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# Analysis of Construction Management at Risk Projects for Unites States Air Force Applicability

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**ANALYSIS OF CONSTRUCTION MANAGEMENT AT RISK PROJECTS FOR UNITED STATES AIR FORCE APPLICABILITY**

THESIS


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THESIS

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## Abstract

Construction management at risk is a project delivery method that sees widespread use in the private and public non-federal construction sectors. There is interest in the federal government of using a project delivery method such as construction management at risk. However, guiding regulations prohibit the federal government from using it as it is utilized in the private sector. This research analyzes private sector use of construction management at risk through a literature review and Delphi Panel, in order to determine its effects on project performance. The Delphi Panel consisted of two rounds of questions; the experts were selected through a peer-nomination process. Statistical analysis revealed the experts generally preferred design-build over construction management at risk, and construction management at risk over design-bid-build. Contextual analysis revealed advantages and disadvantages to using construction management at risk. The Air Force can utilize construction management at risk or a construction management at risk-like project delivery method if the project is accomplished with the Air Force Civil Engineer Center as the construction agent. There is a growing trend of desire to move towards a construction management at risk-like project delivery method in the federal sector.

*To my friends, family, and rugby team. Without your support, this would not have been possible.*

Danielle K. Tabb

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ANALYSIS OF CONSTRUCTION MANAGEMENT AT RISK PROJECTS FOR UNITED STATES AIR FORCE APPLICABILITY

# I. Introduction

The Department of Defense (DoD) received 686 billion dollars in appropriations from Congress for fiscal year 2019, which included the funds for military construction (MILCON) and infrastructure improvements [1]. The United States (US) construction industry values put-in-place construction for fiscal year 2019 at nearly 1.3 billion dollars [2]. Construction in the DoD has traditionally followed trends of the private sector [3]. In modern society, there are several different types of project delivery methods. Traditionally, design-bid-build (DBB) is utilized for construction. However, 32% of private owners are leaning towards other delivery methods that provide additional options and flexibility for construction projects [4]. This research focuses on Construction Management at Risk as used by the private sector, and how it can be applied to Air Force construction projects.

## Background

The US Air Force has a Project Delivery System (PDS) designed to consistently provide infrastructure to support and accomplish the mission, while simultaneously meeting established standards using available authority and resources. Each of these projects must meet the criteria of several regulations [5], to include a series of Federal Acquisition Regulations (FAR), Air Force Instructions (AFIs), Unified Facilities Criteria (UFCs), and other regulations in all design and construction contracts. Infrastructure is critical to the US Air Force as it enables the warfighter to conduct operations in multiple domains, to include air, space, and cyberspace. Furthermore, the creation of the Air Force Infrastructure Investment Strategy (I2S) demonstrates the need for data driven decision-making, ensuring the resilience and capability of the infrastructure to complete the mission.

Construction in the Air Force follows a lengthy process: requirements are identified and defined, scoped and packaged into projects, and finally pushed through multiple layers of approvals before being authorized by Congress and appropriated funding. These appropriations include MILCON, unspecified minor military construction (UMMC), operations and maintenance (O&M), as well as facilities sustainment, restoration, and modernization (FSRM). Once this is complete, the project delivery method and acquisition strategy determine the contract process that follows. Currently, the Air Force utilizes Design-Bid-Build (DBB) and Design-Build (DB) methods for construction.

Innovation through technology is one of the key points of the newest National Defense Strategy [6]. This strategy asserts that we must integrate technology into the realm of war and discard outdated practices. The I2S encourages the Air Force as a whole to capitalize on new technology and best practices from the private sector and academia in order to provide more resilient bases and support the warfighter [7]. New project delivery methods from the private sector have the potential to shift the Air Force's approach towards construction management and contracting, and possibly save funding that can be used for other infrastructure projects.

The Air Force has followed federal initiatives in implementing Category Management, a business process aimed at standardizing practices such as bulk purchasing and brand specification across the Air Force in order to save funding that can be otherwise applied. Category Management is also known as strategic sourcing. This framework enables the federal government to make purchases more like a single enterprise instead of at the individual organizational level, a practice common to the private sector. As part of the facilities and construction category, this research will analyze the benefits and limitations of currently utilized project delivery methods and compare them to those that are achieved in the private sector, in order to determine the feasibility of the use of construction management at risk, henceforth known as CMAR. Other known names for CMAR include CM@R, CM @ Risk, and CM at Risk.

### Research Problem

The Air Force spends billions of dollars on construction per year [8], using the DBB and DB project delivery methods. The National Defense Authorization Act for Fiscal Year 2019 (NDAA 2019) appropriated over 1.7 billion dollars for the Air Force MILCON program [9]. In following the private sector, the Air Force as well as the federal government has implemented the use of the DB project delivery method [3]. The private sector has shifted towards using CMAR, a newer project delivery method that focuses on shifting responsibility from the owner through the established contract [3] [10]. The Air Force and other federal entities currently do not use CMAR as generally defined in the non-federal sector due to concerns with FAR compliance.

### Research Objective and Investigative Questions

The objective of this research is to analyze the capability of CMAR as a viable project delivery method for the US Air Force, and its implications on the current PDS. The following research questions were addressed:

1. How can a specific project delivery method influence project performance?
    (a) How does a chosen project delivery method affect the schedule?
    (b) How does a chosen project delivery method affect cost?

(c) How does a chosen project delivery method affect the quality of construction?

2. How does CMAR performance compare with other delivery methods?
3. What are the challenges to implementing a new project delivery method for the Air Force?

## Methodology

This research utilizes the Delphi panel method to elicit the opinions of experts in the private sector of the construction field. The Delphi panel method allows the organizer to determine expert eligibility criteria and obtain data on those experts' points of view, based on their experience in the subject of study. The first phase included the literature review, expert criteria determination, and pilot study. The literature review, as well as interviews with experts provided a basis as to determine the eligibility criteria. Experts were required to have a minimum of ten consistent years in the construction management field, be recognized and acknowledged by their peers in a peer-nomination process, and have experience with CMAR projects. The pilot study screened the questions of each phase for bias, relevance, and clarity. Members of the panel were asked to answer two phases of questions. The answers to the first phase were used to establish the questions for the second phase of the panel. Data was collected and then cleansed for final analysis. Textual and statistical analysis, including paired comparisons, descriptive statistics, the Mann-Whitney Test, and the Kruskal-Wallis Test, were applied to analyze expert preferences.

## Research Scope

The research focuses on CMAR and compares its performance against other acquisition methods. DB, DBB, and CMAR are currently the most popular project delivery systems used in the United States [11]. CMAR will be compared to DB and DBB, the project delivery methods currently used by the Air Force. This research does not cover Integrated Project Delivery, DB-Bridging, Multi-Prime, or other project delivery methods. The applicablity of CMAR for the Air Force will be determined through thorough inquiry of the FAR, as well as other applicable contracting documents, a comprehensive literature review, and an expert elicitation to establish desirability.

### Research Implications

The results of this study will provide the Air Force Civil Engineer Center (AFCEC) Facilities Engineering Directorate decision makers the basis for possible implementation of CMAR through the Air Force wide Category Management framework as a project delivery method for the Air Force. Implementation would include researching and proposing potential changes to the FAR, as well as business processes currently utilized across the Air Force. AFCEC decision makers will create a Category Intelligence Report (CIR) with the results of this research, to identify the value associated with adopting a new project delivery method such as CMAR.

### Overview

This thesis is divided into five different chapters, following a traditional format. Chapter II details the literature reviewed for information on construction in general, construction in the Air Force, different project delivery methods, CMAR specifically, as well as relevant research into different testing methods. Chapter III illustrates the methodology used in this research, as well as the different steps taken in data collection and analysis. Chapter IV examines the results of the analysis and discusses implications, as well as any limitations and assumptions made in the analysis. Chapter V provides the conclusion and a summary of the research, as well as recommendations for further research.

# II. Literature Review

This chapter is divided into five different sections. The first section gives a broad overview of the history of construction and different types of project delivery methods. The second section clarifies Air Force construction procedures, issues specific to the Air Force, contracting, and the Category Management framework. The third section describes CMAR as a project delivery method in the public sector, to include use of Early Contractor Involvement, Construction Manager as Constructor, and use by other authorities. The fourth section continues the discussion on CMAR from the perception of the private sector. The fifth section details relevant research to this study, to include the Delphi Method and different statistical tests that were completed.

## History of Construction

For centuries, master builders were prepared to oversee the design and construction of a building in its entirety as a single individual [12] [13]. Master builders date back to ancient societies such as Egypt and Greece [14]. From concept to completion, the master builder wisely instructed their crews on all things related to the construction and management of the project. They were responsible for the design, surveying, layout, management, and successful completion of the construction project [15]. As construction became more complex and innovative, specialization in design and construction separately began to become normal within the industry [16] [14]. During the mid to late nineteenth century, the architecture craft began to change into its own profession [12]. By World War II, the United States was primarily using the DBB project delivery method, in which the design and construction of a building are two separate components [17].

The transition from the master builder concept to that of separate professions was slow, and has basis in many different societies [14][18]. This resulted in the DBB project delivery method, which has helped modern construction and legislation to mature [13]. However, construction is returning to its original state as it moves back towards an integration of design, construction, and project management [14]. Alternative delivery methods emerged as mechanisms to handle the issues implicit in DBB, such as DB and CMAR [13]. The growth of these alternatives are due to the advantages in performance that are driven by owners [13].

The Military Construction Authorization Act of 1986 authorized the use of DB for MILCON programs [16]. This allowed the military to use the DB project delivery method on a trial basis to determine the fairness and effectiveness of its use on MILCON projects [19]. Each service was allowed to evaluate three pilot DB projects annually. Following this Congressional Act, the 1996 Federal Acquisitions Reform Act, also known as the Clinger-Cohen Act, allowed the widespread use of DB by the military [16] [20].

Each delivery method's history provides a general overview of the reasoning behind its usage and formation. This informed the researchers basic knowledge of the project delivery methods and eliminated the appeal to recommend a method based on its age.

**Project Delivery Methods.**

A project delivery method characterizes the relationships, roles, and responsibilities of parties involved with a construction project [22]. There are many different types of project delivery methods, and various definitions exist for each project delivery method [22] [23]. All of the different project delivery methods have contrasting combinations of financing, phasing, and responsibilities inherent to them [17]. A project delivery method, as defined by Miller et al, is a system that establishes the

**Table 1. Typical and Defining Characteristics of Different Project Delivery Methods (adopted from the AIA [21])**

| *Project Delivery Method* | *Defining Characteristics* | *Typical Characteristics* | *Other Characteristics* |
|---|---|---|---|
| Design-Bid-Build | • Three prime players – owner, designer, contractor<br>• Two separate contracts – owner-designer, owner-contractor<br>• Final contractor selection is based on Low Bid or Best Value: Total cost | • Three phases – design, bid, build. These phases may be linear or overlapping if a project is fast-tracked or bid-out to multiple prime contractors<br>• Well-established and broadly documented roles<br>• Contract documents that are typically completed in a single package before construction begins, requiring construction-related decisions in advance of actual execution<br>• Construction planning based on completed documents<br>• Complete specifications that produce clear quality standards<br>• Configuration and details of finished product agree by all parties before construction begins | |
| Design-Build | • Two prime players – owner, design-build entity<br>• One contract – owner to design-build entity | • Final design-builder selection may be based on any of the following: Direct Negotiation, Qualifications Based Selection, Best Value: Fees or Total Project Cost, or Low Bid<br>• Project-by-project basis for establishing and documenting roles<br>• Continuous execution of design and construction<br>• Overlapping phases – design and build<br>• Some construction-related decisions after the start of the project<br>• Overall project planning and scheduling by the design-build entity prior to mobilization | • Preconstruction services offered by the architect, construction manager, or contractor |
| Construction Manager at Risk | • Three prime players – owner, architect, construction manager<br>• Two separate contracts – owner-architect, owner-construction manager<br>• Final provider selection based on Qualifications Based Selection or Best Value: Fees | • Hiring of the construction manager during the design phase<br>• Clear quality standards produced by the contract's prescriptive specifications<br>• Establishment of a guaranteed maximum price | • Overlapping phases – design and build<br>• Preconstruction services offered by the architect, construction manager, or contractor |

delivery of a good or services through organization of financing, design, construction, and operations and maintenance [17]. Project delivery methods assign risk and legal and financial responsibility to an organization or individual for a project [21]. The importance of selecting a proper project delivery method is critical, as selection of an improper delivery method can negatively impact project performance, as well as liability upon the responsible party, whether the owner or the contractor [11].

