



**PHASE GATE IMPLEMENTATION OF PROJECT DEFINITION RATING
INDEX (PDRI) ON AIR FORCE MILCON PROJECT DEVELOPMENT:
A COMPREHENSIVE ANALYSIS**

THESIS

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Abstract

The \$1.3B Air Force Military Construction (MILCON) program has shown a trend of 6% cost growth and 12% schedule growth in the construction phases of its projects. Air Force leadership has attributed this to a shortfall in the standardized processes for requirements definition and scope development. The Project Definition Rating Index (PDRI) has been in use on Air Force MILCON projects for almost a decade, but the development and approval process for these projects does not lend itself to direct PDRI implementation. 96 PDRI MILCON projects executed from 2009 to 2016 were analyzed for trends in project development implementation strategies using Analysis of Variance and Regression. It is suggested that the Air Force provides clear, mandated guidance for earlier project development and improve data collection, storage, and analysis methods to aid additional research efforts.

This paper is dedicated to my family for all the love and support they have given me throughout my life and my Air Force career thus far.

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Jared R. Breuker

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List of Acronyms

Acronym	Definition
ACC	Air Combat Command
ACES-PM	Automated Civil Engineering System - Project Management
AETC	Air Education and Training Command
AFCEC	Air Force Civil Engineer Center
AFGSC	Air Force Global Strike Command
AFI	Air Force Instruction
AFIMSC	Air Force Installation and Mission Support Center
AFMC	Air Force Materiel Command
AFSOC	Air Force Special Operations Command
AFSPC	Air Force Space Command
AMC	Air Mobility Command
ANOVA	Analysis of Variance
APRA	Advanced Planning Risk Analysis
BCE	Base Civil Engineer
BOD	Beneficial Occupancy Date
CII	Construction Industry Institute
DOD	Department of Defense

Acronym	Definition
DrChecks	Design Review Checking System
ECB	Engineering and Construction Bulletin
FSRM	Facility Sustainment, Restoration and Modernization
FY	Fiscal Year
HAF	Headquarters Air Force
MILCON	Military Construction
NTP	Notice to Proceed
OSD	Office of the Secretary of Defense
PA	Programmed Amount
PACAF	Pacific Air Forces
PCR	Planning Charrette Report
PDRI	Project Definition Rating Index
RTA	Ready to Advertise
SAME	Society of American Military Engineers
SOCOM	United States Special Operations Command
USACE	United States Army Corps of Engineers
USAF	United States Air Force Academy

PHASE GATE IMPLEMENTATION OF PROJECT DEFINITION RATING INDEX
(PDRI) ON AIR FORCE MILCON PROJECT DEVELOPMENT:
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I. Introduction

1.1 Background

Air Force Military Construction (MILCON) projects have consistently shown a trend of going above their authorized budgets and beyond their planned schedules during the construction execution phase of work. Although MILCON schedule growth has been of less concern to researchers, there have been a few recent studies that have analyzed MILCON cost growth. Barnes (2012) conducted analysis on 407 MILCON projects sampled from 2004 to 2010 and determined an average increase in cost from contract award to final closeout of over 6%. Similarly, Stouter (2016) conducted a research study of 337 Design-Bid-Build Air Force MILCON projects between the years of 2000 and 2013 and found there to be an average of 6.4% cost growth. This is especially important when considering the fact that the Fiscal Year 2017 (FY17) Air Force MILCON budget was approximately \$1.3 billion in United States taxpayers' money (114th Congress, 2016).

This phenomenon is not strictly an Air Force MILCON problem, however. Three separate studies from the private sector have all discovered the same trends of cost performance as well as schedule performance in capital facility construction projects. Their research revealed that of the construction projects studied, they could be expected to experience between 6.5% and 10.6% cost growth and between 16.9% and 17.5% schedule growth (Chen, Jin, Xia, Wu, & Skitmore, 2016; Gibson, Irons, & Ray, 2006; Wang, 2002).

These studies focused on the performance of individual projects, but the increases in cost and schedule of individual projects can impact an organizations entire portfolio of projects.

Since all United States Department of Defense (DOD) projects are competing against each other for funding at the United States congressional level, cost and schedule overruns can impact the funding of future projects in the authorization request. The Headquarters Air Force-Air Force Civil Engineer Center Program Management Plan for Air Force MILCON Execution (Air Force Civil Engineer Center, 2013) outlines a few processes that are in place to handle any funding changes made to the previously authorized budget, but these processes can be lengthy and cumbersome. If a project which is already under construction awaits funding re-approval, construction crews may be at a standstill and the project is exceeding its authorized schedule. If the project has yet to be awarded, the owner must await funding approval prior to construction begins, losing valuable time of full operational capability. In both cases, the project is in jeopardy of cancellation if the change request is disapproved, resulting in loss of mission capability and taxpayer funds.

Air Force MILCON project cost and schedule overruns can have large impacts on the DOD MILCON program and the national budget. For this reason, Air Force Civil Engineer Center (AFCEC) leadership has expressed interest in reducing the causes and effects of these overruns. Industry has determined that these issues can be the result of a few relatively simple front-end planning actions, which are either being done incorrectly or, in some extreme cases, not at all (George, Bell, & Back, 2008; Dvir, Raz, & Shenhar, 2003; Griffith & Gibson, 2001; Hamilton & Gibson, 1996; Oh et al., 2016). One of the most critical yet most basic concepts that Air Force leadership has identified as needing improvement is the need to plan MILCON projects more effectively in the early development phases. Specifically, as recently as the 2017 AFCEC Design and Construction Partnering Symposium in San Antonio, Texas, Air Force Civil Engineer

leadership discussed in depth the need to develop the scope and list of user requirements for our MILCON projects in the early planning stages prior to design and award.

Additionally, The Military Engineer magazine published an article in their January-February 2018 issue titled Improving Project Delivery. The article was an adaptation of a speech given by the author at the 2017 Society of American Military Engineers (SAME) Small Business Conference (Niemeyer, 2018). Niemeyer references the increasing number of projects within the DOD that experience cost overruns and schedule delays. He then outlines several process improvements as possibilities to increase project success rates, including the need for DOD design and construction contracts to improve planning and requirements definition.

The main goal of proper planning in the early stages of project development is to define the scope and requirements of the project such that new requirements or unforeseen conditions will be extremely limited in the later stages of the project (Nicholas & Steyn, 2008). As new requirements are introduced later in the process the costs of those changes increase and the ability to implement those changes decreases drastically (Gibson, Kaczmarowski, & Lore, 1995). The Air Force recognizes the need to eliminate late scope changes and ensure a full requirements list and project definition prior to design finalization and construction to limit these unnecessary expenditures. Figure 1.1 presents a simple illustration of this concept and is a rendering of a similar figure presented in Gibson, Kaczmarowski, and Lore's *Preproject-Planning Process for Capitol Facilities* (1995).

The x-axis represents time and is segregated into phases of a construction project. One line on the graph represents the influence on the project scope the decision makers have at a particular point in time and the "Expenditures" line represents the costs incurred on the project due to any changes to the scope at that time. As the project begins its lifecycle, it should be noted that the influence of change is very high and the cost of those changes is very low. However, as the project progresses through the planning and design stages, the

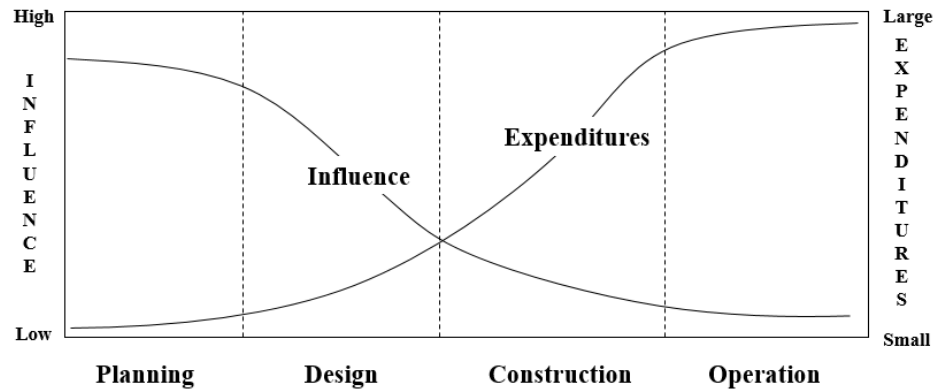


Figure 1.1: Influence vs. Expenditure

influence of the decision makers diminishes while the cost of any changes begins to climb. During construction and operation phases the decision makers have very little influence on the end product and the costs of any changes made at that time are incredibly high.

Striving for effective project planning and early scope development has been a key success factor in construction projects for years (Gibson et al., 1995; Gibson, Wang, Cho, & Pappas, 2006; Muramatsu & Menches, 2010; Williams, 2016; Collins, Parrish, & Gibson, 2017). An effective front-end planning process takes into account several important factors which can lead to project success. These factors include, but are not limited to (George et al., 2008; Gibson, Irons, & Ray, 2006):

- Having a defined front-end planning process
- Having a clearly defined project scope
- Establishing accurate existing conditions
- Having a defined contracting strategy
- Promoting team-building and alignment

- Having clearly defined risks and mitigation strategies
- Establishing clear resource allocation for task execution
- Having clearly defined roles and responsibilities
- Having effective communication mechanisms

Managing this large number of factors can weigh heavily on a project management team. This is why the Construction Industry Institute (CII) has established several best practices for project development and planning and published the Project Definition Rating Index (PDRI). PDRI is a tool that can be used in a variety of ways to assist an organizations planning processes and improve the organizations ability to leverage these factors (Construction Industry Institute, 2013).

The United States Army Corps of Engineers (USACE) and AFCEC officially began using PDRI on Air Force MILCON projects in 2009 and it has been proven to reduce cost and schedule on those projects (United States Army Corps of Engineers, 2009, 2010; Dicks, Molenaar, & Gibson, 2017). However, Air Force Civil Engineer leadership understands that our current planning process and management teams may not be using the tool as effectively as possible. Specifically, the PDRI process as suggested by the CII does not directly translate to the unique project development and approval process of the DOD and Air Force MILCON program.

The Air Force MILCON project planning process can be separated into two categories; the Project Development category and the Project Approval Category. Project Development is where the work is being done to plan and design the actual projects and Project Approval is where the various levels of Air Force and DOD staff offices work to approve and fund the projects for execution. There are many interconnected checkpoints between the two planning focus areas which have been established by various policy documents. The unique nature of this process resides in the fact that all projects are tied to Fiscal Year budgets

which are approved by the President of the United States and signed into law by Congress on a yearly basis. The details of this process are explained further in the following chapter, but this uniqueness has forced Air Force Civil Engineers to develop a strategy of project planning that is tailored to this process. As a result, the Air Force has implemented a variety of different tools and methods to better integrate the desired benefits of the PDRI into the MILCON processes.

Although there are some “in-house” tools which have been used on projects, the PDRI is the only tool that has been tested and validated in industry to improve project performance. PDRI has also had the most exposure to Air Force MILCON projects and is a standardized tool using certified facilitators during implementation. For this reason, the current research effort will be limited to the use of PDRI on Air Force MILCON projects and attempt to answer the question of how to better integrate the tool into the MILCON process.

1.2 Previous Research

A research effort led by Dicks et al. (2017) was one of the first to analyze Air Force MILCON projects by comparing projects which underwent PDRI facilitation against projects which had not used PDRI. Their research suggests that a standardized process for PDRI implementation improved project performance in cost and schedule growth (Dicks et al., 2017).

Their research did not, however, include identifying statistical differences in timing of PDRI implementation during the project planning phase for Air Force MILCON projects and how that relates to the level of success experienced in the project. Furthermore, the researcher has not found any evidence of a research effort conducted in the DOD or in industry to statistically analyze real-time completed projects and how their success metrics are influenced by the various independent variables associated with the PDRI implementation timeline.

1.3 Problem Statement

This paper analyzed completed PDRI MILCON project data with regard to the timeline of PDRI implementation in the MILCON project planning process. Using real-time PDRI and construction completion data, the researcher analyzed the planning effort and determined if there is a statistically proven benefit of one PDRI implementation strategy versus another. The project success metrics used were cost and schedule growth. The specific research questions answered in this paper include:

1. Does project success change as the number of PDRI implementations changes?
2. Does there exist a combination of PDRI implementation phases which improves project success as compared to another?
3. Can project success be predicted if the number of days between the latest PDRI implementation date and the project award date is known?

1.4 Methodology

The data collected for this research effort was analyzed using both Analysis of Variance (ANOVA) and regression methods. For the ANOVA testing, the projects were assigned levels based on the number of PDRI implementations conducted, the phase gates in which the PDRI were conducted, project cost, and project duration. These categories were tested against each other to determine if the variances of project performance metrics differ significantly between the levels of each category. This analyzed which combination of phase gates, number of iterations, project costs, and project durations were more likely to result in greater project performance. Regression testing was used to determine if project success could be predicted based on the number of days from PDRI implementation to project award. The appropriate statistical tests were applied to ensure accuracy and a further explanation of the testing can be found in Chapter 3.

