.110669		0.145905		0.022834	
t Critical one-tail	1.669402		1.674689		1.655285		1.659637	

Design-Build vs. traditional modifications per $M comparison within year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97		FY98-99		FY00-01		FY02-03		FY04-05	
	DB	*T*	*DB*	*T*	*DB*	*T*	*DB*	*T*	*DB*	*T*
Mean	2.96536	5.705986	3.17173	6.117081	2.116389	4.587058	1.798117	3.799906	1.183972	2.233795
Variance	4.161619	39.01531	30.93135	36.83073	4.247715	127.7004	2.77546	35.5635	2.807132	6.409343
Observations	24	147	46	145	78	91	77	99	50	66
Hypothesized Mean Difference	0		0		0		0		0	
df	108		82		97		117		112	
t Stat	-4.137243		-3.060072		-2.046311		-3.183979		-2.6817	
P(T<=t) one-tail	3.49E-05		0.001495		0.021716		0.000931		0.004216	
t Critical one-tail	1.659085		1.663649		1.660715		1.657982		1.658573	
P(T<=t) two-tail	6.98E-05		0.00299		0.043432		0.001862		0.008433	
t Critical two-tail	1.982173		1.989319		1.984723		1.980448		1.981372	

Traditional modifications per $M comparison between year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	*FY04-05*	*FY98-99*	*FY00-01*	*FY00-01*	*FY02-03*	*FY02-03*	*FY04-05*
Mean	5.705986	2.233795	6.117081	4.587058	4.587058	3.799906	3.799906	2.233795
Variance	39.01531	6.409343	36.83073	127.7004	127.7004	35.5635	35.5635	6.409343
Observations	147	66	145	91	91	99	99	66
Hypothesized Mean Difference	0		0		0		0	
df	209		123		134		142	
t Stat	5.766825		1.188493		0.592912		2.31835	
P(T<=t) one-tail	1.44E-08		0.118464		0.27712		0.010929	
t Critical one-tail	1.652177		1.657336		1.656305		1.655655	
P(T<=t) two-tail	2.88E-08		0.236929		0.554239		0.021858	
t Critical two-tail	1.971379		1.979439		1.977826		1.976811	

Appendix G: CWE/PA Performance over Time t-tests

Design-Build CWE/PA comparison to FY96-97 year group

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	FY98-99	FY00-01	FY02-03	FY04-05
	Variable 1	*Variable 2*	*Variable 2*	*Variable 2*	*Variable 2*
Mean	1.017865	0.979704	0.997466	0.971035	1.004363
Variance	0.009281	0.008852	0.013917	0.014772	0.014567
Observations	24	46	78	78	50
Hypothesized Mean Difference		0	0	0	0
df		46	46	48	56
t Stat		1.585756	0.858109	1.95111	0.518537
P(T<=t) one-tail		0.059823	0.197641	0.028447	0.303063
t Critical one-tail		1.67866	1.67866	1.677224	1.672522

Design-Build CWE/PA comparison between year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	FY98-99	FY98-99	FY00-01	FY00-01	FY02-03	FY02-03	FY04-05
	Variable 1	*Variable 2*	*Variable 1*	*Variable 2*	*Variable 1*	*Variable 2*	*Variable 1*	*Variable 2*
Mean	1.017865	0.979704	0.979704	0.997466	0.997466	0.971035	0.971035	1.004363
Variance	0.009281	0.008852	0.008852	0.013917	0.013917	0.014772	0.014772	0.014567
Observations	24	46	46	78	78	78	78	50
Hypothesized Mean Difference	0		0		0		0	
df	46		111		154		105	
t Stat	1.585756		-0.922338		1.378153		-1.520041	
P(T<=t) one-tail	0.059823		0.179176		0.085078		0.065753	
t Critical one-tail	1.67866		1.658697		1.654808		1.659495	

Design-Build vs. traditional CWE/PA comparison within year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97		FY98-99		FY00-01		FY02-03		FY04-05	
	DB	*T*	*DB*	*T*	*DB*	*T*	*DB*	*T*	*DB*	*T*
Mean	1.017865	0.987395	0.979704	1.013713	0.997466	0.967764	0.971035	0.98415	1.004363	0.994009
Variance	0.009281	0.055489	0.008852	0.091866	0.013917	0.031371	0.014772	0.027232	0.014567	0.027141
Observations	24	147	46	145	78	91	78	99	50	66
Hypothesized Mean Difference	0		0		0		0		0	
df	78		189		158		174		114	
t Stat	1.10224		-1.183356		1.29859		-0.60855		0.390614	
P(T<=t) one-tail	0.136873		0.119077		0.097988		0.271808		0.348406	
t Critical one-tail	1.664625		1.652956		1.654555		1.653658		1.65833	
P(T<=t) two-tail	0.273747		0.238154		0.195977		0.543617		0.696811	
t Critical two-tail	1.990847		1.972595		1.975092		1.973691		1.980992	

Appendix H: Construction Timeline PA<$5M Time t-tests

Design-Build Construction Timeline PA<$5M comparison to FY96-97 year group

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	**FY98-99**	**FY00-01**	**FY02-03**	**FY04-05**
	Variable 1	*Variable 2*	*Variable 2*	*Variable 2*	*Variable 2*
Mean	369.3333	320	166.7333	172.2941	56.07692
Variance	60407.5	50688.67	25364.35	63458.22	32377.08
Observations	9	13	15	17	13
Hypothesized Mean Difference		0	0	0	0
df		16	12	17	14
t Stat		0.478918	2.210166	1.927982	3.265482
P(T<=t) one-tail		0.319238	0.023633	0.035366	0.002818
t Critical one-tail		1.745884	1.782288	1.739607	1.76131

Design-Build Construction Timeline PA<$5M comparison between year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	**FY98-99**	**FY98-99**	**FY00-01**	**FY00-01**	**FY02-03**	**FY02-03**	**FY04-05**
	Variable 1	*Variable 2*	*Variable 1*	*Variable 2*	*Variable 1*	*Variable 2*	*Variable 1*	*Variable 2*
Mean	369.3333	320	320	166.7333	166.7333	172.2941	172.2941	56.07692
Variance	60407.5	50688.67	50688.67	25364.35	25364.35	63458.22	63458.22	32377.08
Observations	9	13	13	15	15	17	17	13
Hypothesized Mean Differenc	0		0		0		0	
df	16		21		27		28	
t Stat	0.478918		2.049928		-0.07551		1.473185	
P(T<=t) one-tail	0.319238		0.026532		0.470184		0.075927	
t Critical one-tail	1.745884		1.720743		1.703288		1.701131	

Design-Build vs. traditional Construction Timeline PA<$5M comparison within year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97		**FY98-99**		**FY00-01**		**FY02-03**		**FY04-05**	
	DB	*T*	*DB*	*T*	*DB*	*T*	*DB*	*T*	*DB*	*T*
Mean	369.3333	172.557	320	186.8353	166.7333	125.2105	172.2941	182.4651	56.07692	63.63636
Variance	60407.5	39097.63	50688.67	41973.23	25364.35	60326.71	63458.22	40038.64	32377.08	33321.74
Observations	9	79	13	85	15	38	17	43	13	33
Hypothesized Mean Difference	0		0		0		0		0	
df	9		15		39		24		22	
t Stat	2.317929		2.009148		0.725185		-0.14893		-0.12777	
P(T<=t) one-tail	0.02282		0.031435		0.236334		0.441426		0.449745	
t Critical one-tail	1.833113		1.75305		1.684875		1.710882		1.717144	
P(T<=t) two-tail	0.04564		0.06287		0.472667		0.882852		0.89949	
t Critical two-tail	2.262157		2.13145		2.022691		2.063899		2.073873	