DBB is characterized by two, normally sequential contracts: owner to designer or Architect/Engineer (A/E) firm, and owner to general contractor. DB is characterized by one contract between the owner and a firm that can conduct both design and construction. DBB and DB are currently utilized by the Air Force. These project delivery methods, as well as CMAR are the focus of this study, as they are the three principal systems used in the United States today [22] [13]. The typical organization for these methods are shown in Figure 1. There are typical and defining characteristics for each delivery method that are often confused with expected results or benefits, as typical characteristics are not guaranteed [10]. Table 1 identifies typical and defining characteristics of each project delivery method to be discussed.

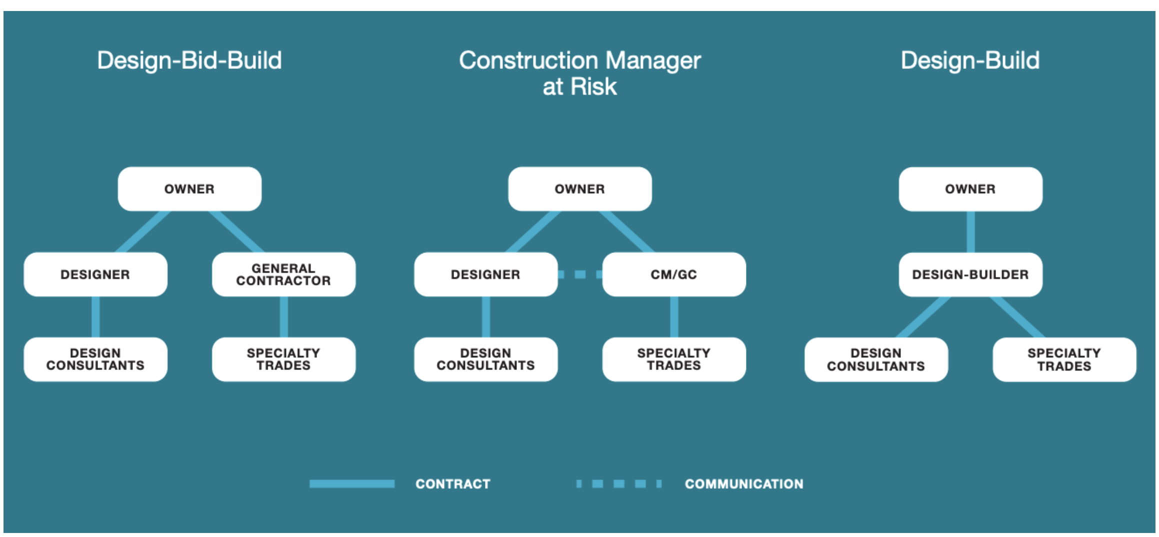


**Figure 1. Organizational Structure of Design Build, Design Bid Build, and Construction Manager at Risk (adopted from Molenaar and Franz [24])**

A research study completed by the Construction Industry Institute (CII) and the Pankow Research Foundation in late 2018 compared schedule and cost metrics to a similar study done by the same organizations in 1998. CII and Pankow studied 212 projects for common themes and developed construction industry recommendations [24]. The most successful projects had two themes: an owner's high emphasis on project culture, and the repeated use of the same contractor. The least successful projects had three overall themes: inexperienced project managers, poor communication between the owner and constructor, and understaffing or turnover within the owner, contractor, and design organizations of the project delivery team [24]. Table 2 details the findings of the study.

**Table 2. Results of the CII and Pankow Research Foundation Study [24].**

| Performance Measure | DB vs. CMAR | CMAR vs. DBB | DB vs. DBB | R^2 |
|---|---|---|---|---|
| *Unit Cost* | 1.9% less | 1.6% more | 0.3% less | .99 |
| *Cost Growth* | 2.4% less | 1.4% less | 3.8% less | .22 |
| *Schedule Growth* | 3.9% less | 2.2% more | 1.7% less | .21 |
| *Construction Speed* | 13% faster | 20% faster | 36% faster | .88 |
| *Delivery Speed* | 61% faster | 25% faster | 102% faster | .89 |

A complete understanding of the project delivery methods in question gives the researchers the necessary knowledge to make informed decisions about the Air Force's project delivery system potential. This also provided defining, typical, and possible characteristics of each method that are compared with current Air Force methods. Grasping this knowledge allowed researchers to visualize the feasibility of implementing a new project delivery method.

### Design-Bid-Build.

Design-Bid-Build is a traditional project delivery method, that involves a sequential process and separate contracts for the designer and builder [11] [17]. The contract for the builder is solicited based on the documents obtained by the owner from the design contract [17], and the owner assumes liability of those design documents according to the Spearin Doctrine [25] [22]. Once the design is 100% complete, the owner solicits the construction contract, and can, once awarded, begin construction on the project.

One of the biggest disadvantages to DBB is the frequency of changes [5]. The contractor defines the cost of the changes in a negotiation, which forms an adversarial relationship between the owner, A/E firm, and contractor. DBB has been found to have more modifications than other project delivery methods [18] [26].

Familiarity is one of the largest advantages of the DBB project delivery method. DBB is well understood by contractors and project managers, and the process is thoroughly defined in literature and research [18]. This project delivery method is proven to work historically and prior to 2007 has comprised the majority of MILCON projects [18]. The advantages and disadvantages of DBB are shown in Table 3.

#### Design-Build.

Another project delivery method is the DB method. It involves a nonlinear process in which the owner forms a contract with a single entity that can provide, either in-house or through subcontractor agreements, both the design and construction of the project [17] [27]. This gives the owner a single point of contact for the project, which has been cited by many as a critical benefit [11].

The study completed by CII in collaboration with the Pankow Research Foundation compared DBB, DB, and CMAR, as shown in Table 2. Overall, DB was the leading method in terms of lower cost and schedule growth [24]. The advantages and disadvantages of DB are shown in Table 3.

**Table 3. Advantages and Disadvantages of Project Delivery Methods (adopted from the Finnish Road Enterprise [28])**

| *Delivery Method* | *Advantages* | *Disadvantages* |
|---|---|---|
| Design-Build | • Reduced administration<br>• Single-source responsibility<br>• Quality equal or better than Design Bid Build<br>• Innovation<br>• Cost savings<br>• Projects completed faster<br>• Improved risk management<br>• Early knowledge of total costs<br>• Accountability<br>• Constructability optimized<br>• Early partnering potential and trust building<br>• Integrating design and construction<br>• Most risks transferred to the Design-Builder<br>• Design reflects contractor strengths and ability<br>• More rewards/profit for contractors | • Limiting competition<br>• High tendering costs<br>• Newer method<br>• Client needs to make quicker decisions<br>• Clients bringing design requirements > 30% (reduces the innovation) |
| Design-Bid-Build | • Long history of acceptance<br>• Open competition<br>• Distinct roles are clear<br>• Owner flexibility<br>• Easy to tender | • Innovation not optimized<br>• Usually cost overruns<br>• Disputes between parties<br>• Client retains most risks<br>• Usually low bid – incentive for change orders<br>• Owner responsible for errors and omissions<br>• Linear process |
| Construction Management at Risk | • Provides managing and administering for all phases of a project<br>• Treats planning, design, and construction as an integrated task<br>• Some cost and schedule control<br>• Good for clients with insufficient staff<br>• Owner flexibility<br>• Responsible for time and cost overruns<br>• Holds and manages the trade contractors<br>• Constructability design review<br>• Same legal position as a general contractor<br>• Provides a guaranteed maximum price (GMP)<br>• Works closely as a teaming effort and encouraging partnering and trust<br>• Owner flexibility | • No contractual relationship with trade contractors<br>• No contractual responsibility for outcomes of a project<br>• Duplication of administration and additional paperwork<br>• Fast tracking difficult to control<br>• Can be difficult to manage all phases of the project |

#### Construction Management at Risk.

Construction Management at Risk is characterized similarly to both DBB and DB. It involves a contract with a construction manager and a separate contract with an A/E firm that are integrated to work together, similarly to DBB, as shown in Figure 1 [21]. In this delivery method, the construction manager is often hired during the design process, and can provide preconstruction services for the owner [29]. The hiring of the construction manager in the design phase is desirable, but not always accomplished, leading to its identification as a typical characteristic in Table 1. The construction manager negotiates with the owner near the end of the design phase for a guaranteed maximum price of the project, and may start construction before design is complete if this has been achieved.

As a project delivery method, CMAR has spread rapidly through the private sector and is beginning to touch the public sector. In a personal interview, Patrick Suermann, Associate Professor and Department Head of Construction Science in the College of Architecture at Texas A&M, explained that CMAR is often the choice of owners for large, complex projects such as that of universities and professional sports teams [30]. 70-80% of Texas public university projects between 2006 and 2007 utilized CMAR [31]. The use of CMAR began in the 1960s as a reaction to the incapability of other delivery methods to adapt to newer technology, materials, and methods [32]. As the Air Force continues to innovate and implement Category Management processes, the Air Force is also researching implementation of a version of CMAR.

The principal advantage of CMAR is the ability to conduct design and constructability reviews through the integration of planning, design, and construction. In theory, this gives the owner more flexibility for design decisions and allows the contractor to give input on the design, thereby lowering costs, streamlining schedules, and ensuring that the design has no omissions and errors before construction begins [10]. However, scholars, academia, and industry opinions differ on the benefits of different project delivery methods[10]. For example, a study completed by the CII and Pankow Research Foundation in 2018, shown in Table 2 demonstrates that DB has less cost growth and less schedule growth than CMAR. Table 2 also shows that DBB has less schedule growth than CMAR. Several studies show that there is no statistically significant difference between CMAR and DBB [10] [33] [34], which is contrary to other studies [24] [29] [31]. The general advantages and disadvantages of CMAR are shown in Table 3.

### Air Force Construction

The Federal Acquisition Reform Act, also known as the Clinger-Cohen Act of 1996, authorized the federal government to begin using the DB project delivery method after a ten year trial period [35]. Until this point, DBB was the only project delivery method authorized for use; prior to 2007, DBB constituted the majority of MILCON projects being completed [18]. After seeing the success of CMAR in the private industry, the AFCEC, as well as other DoD entities are now considering it as another option for project delivery under the Category Management program.

Military Construction is defined in *Title 10, United States Code*, Section 2801, as any construction, development, conversion, or extension of any kind carried out with respect to a military installation. Air Force Instruction 32–1023, Designing and Constructing Military Construction Projects, describes the typically five-year MILCON process [36]. The PDS Planning and Programming phases are listed below (adopted from AFI 32-1023 [36]).