1.5 Assumptions and Limitations

There are several limitations with regards to the current research effort. First, the research involved no data creation effort and relied solely on currently existing data. All data analyzed in this effort was created, collected, and stored outside of the researchers control. When the researcher obtained the data, it was transcribed into the proper format to some degree by human effort. The potential for human error to be introduced into any of the factors for all of the projects is high, but a basic “sanity check” review of the data was done by the researcher in an attempt to analyze only valid data. To that end, the researcher realizes there is still the possibility of error in the data.

Additionally, the PDRI implementations on the projects have all been conducted and recorded by a large variety of individuals who have been trained to conduct those facilitations. This means there are varying styles and degrees of effort which may influence the quality of the PDRI facilitations for any individual project and therefore increase the variance within the dataset. The assumption must be made that the facilitators of the PDRI were all operating under the same guidelines and training and a consistent level of effort and detail was implemented across all projects.

A majority of the PDRI projects analyzed in this research effort were also analyzed by Dicks et al. (2017). This is partially due to the desire to ensure consistency in methods and results for selecting the data set. However, the ability to retrieve additional data was limited due to the deletion of the main source of PDRI data by the U.S. Army Corps of Engineers. The researcher only had limited access to PDRI data which had previously been retrieved from that source by Dicks et al. An assumption must therefore be made that the data originally collected was not altered in any way and is complete and usable.

1.6 Implications

Conclusions reached from this research could result in substantial improvement to the success of Air Force MILCON projects. Improving the Air Force MILCON project

planning process could save time and money by increasing the readiness of projects for execution, thereby decreasing unexpected changes in construction. It is expected that the results shown from this research will inform AFCEC and Headquarters Air Force (HAF) staff on project planning decisions. Specifically, civil engineers should be able to implement a consistent strategy of PDRI implementation in the MILCON project planning process. This strategy should outline the number of times the PDRI should be conducted on MILCON projects as well as when those implementations should take place. This consistent strategy is expected to yield significant increases in project success rates with regard to cost and schedule growth.

1.7 Summary

This research effort was first initiated by conducting an extensive review of the literature with regard to front-end planning, project success factors and criteria, the Project Definition Rating Index, DOD and Air Force MILCON specific policies and issues, as well as previous research efforts on Air Force MILCON project performance. This review of literature identified a gap in the research of how varying PDRI implementation timeline strategies effect Air Force MILCON project performance. A data set of completed Air Force MILCON projects was obtained through various DOD entities and analyzed for validity prior to statistical testing. Using JMP statistical analysis software and the appropriate methodology, the researcher determined the effectiveness of the Air Force policy on PDRI tool implementation for Air Force MILCON projects. This analysis is reviewed in depth and conclusions are drawn from the dataset. Finally, recommendations are provided for potential policy implementation to continue improving construction project performance in the Air Force and DOD, and future research opportunities are presented.

II. Literature Review

This chapter summarizes the efforts to review existing literature with regard to project planning including its facets and benefits, the Project Definition Rating Index, military construction, and project success. This literature review provided the researcher with a strong basis of knowledge to ensure appropriate research is done that can contribute to the existing body of knowledge. Specifically, the researcher sought to define and measure the effects of a proper planning effort for construction projects in the civilian industry with specific focus on the PDRI. Then research the adaptation of these practices and principles into the United States Air Force Military Construction program. Next, it was important for the researcher to define the metrics which are used for project success, as this is a critical step in the research effort. Finally, gaps in the literature and previous research are identified to develop a strong basis of research for the author.

2.1 Front-End Planning

2.1.1 Background.

Industry leaders and researchers have agreed that one of the key success factors in construction projects is the quality of the planning effort prior to construction (Gibson et al., 1995; Dvir et al., 2003; Gibson, Pappas, & Federal Facilities Council, 2003; Gibson, Wang, et al., 2006; Muramatsu & Menches, 2010; Hwang & Ho, 2012; Williams, 2016). Front-end planning has undergone several iterations of definition in the time of modern construction project management. As new planning factors are introduced and processes are developed and edited, the definition undergoes small adjustments to more accurately identify the most critical aspects of project planning. It has gone by many names in the past as well: pre-project planning, front loading, advanced planning, design development, feasibility analysis, among several others (Construction Industry Institute, 2013; George et

al., 2008). Each iteration of renaming and redefinition was an argument that the definition at the time was inadequate and required additional focus on a certain aspect of the process. Gibson et al.(1995), as a part of the Construction Industry Institute (CII), again argued that the existing definitions did not embody the full process from idea to execution. The terms and definitions proposed by CII have since become highly regarded and widely used throughout the global construction industry.

Established in 1983, CII is now a consortium of 150+ member companies around the world that come from both the public and private sector and include owners, architecture and engineering firms, construction contractors, and suppliers (Construction Industry Institute Research Team 268, 2012; Valency Inc., 2017). All CII research is driven by members of the institute and has been renowned for creating industry best practices in front-end planning methodologies. As a result of these research efforts, CII has developed several tools and best practices with the specific goal of aiding the front-end planning process. They do this by providing standardized processes to be used on a variety of project types, establishing quantitative measurements for projects to score and compare against each other, and correlating the quantifiable measurements to project success metrics that aid an organizations decision making processes (Collins et al., 2017). The reputation of CII led the United States Army Corps of Engineers to become a member and adopt the use of the Project Definition Rating Index. As the Air Force works closely with the Corps of Engineers on many projects, PDRI was then implemented on Air Force construction projects in partnership with the Air Force Civil Engineer (United States Army Corps of Engineers, 2009, 2010).

2.1.2 Frond-End Planning Defined.

The Construction Industry Institute established the term front-end planning which has become a widely used terminology for project planning and development. Front-end planning has been defined by the CII as “the process of developing sufficient strategic

information with which owners can address risk and decide to commit resources to maximize the chance for a successful project” (Gibson, Irons, & Ray, 2006). This definition is concise, yet includes highly important information in each of its components.

The first important aspect of this definition is that front-end planning has been labeled as a process. This is crucial for organizations to understand because a process takes inputs, performs activities with those inputs, and creates outputs that serve the system or organization as a whole (Hammer & Champy, 1993). In the case of construction project planning, inputs can be everything from business goals to site-specific information. These inputs are gathered by a variety of entities, but the focus should be on the customer and their requirements. These requirements will build the scope of the project and must be identified and locked in early in the process. Those inputs are then used in planning activities, such as business meetings or design charrettes. In these planning activities, inputs such as user requirements and the definition of scope are used to make actionable plans and designs. These are the outputs of the process. Outputs can include anything from the strategic direction of the project and how it relates to the company or a draft design and technical specifications, depending upon the phase of the process. The inputs and outputs produced with this process are labeled in the CII definition as strategic information.

Strategic information may be different for every organization depending on its current goals and the development phase of a particular project. Each phase of project development relies on different sets of strategic information. The project team must identify the cutoff points within the planning process for when the information they have gathered is insufficient for the amount of risk they are willing to take. When the risk is high on a project, an organization should have a high standard for the quality of strategic information at each phase of the project.

The scope of a project and the list of user requirements are good examples. If a high risk project has very little user input for requirements and the scope is ill-defined, the

project team may decide to stop project development if they feel that strategic information is insufficient. To make this decision, the team must have a clear idea of the potential benefits of the project and weigh those against the costs and risks of continuing with inadequate information. Additionally, the development of that strategic information must be communicated to the entire team as a priority. Longman and Mullins (2004), explain that "communicating the rationale behind project definition, planning, and implementation is fundamental to the successful use of project management."

The identification of risks in the construction industry has been a largely studied topic in itself. The central idea of risk in construction revolves around uncertainty and the potential for loss, be it financial, schedule, quality, safety, etc. (Akintoye & MacLeod, 1997; Wang, 2002). Risk is a rather subjective concept and the definitions, management strategies, and effects of accepting risk vary between industries and managers. One aspect of risk that has been agreed upon is that risk can be mitigated through the quality and completeness of information, and limiting diversity of interests and susceptibility to external influences in a project (Atkinson, Crawford, & Ward, 2006).

Through proper front-end planning, the end result is a complete project definition with all information required for execution and the entire project team and the projects stakeholders will be aligned and striving for the same product and end goals (Gibson et al., 2003). Additionally, the robust definition of a project will limit the potential for future changes to work their way into the plan. When a project has been developed to its fullest extent possible, given full access to the known requirements and existing conditions, the risks have been mitigated sufficiently to ensure a successful project (Wang, 2002). When critical information has been ignored or forgotten, those risks manifest themselves as scope changes or additional requirements and become potentials for increased cost or schedule during project execution. A proper front-end planning process, however, cannot be done without a substantial commitment of resources (Gibson et al., 2003).

Once the critical strategic information has been collected and weighed against the known risks, if the organization continues pursuit of the project, they must commit adequate resources to develop the project sufficiently in all phases to mitigate the risks as greatly as possible. If the resources are not available to develop the project adequately, the organization and project team must again decide if project continuation is feasible. This decision can be made at any stage of the front-end planning process. Given the information known at any particular stage, the organization can determine whether or not they feel it is necessary or desired to press forward with project development and expend additional resources. In the CII strategy of front-end planning, these decisions are generally made at certain points in the process called phase gates (Construction Industry Institute, 2013). Each phase is intended to have a primary focus on different aspects of the projects development. When done properly and thoroughly, the project has a much greater chance to be successful.

2.1.3 Phases.

The three main phases in the CII front-end planning process include Feasibility, Concept, and Detailed Scope and are shown in Figure 2.1 as a rendition of the CII published Project Life Cycle Diagram (Construction Industry Institute, 2013). These three phases are punctuated by Phase Gates. Phase gates are decision-making points where an organization can review the information and products gathered in the previous phase or phases and determine whether or not the project is ready to move on. This is a critical aspect of the front-end planning process, as it allows for multiple thorough progress reviews of the project, and enables the stakeholders to make informed decisions on the future of the project and the resources required to complete it.

2.1.3.1 Feasibility.

The feasibility section of the front-end planning process refers to the initial phases of development where an organization initializes a project based on business case analysis

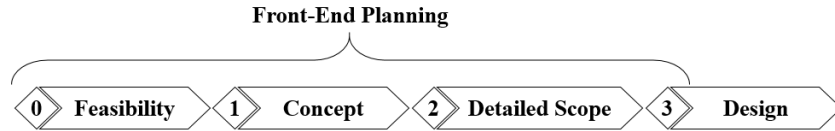


Figure 2.1: Front-End Planning Phases of the Project Life Cycle

and determines if the project makes sense for the organization to complete (Construction Industry Institute, 2013). This is generally done using rough orders of magnitude for project size and scope. The intent of the feasibility analysis is to measure the projected benefits of the project against the costs. This is where the organization presents the business case for the project (Gibson et al., 1995). It is critical for the project to have a robust list of requirements from the end user at this stage (Pemsel & Widén, 2010). The list of requirements is what the organization will be using to determine its value and should be the result of thorough communication between the planning team and all key stakeholders, as well as prospective material suppliers (George et al., 2008). Additionally, the organization will determine if the project conforms to its overall strategic objectives. If the planning feasibility planning has been completed sufficiently at phase gate 1, the project can proceed to the conceptual planning phase.

2.1.3.2 Concept.

Next, the project team within the organization further details the general requirements for the project and establishes a rough plan for how to execute the project and the physical components of the project. This is known as the Concept phase. David Johnson (2008) states that "the conceptual design planning phase of a project has always been the most important aspect of project development" in residential planning projects. This is where the site layout is established and the mechanical, structural, and utility requirements are defined (Construction Industry Institute, 2013). Furthermore, Clyde Tatum (1987) argues that the constructibility aspect of a project can be drastically improved by expending sufficient

effort in the conceptual phase of front-end planning. Once the physical requirements have been established and the project team is comfortable with level of project definition at this point, the decision to proceed to the detailed scope phase of front-end planning can be made at phase gate 2.

2.1.3.3 Detailed scope.

The final front-end planning phase is known as the detailed scope. The detailed scope of the project finalizes the specific requirements and design features of the project before the execution process of design and construction. In addition to finalizing the site layout and physical requirements, the project team is developing the plan for funding, procurement, and execution (Construction Industry Institute, 2013). At this point, the final cost estimate should be established to ensure the organization has the ability to move forward with design and construction execution in the next phase. The project team will also be generating a list of required deliverables based on the physical requirements list established in the concept phase. By the end of the front-end planning process, the project should have a full scope definition and be ready to proceed to design. This decision is then made at phase gate 3 and signifies the end of the front-end planning process.