Traditional Construction Timeline PA<$5M comparison between year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	*FY04-05*	*FY02-03*	*FY04-05*
Mean	172.557	63.63636	182.4651	63.63636
Variance	39097.63	33321.74	40038.64	33321.74
Observations	79	33	43	33
Hypothesized Mean Difference	0		0	
df	65		72	
t Stat	2.807963		2.697256	
P(T<=t) one-tail	0.003288		0.004351	
t Critical one-tail	1.668636		1.666294	
P(T<=t) two-tail	0.006575		0.008702	
t Critical two-tail	1.997138		1.993464	

Appendix I: Construction Timeline $5M<PA<$20M Time t-tests

Design-Build Construction Timeline $5M<PA<$20M comparison to FY96-97 year group

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	FY98-99	FY00-01	FY02-03	FY04-05
	Variable 1	*Variable 2*	Variable 2	*Variable 2*	*Variable 2*
Mean	185.1429	165.1	241.5833	137.1404	47.90625
Variance	20757.82	96621.13	61009.57	77886.44	19080.93
Observations	14	30	60	57	32
Hypothesized Mean Difference		0	0	0	0
df		42	33	40	24
t Stat		0.292249	-1.12892	0.899307	3.009849
P(T<=t) one-tail		0.385767	0.133537	0.186936	0.003031
t Critical one-tail		1.681952	1.69236	1.683851	1.710882

Design-Build Construction Timeline $5M<PA<$20M comparison between year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	FY98-99	FY98-99	FY00-01	FY00-01	FY02-03	FY02-03	FY04-05
	Variable 1	*Variable 2*	*Variable 1*	*Variable 2*	*Variable 1*	*Variable 2*	*Variable 1*	*Variable 2*
Mean	185.1429	165.1	165.1	241.5833	241.5833	137.1404	137.1404	47.90625
Variance	20757.82	96621.13	96621.13	61009.57	61009.57	77886.44	77886.44	19080.93
Observations	14	30	30	60	60	57	57	32
Hypothesized Mean Difference	0		0		0		0	
df	42		48		112		86	
t Stat	0.292249		-1.17493		2.13941		2.014202	
P(T<=t) one-tail	0.385767		0.12291		0.017287		0.023557	
t Critical one-tail	1.681952		1.677224		1.658573		1.662765	

Design-Build vs. Traditional Construction Timeline $5M<PA<$20M comparison within year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97		FY98-99		FY00-01		FY02-03		FY04-05	
	DB	*T*	*DB*	*T*	*DB*	*T*	*DB*	*T*	*DB*	*T*
Mean	185.1429	109.0714	165.1	154.0144	241.5833	67.17308	137.1404	118.0385	47.90625	37.64
Variance	20757.82	66603.89	96621.13	74759.58	61009.57	34350.58	77886.44	26230.19	19080.93	18025.24
Observations	14	56	30	55	60	52	57	52	32	25
Hypothesized Mean Difference	0		0		0		0		0	
df	37		54		108		91		52	
t Stat	1.47163		0.163806		4.258453		0.441628		0.28286	
P(T<=t) one-tail	0.074788		0.435248		2.2E-05		0.329903		0.389204	
t Critical one-tail	1.687094		1.673565		1.659085		1.661771		1.674689	
P(T<=t) two-tail	0.149576		0.870496		4.41E-05		0.659806		0.778407	
t Critical two-tail	2.026192		2.004879		1.982173		1.986377		2.006647	

Traditional Construction Timeline $5M<PA<$20M comparison between year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	*FY04-05*	*FY02-03*	*FY04-05*
Mean	109.0714	37.64	118.0385	37.64
Variance	66603.89	18025.24	26230.19	18025.24
Observations	56	25	52	25
Hypothesized Mean Difference	0		0	
df	77		56	
t Stat	1.634298		2.29669	
P(T<=t) one-tail	0.053139		0.0127	
t Critical one-tail	1.664885		1.672522	

Appendix J: Total Project Time Performance over Time t-tests

Design-Build total project time comparison to FY96-97 year group

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	FY98-99	FY00-01	FY02-03	FY04-05
	Variable 1	*Variable 2*	*Variable 2*	*Variable 2*	*Variable 2*
Mean	3.619749	3.413455	3.541342	3.19356	2.781381
Variance	1.315913	1.619136	1.562872	1.280731	0.837177
Observations	24	45	78	77	49
Hypothesized Mean Difference		0	0	0	0
df		51	41	38	38
t Stat		0.68457	0.286557	1.594274	3.126259
P(T<=t) one-tail		0.248357	0.387947	0.05958	0.001694
t Critical one-tail		1.675285	1.682878	1.685954	1.685954

Design-Build total project time comparison between year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	FY98-99	FY98-99	FY00-01	FY00-01	FY02-03	FY02-03	FY04-05
Mean	3.619749	3.413455	3.413455	3.541342	3.541342	3.19356	3.19356	2.781381
Variance	1.315913	1.619136	1.619136	1.562872	1.562872	1.280731	1.280731	0.837177
Observations	24	45	45	78	78	77	77	49
Hypothesized Mean Difference	0		0		0		0	
df	51		91		152		117	
t Stat	0.68457		-0.540335		1.816157		2.244678	
P(T<=t) one-tail	0.248357		0.295143		0.035658		0.013334	
t Critical one-tail	1.675285		1.661771		1.65494		1.657982	

Design-Build vs. traditional total project time comparison within year groups

t-Test: Two-Sample Assuming Unequal Variances

	FY96-97		FY98-99		FY00-01		FY02-03		FY04-05	
	DB	*T*	*DB*	*T*	*DB*	*T*	*DB*	*T*	*DB*	*T*
Mean	3.619749	3.056374	3.413455	3.188428	3.541342	2.869297	3.19356	3.244943	2.781381	2.830303
Variance	1.315913	1.729393	1.619136	1.758024	1.562872	1.895039	1.280731	2.57226	0.837177	1.052073
Observations	24	137	45	144	78	92	77	99	49	66
Hypothesized Mean Difference	0		0		0		0		0	
df	35		76		167		172		109	
t Stat	2.169184		1.025083		3.333861		-0.248905		-0.269202	
P(T<=t) one-tail	0.018473		0.154288		0.000528		0.401865		0.394142	
t Critical one-tail	1.689572		1.665151		1.654029		1.653761		1.658953	
P(T<=t) two-tail	0.036946		0.308576		0.001055		0.803731		0.788283	
t Critical two-tail	2.030108		1.991673		1.974271		1.973852		1.981967	