1. Planning Phase:

    (a) Identify future facility needs 3–5 years in the future and complete Department of Defense Form 1391 (DD 1391) Military Construction Project

Data

   (b) Identify possible alternative actions to accommodate facility needs

   (c) Installation commanders review, validate, and prioritize installation facility requirements in the Installation Facilities Board

   (d) Obtain signed Certificate of Compliance from installation commander

   (e) Submit prioritized list of projects to the Major Command (MAJCOM) or Direct Reporting Unit (DRU)

2. Programming Phase:

   (a) MAJCOM/DRUs compile, validate, and submit prioritized command programs to the Air Force Headquarters Air Staff MILCON Program Manager (AF/A7CP)

   (b) AF/A7CP advocates for MILCON resources through the Air Force Corporate Structure, Office of the Secretary of Defense, Office of Management and Budget, and Congress

Following the planning and programming phases, installations are given the ability to award projects. A contract for the design phase is then bid and awarded. Depending on the project delivery method selected for the project, the construction contract begins either during or after the design phase.

**Issues Specific to the Air Force.**

The Air Force, DoD, and federal government as a whole experience different obstacles that are not inherent in the private sector. Turnover between project managers and inefficient front-end planning are challenges that the federal government faces for every acquisition contract, especially that of construction. Turnover and understaffing are two of the major themes in unsuccessful project performance [24]. Military members that are in project management roles often see the start of a project but may not be there to see its completion. The same happens in the opposite manner; members see the completion of the project but were not part of the beginning phases. This results in project managers that do not retain a complete understanding of the project and the surrounding necessary details [24].

Another issue faced by the Air Force is poor front-end planning. While this issue is not exclusive to the Air Force, it contributes to the large cost and schedule growth of Air Force projects [37]. An analysis of 3560 completed Air Force A/E service projects from the Federal Data Procurement System awarded between fiscal year 2015 and 2019 found that 15.6% of projects experienced cost growth, 46.5% of projects experienced schedule growth, and 58.5% of projects had modifications to change the scope of the project. While the actual cause of the overruns is unknown, costs can typically be attributed to one of 15 reasons mentioned by Rosenfeld in their analysis, the results of which are shown in Table 4 [38]. Rosenfield's analysis is consistent with the literature [37]. However, when analyzing this data, one should take into account the nature of the data: the projects are for A/E services only, and not construction.

**Table 4. The 15 Construction Over-run Root Causes (adapted from Rosenfeld [38])**

| Number | Cause | Number of votes | Percentage | Rank order | Original sequence before randomization |
|---|---|---|---|---|---|
| 1 | Premature tender documents (drawings, bill of quantities, specifications, contracts and legal documents) | 169 | 86.7 | 1 | 10 |
| 2 | Insufficient information about ground conditions | 56 | 28.7 | 7 | 9 |
| 3 | Too small a design budget | 63 | 32.3 | 6 | 3 |
| 4 | Force majeure (strikes/weather/regulation changes/accidents, etc.) | 10 | 5.1 | 15 | 15 |
| 5 | Too many changes in owners' requirements or definitions | 139 | 71.3 | 2 | 12 |
| 6 | Late start of the planning process, and with too low a budget | 56 | 28.7 | 7 | 6 |
| 7 | Insufficient, unstandardized owner's brief | 70 | 35.9 | 5 | 14 |
| 8 | Shortage in high-quality management personnel | 53 | 27.9 | 9 | 1 |
| 9 | Culture of conflicts and lack of trust | 35 | 17.9 | 11 | 4 |
| 10 | Unconstructable design | 31 | 15.9 | 13 | 13 |
| 11 | Tender-winning prices are unrealistically low (suicide tendering) | 127 | 65.1 | 3 | 7 |
| 12 | Lack of standard requirements from designers and poorly enforced professional liability of designers | 33 | 16.9 | 12 | 8 |
| 13 | Unclear, ambiguous, and contradicting terms in the tender documents | 75 | 38.5 | 4 | 11 |
| 14 | Unbalanced distribution of risk between owner and contractor | 42 | 21.5 | 10 | 2 |
| 15 | Unclear division of responsibilities and lack of clear requirements for professional management | 16 | 8.2 | 14 | 5 |

The CII began researching front-end planning in the early 1990s, resulting in the creation of the Project Definition Rating Index (PDRI) [39]. This is a tool that is intended to be used by the project team during the design phase, in order to evaluate the completeness of scope definition before making decisions that can become costly. The Air Force begun the use of PDRI on MILCON projects in 2008. Projects that use PDRI statistically out-perform those projects that do not, in terms of cost and schedule growth [39]. A study found that MILCON projects are comparable to building projects industry-wide, suggesting that front-end planning is useful on all projects [39].

Issues specific to the Air Force and the DoD in general are critical to the established research objectives. Researchers utilized this information to discern how project success is different for the Air Force than the private sector, conceive implementation strategies, and ultimately address challenges to implementation.

**Guiding Regulations.**

The FAR is the guiding policy for all federal purchases. The DoD and the Air Force have supplemental policy in place on top of the FAR, in the form of the DFARS and AFFARS, respectively. In the private sector, CMAR requires a set GMP, as well as contractor selection based on qualifications or best value. Therefore, the main reason this delivery method is not being used currently by the Air Force is the structure of the project delivery method itself.

While the Brooks Architect-Engineers Act grants Air Force construction managers the authority to select an A/E firm for design solely based on their qualifications, there is no such policy for construction contractors. Construction contractors are selected based on their past performance and ability to complete the project, which are determined using a system called the Contractor Performance Assessment Rating

System (CPARS) and a technical evaluation of the contractor's proposal, respectively. Currently, construction is bid through a competitive process that favors lower bids, which can result in low quality, as well as cost and schedule overruns [18].

### Air Force Contracting.

Construction and acquisition contracts are managed through an available contracting office, whether that is a base contracting squadron or a larger organization such as that of an enterprise support squadron located at headquarters. When soliciting for bids, contracting normally uses Best Value or Lowest Price Technically Acceptable (LPTA) [40]. With an increasing need for budget accountability and cost decreases, contracting officers are pressured to use LPTA; this can cause unrealistically low bids to be submitted and contractors to cut corners on awarded contracts [40].

This section details the different types of Air Force contracts, as well as Category Management. These topics, as well as the different project delivery methods, give the researchers a foundation for possible implementation of a new method.

#### Types of Air Force Contracts.

According to the FAR, there are several different types of contracts that can be used for Air Force acquisitions. This section provides a quick overview of those different types of contracts. In order to make the best use of available funds, contracting officers must select the correct type of contract to issue. The factors that influence selection are price competition, price analysis, cost analysis, type and complexity of the requirement, urgency of the requirement, period of performance, contractor capability, and possible combination of contract types. There are two broad categories for contracts: fixed-price and cost-reimbursement [41]. Other contract types include time and materials and indefinite-delivery, which can have definite or indefinite quantities. The most common type of Air Force contract for construction is firm-fixed price.

Fixed-price contracts are contracts that can either have a firm price or adjustable price [41]. A firm-fixed price contract is not adjustable and places risk on the contractor for all profits or losses. A fixed-price contract with economic price adjustment can be adjusted for three different situations: changes in established prices, changes in actual costs of labor or material, and changes in cost indexes of labor or material [41]. The contracting officer can also use incentives based on award, performance and delivery. According to Ms. Sally Kite, Chief of Construction Flight and Contracting Officer for the 772 Enterprise Sourcing Squadron, non firm-fixed price contracts are rare, but non-federal sector CMAR projects often use firm-fixed-price incentive fee contracts [42]. These contracts adjust profit and establish a final price based on final negotiated costs and target costs [41].

Cost-reimbursement contracts pay the costs associated with the contracts by estimating the total cost and establishing a ceiling for the contractor [41]. There are three types: cost-plus-incentive-fee, cost-plus-award-fee, and cost-plus-fixed-fee. In a cost-plus-incentive-fee contract, the fee is initially negotiated and can be adjusted later, depending on the contract. In a cost-plus-award-fee contract, an award amount is given to the contractor based on the government's evaluation, which is intended to motivate performance. In a cost-plus-fixed-fee contract, a fixed fee is negotiated at the beginning of the contract but can be adjusted based on the result of the work [41].

### Category Management.

The AFCEC aligned with higher headquarters initiatives in 2014 for Category Management in researching and implementing standardization of practices. Through the Office of Management and Budget, all federal agencies have been mandated to take steps towards Category Management, also known as Strategic Sourcing [43]. In fiscal year 2013, contract spending decreased by over 55 billion dollars because of efforts to implement smarter buying strategies [43]. However, Category Management is not just about spending; the improvement and development of common practices, standards, and data analysis also drive this effort.

The Federal Category Management Structure is broken down into 19 categories [44], as shown in Table 5. These do not include the DoD centric categories. The category of consideration is Category 4: Facilities & Construction. Category Management's success is measured through three metrics: Savings, Spend Under Management (SUM), and Small Business [44]. Savings entails the plain meaning of the word; the Federal Government needs to make better use of its resources and decrease the total cost of ownership. SUM is an overall measure of maturity, highlighting areas that are improvements on others that can be spread at an agency-wide and government-wide level. Small Business encompasses increasing the participation of the number of small businesses in government contracts [44].

The private sector has seen improvements in project delivery cost and schedule with the use of CMAR [10]. Appropriate use of this project delivery method can result in cost savings for MILCON projects conducted by the Air Force, and is being considered under the Category Management effort. This research studies CMAR through the lens of Category 4 with the intent of finding potential improvements for the Air Force project delivery system.

### Public Sector - Construction Management at Risk

The public sector is very broad in its scope. Projects completed for universities are vastly different from those that will be completed by the government or military,

**Table 5. The Federal Category Management Structure - General Government Categories (adapted from Bullock [44])**

| | |
|---|---|
| 1. IT | 1.1 IT Software<br>1.2 IT Hardware<br>1.3 IT Consulting<br>1.4 IT Security<br>1.5 IT Outsourcing<br>1.6 Telecommunications |
| 2. Professional Services | 2.1 Business Administration Services<br>2.2 Legal Services<br>2.3 Management Advisory Services<br>2.4 Marketing and Distribution<br>2.5 Public Relations and Professional Communications Services<br>2.6 Real Estate Services<br>2.7 Trade Policy and Services<br>2.8 Technical and Engineering Services (non-IT)<br>2.9 Financial Services<br>2.10 Social Services |
| 3. Security and Protection | 3.1 Security Animals & Related Services<br>3.2 Security Systems<br>3.3 Security Services |
| 4. Facilities and Construction | 4.1 Construction Related Materials<br>4.2 Construction Related Services<br>4.3 Facility Related Materials<br>4.4 Facility Related Services<br>4.5 Facilities Purchase & Lease |
| 5. Industrial Products and Services | 5.1 Machinery & Components<br>5.2 Fire/Rescue/Safety/Environmental Protection Equipment<br>5.3 Hardware & Tools<br>5.4 Test & Measurement Supplies<br>5.5 Industrial Products Install/Maintenance/Repair/Rebuild<br>5.6 Basic Materials<br>5.7 Oils, Lubricants, and Waxes |
| 6. Office Management | 6.1 Office Management Products<br>6.2 Office Management Services<br>6.3 Furniture |
| 7. Transportation and Logistics Services | 7.1 Package Delivery & Packaging<br>7.2 Logistics Support Services<br>7.3 Logistics Civil Augmentation Program<br>7.4 Transportation of Things<br>7.5 Motor Vehicles (non-combat)<br>7.6 Transportation Equipment<br>7.7 Fuels |
| 8. Travel and Lodging | 8.1 Passenger Travel<br>8.2 Lodging<br>8.3 Travel Agent & Misc. Services |
| 9. Human Capital | 9.1 Alternative Educational Systems<br>9.2 Educational Facilities<br>9.3 Educational Institutions<br>9.4 Specialized Educational Services<br>9.5 Vocational Training<br>9.6 Human Resources Services |
| 10. Medical | 10.1 Drugs and Pharmaceutical Products<br>10.2 Medical Equipment & Accessories & Supplies<br>10.3 Healthcare Services |

which can also differ from those completed for state and municipal authorities. As CMAR continues to see success in the public non-federal sector, different organizations within the federal government have attempted utilization of this method. The United States Army Corps of Engineers (USACE) began use of Early Contractor Involvement (ECI), of which CMAR is a subset, to use on large construction projects [3]. The General Services Administration (GSA) created new policy and added to the GSA Acquisition Regulation (GSAR) section of the Federal Register in order to use Construction Manager as Constructor, a form of CMAR [45].