2.1.4 Benefits.

2.1.4.1 High influence, low cost.

Establishing and enforcing a detailed strategy for front-end planning will ensure project teams develop scope definition in such a way that no requirements have been omitted. When requirements are omitted in the planning phase and introduced later in the design or construction process, costs can add up quickly. As shown in Figure 2.2, when project requirements are introduced during construction, the costs of design changes increase dramatically as compared to the same changes occurring in the front-end planning stage (Gibson et al., 1995). For this reason, early and in-depth requirements identification has been determined one of the most crucial tasks in a project in terms of success.

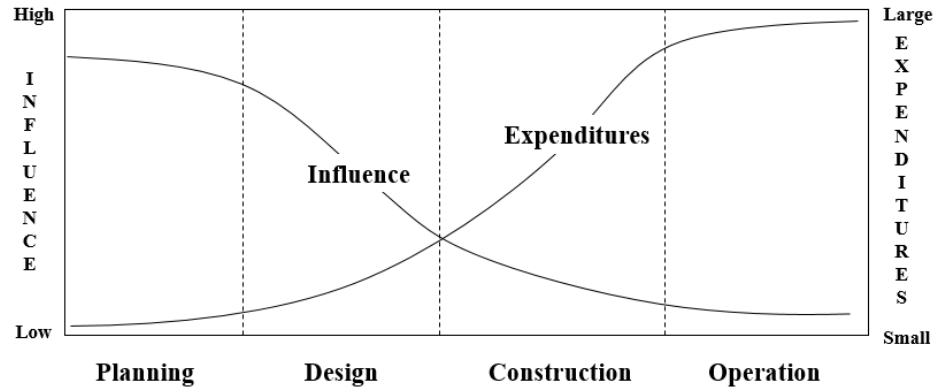


Figure 2.2: Influence vs. Expenditure

2.1.4.2 Risk assessment and mitigation.

Assessment and mitigation of risk in front-end planning stages of a project has been proven as an effective practice to increase project success (Gibson et al., 2003; C.-S. Cho & Gibson, 2000; Batson, 2009; Wang, 2002; Le, Caldas, Gibson, & Thole, 2009). Risk in a project can be defined in several ways based on the perspective of the stakeholder. However, risk has generally been defined as the presence of uncertainty and its associated consequences of those unforeseen factors (Akintoye & MacLeod, 1997; Wang, 2002; Nicholas & Steyn, 2008). Proper assessment of risk in the front-end planning stages of a project, however, is dependent upon the quality of the project scope and list of requirements (Gibson et al., 2003). After all, the goal of proper scope and requirements definition is to reduce the sources of uncertainty where risk can propagate. With early risk identification through front-end planning comes the ability to monitor that risk through all phases of the project life cycle. Depending on the type of project, risk in a particular area will change as the project progresses. The ability to monitor this change can allow the project management team to properly mitigate its effects.

2.1.4.3 Communication and alignment.

Another main benefit to early scope definition through front-end planning is the ability to foster communication in the project team and stakeholders and promote the alignment of those team members (Gibson et al., 2003; Griffith & Gibson, 2001). This alignment enables the entire team to understand the directions in which all aspects of the project are headed and limits their ability to input changes. The most important aspect of this that all members of the team agree upon the scope of the project and the listed requirements. The best to ensure agreement and leave no room for interpretation is early scope development and requirements definition. This is most easily done by ensuring the correct stakeholders are involved in the project throughout its life-cycle, especially early in development (Williams, 2016).

2.1.4.4 Benchmarking.

Benchmarking is a way for an organization to continuously and systematically improve their front-end planning efforts (Hamilton & Gibson, 1996). An established front-end planning strategy and process allows an organization to compile a portfolio of projects which underwent a consistent planning process. This benefits the organization in a few ways. First, the teams become more efficient when planning projects as they become familiar with the process and its benefits, as well as its limitations. The more historical data the organization has from a process, the better postured it is to make positive changes.

An additional benefit to a formal benchmarking process is the fact that, depending on the size of the organization, the database may be expanded to include several portfolios which contain like projects, each with unique front-end planning requirements. The result of proper benchmarking should be tailored processes for each type of project. These individual processes are the backbone to a robust front-end planning strategy for a large organization which has been proven to increase cost and schedule performance in projects (Hamilton & Gibson, 1996; Yun, Suk, Dai, & Mulva, 2012).

Finally, the benchmarking process can establish thresholds in certain criteria against which an organization can compare ongoing projects. This comparison to thresholds can be a decision aid in resource allocation (Wang, 2002). Thresholds in criteria can be very useful in the phase gate decision making stage of the process. Historical data can help identify cutoff points where a project team can easily compare the level of scope definition to the success rates of previous projects with a similar level of definition. These thresholds will help the team decide whether or not to move on to the next phase.

2.1.5 Effects of improper planning.

One of the most common results of improper scope definition and front-end planning is change orders due to scope alteration in the later stages of design or in construction (Chester & Hendrickson, 2005). In some cases, change orders are inherent to the nature of the construction industry, but many of these change orders are the result of scope change requests or misidentified requirements. These changes could be prevented by ensuring an accurate scope and requirements list, both design and technical, in the early stages of project planning. Chang (2002) studied just four completed projects from California with greater than average cost and schedule increases to determine the reasons for those increases. In that analysis, ten reasons for change requests were identified and 60% of those changes were directly related to an insufficient scope definition prior to construction.

From the review of literature, the current researcher has not found much evidence of studies related to the direct quantifiable impact of change orders on cost and schedule. However, Chester and Hendrickson (2005) developed a simulation of a single construction project which experience seven different change scenarios. The respective impacts due to those scenarios was based on theoretical changes to material and labor as a result of each individual change scenario. Although not based on strictly empirical research, their simulation was a good representation of typical impacts. Namely, the change of scope scenario was the second largest contributor to both cost and schedule increase behind delay.

This is further evidence of two points; 1) there needs to be more empirical research related to the direct impacts of scope changes on cost and schedule measures, because 2) late changes in scope can have significant effects in both cost and schedule.

Although not much research has been conducted on direct cost and schedule impacts due to scope changes in construction, there is substantial research linking the specific front-end planning tasks of scope and requirements definition to improved cost and schedule performance (Clarke, 1999; Smith & Bohn, 1999; Dvir et al., 2003; Hwang & Ho, 2012). Dvir et al. (2003) suggest that every effort should be made to ensure all stakeholders have developed project requirements early in planning to increase the likelihood of project success. Hwang and Ho (2012) have also verified the importance of front-end planning and scope definition as it is being introduced to the construction industry in Singapore.

Additionally, a few researchers have studied quantifiable impacts of change on labor productivity (C. W. Ibbs, 1997; W. Ibbs, Nguyen, & Lee, 2007; W. Ibbs, 2012; Thomas & Napolitan, 1995; Moselhi, Assem, & El-Rayes, 2005). These studies have all shown a trend of decreased productivity after changes of scope increase rework. This change in productivity is a second order effect on the impact to schedule. As contractors rely on accurate estimates of their labor productivity rates to build schedules, small changes in these rates can dramatically influence an activity on the critical path of a project. This productivity will also inevitably influence the cost of labor on the project.

2.1.6 Useful tools.

A successful front-end planning process can be aided by the use of tools designed to assist managers in the planning effort. A few methodologies have been developed to provide all-encompassing tools that aim to reduce risk in the construction planning process. A few notable systems include the Advanced Planning Risk Analysis (APRA) framework, Design Review Checking System (DrChecks), SMART project planning framework, among others, as well as general checklists to be used as aids rather than specific tools

(Hartman & Ashrafi, 2004; Le et al., 2009; Parfitt & Sanvido, 1993; Soibelman et al., 2003).

Many of these tools have been developed for specific types of projects. However, very few achieved an all-encompassing checklist general enough to be applied to any type of project. This is challenging due to the unique characteristics of every sector of the construction industry. For this reason, the Construction Industry Institute set out to create a generalized tool that can be modified to fit the mold of several types of projects while still retaining an easy-to-use and familiar format (Collins et al., 2017). This tool is the Project Definition Rating Index and is the foundation of the current research effort as it applies to the Air Force Military Construction process and its ability to generate project success.

2.2 Project Definition Rating Index

The PDRI is a tool which was originally established by CII in the late 1990's for Industrial construction projects, but has since undergone several updates as well as specialized version developments to apply to multiple sectors of the construction industry. The Project Definition Rating Index is an example of the sector-specific front-end planning tools that have been widely successful over the years. This tool was first put into practice on large industrial projects in the late 1990's after years of extensive research and development by the Construction Industry Institute (Dumont, Gibson, & Fish, 1997). After several years of implementation, revisions were made and a few successors were developed in similar fashions (Bingham & Gibson, 2017; C.-S. Cho & Gibson, 2000; Collins, Parrish, & Gibson, 2016; Collins et al., 2017). Each research effort tailored the tool to specific forms of construction using the same development strategy as the very first iteration for industrial projects.

2.2.1 Development strategy.

To develop a detailed list of the required elements within a good scope definition package, the CII research team utilized four primary sources: the expertise of the research

team members, an extensive literature review, documentation from a variety of owner and contractor companies, and a separate workshop of project managers and estimators (Dumont et al., 1997). The resulting list of possible elements was then analyzed and refined into a standardized list of terms and definitions that were agreed upon by all parties. The standardized list was then shown to a focus group of individuals from within the industry but outside the original collaborators. This focus group then provided feedback and adjusted the list of terms and definitions if they saw ambiguity or contradiction. The next step in developing the tool was to categorize and assign weights to the individual elements.

According to Dumont et al. (1997), an additional group of experienced professionals in the project management and estimating career fields were then invited to two separate workshops to assist the researchers in assigning weights. Several surveys were collected that scored the importance of each element based on a particular project from their recent history. When each survey was completed, all total scores were normalized to a standard score of 1,000. The collection of normalized scores was statistically analyzed to determine the correct weighting of each element. The list of elements, terms, definitions, and corresponding scores then made up the first prototype of the Project Definition Rating Index for Industrial Projects (Dumont et al., 1997). Validation of the tool and index was the next step.

Validation of the tool was important for the researchers to achieve prior to publishing the tool for use. To do this, they used an after-the-fact approach by analyzing forty projects worth a total greater than \$3.3 billion in authorized costs (Dumont et al., 1997). These projects were all completed within eight years prior to this validation phase and ranged in costs from \$1 million to \$635 million. The researchers surveyed the management teams involved with each project and asked them to complete the PDRI score sheet based on their recollection of the definition of the project prior to execution. These scores were

then analyzed against a standard list of front-end planning success criteria. These criteria were cost performance, schedule performance, percentage design capacity attained at six months, and plant utilization at six months (Hamilton & Gibson, 1996).

After the final results of the validation effort revealed a significant trend of PDRI score correlation to the project success metrics, CII went about publishing the tool and related research content for official use. With the roll-out of the new tool, several articles were published to describe the pre-planning process, tool development strategy, and its potential influences for other organizations. Organizations which have utilized the tool have generally described it as easy to use and straightforward. The layout and organization of the tool makes it very user friendly and easy to understand the results for anyone on the management team.

2.2.2 *Mechanics.*

The tool is comprised of three sections titled Basis of Project Decision, Basis of Design, and Execution Approach (Construction Industry Institute, 2013). Each section is designed to score the definition of the project as it relates to different checkpoints in the front-end planning process. Basis of Project Decision is intended as a checklist for upper management to determine if the overall goals of the project are in line with the business model and philosophy of the organization. The organization is asking itself whether or not the project makes sense. The Basis of Design section is referring to the details of the project.

The requirements for design should be well established for this section to receive a perfect score. The most important inputs to this section are the existing conditions and the equipment requirements that will meet the output objectives for the facility or plant. Finally, Execution Approach is a check against how the organization is planning to fund and procure the contracts and materials, as well as initialize the operations phase of the facility. Within these 3 sections are a total of 15 categories and 70 individually scored

elements. These elements each have their own definition and description as created in the PDRI development process and have been created for each new edition of the PDRI. Therefore, PDRI for Industrial projects does not have the exact same elements as PDRI for Building or PDRI for Infrastructure. These descriptions include terminology clarifications and suggested discussion points for the members in the session to consider.

For each element a score is given during the facilitation session of the PDRI. The members are encouraged to come to a consensus on the appropriate score based on the level of information available and the actions either taken, in process, or not started at the time of scoring. The scores available during the session range from 0-5 with a score of zero representing an element that is not applicable to the project. A score of 1 is considered to be excellent, indicating the element is fully defined and all activities have been accomplished. A score of 5 means there are significant gaps in the definition or information available in the element and a great deal of work is necessary to score a 1. Once all elements have been scored on their 0-5 scale, they are normalized to the 1000 point scale by factoring in the pre-established weighting for each element. The final score for each category and section are calculated and annotated for further analysis.