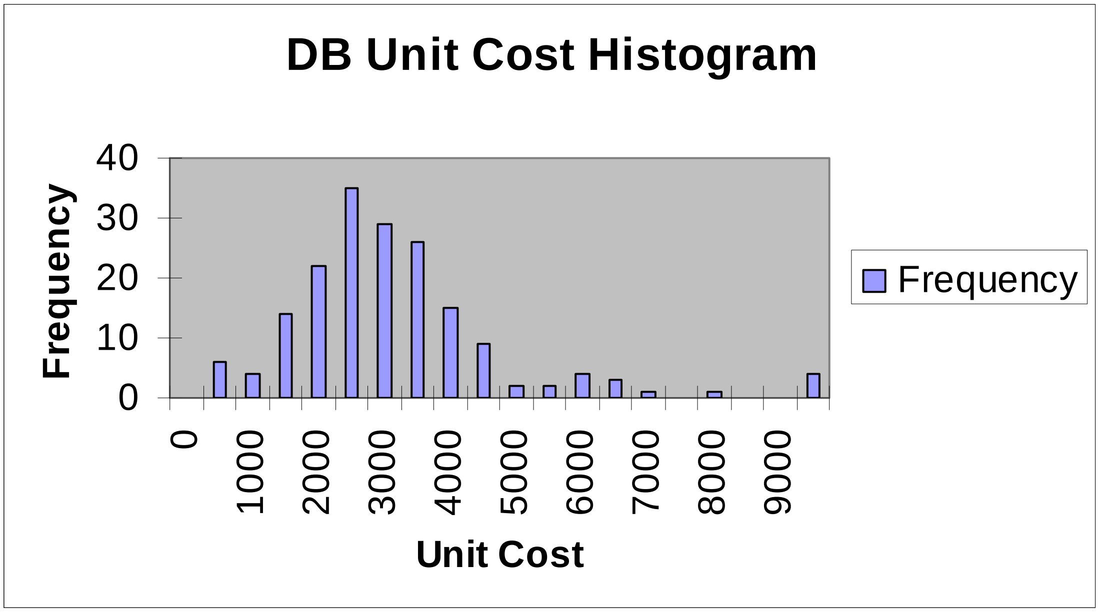
Traditional total project time comparison between year groups

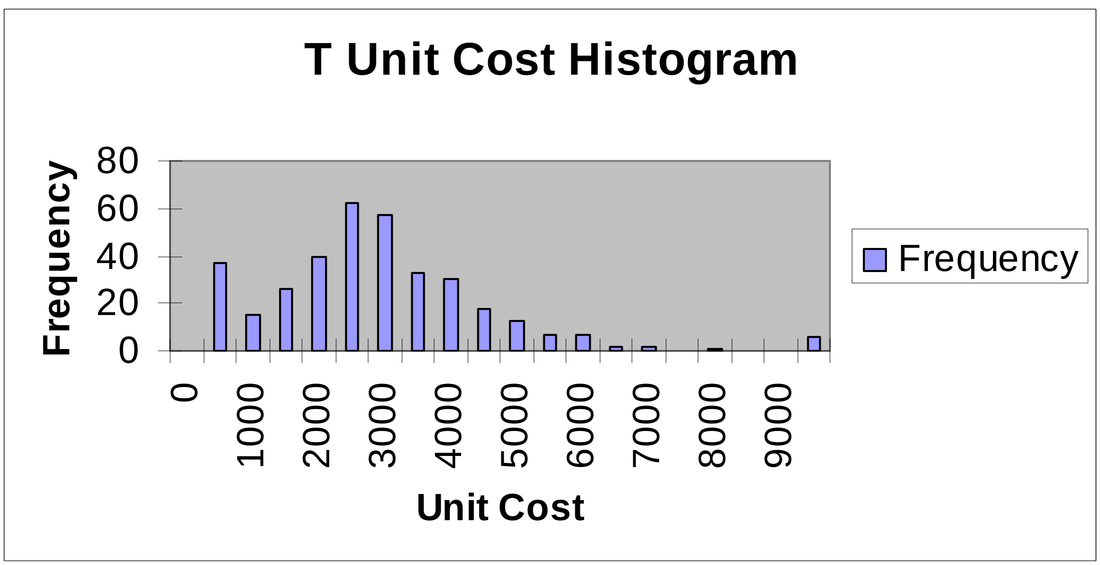
t-Test: Two-Sample Assuming Unequal Variances

	FY96-97	*FY04-05*	*FY00-01*	*FY02-03*	*FY02-03*	*FY04-05*
Mean	3.056374	2.830303	2.869297	3.244943	3.244943	2.830303
Variance	1.729393	1.052073	1.895039	2.57226	2.57226	1.052073
Observations	137	66	92	99	99	66
Hypothesized Mean Difference	0		0		0	
df	161		188		163	
t Stat	1.337634		-1.7405		2.025093	
P(T<=t) one-tail	0.091451		0.041703		0.022245	
t Critical one-tail	1.654373		1.652999		1.654256	
P(T<=t) two-tail	0.182902		0.083407		0.04449	
t Critical two-tail	1.974808		1.972663		1.974625	