**Early Contractor Involvement.**

The USACE provides civil works, military, and interagency construction, as well as environmental restoration; they are the world's largest public engineering, design, and construction management agency [3]. In an effort to drive procurement innovations, the USACE adopted a FAR compliant adaption of CMAR and Integrated DBB known as Early Contractor Involvement (ECI). ECI is a working relationship between an owner or designer and a contractor that leverages knowledge and experience from the contractor, starting early in the design phase of the project [46]. It combines elements of both DBB and DB to enhance consistency throughout construction projects [47]. This is typically achieved through a cost-plus-fee contract. ECI can also be described as a process that aims to involve the contractor early in the planning phase [48]. CMAR is just one of the project delivery methods that utilizes the concept of ECI.

ECI was initially adopted by the Kansas City District of the USACE in 2004 [3]. Several smaller projects were completed using this method, however the USACE legal community began to question its compliance with the FAR [3]. Early involvement of project team members is one of the factors that provides benefits in ECI; it is a key recommendation in the findings of the most recent Construction Industry Institute study on project delivery methods [24].

The USACE is currently revising their brand of ECI in hopes to again use a CMAR-like project delivery method. The federal government recognizes the benefits in using it - for example the Federal Highway Administration (FHA) is conducting the majority of their projects using CMAR, as mentioned by Mr. David Curfman, Chief Engineer and Assistant Commander for Capital Improvements, Naval Facilities Engineering Command (NAVFAC) [49].

Currently, NAVFAC is running a pilot project utilizing ECI for a new Mariner Skills Training Center in Norfolk, Virginia. This project has a critical time deadline to meet training requirements and facilitate the receipt of equipment. It was determined that DBB would be faster than DB, but would still cause delays, which lead to the decision to use ECI [50]. This solicitation was opened to Multiple Award Construction Contract (MACC) contractors, with a selection criteria in the following order: approach for pre-construction services including key personnel, schedule, and finally price. The base contract was awarded for pre-construction services and funded with design funds, with an option for construction services. This option includes the total initial target price, which is comprised of the initial target cost and initial target profit. However, the project manager described the use of the MACC contractors as critical, as the acquisition process would be lengthy in comparison to DBB [50].

ECI has been used as a successful procurement strategy in Australia, New Zealand, and the United Kingdom [47]. This strategy engages the contractor before beginning construction work, in order to help with design inputs, create a detailed project plan, and negotiate a GMP, with selection based on a non-price basis.

The South Australian Department of Transport, Energy, and Infrastructure (DTEI) uses a two phase ECI model: design development, and design and construction [47].

In this model, the first phase includes selection of either a contractor, or a contractor and a designer. The contractor is brought on to help with the design. The design is then completed as part of the first phase. At approximately 70% design completion, phase two is implemented, in which negotiations occur to facilitate agreement of a final price. If negotiations fail to meet an agreement, the owner typically opens competition for the rest of the contract [47].

The New Zealand Transport Agency (NZTA) conducts a three portion model of ECI. The first portion includes investigation and research. The second portion consists of detailed design preparation, as well as negotiation of commercial terms, price, and duration. The third portion incorporates the completion of the design as well as physical works [47]. This model differs from others as the owner and contractor negotiate a fixed price for each portion, prior to the start of work.

ECI has become the preferred procurement route for the Highways Agency in the United Kingdom since it was first adopted in 2001 [47]. Similarly to the other models, this model selects the contractor on basis of qualifications for design and construction. This model also conducts the development of an open book target pricing system, which will later become the fixed baseline price [47].

**Construction Manager as Constructor.**

The General Services Administration (GSA) has adopted Construction Manager as Constructor (CMc), a method that has been used by the industry for a number of years and follows already established best practices [45]. Early engagement by the contractor is not only one of the key recommendations of the CII and Pankow research study [24], but also has been shown by the GSA's research to provide reduced cost growth and schedule growth, as well as administrative savings [45]. The CMc project delivery method includes concurrent contracting for both the design and construction phases of the work. Both a designer and construction contractor are hired before the design documents are completed [45]. The constructor conducts design phase services, which are structured as a firm-fixed price contract; the construction phase is a bid option with a guaranteed maximum price [45].

**Other Public Projects.**

The Miami Intermodal Center is a multi-modal transportation center that recently underwent a renovation to improve the roadways and add several new facilities [51]. This project was considered a mega-project by the US Department of Transportation, and was sponsored by the Florida Department of Transportation. This project utilized CMAR in the first phase, which included right-of-way acquisition, access improvements, a consolidated rental car facility, the airport mover facility, and the airport core [51]. This project was set up as a cost-plus-fee contract with a GMP, in order to incentivize the contractor.

Two important elements are noted by this case study: the construction manager must be contracted no later than the 35% plans review, and the designer must work quickly between the 65% plans review and completion [51]. Early involvement allows the designer to use the expertise of the contractor, as also noted in earlier mentioned studies [24]. The second note allows the project to keep its fast-track advantage by giving the construction manager ample time to obtain licensing and permits [51]. The biggest advantage noted is the relationship developed by the project team, which was better than that of a DBB system [51]. The project contained five guaranteed maximum prices for the first phase. The first two were completed under budget but they exceeded contract duration due to delays in beginning the project [52].

### Private Sector - Construction Management at Risk

Since the private sector is not regulated by the same governance that restricts the public sector, there are many more choices of project delivery method to utilize. CMAR is being applied to more and more contracts in the private sector - especially for large, complex projects such as that of sports stadiums, healthcare centers, and building expansions [30]. A nonresponse sampling study completed by Konchar and Sanvido indicated that on terms of cost growth, DB outperforms DBB, and DBB outperforms CMAR. Similarly, on terms of schedule growth and quality, DB outperforms CMAR, which outperforms DBB [29]. A similar study completed by Sullivan, Asmar, Chalhoub, and Obeid found in terms of cost growth that DB outperformed both DBB and CMAR, in that order [13]. They also found that CMAR outperformed DB and DBB in that order on terms of schedule with statistically significant results. Many studies have been completed on CMAR in the private sector with contradictory results.

### Relevant Methods

This section details the research completed to build the basis of this study's methodology and analysis. First, the Delphi Method and its efficacy were researched in an effort to select this mode of data collection. Finally, nonparametric statistical analysis techniques were reviewed to formulate the method for the analysis of data.

#### The Delphi Method.

The US Air Force sponsored a program run by the Rand Corporation in the 1950s that developed the Delphi process [53]. Used more and more in healthcare studies and research, the Delphi Method allows experts to anonymously respond to iterative questionnaires on complex issues within their specific field. Four principles define a

Delphi process: iteration, anonymity, controlled feedback, and statistical aggregation [54]. Belton et al describe a six-step practical and defensible Delphi process that will be used for the purposes of this research [55].

Selecting experts for the panel is a key success factor in the design of the Delphi process [56]. Criteria for expert selection needs to be developed while considering things such as geographic location, number of experts, potential attrition rates, and a pilot study [55]. Samples should be random and representative of the population. However, since the population parameters are unknown in terms of expertise and knowledge, samples are often those of convenience [57] [58].

Common sense should be used to determine the sample size, in order to satisfy the audience to which the research is aimed [55]. The number of experts required for a successful panel varies in past research. In a meta analysis, de Loë et al found the range to be less than ten to over a thousand participants [57]. A large panel of experts will result in convergence of opinions but is not always practical. Many ranges are suggested by past research: 5–20 [54], 15–60 [59], or 15-30 [60].

Panel members for a Delphi study in the construction industry are typically selected via specific requirements or a point-system [61]. Panel member eligibility ranges, but typically experience and dollar value of projects are used as criteria. Experience for panel members ranged from greater than 5 years to greater than 11 years [62] [53]. Although the literature is ambiguous, the number of panel members specific to the construction industry ranges from 3 to 93, with the majority between 8 and 20 [61] [62]. Okoli and Pawlowski recommend 10 to 18 experts [63].

A high dropout rate can lead to biased study findings and affects the level of consensus achieved, so a high response rate is desired [53]. However, the literature does not generally agree on specific criteria to determine the achievement of consensus [64]. Financial incentivization is often used by researchers to maintain a high response rate because it is more effective than nonmonetary strategies [65] [66]. However, the quality of the responses received can vary, as the panelists may rush their efforts, skip items, or deny the questions the attention that is needed [67].

Iterations of the panel allow the panelists to refine their views on the subject matter [68]. Iterations are conducted through both contextual and statistical analysis, depending on the type of question. Themes and common answers are carried on to the next round of questions, with 70–80% being a conclusive threshold [68] [56]. The literature is inconclusive on the optimum number of iterations, as it depends on the researchers desired level of consensus [61].

**Statistical Testing and Analysis.**

Statistical testing and analysis are crucial to the research as it reveals levels of consistency amongst the panelists as well as the questions used to determine the preferences of the experts. These conclusions will become the basis of the recommendations established by the researchers. Descriptive statistics, contextual and thematic analysis, and two statistical tests will be used: the Mann-Whitney $U$ test, and the Kruskal-Wallis test.

The statistical analysis tests to be performed are determined by the type of data that is obtained, whether qualitative or quantitative. Likert scales, which produce qualitative data, are generally used in Delphi studies [53]. These scales have a rank order, and there are typically five different categories or intervals of response, ranging from strongly disagree to strongly agree [69]. Since these intervals are ordinal, they cannot be presumed equal and measurements of central tendency should not be used [69]. Also, panelists may have different opinions on the meaning of the intervals, which can lead to errors in the study. Therefore, a nonparametric statistical analysis technique will be used.

Analysis of qualitative data can be accomplished through contextual and thematic analyses [53] [57]. Depending on the questions, researchers can draw conclusions and themes from panelists' textual responses and present them graphically [53]. Contrarily, quantitative data can be analyzed in many different ways. Descriptive statistical analysis, such as measurement of central tendency and level of dispersion, is common to Delphi studies [59]. Many researchers believe that nonparametric statistic analysis is appropriate for Delphi studies [69] [70] [71]. The Mann-Whitney $U$ test and Kruskal-Wallis test are two nonparametric statistical tests that can be used to analyze Likert data. Kendall's coefficient of concordance ($W$) uses a least squares solution and can determine a level of consensus [72].

Internal consistency is a measure of reliability for which there are two methods: the split-half method and Cronbach's alpha [73]. It is important for a test to be reliable so that it can yield consistent results. Split-half reliability is determined by scoring a single test as if it is two separate tests and then correlating the scores. Cronbach's alpha ($\alpha$) is calculated using equation 1.

$$\alpha = \left(\frac{k}{k-1}\right)\left(1 - \frac{\sum_{i=1}^{k} \sigma_{y_i}^2}{\sigma_x^2}\right) \tag{1}$$

where $k$ is the number of scale or test items, $\sigma_{y_i}^2$ is the variance associated with item $i$, and $\sigma_x^2$ is the variance associated with the observed total scores [74]. This equation correlates the score for each scale item with the total score for each observation and compares it to the variance for each item score.