The final score for the project for a particular session will be anywhere from 70 to 1000. Even when a number of elements have been scored a 0, the total score goes through a normalizing calculation which discounts the scores for the non-applicable elements. This normalization is to ensure a standardized scoring system between projects so an organization can more readily analyze their entire portfolio of projects against each other and identify trends. As stated previously, the tool is set up such that it can be used multiple times throughout the front-end planning process of a single project.

2.2.3 Implementation strategy.

CII identifies 4 distinct points along the timeline where it is recommended to use the index. PDRI 1 is most typically used after the feasibility stage. PDRI 2 is recommended

to be implemented at the end of the concept phase. PDRI 2i is an interim implementation, which can be used as a vector check in the final planning stages of the Detailed Scope phase. Finally PDRI 3 is suggested to be used at the end of the detailed scope phase and before entering the design portion of project execution. Depending on the implementation phase 1, 2, and 3, there are suggested target scores for each iteration of the project. These scores are only notional, however, and CII states that the organization can develop their own general score cutoffs for projects if they deem that to be necessary.

In the first implementation of the PDRI, Section 1: Basis of Project Decision is the main focus. After the feasibility stage of front-end planning, the project should be weighed against the business plan and philosophies of the organization to ensure the project is the right investment for the organization to pursue. In implementation 2, the focus is on Section 2: Basis of Design. The concept phase of the front-end planning process is when the design requirements should be finalized and all performance criteria are outlined. Finally, implementation 3 is when the major milestone of final project planning and detailed scope design should be complete. A total expected score of 200 has been typically seen in the CII research as a cutoff point for when to expect higher success rates for project execution (Bingham & Gibson, 2017; C.-S. Cho & Gibson, 2000; Collins et al., 2016, 2017).

2.2.4 Updates and version development.

Since the first version of the PDRI for Industrial projects was released in 1996, there have been three new versions that created updates to verbiage and slightly adjusted weighting of elements (Construction Industry Institute, 2013). One of the most influential updates to the tool has been the inclusion of specific risk factors for renovation and revamp projects in applicable elements. Additionally, other sectors of the construction industry have received their own versions of the tool. PDRI for Buildings, PDRI for Infrastructure, PDRI for Small Industrial, and PDRI for Small Infrastructure have all been developed and released by CII since 1996. Additionally there is currently a research effort for the

development of PDRI for Manufacturing and Life Sciences. The development process for each of these was very similar to that of the original industrial version with the exception of a few nuances associated with the particular type of construction. For the purposes of the current research effort, it should be noted that PDRI for Buildings the primary tool used for Air Force Military Construction projects.

2.2.5 Proven benefits.

Over the course of each development effort, the new CII research team thoroughly analyzed the successes of the previous PDRI developments and implementations to ensure the next tool could benefit from the lessons learned. Each iteration revealed new benefits and reaffirmed known benefits via the literature review and statistical validation processes.

The most common use of the PDRI among CII member organizations is as a planning checklist for scope development of projects (Dumont et al., 1997). The idea of using the tool as a checklist is similar to that of the intended purpose as an index to score a project at a given time. Using it as a checklist ensures that the necessary actions are being completed for when the scoring process occurs. Many companies found this to be one of the largest benefits of the tool. Similarly, the tool can be used as a “Gate Check” tool (C.-S. Cho & Gibson, 2000). In this practice, project is scored against the index and the organization can compare the resulting score and commentary against a set of predetermined benchmarks or criteria to determine if the project is ready to move on to the next phase of planning or construction. If the implementation is not being used to inform a decision, it can simply be used as a way to check the progress of the planning effort.

One of the other main benefits as determined by CII is the ability to use the tool as a list of published terms and definitions for standardized use across the construction industry (Dumont et al., 1997). When firms work with each other and use different terminology, the risk of miscommunication is great and can result in cost and schedule increases if not caught early on. The use of a standardized list of terms will alleviate the possibility of

miscommunication between project members and increase the likelihood of a successful project.

In terms of risk, the tool is an excellent method of discovering where the risks in the project may occur (Wang, 2002). As the tool is being used as a checklist or being scored as a gate deliverable, discussion during the sessions will reveal where the project is lacking in definition and where the overall plan or design needs to be improved prior to proceeding. This is a crucial step in the planning process. The reduction of uncertainty in projects is the main factor in reducing risk (Atkinson et al., 2006). Using the PDRI tools can ensure the right people are discussing the right things to ensure nothing is missed in early planning.

There are many other benefits that organizations have found with the implementation of the tool, but there is one that many can agree on as one of the leading benefits: Project team alignment early in the project development. The concept of team alignment in construction projects has been studied and proven effective in previous research (Griffith & Gibson, 2001; Safa et al., 2015). Alignment in a construction project team has been defined as, the condition where appropriate project participants are working within acceptable tolerances to develop and meet a uniformly defined and understood set of project objectives (Griffith & Gibson, 2001). The terminology of alignment should be viewed different from teamwork. In alignment, the whole team can be working separately but still moving in the same direction with the same goals in mind. Teamwork, however, means everyone is working together, but does not necessarily have the same objectives or goals as the rest of the team (Griffith & Gibson, 2001). Alignment is desired in front-end planning.

With the standardized terms and discussion created during the PDRI sessions, the entire team has the opportunity to come to a consensus on the direction of the project. This team unity is crucial to establish early as opposed to in the execution phase, as it is much more difficult and more costly to address conflicts after construction has begun (Gibson et al., 1995). This aspect of project planning is very important because it ensures the entire

team is tracking to the same goals with their individual aspects of the project. If each person had a different idea of where the project was going, the risk of complication in the execution phase of the project is extensive and could result in a standstill if not handled properly.

2.3 Military Construction

2.3.1 Qualifying projects.

The Military Construction program is established for a particular type of project. The MILCON program is defined by Title 10, United States (U.S.) Code, Section 2801 as the “construction, development, conversion, or extension of any kind carried out with respect to a military installation. MILCON includes construction projects for all types of buildings, roads, airfield pavements, and utility systems” (Department of the Air Force, 2016). Engineering projects which establish new footprint are considered to be construction rather than Facility Sustainment, Restoration and Modernization (FSRM). The FSRM program is separate from MILCON and receives a separate budget. Military Construction projects costing greater than \$1,000,000 are generally funded under the MILCON program. This is a recent change as the previous project minimum was \$750,000. For the purposes of this research, the previous minimum is used for project selection as all projects within the data set were executed under those guidelines.

2.3.2 Project development.

MILCON projects are generally formulated at the installation level and the initial scope definition and programming are completed by installation personnel. During the initial programming and approval processes, estimates are made by the installation programmers based on the level of requirements definition and submitted on a DD Form 1391: *Military Construction Project Data* (see Appendix A). These forms require an accurate estimate of total project cost (Programmed Amount) in order to be approved at the installation and Major Command (MAJCOM) levels. The estimates developed on

every project are then rolled into MAJCOM-, Air Force-, and DOD-level budgets, which ultimately are approved for funding by Congress on an annual basis. At each level of approval, the estimates are verified based on the existing list of requirements and scope definition of the project.

As the requirements are less defined and the estimates are conducted on projects across the enterprise, those project estimates are rolled into a single congressional budget line item. Without accurate requirements and scope definition, the potential for estimation error at the Air Force and DOD levels is extensive, leaving Congress with a potentially widely inaccurate figure with which to base their decisions to spend taxpayer dollars. Additionally, budgets for the fiscal years portfolio of projects are approved based on the assumption that the authorized funding amount is accurate, so when the final list of funded projects is released, congress has optimized the budget to include the most necessary projects. When a few or several of these projects are later realized to be poorly estimated, or more realistically poorly scoped, congress may have made a different decision and funded other projects that may have been more beneficial or justified based on accurate costs.

To make matters worse, when the list of approved projects is published and the final documents are being prepared for the individual projects to be awarded, a few projects every year are found to be inadequately defined or the need for the project no longer justifies the cost. Some of these projects are then discarded and the funding is then rolled down to the next project in line. This next project then is required to have a full project package ready to advertise and award in a much shorter timeline than its counterparts. This abbreviated timeline leads to potentially inaccurate project packages and an increased risk of cost and schedule overruns (Griego & Leite, 2016).

2.3.3 Approval process.

Construction project approval processes across the civilian construction industry are generally similar. In very simple terms, the user identifies a potential project, conducts

analysis and front-end planning to develop scope, conducts preliminary and final designs, and proceeds into the construction phases of the project (Nicholas & Steyn, 2008; Gibson, Wang, et al., 2006). The individual owners may have their own approval processes within this construct, but their process is generally free flowing and dependent on the owners needs. In contrast, the Air Force MILCON project approval timeline is much more stringent and complex, requiring several levels of approval, paperwork, coordination, competition for funds with projects from throughout the Air Force and DOD, and reliant on the congressional approval of an annual budget. In general, the number of project requirements far exceeds the available funding in a given year. This process is unique to the Department of Defense and provides many challenges when publishing front-end planning and approval process guidance. Ensuring the timeline for the processes are appropriate for the projects is a key challenge which inspired the current research.

The Air Force has established a notional approval process, which every project is ideally meant to follow. The project planning process for MILCON projects can be split into two major categories: Project Development and Project Approval. In the Project development category, the major phases include Planning, Conceptual Design, Preliminary Design, Final Design, and Construction (Department of the Air Force, 2015b, 2016). These are the phases in which scope development, requirements definition, and physical design actions take place. The second category, Project Approval, includes Planning, Programming, Budgeting, and Execution phases. These phases are generally meant to address the administrative tasks of the project. These administrative tasks include scope validation, budgeting, project approval, final funding actions, and the award of the contract. A visual timeline can be seen in Figure 2.3 with an explanation of terms found in Appendix B. The Air Force front-end planning effort spans from the planning phase to the initial stages of the final design. Not all projects follow this timeline as there are urgent mission

requirements that develop and require fast action, leading to shortened approval timelines (Air Force Civil Engineer Center, 2013; Department of the Air Force, 2015b, 2016).

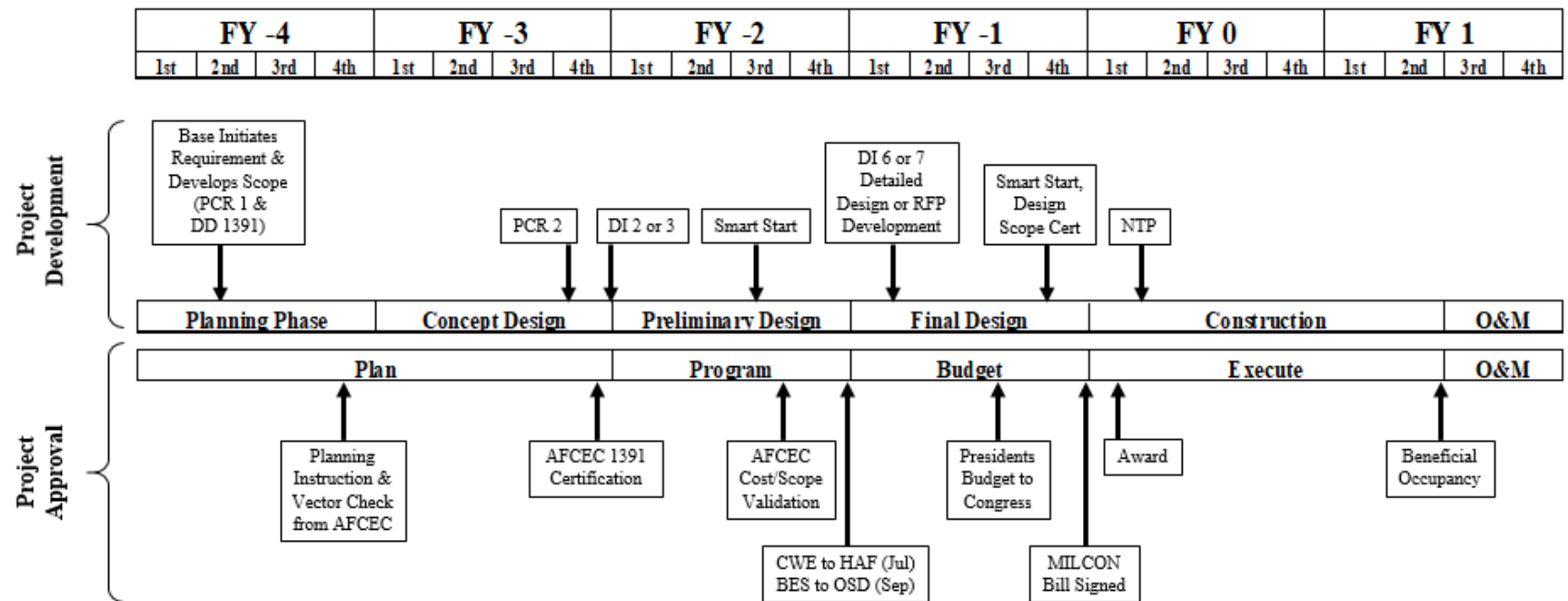


Figure 2.3: Air Force MILCON Project Development Timeline

2.3.4 Congressional re-approval.

The amount of the total change order funding requests which must attain congressional re-approval for a single MILCON project is \$2M or 25% of the approved project authorization amount, whichever is lower (Air Force Civil Engineer Center, 2013). If a project ever exceeds this difference during contract award or construction phases, the government is no longer allowed to expend additional funds to that project until congress reviews and approves the justification for the request. At best, this process can take several weeks to accomplish due to routing procedures and the number of offices which are required to review the request. When requesting re-approval in the contract award phase, the project start can be delayed severely until sufficient funds are authorized to award the contract. On the other hand, the resulting delay of congressional re-approval once construction has begun can result in stop work notices and severe schedule impacts for the project and the customers. This delay on top of the additional funds needed to make the change could result in loss of mission capability depending on the project and affect the ability of the DOD agency to conduct its mission appropriately.