Appendix K: Performance Metric Histograms

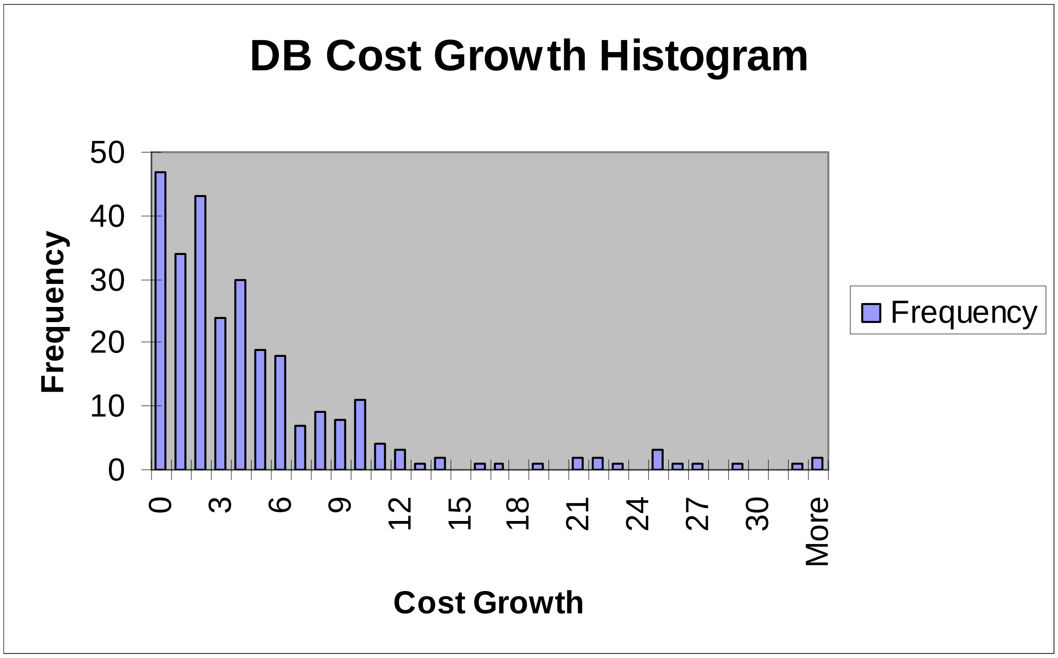
Unit Cost Histograms

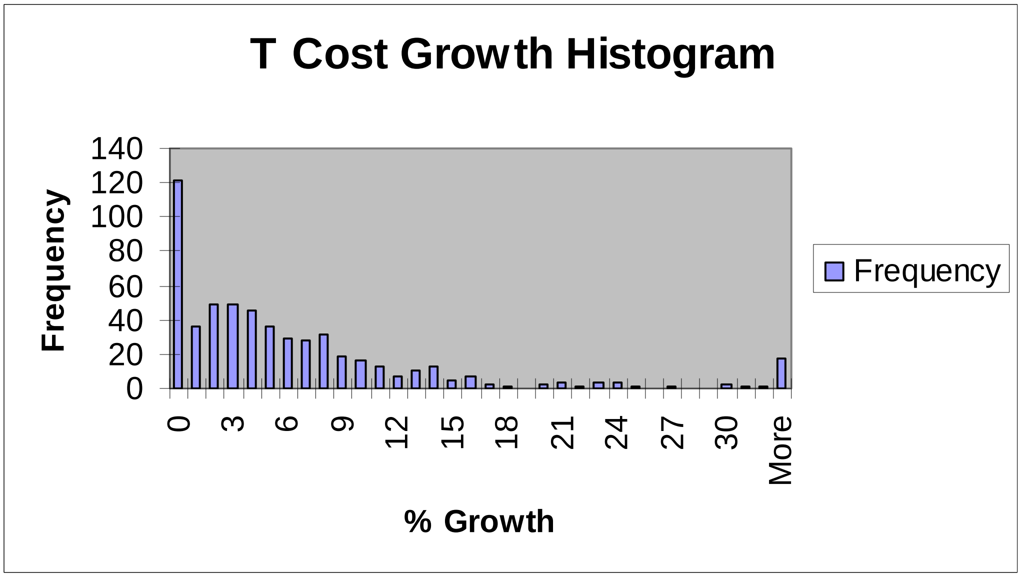




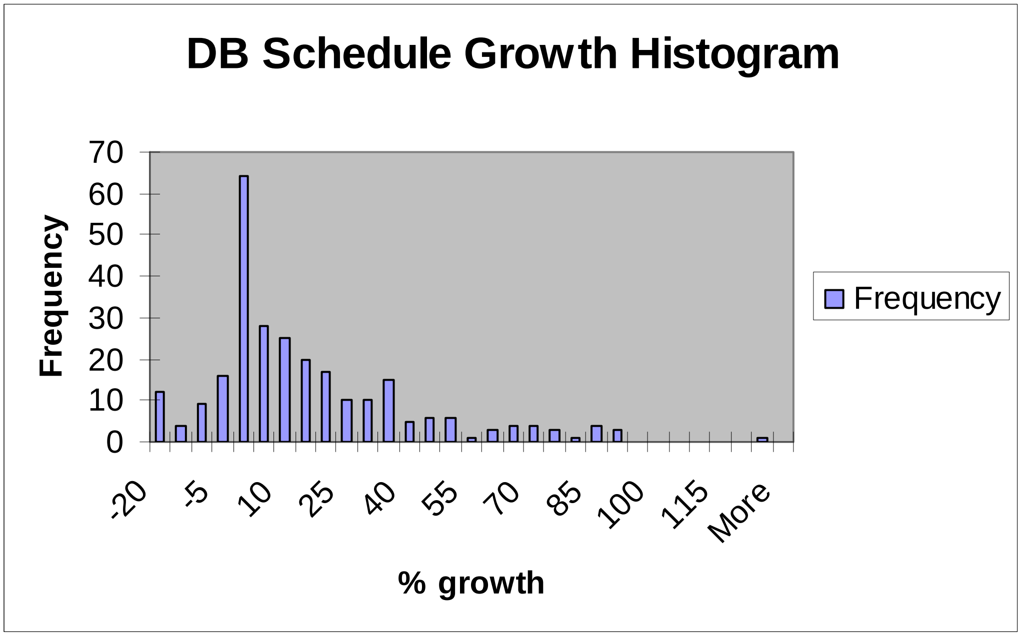
Cost Growth Histograms

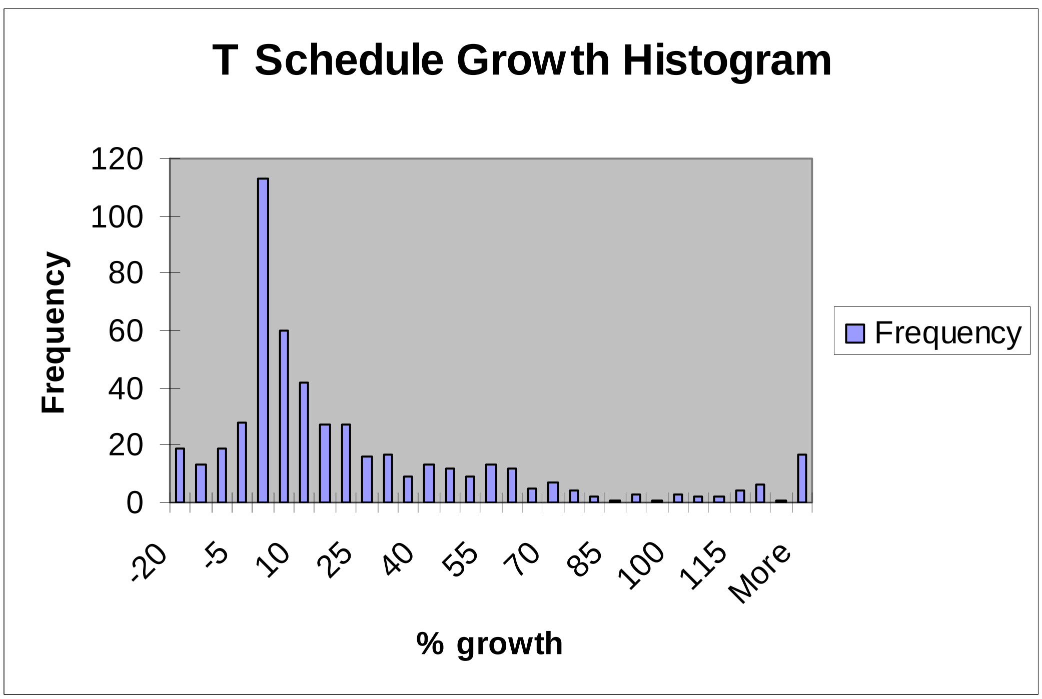
Cost Growth Histograms are approximated normal due to a cost growth starting value of zero.