The validity of a test describes if the test measures the subject that is intended to be measured. This can be measured either concurrently or predictably. There are two types of validity: internal validity and external validity. A test with strong internal validity can justify its intent for research. A test with strong external validity can be generalized to another sample or group. There are nine threats to internal validity and four threats to external validity [75]. These are detailed below (adopted from [75]).

**Threats to Internal Validity [75]**

1. Ambiguous Temporal Precedence: Lack of clarity about which variable occurred first may yield confusion about which variable is the cause and which is the effect.
2. Selection: Systematic differences over conditions in respondent characteristics that could also cause the observed effect.
3. History: Events occuring concurrently with treatment could cause the observed effect.
4. Maturation: Naturally occurring changes over time could be confused with a treatment effect.
5. Regression: When units are selected for their extreme scores, they will often have less extreme scores on other variables, an occurrence that can be confused with a treatment effect.
6. Attrition: Loss of respondents to treatment or to measurement can produce artifactual effects if that loss is systematically correlated with conditions.
7. Testing: Exposure to a test can affect scores on subsequent exposures to that test, an occurrence that can be confused with a treatment effect.
8. Instrumentation: The nature of a measure may change over time or conditions in a way that could be confused with a treatment effect.
9. Additive and Interactive Effects of Threats to Internal Validity: The impact of a threat can be added to that of another threat or may depend on the level of another threat.

**Threats to External Validity [75]**

1. Interaction of the Causal Relationship with Units: An effect found with certain kinds of units might not hold if other kinds of units had been studied.
2. Interaction of the Causal Relationship Over Treatment Variations: An effect found with one treatment variation might not hold with other variations of that treatment, or when that treatment is combined with other treatments, or when only part of that treatment is used.

3. Interaction of the Causal Relationship With Outcomes: An effect found on one kind of outcome observation may not hold if other outcome observations were used.

4. Interactions of the Causal Relationship with Settings: An effect found in one kind of setting may not hold if other kinds of settings were to be used.

**The Mann-Whitney *U* Test.**

The Mann-Whitney $U$ test, also known as the Wilcoxon rank-sum test, is a non-parametric test for small, independent samples which involves the summation of rankings. This tests the equality of means between two sample groups that have the same size sample. The hypotheses for the test are as follows:

$H_0$: The two populations are equal

$H_a$: The two populations are not equal

where $H_0$ is the null hypothesis and $H_a$ is the alternative two-sided hypothesis [76]. The test statistic for the Mann-Whitney $U$ test is as follows:

$$U_1 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1 \tag{2}$$

$$U_2 = n_1 n_2 + \frac{n_2(n_2+1)}{2} - R_2 \tag{3}$$

where $U_1$ and $U_2$ are the respective test statistics, $n_1$ and $n_2$ are the respective sample sizes, and $R_1$ and $R_2$ are the sum of the ranks for the respective groups. If the minimum of the two test statistics is less than or equal to the critical value at a given level of significance ($\alpha$), reject $H_0$ [76]. The critical values can be found in a table [76]. The procedure includes ordering data from smallest to largest, while keeping the two samples separate, and then assigning ranks to each set.

### The Kruskal-Wallis Test.

The Kruskal-Wallis test is another nonparametric test that is used to compare medians among multiple groups [76]. The procedure is similar to that of the Mann-Whitney $U$ test, but it involves multiple groupings instead of two. The hypotheses for the test are as follows:

$H_0$: The $k$ populations are equal

$H_a$: The $k$ populations are not equal

where $H_0$ is the null hypothesis, $H_a$ is the alternative two-sided hypothesis, and $k$ is the number of samples researched [76]. The test statistic for the Kruskal-Wallis test is as follows:

$$H = \left( \frac{12}{N(N+1)} \sum_{j=1}^{k} \frac{R_j^2}{n_j} \right) - 3(N+1) \tag{4}$$

where $H$ is the test statistic, $N$ is the the total sample size, $j$ is each respective group, $n_j$ is the sample size in each respective group, $j$, and $R_j$ is the sum of the rank in each respective group, $j$ [76]. The test statistic, $H$, is then compared to the critical value at a set significance level ($\alpha$). If there are 3 or more comparison groups and 5 or more observations in each the test statistic, $H$ approximates a chi square distribution with degrees of freedom equal to $k - 1$ [76].

## Summary

This chapter is divided into five sections that give the foundational knowledge and background required to accomplish this research. The first section provides background on the general history of construction, as well as the development of different project delivery methods that exist today. The second section details Air

Force construction, as well as guiding regulations, Air Force specific contracting, and the impact of the new Category Management business processes that are being established around the globe. The third section describes CMAR in the public sector, in addition to methods utilized by other services and federal entities. The fourth section details CMAR in the private sector. Finally, the fifth section clarifies the Delphi Method and statistical analysis to be used in this research.

# III. Methodology

This chapter is divided into two different sections. The first section details the theory behind the Delphi Panel Method and why it was chosen as a data collection instrument. The second section establishes the seven step process loosely based off Belton et al's method [55] used to collect and analyze data from the two phases of expert elicitations.

## Theory

This research aims at analyzing the viability of CMAR as a project delivery method for the Air Force. Currently, because of the FAR's call for competition between contractors, the general use of CMAR is prohibited and there is no existing data. This research uses existing publications and references to set context for expert elicitation to assess CMAR applicability to Air Force construction.

## Procedures

The following sections outline the steps used in this research to conduct the expert elicitations for the Delphi Panel. These are adapted from Belton et al's method [55] with some slight modifications. The six steps from Belton et al are shown in Table 6.

The modifications combine several steps into the setup process, to ensure these choices are made without bias or interference of the questions. In addition, a pilot study was added to the process in order to assure readability and understanding of the questions. These changes allow the process to be more repeatable in future studies.

**Table 6. The Six Steps of a Successful Delphi Application (adapted from Belton et al [55])**

6-Step Delphi application.

| The Six Steps of a successful Delphi application |
|---|
| Step 1: Setting up a Delphi process |
| • Determine the overall goals of the exercise |
| • Choice of experts |
| ○ Use heterogeneous experts |
| ○ At a minimum, use 5–20 experts |
| ○ Consider using an expert nomination process |
| • Initial considerations |
| ○ Geographical dispersion of experts |
| ○ Relative expense and time-demand of Delphi versus alternatives |
| ○ Severity of disagreements amongst experts |
| • The survey |
| ○ Generate issues for consideration in the Delphi survey by open-ended questioning |
| ○ Write an introduction and a closure |
| ○ Restrict the survey to what can be answered in 30 minutes |
| ○ Estimate the Delphi time-line |
| ○ Pilot the survey |
| Step 2: Developing question items and response scales |
| • Decide on the number of issues to explore |
| • Creating questions |
| ○ Formulate clear, concise questions, and group by issue explored |
| ○ Start with simple questions |
| ○ Are the capabilities of the panellists matched to the questions posed? |
| • Formulate clear response formats |
| ○ When taking measurements, choose between categorical, ordinal or interval scales |
| ○ If using ordinal, Likert-type scaling, decide on even or odd number of response categories |
| ○ Define the end points of the response category |
| Step 3: Software delivery choice |
| • Paper and pencil? |
| • *E*-mail? |
| • Web-based? |
| • Tailor-made or off-the-shelf? |
| • Conventional Delphi rounds or real-time? |
| Step 4: Providing feedback to panellists |
| • Provide median responses |
| • Provide either range or inter-quartile range of responses for each question |
| • Elicit and utilise respondents' rationales for their numerical responses |
| • Remove indicators of the prevalence of majority opinions |
| • Develop and apply a criterion of consensus |
| • Continue polling until responses show stability, generally 3 rounds are enough |
| • Be alert to continuing dissensus in panellists' opinions |
| Step 5: Preventing and dealing with panellist drop-out |
| • Note that self-rated experts tend not to drop out |
| • Use social rewards |
| • Consider using financial rewards |
| • Use personal communications with panellists |
| • Note that the greater the number of rounds, the greater the degree of dropout |
| Step 6: Analysing and presenting the Delphi data |
| • Make use of descriptive statistics to describe the data |
| • Note that small sample sizes and non-random sampling limit statistical analyses |
| • Use non-parametric statistical analyses |
| • Make use of graphical representations of data |
| • Integrate Delphi results with knowledge of the broader picture provided by other, perhaps more quantitative, research |

#### Step One - Setting Up a Delphi Process.

The setup of a Delphi process is critical to the success of the study. This includes deciding on what variables to test, creating a hypothesis about those variables, and choosing how the study will be administered. These decisions allow the research methods to be applied to different situations by ensuring they are repeatable. A pilot study was also added to the process to eliminate any bias and maximize readability of the questions. Choosing the methods for the pilot study are also included in the vital setup process for the Delphi.

##### Create Hypotheses.

The first step to the creation of hypotheses is to decide on what variables to test. One of the aims of this study is to analyze the affects of CMAR utilization on the performance of the current project delivery system. The Air Force, like any other organization, will value methods that lead to success. Therefore, researchers had to define project success. Cost, quality, and time are often seen as the main criteria for project success [17], so these traits were adopted in the hypotheses. The hypotheses for this study are as follows:

- CMAR will positively influence Air Force project success
- Experts believe CMAR is associated with lower project costs
- Experts believe CMAR is associated with shorter project durations
- Experts believe CMAR is associated with higher project quality

The goal of the first phase of the Delphi process was to assess experts' overall preferences of each project delivery method, and to determine their views on the benefits and limitations of each project delivery method. The goal of the second phase of the Delphi process was to further narrow down those views on the benefits and limitations in order to reach consensus. These goals will help to quantify the overall hypothesis that CMAR will positively influence Air Force project success.

The expert participants of the panel were identified through a peer-nomination process. Electronic mail were sent to former instructors, research sponsors, and other industry members to solicit participation in the panel. The criteria for the panel were identified as a specific requirement through the literature review and an interview with research sponsors [61]. The criteria for inclusion was determined to be at least ten years of experience in the construction industry with experience in multiple project delivery methods, to include CMAR, based on the literature review. Seventeen experts were selected for participation in the panel, which is justified by the literature review [61] [62]. The experts' experienced and backgrounds varied between ten years and over thirty years. The majority of the experts did not have military experience, but were familiar with working as a contractor for the military.

#### Software Delivery Choice.

Instead of postal mail or phone survey, software delivery was chosen for this study. This would reach people throughout the industry more efficiently than other methods. The method of software delivery chosen for this study was based off of ease of use for both the researchers and the panel participants. Potential software choices were Google Forms and Survey Monkey. Both Google Forms and Survey Monkey allow anonymity, download of data, and customization of questions. In addition, Google Forms presents visualization of data on a web basis, and facilitation of Google accounts. The data visualization and ease of use of Google Forms contributed to the decision to use this software to manage the Delphi Process for this study.

#### Pilot Study.

The purpose of the pilot study was to ensure the questions were unbiased, proper inclusion of content, and readability of the questions. After identification of experts for the panel, two were randomly selected for the pilot study. Two were selected in order to allow for multiple opinions and to not detriment the number of potential participants in the Delphi panel. Pilot studies were conducted before both phases of the study, in order to ensure both panel instruments contained the desired qualities.

#### Preventing and Dealing with Panelist Drop-Out.

Panelist drop-out is a common threat to the validity of Delphi studies [55]. Incentivization is often achieved through financial means in order to increase attrition rates for studies [65] [66]. For this study, financial resources were unavailable, and resulted in no extra incentivization other than the promise of accessibility to the completed results. The attrition rate for this study was expected to be higher than that of other Delphi panels, however the researchers hope the appeal of a report that could benefit the federal government justified the panelists' time and participation in the panel.