2.3.5 Front-end planning requirements.

As shown in Figure 2.3, there are several document reviews listed in the Air Force MILCON front-end planning process. However, the emphasis on front-end planning is limited within the policy documents reviewed. The AFCEC Program Management Plan for Air Force MILCON Execution (Air Force Civil Engineer Center, 2013) states that “it is imperative that all organizations with a vested interest in a MILCON project be involved in the project execution process from inception through completion of construction, with the most critical points being the development of the requirements document and the DD Form 1391: *Military Construction Project Data*” (Air Force Civil Engineer Center, 2013). Meanwhile AFI 32-1021: *Planning and Programming Air Force MILCON Projects* simply states that effective project planning provides an effective and economical means

of accomplishing the requirements which are most critical to the mission and that “project development is one of the most important actions in MILCON Programming” (Department of the Air Force, 2016). The ideas of front-end planning are emphasized as being critical, but there lacks any detailed execution plan or strategy.

Currently, the Air Force MILCON program mandates the use of the PDRI tool during the front-end planning process (Department of the Air Force, 2016). However, the verbiage in the program documents do not provide detailed instruction on how the PDRI should be implemented into the process. In fact, the only mention of the PDRI in the three major Air Force MILCON policy documents is in Air Force Instruction (AFI) 31-1021 and states under the roles and responsibilities section that AFCEC “Facilitates (PDRI) assessment during the planning charrette process to evaluate and mitigate project risk” (Department of the Air Force, 2016). It goes on to reference a United States Army Corps of Engineers document, Engineering and Construction Bulletin (ECB) 2010-17: *Implementation of Project Definition Rating Index* or the most current guidance for PDRI development. Unfortunately, ECB 2010-17 has expired and was not renewed or replaced by the Corps of Engineers (United States Army Corps of Engineers, 2010). Therefore, there is no longer any published policy or guidance for DOD implementation of the PDRI, merely an AFI that states it must be completed by AFCEC. That said, there is more guidance within the MILCON policies that mandate the use of other scope development tools, which have been developed by the Air Force to address similar elements of planning as the PDRI. The intent of these tools is to provide a tailored version of the PDRI to more directly reflect the Air Force needs and to cut down on time required to execute the tools.

One such tool is the Planning Charrette Report (PCR). This report has been established to allow project managers to keep track of all requirements gathered for a particular project. Additionally, it can be used as a list of potential items to include to ensure the management team does not overlook important aspects of a project. Its main intent is to

serve as a template while the project team gathers requirements. AFI 32-1023: *Design and Construction of Air Force MILCON Projects* (Department of the Air Force, 2015b) puts a small amount of emphasis on early scope development through the use of Planning Charrette Reports. These reports are defined as a Level I and Level II PCR (PCR-I and PCR-II).

A PCR-I is to be used in the early planning stages of the project as identified in Figure 2.3. The installation personnel gathering requirements and building scope can use this template and fill in the information as they progress. There is no formal method for completing this level of PCR but the Base Civil Engineer (BCE) or equivalent is responsible for completing the form and submitting it with the DD 1391 (Department of the Air Force, 2015b). PCR-I is intended to be one of the first official documents formalizing the project requirements and scope definition.

A PCR-II is the same formatted template with the same information as a Level I PCR, but the completion process is formalized and completed by AFCEC Project Managers (PMs) assigned to the project rather than the installation personnel. PCR-II builds on the information from PCR-I and the original draft of the DD 1391. A new revised DD 1391 will be drafted from the more comprehensive PCR-II information (Department of the Air Force, 2015b). Prior to authorization of funds, the PCR-II must be signed off indicating the project has a well enough defined scope and justification for approval and funding authorization.

AFI 32-1023 (2015b) also mandates the use of a Project Management Plan (PMP) during the middle stages of project development. The AFI states that the PMP presents the strategic decisions on the project schedule, design, acquisition, and construction that are agreed upon by the project stakeholders (Department of the Air Force, 2015b). This document organizes the execution plan for the entire facility acquisition process from planning to construction. This document will also be completed by AFCEC personnel and is intended for use in the design phase of the project. Although this document is

targeted for use beyond the front-end planning process, it is still a planning document that encompasses the efforts of early scope definition and requirements building, and therefore is an important aspect of the planning process.

There are several other unpublished tools established by the Air Force Civil Engineer Center, among other organizations, that aim to assist the CE community in developing projects prior to funding and execution. The success of these tools is not widely known as there has been little published research regarding their effectiveness. However, it is known that any planning effort is better than none, as long as there is an organized process (Gibson et al., 1995). These tools established by the Air Force may assist the front-end planning effort, but there is little in the way of an organized, standardized, repeatable process which has been mandated for all projects to follow. It is the assertion of the research that project success is negatively affected by this lack of standardized front-end planning process. Establishing a standardized process with the proven success of the PDRI as its focus may improve project performance.

2.4 Project Success Definition

An important aspect of this research is using the appropriate definition of success for construction projects. A review of literature by Chan, Scott, and Lam (2002) revealed that several authors have determined that the definition of success is dependent on the perspective of the stakeholder defining it. Different stakeholders can be interested in different aspects of the project and completely indifferent to factors that another stakeholder uses as their primary definition.

One of the most important distinctions to be made is the difference between a success criteria and a success factor (Griffith, Gibson, Hamilton, Tortora, & Wilson, 1999). When conducting the review of literature, it was evident that more emphasis has been placed on defining the success factors for a project (Chan et al., 2002; Parfitt & Sanvido, 1993). These factors represent things that can be changed or implemented differently between

projects to affect the outcome of the project. Success factors can be seen as a list of independent variables. In the case of this research, the success factors are associated with the front-end planning strategy using the PDRI. Success criteria on the other hand, are those defining metrics upon which a projects performance can be judged. In other words, the implementation of success factors can result in changes to the success criteria. For this reason, the success criteria are generally the dependent variables. For years the most common criteria upon which to judge a project have been Cost and Schedule performance, with a third more subjective criteria of product quality (Atkinson, 1999). This concept of time, cost, and quality as the main success criteria for project management has come to be known as the "Iron Triangle" (Atkinson, 1999).

Although the "Iron Triangle" has been the commonly referred to measure of project success, Chan, Scott, and Lam (2002) conducted an extensive review of literature exploring other methods. Namely, they identified 17 potential criteria proposed by 20 individual publications. Those 17 criteria were segregated into three objective measures and 14 subjective measures, combining cost and schedule into one of the three objective criteria. Quality was listed as a stand-alone subjective criteria and was tied as the most referenced measure cited with cost and schedule. These measures were referenced in 75% of the publications while the next most referenced was customer and project team satisfaction at only 35%. It stands to reason that cost and schedule continue to take precedence in success criteria evaluation based on their objectivity. Quality, being a subjective measure and out of the scope of analysis for the current research effort, will not be analyzed.

To further the argument for cost and schedule metrics, it should be noted that Dicks, Molenaar, and Gibson (2017) used three primary metrics for their analysis of MILCON projects. These metrics were cost, schedule, and budget accuracy. Cost and schedule were both metrics that analyzed the construction phase performance of the projects. The cost metric included the percentage difference between the contract award price and the

contract award price plus the sum of the modifications to the contract. The schedule metric measured the estimated construction timeframe known as the Period of Performance as compared to the final actual construction duration from Notice to Proceed (NTP) to the beneficial occupancy date (BOD). Finally, the budget accuracy metric measured the initial estimate at project approval known as the Programmed Amount (PA) against the amount of the original contract amount at award. Significant results were found in the cost and schedule metrics, but not in the budget estimate. For this reason, the current research will only measure the success of the projects on the cost and schedule performance metrics.

2.5 Research Gap

One of the major gaps in the research was a lack in analysis of real time projects with respect to the PDRI implementation. A majority of the research conducted included projects that had already been completed and the PDRI was implemented after-the-fact based on the memories of the project management team. This research will follow in the footsteps of Dicks, Molenaar, and Gibson (2017) by analyzing projects that had conducted PDRI sessions prior to construction. All of these projects were also completed prior to analysis, providing real-time success data.

Another major aspect of the current research which has not been done to the authors knowledge, is the analysis with respect to differences in the timeline of PDRI implementation. The notional phase gate implementation has been developed based on expert opinion, but this timeline has not necessarily been revalidated. Included in this analysis is the effect of the number of times the PDRI was used and the times along the planning process the tools were used. This will be compared against the MILCON program timeline for project development to determine any shortcomings of the current process.

2.6 Summary

The review of literature provided the researcher with an understanding of the existing body of knowledge related to the proposed research topic. Many facets of front-end planning were reviewed to include the definition, phases, and benefits of proper implementation. The potential effects of improper use of the process were also introduced before discussing a variety of useful front-end planning tools. The PDRI was then discussed in detail. The review transitioned to specific requirements and characteristics regarding the MILCON program and how the Air Force implements front-end planning strategies. Finally, the research gap was presented after a brief explanation of the definition of project success as it relates to the research.

The next chapter is a detailed description of the specific tasks associated with the analysis of data. The methodology of data collection is presented followed by detailed explanations of the various statistical analysis performed. The tests performed are based on additional review of literature to ensure validity of analysis and results. Chapter 4 then presents the results and discussion produced from the tests outlined in chapter 3. The final chapter then draws conclusions from the results and discussion.

III. Methodology

This chapter outlines the specific steps taken to collect and analyze a set of 96 projects to answer the stated set of research questions. The chapter begins with a brief justification of the research methodology strategy and continues into data collection and organization activities. A detailed description of applying constraints to the dataset and removing outliers is provided. The methodology for developing independent variables is supported by an analysis of the characteristics of the final dataset. Assumptions of normality and equal variances are checked and the results are presented. Finally each step in the statistical analysis is outlined. This chapter describes a repeatable process which can be replicated by future researchers. Therefore, the descriptions of every step are very detailed to ensure clarity.

3.1 Empirical Research

Determining the relationship between PDRI implementation variables (i.e. number of iterations, which phase gates were implemented, and duration between implementation and award) and the project success metrics of cost and schedule growth requires empirical analysis. The research questions examine potential relationships between the independent variables (both categorical and continuous) and the continuous dependent variables. The nature of the relationship between the independent and continuous dependent variables requires quantitative analysis and empirical research methods (Kothari, 2004). As each individual project is comprised of unique values for each variable, the units of analysis for this research effort are the individual projects.

3.2 Data Collection

The data collected for this research was pulled from two primary sources. The individual project descriptions and performance data for all projects were collected from

the Automated Civil Engineering System-Project Management (ACES-PM) database on 08 May, 2017. ACES-PM is managed by the Air Force Civil Engineer Center as the primary repository for Air Force construction project data (Department of the Air Force, 2015a, 2015b). The data is collected and maintained by project managers and leadership at all levels of the Air Force Civil Engineer career field, to include base or installation level, MAJCOM, AFCEC, and the Air Force Installation and Mission Support Center (AFIMSC). Personnel must be trained and authorized prior to being given access to edit fields in the database. The data received on 08 May, 2017 was retrieved from the database by a senior project manager in AFCEC.

AFCEC and ACES-PM do not maintain PDRI data for any projects. The U.S. Army Corps of Engineers previously collected and stored Air Force PDRI data in an online database. Recently, the Corps of Engineers made the decision to discontinue the online database, and the dataset has since been lost. For this reason, the current researcher contacted Dicks et al. (2017) to retrieve a copy of previously analyzed PDRI worksheets. This set of worksheets is the most current source of PDRI projects for the Air Force and was therefore the only database for the current researcher to analyze.