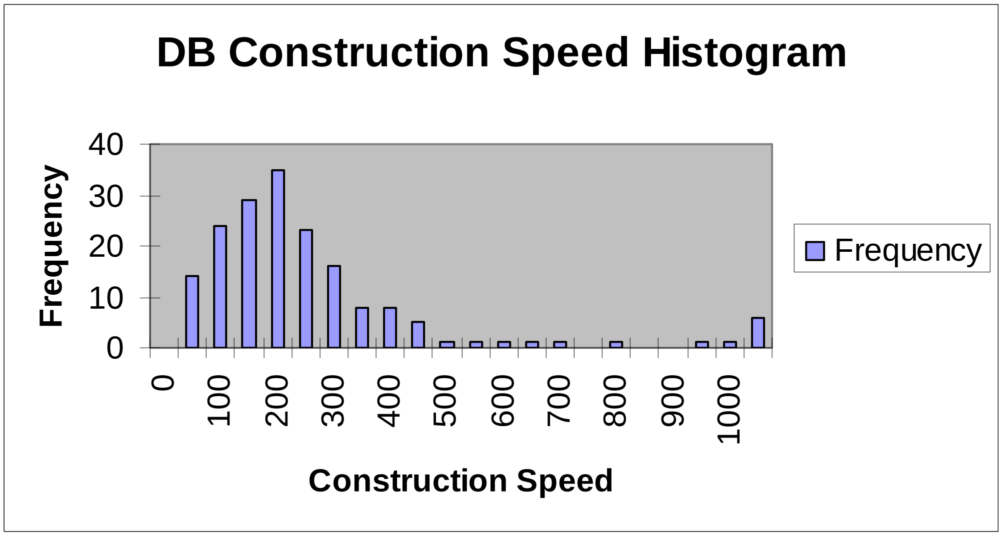


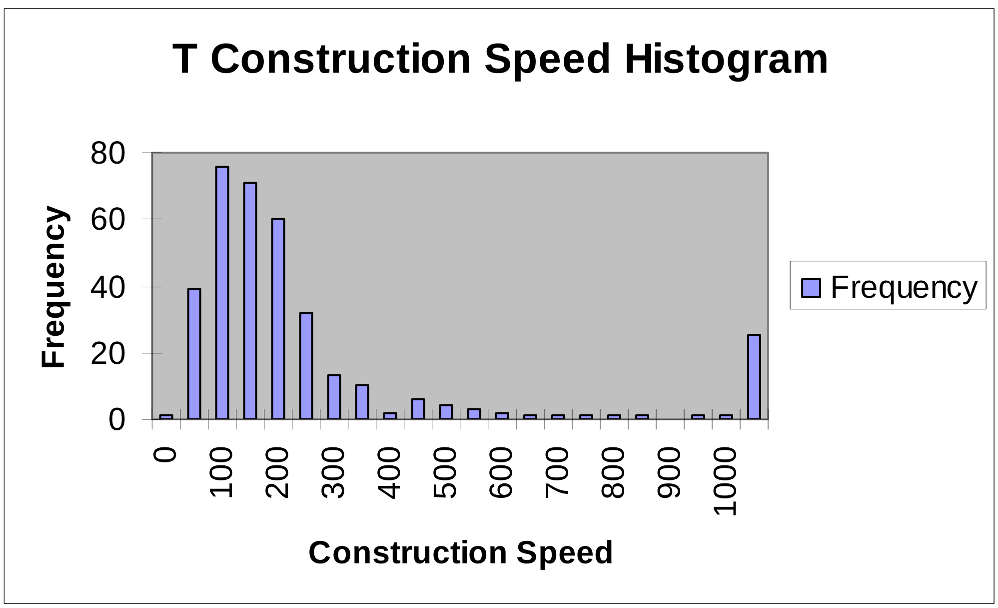
Schedule Growth Histograms



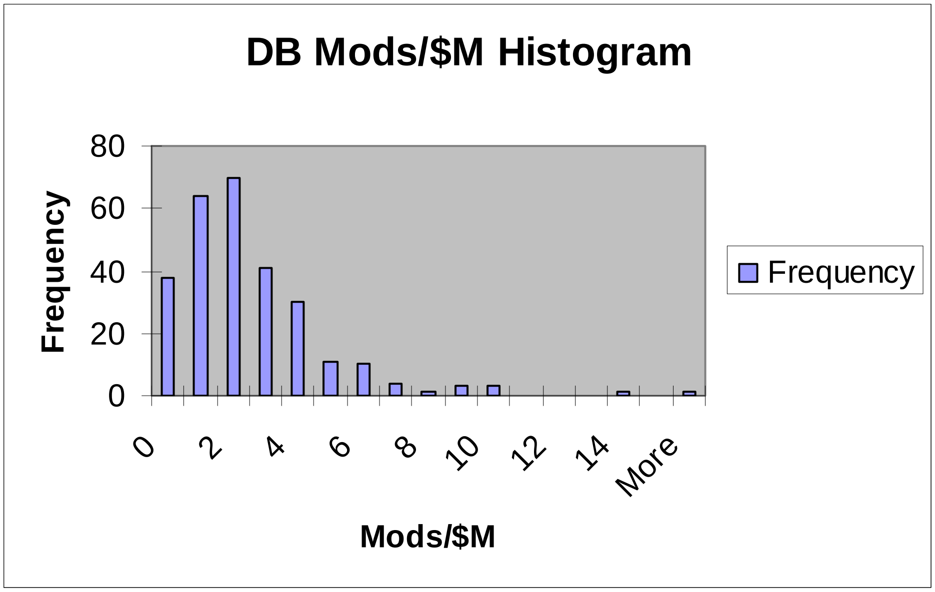


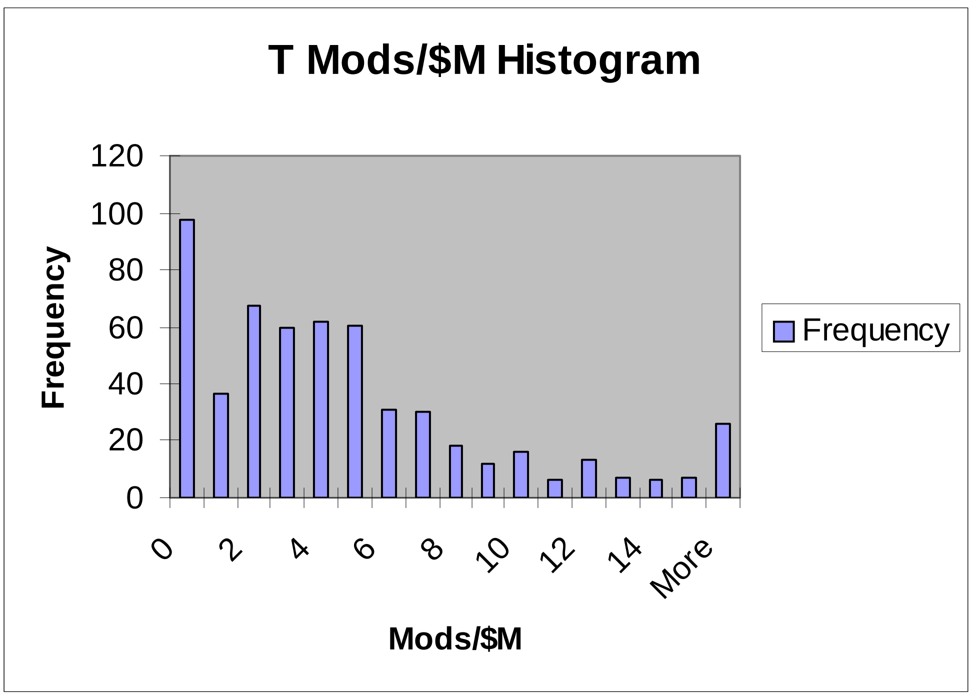