### Step Two - Create Phase I Instrumentation.

Those experienced in CMAR have the general knowledge that it is normally applied to large-scale, complex projects, such as that of MILCON. The experts were thereby engaged tacitly through open conversation and discussion on the scope of projects to be studied. The assumption was made that the experts understood this implicitly.

After the decision to utilize Google Forms was made, the first phase of the panel was generated. Researchers wanted to gather the experts' thoughts and opinions on the perceived benefits and limitations of each project delivery method to be studied. The project delivery methods chosen to be studied were DBB, DB, and CMAR. DBB and DB are already utilized by the Air Force for construction projects, so the appeal to add an additional project delivery method would need to prove its value over those delivery methods currently being used.

The instrumentation consisted of seven different sections. The first section has three questions that examines the benefits of each of the three project delivery methods. The second section is similar to that of the first - it investigates the limitations of the three project delivery methods. Both of these sections are textual answers, as to get the panelists' true opinions without limiting how they can answer the questions.

Additionally, sections three through six consist of multiple choice questions that reflect the panelists' preferences on project delivery methods, while comparing against only one other alternative. Section three asks about their general preference on project delivery method. Section four examines their preference for project delivery method if the project is time constrained. Likewise, section five reviews panelists' preference for project delivery method when the project is budget constrained. Finally, the sixth section questions the perception of panelists' experience with the amount of labor and administrative work conducted by the project manager for each delivery method.

The seventh section inquires panelists on their overall views on project success, quality, and CMAR. All sections contained a general question for comments about the questions or the choices panelists may have selected. These specific questions were chosen in order to retrieve the general opinions of the panelists on their preferences while also soliciting more information about the project delivery methods and their experiences with them.

#### Step Three - Implement Phase I Instrumentation.

Phase I was implemented through the use of electronic mail, as it was the only means of communication with the panelists. Panelists were blind carbon copied in order to ensure anonymity between panelists themselves, as well as the researchers. Instructions were sent via electronic mail, as well as a link to the Google Form. The panelists were given three weeks to fill out the form. However, to accommodate panelists' schedules, panelists were given an extra week. The number of participants and responses was tracked by the researchers through the Google Forms system. A detailed list of the questions is in Appendix A.

#### Step Four - Phase I Data Collection and Permutation.

After the allotted four week period, researchers downloaded the data from the Google Forms website in the form of a CSV delimited text file. This data was analyzed with the objective of garnering further questions for future phases of the Delphi Panel. First, the researchers ran a text analysis on the open-ended questions. Common words and phrases were tallied for each benefit and limitation of each project delivery method. These were then transformed into statements for the second phase of the study, which utilizes Likert scales to determine levels of agreement across the panel. Secondly, the paired comparisons data was analyzed using odds ratios and proportions. This is discussed later in step seven.

#### Step Five - Phase II Instrumentation Creation and Implementation.

The instrumentation for the second phase of the panel consisted of four total sections with the goal of converging the opinions of the panelists. The first section contained statements regarding the DB project delivery method. The second section encompassed DBB, and the third section CMAR. These statements were based on the result of the analysis of the benefits and limitations given by panelists in the textual portion of the first phase. Finally, the fourth section addressed any general comments or concerns the panelists may have had during the allotted time for response. The responses for each of the first three sections were numerical, comprised of a Likert scale, with one meaning "Strongly Disagree" and five meaning "Strongly Agree". Questions 2b, 2f, and 3c were reverse coded to ensure reliability, or yielding of consistent results. A detailed list of the questions is in Appendix B.

A pilot study was again conducted for the second phase. The same members of the first pilot study were utilized, in order to reduce any biases, reliability issues, or validity errors that may be introduced by changing experts. Pilot study members were given two weeks to comment on the validity, wording, and any possible bias of the proposed form.

Implementation of the second phase was similar to that of the first phase. Electronic mail with a link to the Google Form was sent to the panelists encouraging their participation and promising visibility of the results upon completion of the study. Panelists were given three weeks to submit their responses, with a reminder via electronic mail sent a week before the deadline.

#### Step Six - Phase II Data Collection.

Upon arrival of the deadline, data was downloaded from the Google Forms website in the form of a CSV delimited text file and analyzed using Microsoft (MS) Excel. The objective of this analysis was to measure the convergence of panelists' opinions and determine the need for another phase of the Delphi Panel.

**Step Seven - Data Analysis and Feedback.**

Each phase required individual analysis to meet the objectives researchers set for the study. The goal of phase I was to assemble the opinions, thoughts, and experiences of experts on each project delivery method. The benefits and limitations of each method were gathered in order to assist in the creation of instrumentation for the second phase, as well as determine the value of each project delivery method to be studied. The goal of phase II was to compile the opinions of the panelists. This phase utilized Likert scales to determine the spread of the views of panelists. As most researchers use a significance level ($\alpha$) of 0.05, this was the set significance level for statistical analysis in this study.

Phase I contained nominal data. The textual responses were analyzed for content, key words and phrases, and themes consistent between different panelists. Thirteen total responses were recorded for phase I. The literature review suggested that themes that occurred in greater than 70–80% of the responses should be permutated into the next phase [68]. However, with the small size of the panel, researchers decided on using 35% convergence. 75% convergence would have resulted in no statements for the second phase. 50% would have resulted in six statements. 35% convergence resulted in fifteen statements for phase II.

Phase II contained ordinal data in the form of Likert scales. These responses were analyzed utilizing nonparametric statistics and descriptive statistics. Equations 2 through 4, listed in chapter two were used to determine the test statistic for each statement and compare the samples to see if they are the same or different. In this case, the samples are the panelists' responses to each question, and the population is the construction industry's response to each question. These hypotheses are as follows:

**The Kruskal-Wallis Test**

$$H_0\text{: The } k \text{ populations are equal}$$

$$H_a\text{: The } k \text{ populations are not equal}$$

Panelists were sent an electronic mail with feedback on the results of the study. This feedback included the descriptive statistics, as well as the results of the Student's $t$ test for phase I, and the Kruskall-Wallis tests for phase II. Also included were the researchers recommendations for the Air Force.

## Summary

This chapter provides an overview of the methodology used in this research. The first section details the theory behind using the Delphi Method. The second section delves into the seven step process created and utilized by the researcher for this study. The goal of this research is to analyze the potential value of CMAR as a project delivery method for the Air Force. These procedures aim to gather expert's opinions on their personal successes or failures with different project delivery methods and apply them to Air Force construction.

# IV. Results and Discussion

This chapter discusses the results of the analysis of each phase of the Delphi Panel. The original hypotheses are as follows:

- CMAR will positively influence Air Force project success
- Experts believe CMAR is associated with lower project costs
- Experts believe CMAR is associated with shorter project durations
- Experts believe CMAR is associated with higher project quality

The first two sections of this chapter specifically detail the phases of the Delphi Panel, respectively. The third section discusses the study as a whole; it draws conclusions about the results of the Delphi Panel and gives recommendations for the Air Force moving forward.

### Phase I Results

Phase I had a response rate of 86.7%. The first result of phase I was an outline of key themes and phrases that describe the benefits and limitations of each of the studied project delivery methods. These themes and phrases are listed in Appendix C. These key themes and phrases were then utilized to form statements for phase II of the study. These were then distributed using a Likert scale to determine agreement amongst panelists. The descriptive statistics for Phase I are shown in Table 7. The experts' percentage of agreement based on constraints are shown in Figures 2, 3, and 4. Experts preferred DB when constrained. DBB was perceived to have the highest labor requirement for the construction manager.

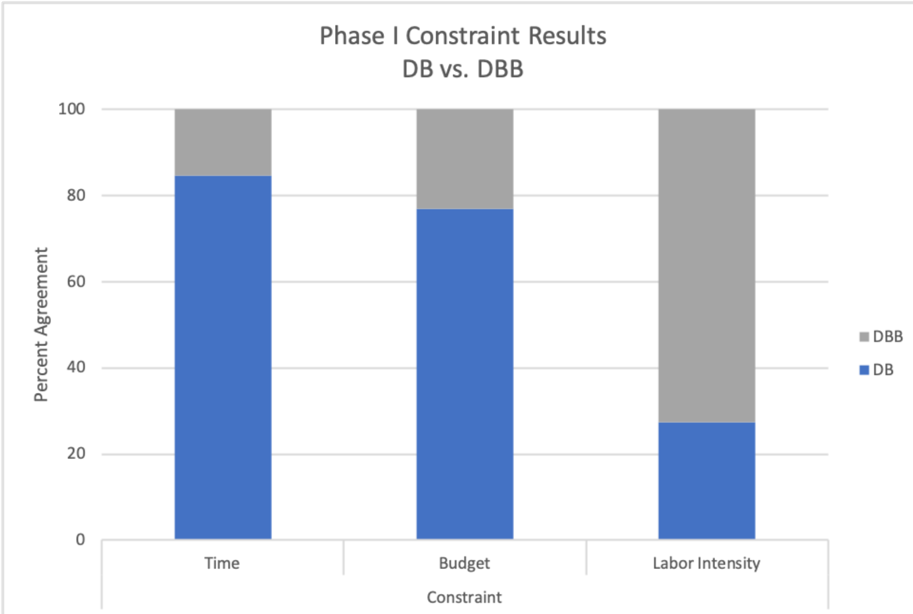


**Figure 2. Results of Phase I for Design-Build vs. Design-Bid-Build: Percent of Expert Agreement on Preferences, Dependent on Time Constraint, Budget Constraint, and Labor Intensity**

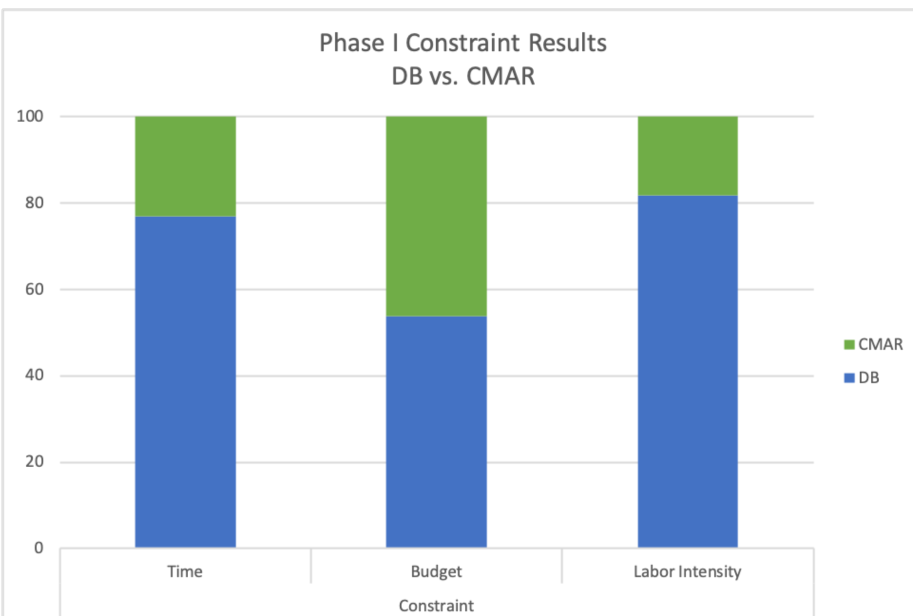


**Figure 3. Results of Phase I for Design-Build vs. Construction Management at Risk: Percent of Expert Agreement on Preferences, Dependent on Time Constraint, Budget Constraint, and Labor Intensity**


**Figure 4. Results of Phase I for Construction Management at Risk vs. Design-Bid-Build: Percent of Expert Agreement on Preferences, Dependent on Time Constraint, Budget Constraint, and Labor Intensity**

## Phase II Results

Phase II had a 61.5% response rate. The Mann-Whitney test for equality of means and the Kruskal-Wallis test for comparison of medians both assess the difference between populations - the Mann-Whitney test between two equal populations, and

**Table 7. Descriptive Statistics for Phase I**

| | | | | | | |
|---|---|---|---|---|---|---|
| Question | 3.1 | 3.2 | 3.3 | 4.1 | 4.2 | 4.3 |
| Majority | DB | CMAR | CMAR | DB | DB | CMAR |
| Mean | 0.692 | 0.615 | 0.846 | 0.846 | 0.769 | 0.923 |
| Standard Deviation | 0.480 | 0.506 | 0.376 | 0.376 | 0.439 | 0.277 |
| | | | | | | |
| Question | 5.1 | 5.2 | 5.3 | 6.1 | 6.2 | 6.3 |
| Majority | DB | DB | CMAR | DBB | CMAR | DBB |
| Mean | 0.769 | 9.538 | 9.769 | 0.727 | 0.818 | 0.636 |
| Standard Deviation | 0.439 | 0.519 | 0.439 | 0.506 | 0.480 | 0.519 |

the Kruskal-Wallis test between $k$ populations. The Mann-Whitney test was run comparing each question to each other, within their respective sections. The Kruskal-Wallis test was run for all questions in the second phase. Descriptive statistics for phase II are shown in Table 8.