As discussed in the review of literature, Dicks et al. (2017) analyzed a similar set of PDRI projects to prove the benefits of PDRI against non-PDRI projects using success metrics of cost and schedule growth. The current analysis tested new independent variables on PDRI projects alone to determine effects on the same dependent success variables. More discussion regarding the specific tests occur later in this chapter.

3.3 PDRI Constraints

Once the initial datasets were collected, the first step in data refinement was to select the PDRI projects which could be used in analysis. This included the review of 119 individual PDRI projects. Based on a simple search of project numbers, all projects were included within the ACES-PM dataset.

The projects selected for analysis were constrained by both location and original cost. All projects were constructed in the United States, including both Alaska and Hawaii. Additionally, the original contract costs were constrained to above \$750k per the AFI regulations (Department of the Air Force, 2016).

Next, the PDRI worksheets were reviewed individually. To verify whether or not the project contained a sufficient amount of scope to be analyzed, the number of “0” score elements was recorded for each project. As in the previous analysis by Dicks et al. (2017), any project which had 17 or more “0” score elements out of 64 were removed from the dataset. This is due to the fact that those projects would not have been of adequate scope to be scored using the PDRI for Buildings template. The Air Force used the PDRI for Buildings template for a few projects which would have been better suited for other templates such as the Infrastructure template. Therefore, the template would not have been applicable to the project. This resulted in 11 projects being excluded. The product was a list of 108 individual projects which utilized PDRI.

Two categories related to the type of MILCON project were also reviewed. These categories were Report Type and Category Code. The Report Type field in ACES-PM identifies the type of MILCON project. For example, a standard MILCON project is labeled MILCON, but a Base Realignment and Closure project is labeled as BRAC and a Military Family Housing project is labeled as MFH. The category codes for project type were also reviewed. Category codes further identify the type of facility being constructed. Certain Report types and Category Codes were not applicable to the analysis because there were not enough projects of similar type to be analyzed. Report Type and Category Codes which were not applicable to analysis were removed. This step excluded five projects from analysis.

Additionally, during PDRI worksheet review, five of the PDRI projects had similar scoring between implementations. This can indicate that one or more PDRI

implementations may not have been administered accurately. However, without proof of inaccurate facilitation, the researcher decided to include those five projects in the dataset. The PDRI data was then imported into the ACES-PM MILCON project list for the associated projects.

3.4 Project success metrics

The original ACES-PM dataset included a large number of metrics for each project which were unnecessary for this analysis. Therefore, the next step was to identify the categories required to calculate the dependent variables for this research. The researcher conducted a thorough review of all data fields provided in the ACES-PM dataset and identified the categories required for accurate calculation of cost and schedule growth metrics. These categories included: Notice to Proceed Date, Beneficial Occupancy Date, Performance Period, Original Contract Amount, and Contract Modification Amount. All applicable fields were labeled appropriately and were easily identifiable.

The performance metrics of cost and schedule growth have been used in similar research efforts and are the standard metrics used in the MILCON program (Air Force Civil Engineer Center, 2013; Department of the Air Force, 2015b; Dicks et al., 2017). Cost growth for this research is defined by Equation 3.1 and is the official calculation used by the Air Force to assess cost performance on projects (Department of the Air Force, 2015b, 2016). The actual project cost is determined by summing the original contract amount and all modifications made to the contract. A negative cost growth represents a total modification amount of less than zero. Any additional fees imposed on the contract at signing are not taken into consideration. Therefore, the cost figures represented in the calculation are strictly related to construction expenses.

$$\text{Cost Growth (\%)} = \left[\left(\frac{\text{actual project cost}}{\text{original contract amount}} \right) - 1 \right] * 100 \quad (3.1)$$

The schedule growth calculation is used to compare the actual project duration to the expected duration set forth by the contract Period of Performance and is defined in Equation 3.2. The actual project duration is the difference between the Beneficial Occupancy Date and the date construction officially began as indicated by the Notice to Proceed. The original contract duration is defined by the Period of Performance.

$$\text{Schedule Growth (\%)} = \left[\left(\frac{\text{actual project duration}}{\text{original contract duration}} \right) - 1 \right] * 100 \quad (3.2)$$

The steps completed up to this point were accomplished in Microsoft Excel. The researcher then imported the MS Excel spreadsheet into the JMP statistical analysis software. The dataset was reviewed to ensure no data transfer errors occurred. The next step was to detect and remove outliers based on the calculated performance metrics.

3.5 Detecting and Removing Outliers

Prior to statistical testing, outliers were identified in the data set in relation to the two success metrics of cost and schedule growth. The causes of the outliers are unknown and it was outside the scope of this research effort to identify the causes. Highly suspect outliers are generally defined as having values greater than or less than three times the inner-quartile range away from the mean (McClave, Benson, & Sincich, 2014). However, for the purposes of this research, values greater than three standard deviations from the mean were identified as highly suspect outliers.

First, the distributions were visually inspected for outliers. Although the dataset appeared to be highly skewed and non-normal, there did not appear to be any outliers. Next, the studentized residuals were analyzed. To do this, a one-way ANOVA was conducted using the MAJCOM category as the x-variable and cost and schedule growth as two individual y-variables. From the test output, a column of studentized residuals of the two y-variables was calculated for each project. The distributions of the studentized residuals were then analyzed.

Studentized residuals which fell outside three standard deviations from the expected mean were considered extreme outliers and removed. Reviewing the projects for schedule growth outliers identified one extreme outlier and a review of the cost growth distribution revealed three outliers. Reviewing the distributions again, after removal of outliers, further identified one outlier based on schedule growth and one outlier based on cost growth. After removing these six data points, it was becoming apparent that the data sets were more than likely not from a normal distribution as there was a high level of skew in both metrics. This process revealed six outliers within the dataset.

A review of the original project cost also revealed that one project was awarded greater than \$141M. The next largest project in the dataset was just under \$68M. The \$141M project was then removed from the dataset because the projects were later grouped into buckets based on project cost and the project would have skewed the bucket analysis.

The final dataset included 96 projects. Figure 3.1 shows the cost and schedule growth distribution after all outliers were removed from the datasets.

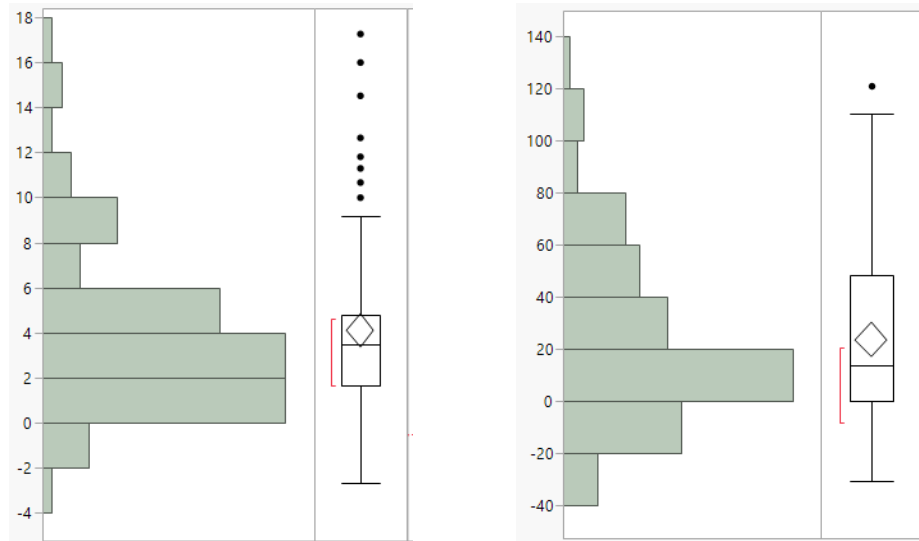


Figure 3.1: Cost Growth (left) and Schedule Growth (right) Distributions (%)

The initial review of distributions lead the researcher to believe that the dataset was not normally distributed. There seemed to be a high amount of positive skew within each subset of the population. The next step taken was to establish the independent variables.

3.6 Establishing Independent Variables

Several independent variable categories were required for analysis. The main categories identified for ANOVA testing included: the number of iterations of PDRI implementation (Number of PDRI), the combination of phase gates in which the PDRI was implemented (PDRI Phases), the size of the project based on the original contract amount (Cost), and the duration of the project in days (Duration). Other ANOVA categories analyzed were Design Method and MAJCOM. These categories were chosen to determine if the PDRI is more or less effective at influencing project success for various project types.

For ANOVA testing, the independent variables were required to be categorical as opposed to continuous. For this reason, the categorical variables were assigned appropriate factor sets and levels to simplify analysis. Additionally, the continuous variables of Cost and Duration were converted to categorical variables. Multiple factor sets were created for each category. Multiple factor sets allowed the researcher to conduct several ANOVA tests with the same criteria. It is predicted that the different factor sets will produce more thorough results and a robust analysis of each category.

3.6.1 PDRI implementation variables.

The first independent variable factor sets were created within the PDRI implementation categories. These included PDRI Number and PDRI Phases. As an overview, Table 3.1 shows the breakout of the PDRI factor sets created.

The researcher began by developing the PDRI Number category. The three levels represent the number of times the PDRI was implemented on a project. This is the only

Table 3.1: PDRI Factor Sets

Category	Factor	Levels	n	Proportion (%)
Number of PDRI		1	25	26%
		2	50	52%
		3	21	22%
PDRI Phases	PDRI Phases 1	A	5	5%
		B	7	7%
		C	13	14%
		D	1	1%
		E	0	0%
		F	49	51%
		G	21	22%
	PDRI Phases 2	Early	13	14%
		Holistic	21	22%
		Middle	49	51%
		Late	13	14%

possible factor set within the PDRI number category. Based on the descriptions, the Air Force is more likely to use the PDRI two times on projects versus once or three times.

Next, the researcher reviewed the PDRI Phases category. Based on the PDRI phases identified, two factor sets were created. The breakdown of each factor set is shown in Table 3.2. PDRI Phases 1 is an exhaustive factor set which lists all possible combinations of PDRI implementation phases. The phases of Planning, Design, and RTA are defined by the USACE and AFCEC project management leadership (United States Army Corps of Engineers, 2010). These labels are not tied to the Feasibility (PDRI 1), Planning (PDRI 2), and Detailed Scope (PDRI 2i and 3) phase gate descriptions provided by CII (Construction Industry Institute, 2013).

Some combinations are not frequently used, including level E, which was not used at all. For this reason, the researcher created the PDRI Phases 2 factor set. PDRI Phases 2 joined lesser used phase combinations from PDRI Phases 1 and also organized the combinations to describe the strategies employed on various projects. These strategies are labeled Early, Holistic, Middle, and Late. This combination of levels is critical as it

Table 3.2: PDRI Phase Gate Factors

Factor	Level	n	Phase Gate		
			Planning	Design	RTA
PDRI Phases 1	A	5	x		
	B	7		x	
	C	13			x
	D	1	x	x	
	E	0	x		x
	F	49		x	x
	G	21	x	x	x
PDRI Phases 2			x		
	Early	13	x	x	
				x	
	Holistic	21	x	x	x
	Middle	49		x	x
	Late	13			x

identifies when USACE and AFCEC use the PDRI during the planning process. Notably, the earliest Planning phase is not used as often as the other two, indicating that the Air Force tends to scope projects later in their planning process.

In ANOVA testing, PDRI Phases 1 will not be analyzed due to the small number of projects within some levels. PDRI Number and PDRI Phases 2 will be the only PDRI strategy factor sets analyzed.

3.6.2 *Cost and Duration variables.*

Several factor sets within the categories of Cost and Duration were also developed. This method of analyzing project datasets based on cost and duration has been done previously. Cho et al. (2009) and Gibson and Bosfield (2012) conducted research focused on potential predictors of project success and determined cost and duration to be a significant predictor. For ANOVA testing, uniformity of bucket range between levels is not as important as having similar numbers of projects in each level (McClave et al., 2014). For this reason the various factor sets were created with emphasis on different aspects of the levels.

In the cost category, the first factor set (Cost 1) was created to mimic the data descriptions conducted by Dicks et al. (2017). Their levels were only created as an effort for dataset characteristic description as opposed to statistical analysis. Therefore, they did not provide a justification for the level characteristics. The second factor set (Cost 2) was created with emphasis on approximately equal bucket ranges. The third factor set (Cost 3) was created with emphasis on each bucket containing approximately equal numbers of projects. Finally, the fourth factor set (Cost 4) split the dataset approximately in half and created only two levels. The breakdown is shown in Table 3.3

Table 3.3: Cost Factor Sets

Category	Factor	Levels	n	Proportion (%)
Cost	Cost 1	<\$5M	19	20%
		\$5-9.9M	36	38%
		\$10-14.9M	23	24%
		\$15-24.9M	14	15%
		\$25-39.9M	2	2%
		≥\$40M	2	2%
	Cost 2	<\$5M	19	20%
		\$5-9.9M	36	38%
		\$10-19.9M	30	31%
		≥\$20M	11	11%
	Cost 3	<\$5M	19	20%
		\$5-6.9M	17	18%
		\$7-9.9M	19	20%
		\$10-15.9	24	25%
		≥\$16M	17	18%
	Cost 4	<\$8M	47	49%
		≥\$8M	49	51%

Figure 3.2 shows the proportions of the four factor sets created within the Cost category. The height of the bars represents the percentage of the total sample of projects contained within that level.