<u>Construction Speed Histograms</u>



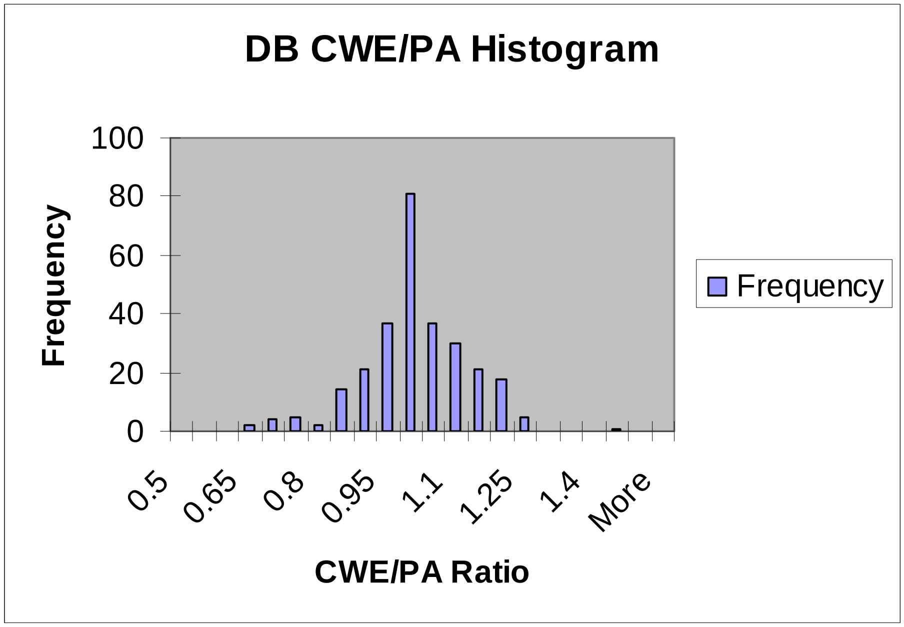


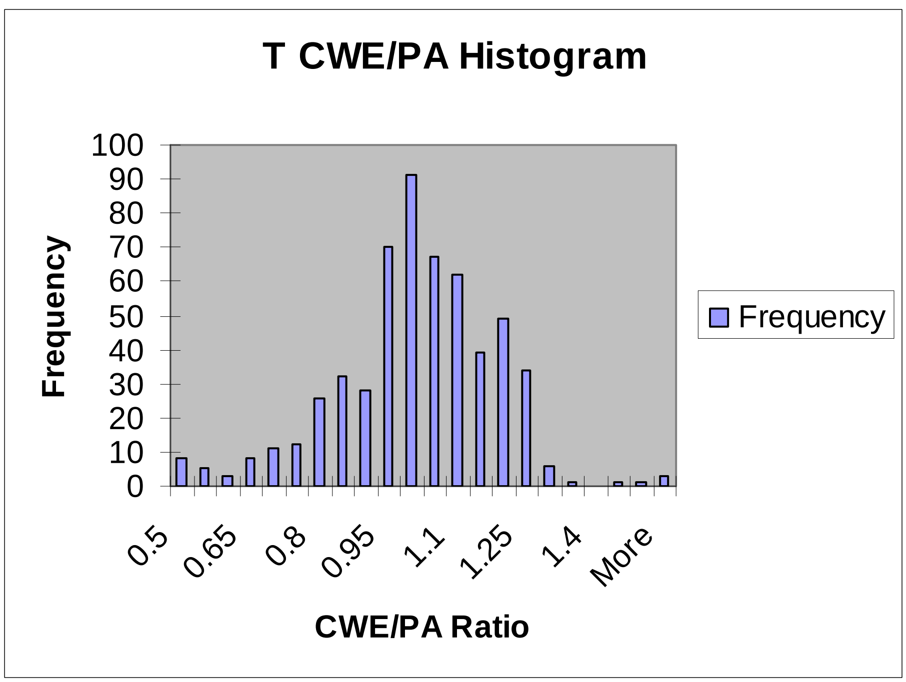
Modifications per Million Dollars Histograms