Internal consistency was measured by calculating Cronbach's alpha using equation 1. The variances measured are shown in Table 9. Cronbach's alpha was calculated to be 0.917. A value of 0.80 is considered to have high internal consistency [73], so the phase II instrument has high internal consistency.

#### Mann-Whitney Test Results.

The Mann-Whitney test compares two samples at a time to test equality of their means. Each question was tested against all the other questions in the same respective category. However, the characteristics of this data made the use of this test purely exploratory. An assumption for the Mann Whitney $U$ test is the samples need to be independent of one another. The Mann Whitney $U$ test would have been appropriate if there were two groups of experts tested against another.

#### Kruskal-Wallis Test Results.

If there are three or more comparison groups and five or more observations in each group, the test statistic $H$ approximates a chi squared ($\chi^2$) distribution with $df = k - 1$. $k$ is equal to the number of groups, which in this case is equal to the number of questions. Since $k = 15$, $df = 14$, and each group had eight observations, a $\chi^2$ distribution was used. Using an $\alpha$ of 0.05, as specified earlier, the critical value is equal to 6.57. Utilizing equation 4 and the process outlined in chapter two, the test statistic was determined to be 22,492.3, which is vastly larger than the critical

**Table 8. Descriptive Statistics for Phase II Questions**

| Question | 1.1 | 1.2 | 1.3 | 2.1 | 2.2 | 2.3 | 2.4 | |
|---|---|---|---|---|---|---|---|---|
| Mean | 3.5 | 3.125 | 3.875 | 4.125 | 3 | 4.5 | 4.125 | |
| Median | 3 | 2.5 | 4 | 4 | 3.5 | 5 | 4.5 | |
| Mode | 3 | 2 | 4 | 5 | 4 | 5 | 5 | |
| Standard Deviation | 1.069 | 1.356 | 1.246 | 0.835 | 1.512 | 1.414 | 1.356 | |
| | | | | | | | | |
| Question | 2.5 | 2.6 | 3.1 | 3.2 | 3.3 | 3.4 | 3.5 | 3.6 |
| Mean | 4.25 | 4.25 | 4.25 | 4.125 | 4.25 | 3.5 | 3.625 | 3.75 |
| Median | 5 | 5 | 5 | 4.5 | 4.5 | 3.5 | 4 | 4 |
| Mode | 5 | 5 | 5 | 5 | 5 | 3 | 4 | 5 |
| Standard Deviation | 1.389 | 1.389 | 1.389 | 1.356 | 0.886 | 1.309 | 1.302 | 1.389 |

**Table 9. Variances Used in Cronbach's Alpha Calculations**

| Item, i | 1.1 | 1.2 | 1.3 | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.6 | 3.1 | 3.2 | 3.3 | 3.4 | 3.5 | 3.6 | $\sigma_x^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\sigma_{y_i}^2$ | 1.143 | 1.839 | 1.554 | 0.696 | 2.286 | 2 | 1.839 | 1.929 | 1.929 | 1.929 | 1.839 | 0.786 | 1.714 | 1.696 | 1.929 | 174.5 |

value, resulting in the rejection of $H_0$ in favor of the alternative hypothesis.

## Discussion

Phase I revealed key themes and phrases that led researchers to believe the majority of panelists favored CMAR and disliked DBB. CMAR had the most benefits at five and the least limitations at one, while DBB had the most limitations at three and the least benefits at two.

- 3.1 - Panelists preferred DB over DBB.
- 3.2 - Panelists preferred CMAR over DB.
- 5.2 - When budget constrained, panelists preferred DB over CMAR.
- 6.1 - On terms of construction manager labor, panelists found DBB to be more

burdensome than DB.

- 6.3 - On terms of construction manager labor, panelists found DBB to be more burdensome than CMAR.

Phase II not only revealed a high level of internal consistency of the test instrument, but also the equality of means in each question section. At a 95% confidence level, all test statistics for the Mann-Whitney $U$ test failed to reject the null hypothesis; the means found in the Delphi Panel were not indicative of the other questions in the same section. The Kruskal-Wallis test illuminated the rejection of the null hypothesis in favor of the alternative, that the medians for the questions are not all equal. Looking back at Table 8, it seems as if the medians all lie between three (neutral) and five (strongly agree). However, with such a small scale, the Kruskal-Wallis test revealed that there are statistically significant differences between these questions. The results of these tests suggest that the validity of the Delphi Panel was weaker than expected, possibly due to type II error, small size of the panel, or limited outreach to other, more unbiased experts, as discussed in the Assumptions and Limitations section.

The opinions of the experts generally favored DB over CMAR, and CMAR over DBB; all of the original research hypotheses were correct. With a conscious knowledge of the assumptions and limitations, it is safe to say there are some benefits to implementing CMAR. The CII and Pankow Research Foundation found that the gap between DB and CMAR has nearly closed. However, the Air Force is already using DBB and DB, which, when utilized correctly can show the benefits that the AFCEC and Category Management leaders seek.

The Navy's utilization of ECI on their Mariner Skills Training Center proves that a CMAR-like project delivery method is possible for the DoD and other federal entities. This study looks specifically at the Air Force, and in doing so has recognized that the size and scale of projects usually completed using CMAR or ECI is that of MILCON size. MILCON projects for the Air Force are typically executed through the USACE or through the NAVFAC, meaning an adoption of CMAR or ECI would be of limited benefit for the Air Force unless conducted through limited cases where the execution agent is the AFCEC.

Another aspect of a new delivery method is the burden of the government representatives. The construction manager is not the only person involved in the delivery method process. The needs of the mission need to be considered first. The results of this Delphi panel are highly dependent on the private industry and may not directly correlate to that of the Air Force or other federal entities. The acquisition process can therefore take longer than expected in the private industry.

### Summary

The first section of this chapter detailed the resulting contextual analysis for phase I. The results of the contextual analysis were utilized to create the questions for the second phase. The second section depicted the results of the Mann-Whitney and Kruskal-Wallis tests. These tests revealed a high level of internal consistency and an equality of the means for each question section. The third section of this chapter discussed the results of these tests and conclusions drawn from the Delphi Panel. The conclusions were synthesized with the literature review to form researchers recommendations for the Air Force.

# V. Conclusions

The current political climate is emphasizing the need for budget accountability and the efficient use of funds in MILCON projects. As a result of this study, different entities within the DoD may conduct further research and pilot studies into the use of CMAR. CMAR can offer benefits to project managers and organizations, but those benefits will take time and effort to realize.

The Delphi Panel, literature review, and personal interviews revealed a desire to move towards CMAR or a CMAR-like project delivery method in the federal sector. However, efforts towards reducing schedule and cost growth should be aimed at front-end planning instead of a new project delivery method. While implementing a new project delivery method is possible, it will not solve the problems in the MILCON process in the long run.

## Review of Results

The research questions studied are as follows:

1. How can a specific project delivery method influence project performance?
   (a) How does a chosen project delivery method affect the schedule?
   (b) How does a chosen project delivery method affect cost?
   (c) How does a chosen project delivery method affect the quality of construction?
2. How does CMAR performance compare with other delivery methods?
3. What are the challenges to implementing a new project delivery method for the Air Force?

### Project Performance.

The first question addressed the affects of a specific project delivery method on project performance. Project performance was broken down in terms of schedule, cost, and quality of construction. The literature review suggested that DB performs better overall, and that the private sector is moving towards CMAR. However, in terms of schedule, cost, and quality, DBB is performing just as well as CMAR.

Phase I of the Delphi Panel resulted in favor of DB over CMAR, and CMAR over DBB. The experts' listed more benefits for CMAR than DB, and DB than DBB. DBB had the most limitations listed. This agrees with the literature review.

**Comparison of CMAR to Other Delivery Methods.**

The second question focused on the performance of CMAR in comparison with other delivery methods. The literature review indicated that CMAR performed better than DBB in cost growth, construction speed, and delivery speed, but worse than DBB in unit cost and schedule growth [24]. The performance of CMAR compared to other delivery methods was not explicitly addressed in the Delphi Panel. However, experts favored CMAR over DBB, as well as DB over DBB, and found DBB to be more burdensome than the other methods.

**Challenges to Implementation.**

The third question addressed challenges with implementation of a new project delivery method for the Air Force. The Delphi Panel did not cover this question. However, interviews with Mr. Curfman, Ms. Kite, and Ms. Britt provided the researchers with examples through Navy's use of ECI. Specifically, the Navy is utilizing a MACC in which all the contractors have experience with CMAR, to conduct a pilot ECI construction project [50]. Unfortunately, the findings of this pilot project are currently limited; this project was still underway at the time of writing. However, the results of the project will be available to researchers and the AFCEC for further study.

### Significance of Research

The Air Force is capable of a CMAR-like project delivery method, if the project is accomplished through the AFCEC. The right project delivery team must be selected for a trial project, to include contracting, an experienced project manager, and legal services. Base leadership and higher headquarters support is also needed. Success should be defined prior to the start of the project, in order to avoid bias and changing standards. Several trial projects will need to occur to amount to enough data for analysis on success. The project should have the structure of CMAR, as shown in Figure 1, and be a cost-plus-fixed-fee contract. NAVFAC recommends the constructor start pre-construction services no later than 15% design complete. The constructor may start acquiring long lead items and mobilizing prior to design complete, with the risk that negotiations may end unfavorably. Negotiations will occur at design complete for a construction bid option to the original contract, which will include the total initial target price. The project team must be mindful of the long closeout time for cost-plus-fixed-fee type contracts, and be aware that benefits may not be achieved right away.

A new project delivery method would be suitable for some of the projects that are currently being completed with DBB and DB. However, researchers believe other issues need to be addressed before adding a new project delivery method; a new project delivery method could further complicate the MILCON process, resulting in failed projects and large overruns. Front-end planning has been identified by the CII as a critical key to success for construction projects. Unfortunately, this is the part of the MILCON process at which Air Force and DoD project managers struggle. Air Force MILCON DBB projects from 2000 to 2013 showed an average cost growth of 6.4% [77], which is much higher than the 1.9% revealed in the CII and Pankow study [24]. Another study found an average of 6.5% cost growth in public sector DB projects [78], while the CII and Pankow found an average of 0.9% [24]. The federal sector needs to evaluate its front-end planning, which has been shown to be a key factor in project success at avoiding delays and cost growth [39]. Once a suitable level of success is achieved, the addition of a new project delivery method would show exponential growth in benefits across the federal government.