Cost 1 shows a typical histogram style set of bins where each bin is approximately equal in range. This provides a good graphical representation of the sizes of projects

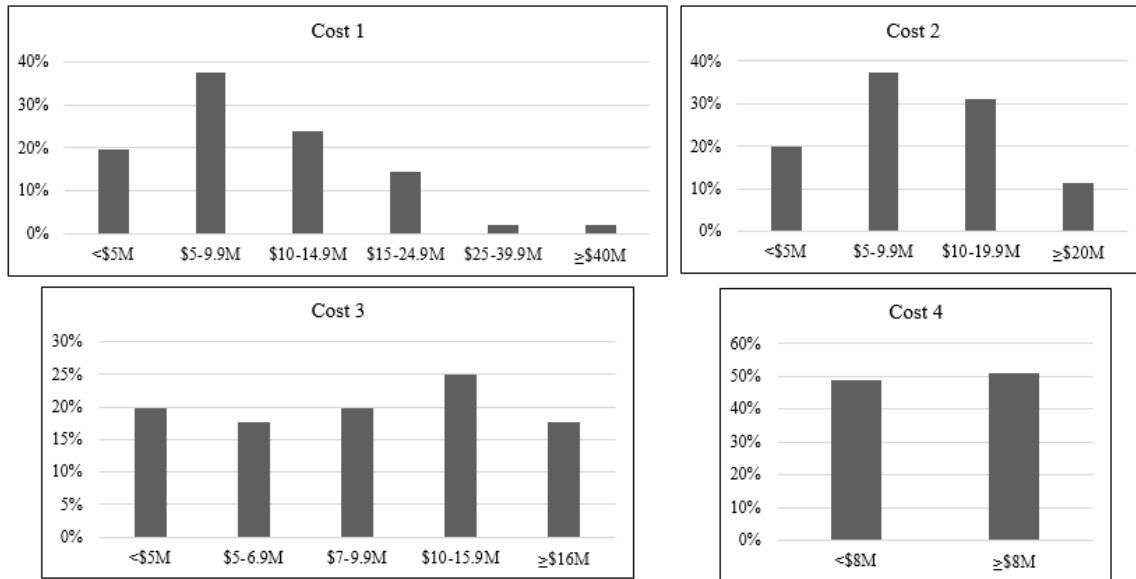


Figure 3.2: Cost Factor Sets

within the dataset. Cost 2 and Cost 3 show the researchers' intent to create levels which contained approximately equal numbers of projects within each bin. The ranges were altered substantially as there were a large number of projects within the \$5-15M range. Finally, Cost 4 divides the dataset approximately in half at the \$8M mark.

Next, the duration category was separated into various factor sets. Project durations are defined by the expected duration at contract award identified by the Period of Performance (POP). Once again, Duration 1 was created based on the data descriptions by Dicks et al. (2017). As stated previously for Cost 1, These levels did not have a particular justification other than to show dataset characteristics. Duration 2 was then created with a focus on maximizing the number of projects in a minimal amount of levels of uniform width. Duration 3 focused on equal numbers of projects per level. Finally, Duration 4 approximately divided the dataset in half. These factor sets are provided in Table 3.4

Figure 3.3 shows a similar set of bar charts by factor within the Duration category. Duration 1 again represents a histogram style distribution with approximately even bin

Table 3.4: Duration Factor Sets

Category	Factor	Levels	n	Proportion (%)
Duration	Duration 1	<365	5	5%
		365-649	66	69%
		650-999	21	22%
		≥1000	4	4%
	Duration 2	<480	13	14%
		480-549	49	51%
		550-699	14	15%
		≥700	20	21%
	Duration 3	<450	11	11%
		450-539	18	19%
		540-549	33	34%
		550-699	14	15%
		≥700	20	21%
	Duration 4	≤540	60	63%
		>540	36	38%

ranges. Duration 2 and 3 represent two efforts to create even sized levels for effective ANOVA testing. One interesting aspect of the duration category is evident in all factor sets, but is very apparent in the Duration 3 factor set. There were a large number of projects which had a POP of 540 days. This equates to approximately 1.5 years. This made it difficult to distribute the projects evenly into levels. This is also apparent in Duration 4, which was unable to achieve an even split of 50% of the projects.

3.6.3 Design Method and MAJCOM variables.

The last set of factors created were related to the Design Method and MAJCOM categories. Table 3.5 provides a detailed list of the factor sets created within the two categories. Since the design method category only contained two possible levels, additional factor sets were unnecessary. The two methods used for design and execution were Design-Build and Traditional Design-Bid-Build.

The projects were completed in nine different MAJCOMs. Two factor sets were created within the MAJCOM category to ensure sufficient degrees of freedom were

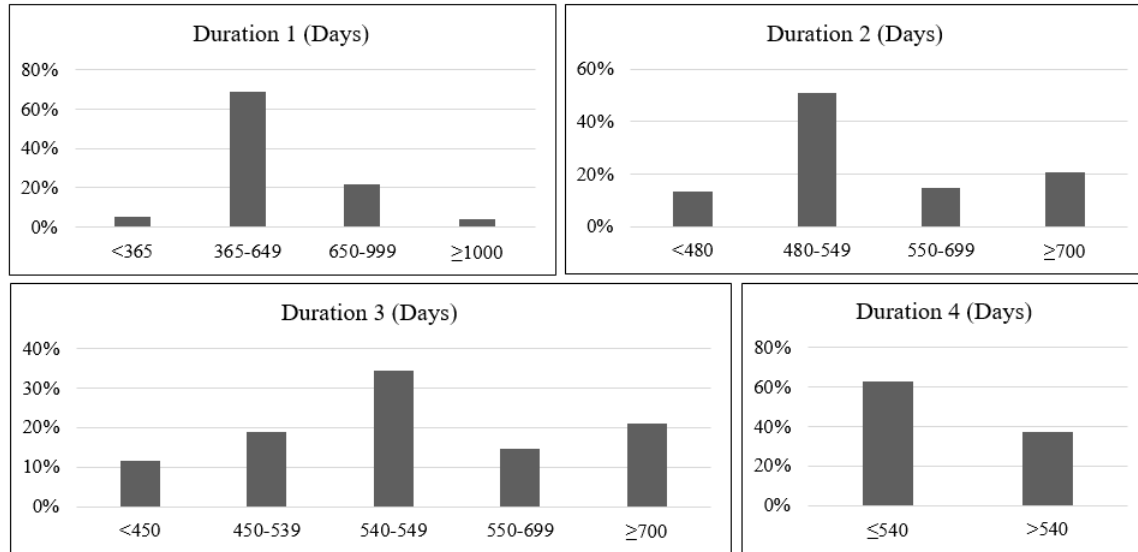


Figure 3.3: Duration Factor Sets

Table 3.5: Design Method and MAJCOM Factor Sets

Category	Factor	Levels	n	Proportion (%)
Design Method		Traditional	28	29%
		Design-Build	68	71%
MAJCOM	MAJCOM 1	ACC	33	34%
		AETC	16	17%
		AFGSC	14	15%
		AFMC	3	3%
		AFSOC	10	10%
		AFSPC	4	4%
		AMC	13	14%
		PACAF	2	2%
	MAJCOM 2	USAFA	1	1%
		ACC	33	34%
		AETC	16	17%
		AFGSC	14	15%
		AFSOC	10	10%
		AMC	13	14%
		Other	10	10%

available during analysis. The MAJCOM 1 factor set included four levels which contained a small number of projects. These included AFMC, AFSPC, PACAF, and USAFA. These

four levels were combined into a single level labeled “Other” within the MAJCOM 2 factor set.

In ANOVA testing, the MAJCOM 1 factor set was not analyzed. Distributions of Design Method and MAJCOM 2 factor sets are provided in Figure 3.4. Based on the distribution of design methods, it would appear the Air Force tended to use the Design-Build method for MILCON PDRI projects. Over 70% of projects used this method. Next, the distributions for MAJCOM 2 present an approximately even distribution between all but the ACC MAJCOM.

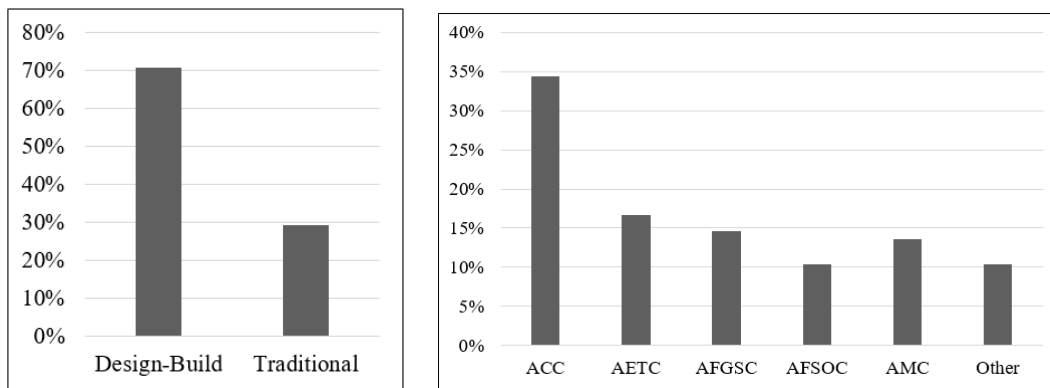


Figure 3.4: Design Method (left) and MAJCOM 2 (right) Distributions (%)

3.6.4 PDRI date variable.

Finally, one independent variable was required for Research Question 3. That variable was the number of days between the last PDRI implementation date and the award date for the project. This was calculated for each individual project. Since Research Question 3 was a regression analysis of continuous variables, there was no need to develop dummy variables or factor sets within this category.

3.7 Checking assumptions

The three assumptions necessary for ANOVA testing include the independence of projects, normality of continuous dependent variables, and homogeneity of variances within factors and levels. These tests are run on the errors within the dependent variables rather than the values themselves. Assumptions associated with running a multi-factor analysis should be checked to validate accuracy of results (Ostle & Mensing, 1975). In some cases the ANOVA test is robust to many of the primary assumptions, but for multi-factor ANOVA tests, it is advised to ensure these assumptions are at least nearly met (McClave et al., 2014). Even with the large sample size of this study, the researcher checked the assumptions to avoid any misreported results which may have been influenced by inaccurate assumptions.

The elements tested were all individual construction projects and one project would be highly unlikely to have effected another. Therefore, the individual projects themselves were assumed to be independent.

3.7.1 Checking normality.

The first step in checking for normality was to conduct an Analysis of Variance test within the factor sets to be analyzed. In the JMP ANOVA output display, the researcher then created a new column for residuals of both the Cost Growth (%) and Schedule Growth (%) residuals. These two columns produced the value of the error for each project. The distributions of the errors were then analyzed for normality.

The distributions and normal quantile plots for both the cost and schedule growth errors were inspected. The distributions for both metrics did not show any obvious signs of non-normality or skew. Additionally, the normal quantile plots showed relative normality with a few minor deviations from the expected normal curve. These visual inspections were not sufficient to determine normality, therefore, statistical testing was required.

A normal distribution curve was fit to both success metric error distributions using the JMP software. Then, a Shapiro-Wilk goodness of fit test was conducted on the normal curves to determine how well the curves match the errors of the dataset. A p-value of less than 0.05 is considered significant, which allows for only a 5% chance of a false positive result. Significant p-values for a Shapiro-Wilk test indicate that the dataset is not normally distributed. The tests revealed that the residuals of the Cost Growth (%) metric were not normal at a p-value of 0.0036 while the Schedule Growth (%) metric passed the Shapiro-Wilk test at a p-value of 0.1044.

One method of achieving normality within a dataset is to conduct a mathematical data transformation (Ostle & Mensing, 1975). A series of logarithmic, exponential, and non-parametric transformations were implemented on the cost growth metric. These transformations did not help achieve normality within the dataset. Therefore, the original values are used in the analysis. Although the assumption of normality is no longer valid for the errors of Cost Growth (%), the analysis of equal variances within the factors must still be conducted.