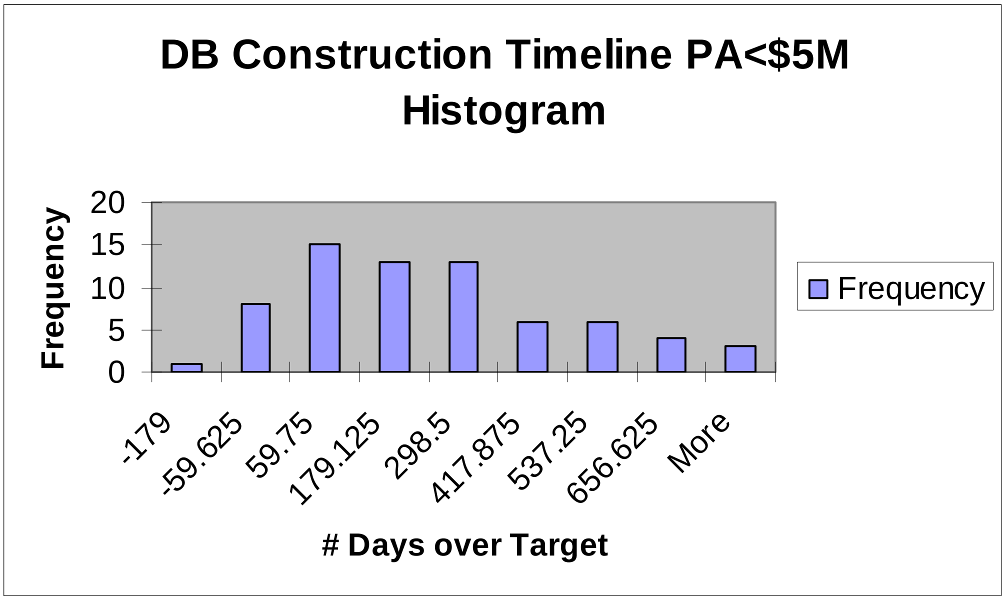


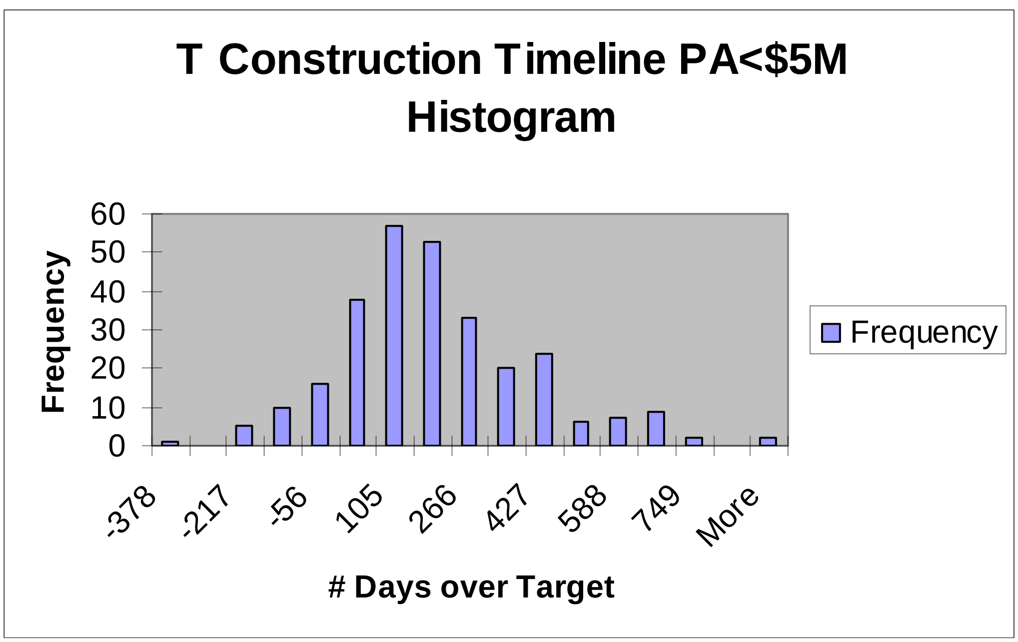
CWE/PA Ratio Histograms



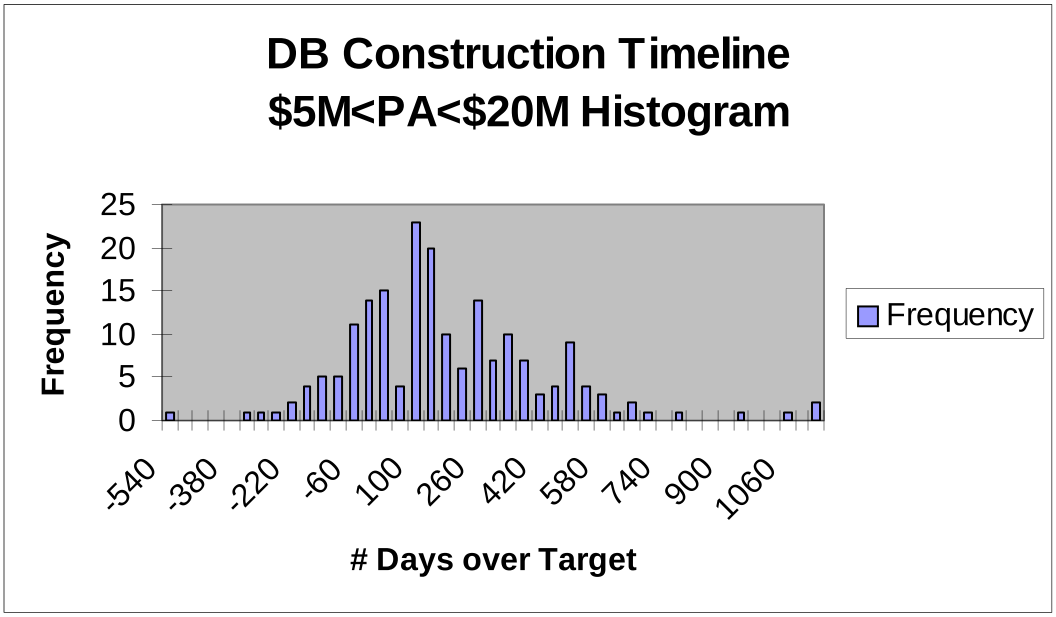


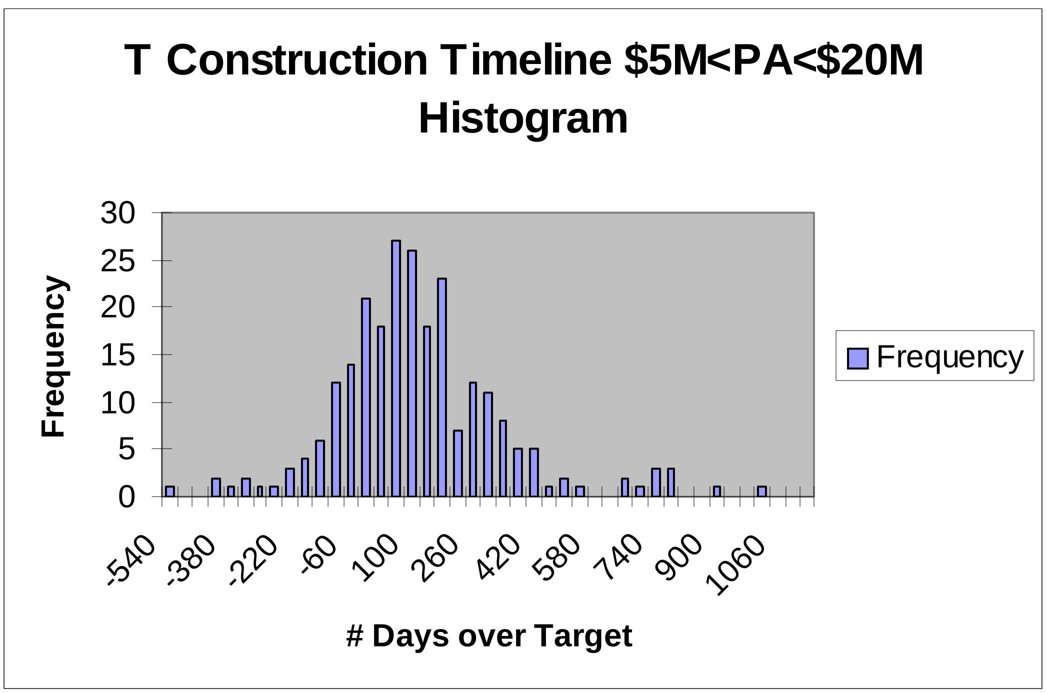
__**Construction Timeline PA<$5M Histograms**__