**Limitations**

The primary limitation of this research stems from the nature of the problem itself: CMAR is not currently a project delivery method used by any federal entity. There is no CMAR project data for any federal projects - it only exists in private and public non-federal sectors due to the lack of competition garnered from this contractual method. The research extrapolated information from private sector expert opinions into the Air Force context. Another limitation of this research is the scope of analysis. Only CMAR is analyzed as a potential new project delivery method for the Air Force, but many others are applied in the private sector.

Other limitations exist in the methodology and processes in the forms of internal and external validity. Ambiguous temporal precedence is not a threat to internal validity because the variables being measured do not have causal relationships. Project delivery methods work independently of one another and cannot cause the other to fail. Selection is a threat to internal validity because the experts on the Delphi panel had varying levels of experience in different places and at different time periods. This could not be prevented unless detailed demographics were received for each panelist, which could compromise the anonymity of the panel. History is a possible threat to internal validity because during the panel, the experts could be undergoing construction projects that change their opinion and change how they respond to different phases of the panel.

Maturation is a threat to internal validity, as some of the experts were in academia and could be contributing to their knowledge of construction project delivery methods. This could not be controlled over the period of time for the Delphi panel. Regression is not a threat to the internal validity of this study, as participants were anonymous and therefore their contributions were not pre-determined or influenced by previous inputs. Attrition is the biggest threat to the internal validity of this study. The response rate between the phases changed from nearly 90% to nearly 60%. This could influence a type II error in the data, which could cause the data to look widely varied instead of precise.

Testing is a possible threat to internal validity, as there were multiple phases of the study. By participating in the first phase, panelists may react differently to the second phase, which could be mistaken for an effect on their answers for the second phase. Instrumentation is not a threat to internal validity, as the instrument did not change after the pilot study of each phase. Finally, additive and interactive effects can be a threat to internal validity, because there are other threats to internal validity.

Interaction of the causal relationship with units is a threat to external validity because all of the experts on the panel had utilized CMAR in the private sector. Since none of them had utilized it in the federal sector, the conclusions drawn from the panel may not be valid for the federal sector. Interaction of the causal relationship over treatment variations is not a threat to external validity, because each panelist received the same Google Form survey. Interaction of the causal relationship with outcomes is a threat to external validity because not all project delivery methods were studied. Only those that were currently being used by the Air Force and the one in question, CMAR, were studied. Finally, interactions of the causal relationship with settings is a threat to external validity because of the instrumentation used. If the panel was conducted via phone or by postal service, the results could have differed from those achieved.

Another factor influencing a type II error is the small panel size. While a panel size of 15 is recognized in the literature, this panel size makes statistical analysis and inference difficult, and threatens the validity of the study. Further, the experts could have different interpretations of the Likert scale; one experts' opinion on the difference between agree and strongly agree may differ from that of another expert.

### Recommendations for Future Research

As the Air Force moves forward and continues to innovate practices and procedures, new project delivery methods as well as changes to the FAR will become a necessity. In order to stay current, the Air Force must continue to analyze the possibility of using new methods for project delivery. Future research can continue the Delphi Panel to achieve convergence of opinions, and further open those panels to questions that are federal government specific. Additional research could analyze the implementation of other delivery methods, such as Integrated Project Delivery (IPD), for use by the federal government. Another opportunity for future research is competitive bidding. New research could analyze the strength and consequences of competitive bidding and determine the necessity of this process. Further, future research could analyze the difference between the efficacy of different project delivery methods used by the Air Force by completing a sensitivity analysis of those used in different locations and/or different sizes of projects. Finally, future research could analyze the LPTA policy within the FAR.

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# Appendix . A - Phase I Questions

**Message to Panelists:**

You are being asked to participate in an expert elicitation being conducted by Danielle Tabb, an Air Force Institute of Technology (AFIT) Master's student, and Dr. Tay Johannes, Instructor from The Civil Engineer School, AFIT. This research is designed to examine three different project delivery methods and their applicability to the United States Air Force.

Your participation in this research is voluntary. You do not have to answer any question(s) that you do not wish to answer. Please be advised that you may choose not to participate in this research, and you may withdraw from participation at any time. There is no penalty for non-participation. Furthermore, there are no anticipated risks associated with participation.

The large Air Force MILCON program uses traditional project delivery methods, such as Design-Bid-Build and Design-Build. Private and public non-federal sectors use Construction Management at Risk (CMAR) or some version thereof, to complete construction projects (Rich and Bartha, USACE). The Federal Acquisition Regulation (FAR) and subsequent regulations restrict the federal government from using CMAR. This research will analyze the current utilization of CMAR. The objective of the investigation will determine potential application to the federal government. Potential outcomes of this research may recommend changes to the FAR to authorize the use of CMAR, or recommend excluding CMAR from Air Force project delivery methods.

This study is designed to gain the perspectives of industry experts on different project delivery methods. No one except the researcher and the advisor will have access to any of your individual responses, and all data will remain anonymous. Remember, you can chose not to answer any of the questions, and you can end your participation at any time without penalty. Thank you so much for volunteering to participate in this study!

**Questions**

1. Benefits of Project Delivery Methods
   (a) What are the benefits of the Design-Build (DB) project delivery method?
   (b) What are the benefits of the Design-Bid-Build (DBB) project delivery method?
   (c) What are the benefits of the Construction Manager at Risk (CMAR) project delivery method?
2. Limitations of Project Delivery Methods
   (a) What are the limitations of the Design-Build (DB) project delivery method?

(b) What are the limitations of the Design-Bid-Build (DBB) project delivery method?

(c) What are the limitations of the Construction Manager at Risk (CMAR) project delivery method?

3. Project Delivery Method Preferences

   (a) Of the following, which project delivery method do you prefer?
      i. Design-Build (DB)
      ii. Design-Bid-Build (DBB)

   (b) Of the following, which project delivery method do you prefer?
      i. Design-Build (DB)
      ii. Construction Manager at Risk (CMAR)

   (c) Of the following, which project delivery method do you prefer?
      i. Construction Manager at Risk (CMAR)
      ii. Design-Bid-Build (DBB)

4. Project Delivery Method Comparisons for Time-Constraints

   (a) If a project is time-constrained, what project delivery method are you likely to chose?
      i. Design-Build (DB)
      ii. Design-Bid-Build (DBB)

   (b) If a project is time-constrained, what project delivery method are you likely to chose?
      i. Design-Build (DB)
      ii. Construction Manager at Risk (CMAR)

   (c) If a project is time-constrained, what project delivery method are you likely to chose?
      i. Construction Manager at Risk (CMAR)
      ii. Design-Bid-Build (DBB)

5. Project Delivery Method Comparisons for Budget Constraints

   (a) If a project is budget constrained, what project delivery method are you likely to chose?
      i. Design-Build (DB)
      ii. Design-Bid-Build (DBB)

   (b) If a project is budget constrained, what project delivery method are you likely to chose?

    i. Design-Build (DB)
    ii. Construction Manager at Risk (CMAR)

(c) If a project is budget constrained, what project delivery method are you likely to chose?
    i. Construction Manager at Risk (CMAR)
    ii. Design-Bid-Build (DBB)

6. Labor Intensity
   (a) Of the given choices, which project delivery method is more labor intensive?
       i. Design-Build (DB)
       ii. Design-Bid-Build (DBB)
   (b) Of the given choices, which project delivery method is more labor intensive?
       i. Design-Build (DB)
       ii. Construction Manager at Risk (CMAR)
   (c) Of the given choices, which project delivery method is more labor intensive?
       i. Construction Manager at Risk (CMAR)
       ii. Design-Bid-Build (DBB)

7. General Questions
   (a) How do you define project success?
   (b) How does a chosen project delivery method affect the quality of the completed project?
   (c) In your experience, how has the use of CMAR affected the outcome of projects?
   (d) Please provide any other comments you may have regarding the above topics.

# Appendix . B - Phase II Questions

### Message to Panelists:

Researchers Danielle Tabb, an Air Force Institute of Technology (AFIT) Master's student, and Dr. Tay Johannes, Instructor from The Civil Engineer School, AFIT request your continued participation on the panel of experts informing this research. The research compares three different project delivery methods and their applicability to United States Air Force construction projects.

Your participation in this research is voluntary, and you may decline or withdraw from it at any time. You do not have to answer any question(s) that you do not wish to answer. There is no penalty for non-participation. Furthermore, we do not anticipate any negative outcomes from your participation.

The large Air Force MILCON program uses traditional project delivery methods, such as Design-Bid-Build and Design-Build. Private and public non-federal sectors use Construction Management at Risk (CMAR) or some version thereof, to complete construction projects (as analyzed by USACE investigators Rich and Bartha). The Federal Acquisition Regulation (FAR) and subsequent regulations restrict the federal government from using CMAR. This research will analyze the current CMAR applications and processes. The research objective is to gain insight on current construction acquisition experiences from construction industry experts and identify new or modified acquisition strategies for potential application to the federal government. Possible research outcomes may recommend changes to the FAR to authorize the use of CMAR, or recommend excluding CMAR from Air Force project delivery methods.

Data collected during from this research is anonymous and contains no personal information. Only the researchers will have access to any individual responses. Remember, you can chose not to answer any of the questions, and you can end your participation at any time without penalty. Thank you so much for continuing to participate in Phase II of this study!

### Questions

1. Design-Build
   (a) A benefit of Design-Build is fewer contracts.
   (b) When using the Design-Build project delivery method, the owner has less control over the design.
   (c) Projects using the Design-Build delivery method have shorter project durations due to the overlap of construction and design.
   (d) Please provide any additional comments on the statements in this section.
2. Design-Bid-Build
   (a) Design-Bid-Build encourages competition between contractors.

(b) A benefit of the Design-Bid-Build project delivery method is greater owner involvement.

(c) Change orders are common when using the Design-Bid-Build project delivery method.

(d) Schedule delays are common when using the Design-Bid-Build project delivery method.

(e) Design-Bid-Build projects have the longest procurement process.

(f) The Design-Bid-Build project delivery method encourages collaboration.

(g) Please provide any additional comments on the statements in this section.

3. Construction Manager at Risk

   (a) A benefit of Construction Manager at Risk projects is earlier involvement of the constructor to help with the design.

   (b) Construction Manager at Risk projects have increased collaboration between stakeholders.

   (c) On Construction Manager at Risk projects, the constructor has limited influence on design decisions.

   (d) Construction Manager at Risk projects have shorter schedules due to the design and construction phases overlapping.

   (e) Projects completed using the Construction Manager at Risk delivery method have better constructability than other delivery methods.

   (f) Construction Manager at Risk projects have earlier cost certainty than other delivery methods.

   (g) Please provide any additional comments on the statements in this section.

4. Please provide any additional comments you may have regarding the above topics.

# Appendix . C - Phase I Key Themes and Phrases

## Design-Build

### Benefits.

- Fewer contracts/more partnering
- Single point of responsibility
- Short project duration due to overlap of construction and design

### Limitations.

- Owner has less control over design

## Design-Bid-Build

### Benefits.

- Greater owner involvement
- Lowest price - encourages competition

### Limitations.

- Discourages collaboration - no contractor input
- Separate design and bid periods add wasted time to project
- Change orders and schedule delays are common

## Construction Management at Risk

### Benefits.

- Earlier involvement of constructor to help with the design
- Overlap of design and construction
- Fewer contracts
- Better constructability
- Earlier cost certainty

### Limitations.

- Construction manager only has implied authority over design/limited influence