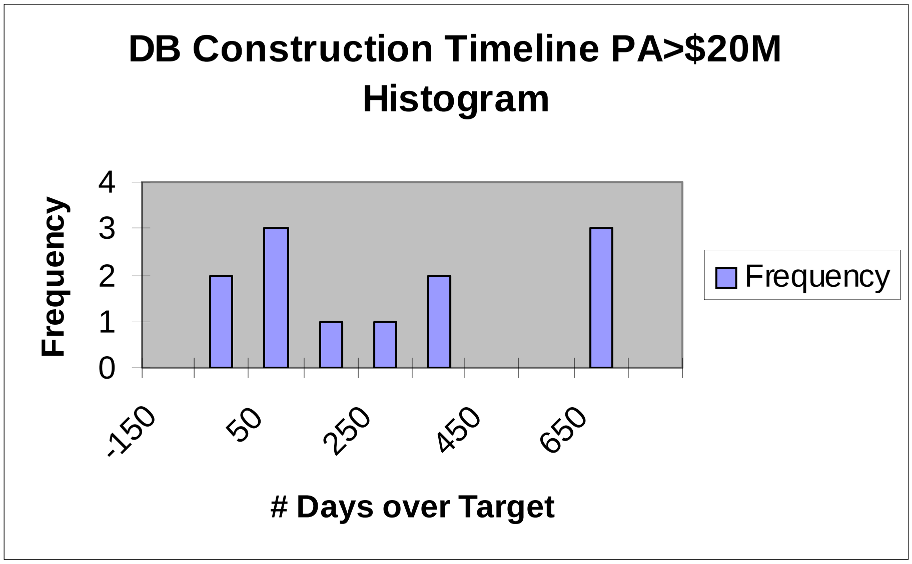


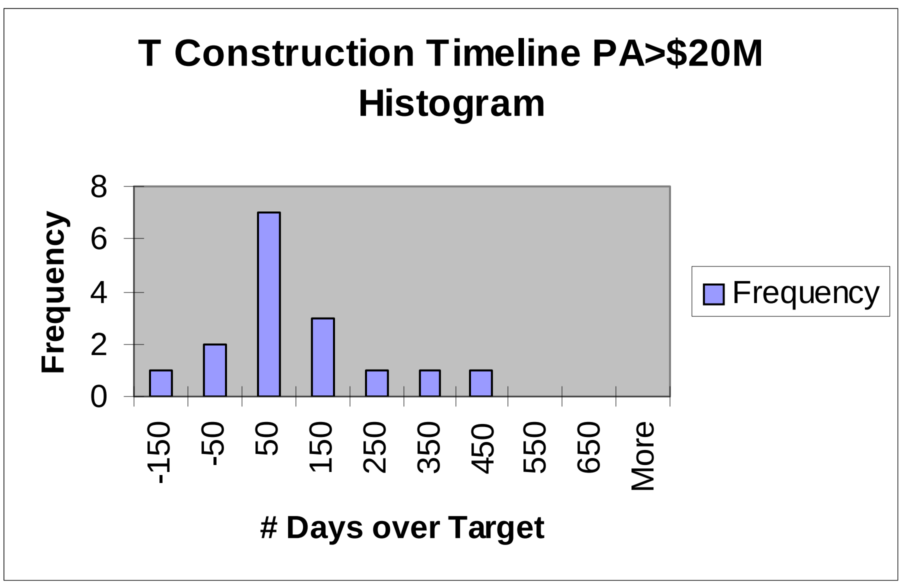
Construction Timeline $5M<PA<$20M Histograms



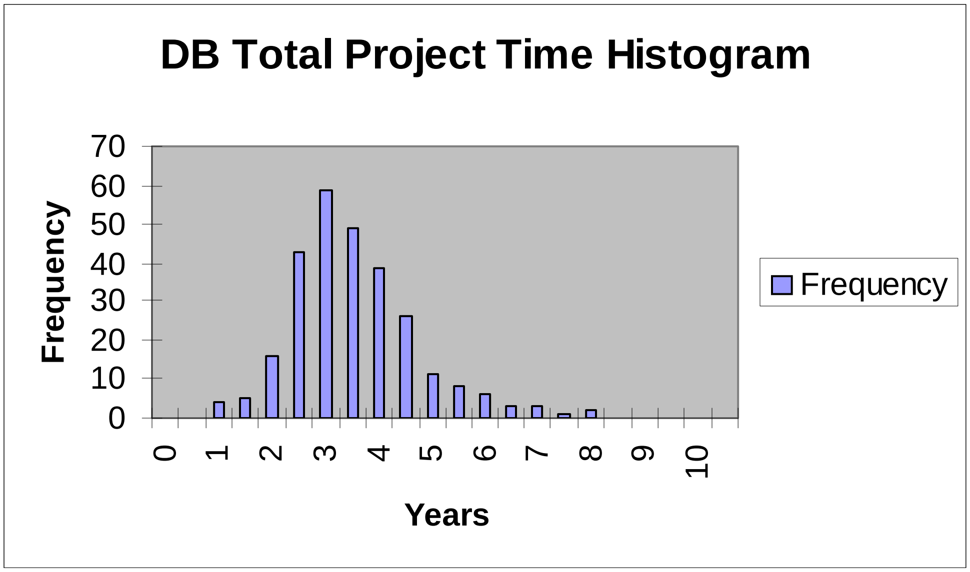


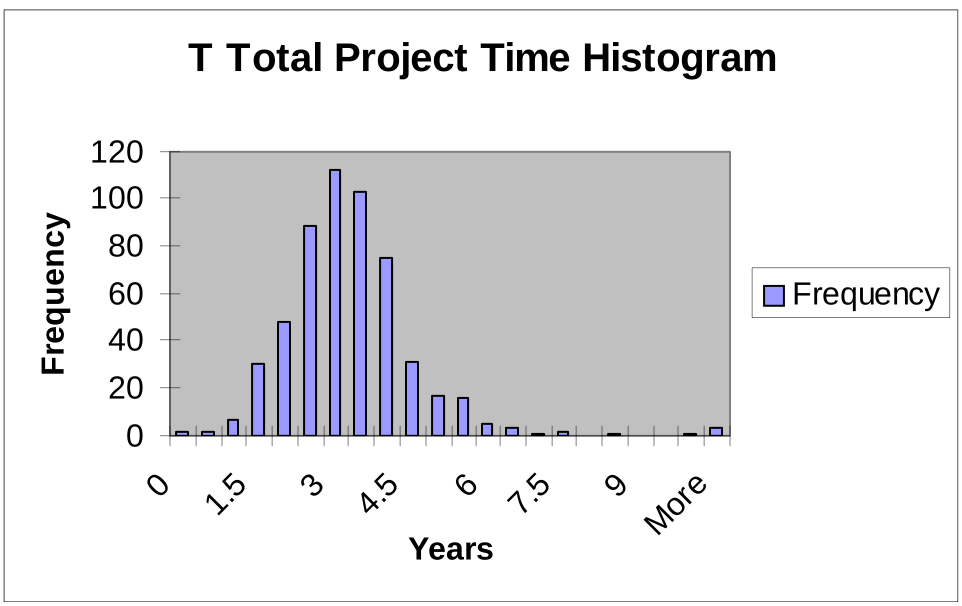
<u>Construction Timeline PA>$20M Histograms</u>





Total Project Time Histograms





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Vita

Captain James W. Rosner was born on 13 March 1980 in Glenwood Springs, Colorado. He attended Doherty High School in Colorado Springs, Colorado and graduated in 1998. He entered undergraduate studies at Colorado State University in Fort Collins, Colorado where he graduated with a Bachelor of Science degree in Mechanical Engineering in May 2003. He was commissioned as a second lieutenant on 16 May 2003 through the Detachment 90 AFROTC at Colorado State University.

His first assignment was to the 82d Civil Engineer Squadron at Sheppard AFB, TX where he worked as a military construction manager and programmer and later, as the Chief of Maintenance Engineering. While there he was selected as the Company Grade Officer of the Year 2006 for the 82d Mission Support Group. During his assignment in Texas he met and later married Lori Charpia of Fort Worth, TX on 18 February 2006. In September 2006, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology, Wright-Patterson AFB, OH. Upon graduation he will be assigned to the 15th Civil Engineer Squadron, Hickam AFB, HI.

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14. ABSTRACT

The design-build method for construction project delivery continues to grow in both the private and public sector. Several government agencies have observed, through experience with design-build, positive results which give “anecdotal” credibility to design-build methods. The objective of this study is to compare the performance of the design-build delivery method with traditional design-bid-build approaches for Air Force (AF) military construction (MILCON).

Data related to 835 (278 design-build, 557 traditional) MILCON projects were gathered from the Automated Civil Engineer System – Project Management Module (ACES-PM) for Fiscal Years 1996-2006. The design-build method had better performance for six of eight metrics with highly significant results for cost growth and number of modifications per million dollars. The traditional method experienced a highly significant advantage for the metrics of construction timeline and total project time. The historical analysis revealed that design-build MILCON has improved significantly for cost growth, modifications per million dollars, construction timeline, and total project time. The traditional method also improved for the cost growth and modifications per million dollars metrics. Finally, the facility type analysis revealed that the design-build method was best suited for seven of the nine facility types. This study provides empirical evidence of where the design-build delivery method provides an advantage to the traditional method for AF MILCON execution.

15. SUBJECT TERMS

Air Force Military Construction, Design-Build, Design-Bid-Build, Traditional, Construction Performance, Project Delivery Methods, t-tests, Facility Type Analysis

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