3.7.2 Checking equal variances.

Next, the homogeneity of variances within factors was tested using the “Fit y by x” function within JMP. The variances were tested in both cost and schedule growth errors. The factors tested for equal variances included Design Method, PDRI Number, and all factors within the categories of MAJCOM, PDRI Phases, Cost, and Duration.

The p-value for each factor within its respective category was analyzed. The p-values represent the probability that the errors of the levels within the specified factor set have equal variances. Again, a p-value of less than 0.05 is considered significant, which allows for only a 5% chance of a false positive result.

All but one factor set passed the test for equal variance at a threshold of 0.05. The only factor set that failed was PDRI Phases 2, which failed for both cost and schedule growth

errors. The Cost Growth (%) p-value was 0.0262 and the Schedule Growth (%) p-value was 0.0456. These significant values indicated that at least one of the levels within the PDRI Phases 2 factor set yielded different errors than the others

A detailed analysis of the errors revealed that the Early PDRI's yielded a lower error value than the others for both cost and schedule growth metrics. This indicated that earlier PDRI implementation resulted in more consistent project performance within this dataset. However, due to the unequal numbers of projects within each level, it is difficult to statistically determine if this is a result of the factor set alone.

As stated, all other factor sets passes the equal variance assumption for errors. This included all for Cost, all four Duration, the two MAJCOM, the Design Method, and the Number of PDRI's factor sets.

Although the normality assumption may not be met for cost growth errors, and the equality of variances failed for one category, the researcher determined that the robustness of the ANOVA test and the equality of variances within Cost, Duration, MAJCOM, and Design method categories should provide sound results. Additionally, as there was no other data available, the researcher was unable to collect additional data for analysis. The next section describes the statistical tests conducted.

3.8 Statistical Testing

3.8.1 PDRI implementation analysis.

The statistical testing of PDRI implementation strategies consisted of the Analysis of Variance (ANOVA) method as well as a simple regression. The ANOVA method was used to determine if different categories of projects as defined previously resulted in statistically different degrees of success. Since the research includes analysis of multiple factors and their possible interactions, a multi-factor analysis of variance approach is required (Ostle & Mensing, 1975). Regression was used to determine if the duration between PDRI

implementation and project award was a possible predictor of project success in both cost and schedule growth. The hypotheses tested included:

1. H_0 : The mean performance of projects which underwent PDRI implementation is not influenced by the number of PDRI implementations.

H_a : The mean performance of projects which underwent PDRI implementation differs for one or more of the levels of number of PDRI implementations.

2. H_0 : The mean performance of projects which underwent PDRI implementation is not influenced by the combinations of phases of PDRI implementation.

H_a : The mean performance of projects which underwent PDRI implementation differs for one or more of the combinations of phases of PDRI implementation as compared to the others.

3. H_0 : The slope of a linear regression line predicting project performance based on the number of days between latest PDRI implementation and project award equals zero.

H_a : The slope of a linear regression line predicting project performance based on the number of days between latest PDRI implementation and project award does not equal zero.

3.8.1.1 Introduction to ANOVA.

The Analysis of Variance (ANOVA) method is used to analyze the means between groups of a population while taking into account the variances between and within the groups (McClave et al., 2014). This method of analysis is typically used when attempting to determine the influence of categorical independent variables on continuous dependent variables. The ANOVA method analyzes the various forms of error between and within groups and provides a test statistic which is a measure of those errors and the accuracy of the predictive variable.

Thal, Cook, and White (2010) conducted ANOVA analysis on MILCON projects to estimate construction contingency costs. Their analysis began by using the ANOVA method to test 42 variables for potential predictive significance. They converted quantitative, continuous variables to categorical data by using various levels of dummy variables. The ANOVA tests identified 10 significant variables, upon which a regression model was developed. The current study implemented a similar approach in that it used levels of categorical variables to determine potential predictive variables related to the project success metrics.

For ANOVA testing, p-values of 0.05 or less are considered to be statistically significant. Significant findings with regard to multi-factor ANOVA tests indicates that the combination of factors tested in some way influence the dependent variables. Specifically, the mean for a particular interaction group is different that that of other groups. This test analyzes the variances of the interaction groups to determine the degree of difference between the means. No significance within this test indicates that the combinations of factors do not influence the mean of the dependent variables for that group.

3.8.1.2 Correlation between Number of PDRI implementations and success.

The first research question asked if PDRI project performance changed between varying numbers of PDRI implementations. There were 15 variations of one-way, two-way, and three-way interaction ANOVA tests conducted. These tests determined if any combinations of implementation strategy and project type were more influential on the project success metrics than any others. For example, it was possible that lower cost projects benefit more from using the PDRI only once as opposed to twice, or longer duration projects benefited more from using the PDRI all three times.

These tests were run in JMP using the “Fit Model” function. The y-variable included both Cost Growth (%) and Schedule Growth (%). Next, the PDRI Number variable, including any other variable being tests, were selected as the independent variables. Using

the “Macro-Full Factorial” function, the independent variables were inserted and the test was run.

The researcher then analyzed the ANOVA model output table for significant F-test results. If no significance was found in the model as a whole, the interaction test was determined to have an insignificant relationship to the cost and schedule growth metrics. The results were recorded and the next series of tests were conducted.

If significance was found in the overall ANOVA model, the Effects table was reviewed. The individual effects, as well as the effects of the interactions, were reviewed to determine if a single factor was creating significance as opposed to the combination of factors. Additionally, the Least Squared Means Plot was reviewed to visually analyze any trends in the results between levels. If an interaction reported significantly different results between its combination of levels, a Tukey test was run and the Connecting Letters table reviewed. This allowed the researcher to determine which specific combinations of levels differed from the others. Any significant results were recorded and annotated.

3.8.1.3 Correlation between PDRI implementation phases and success.

The second research question asked if PDRI project performance changed based on phase gate implementation strategies. As described earlier in the chapter, these phase gate strategies included Early, Holistic, Middle, and Late. The same methodology from Research Question 1 was applied to Research Question 2. The only change was from analyzing PDRI Number to the PDRI Phases 2 factor set in combination with the remaining variables. Once again, 15 combinations were tested for both cost and schedule growth.

3.8.1.4 Regression of PDRI dates and project success.

The final research question focused on the number of days between the latest PDRI implementation and the award date of the project. Only the latest PDRI implementation is used because the dataset retrieved from Dicks et al. (2017) did not contain the dates for the

other PDRI implementations on a project with multiple PDRI reports. The researcher was not able to obtain the remainder of the PDRI implementation dates for testing.

Four projects reported negative values for the number of days between PDRI implementation and project award. This indicated that the project was awarded prior to PDRI being conducted. These projects were Design-Build projects, meaning the PDRI implementation may have occurred in the design portion of the project after the award of the contract. However, there is the possibility that the data was entered incorrectly. The researcher discarded these projects as outliers based on the trend of the remaining 92 projects to have a positive value for this metric.

A simple regression test was conducted using the “Fit y by x” function in JMP. The difference in PDRI dates and award dates was used as the x-variable while both cost and schedule growth were included as separate y-variables. The data was plotted as two scatter plots, one for each success metric. The researcher then used the “Fit Line” function to create a linear best fit model on each of the scatter plots. The R Squared values and Lack of Fit F statistics were then reviewed for model accuracy. An R Squared value of close to 1 indicated a statistically high degree of fit for the line. A Lack of Fit F statistic p-value of less than 0.05 indicated that the line was statistically inaccurate with respect to the data plotted. If either of the two tests failed to indicate significance, the x-variable was statistically not a predictor of project success.

3.9 Summary

This chapter outlined the empirical research methodology for collecting, organizing, and testing the data used to answer the research questions. The data was collected from multiple sources and compiled into a single dataset in MS Excel. Next, the data was cleansed, organized, and grouped to ensure usability and accurate statistical analysis. The data was then transferred to the JMP software where outliers were removed and testing was conducted with relation to the research questions.

The following chapter describes the results of the statistical testing. All results pertinent to the validation of assumptions, as well as the research questions, are presented and explained. Significant findings are presented and a brief explanation of the overall analysis is given. A more in depth discussion of the conclusions of the analysis can be found in the final chapter.

IV. Results and Discussion

This chapter provides a detailed explanation of all statistical findings produced during the execution of the methodology presented in Chapter 3. A brief recap of the intent of the study leads into the discussion of the results. The statistical results are presented by research question before the chapter concludes with a summary of the key statistical findings presented throughout the chapter.

4.1 Intent of Study

The intent of the study is to determine the most effective implementation strategy for PDRI on Air Force MILCON projects. This was done by answering three research questions using various statistical methods in JMP statistical analysis software. The three research hypotheses are:

1. H_0 : The mean performance of projects which underwent PDRI implementation is not influenced by the number of PDRI implementations.

H_a : The mean performance of projects which underwent PDRI implementation differs for one or more of the levels of number of PDRI implementations.

2. H_0 : The mean performance of projects which underwent PDRI implementation is not influenced by the combinations of phases of PDRI implementation.

H_a : The mean performance of projects which underwent PDRI implementation differs for one or more of the combinations of phases of PDRI implementation as compared to the others.

3. H_0 : The slope of a linear regression line predicting project performance based on the number of days between latest PDRI implementation and project award equals zero.

H_a : The slope of a linear regression line predicting project performance based on

the number of days between latest PDRI implementation and project award does not equal zero.

4.2 PDRI Categorical Results

4.2.1 *Correlation between Number of PDRI implementations and success.*

The first research question asked; Does project success change as the number of PDRI implementations changes? The hypothesis for this particular test was:

- H_0 : The mean performance of projects which underwent PDRI implementation is not influenced by the number of PDRI implementations.
- H_a : The mean performance of projects which underwent PDRI implementation differs for one or more of the levels within the Number of PDRI implementations factor set.

A total of 15 combinations of ANOVA tests were conducted to determine the influence of the number of PDRI implementations on project performance. First, a single factor ANOVA analyzing only the number of PDRI implementations was conducted to determine its sole effects on project performance. Then, each additional factor combination was analyzed separately in an interaction ANOVA test. The overall ANOVA test results for each combination of factors are provided in Table 4.1.

As stated, p-values of less than 0.05 were considered significant. This significance indicated that the model of combined factors had some influence on the identified project success metric. Factor set combinations found to be significant were then reviewed in further detail.

The first test was a one-way ANOVA conducted on the Number of PDRI implementations. This is the main factor for the remainder of analysis in research question 1. The p-values indicated not enough significance to reject the null hypothesis. Therefore, the

Table 4.1: Number of PDRI Implementations ANOVA Results

Category	Number of PDRI x Factor	ANOVA p-value	
		Cost Growth (%)	Schedule Growth (%)
PDRI	Number only	0.2897	0.3716
Project Type	MAJCOM	0.0595	0.1172
	MAJCOM 2	0.1384	0.0746
	Design Method	0.6323	0.6840
Cost	Cost 1	0.2430	0.2277
	Cost 2	0.2253	0.1637
	Cost 3	0.0047*	0.2964
	Cost 4	0.0050*	0.0297*
Duration	Duration 1	0.7605	0.0257*
	Duration 2	0.6624	0.0163*
	Duration 3	0.8020	0.0404*
	Duration 4	0.3257	0.0177*
3-Way ANOVA	Cost 4 x Duration 4	0.0389*	0.0010*
	Cost 4 x Design Method	0.0258*	0.0401*
	Duration 4 x Design Method	0.6924	0.1674

*Statistically Significant

means were not different between the levels. There was no significant trend that identified a particular number of PDRI implementations was worse or more beneficial than any others when reviewing the dataset as a whole.

The first significant finding reported in Table 4.1 was the two-way interaction model between Number and Cost 3. Specifically, the cost growth category yielded a p-value of 0.0047. Since the model showed some significant influence on the cost growth metric, the next step was to determine the scope of influence. The full ANOVA results are presented in Table 4.2. Also, the Least Square Means Plot (LS Means Plot) is presented in Figure 4.1.

Table 4.2: Two-Way ANOVA results of Number and Cost 3 Factors in Cost Growth (%)

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	14	385.10	27.51	2.5322	0.0047*
Error	81	879.90	10.86		
C. Total	95	1265.00			

*Statistically Significant

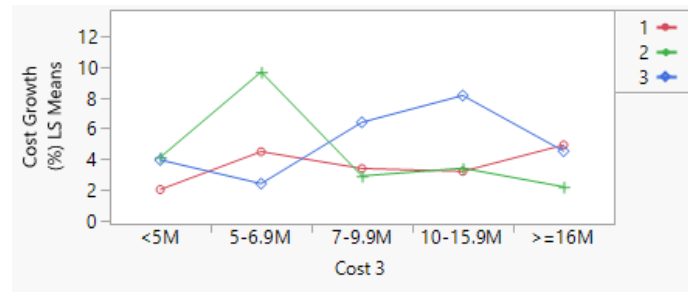


Figure 4.1: Least Square Means Plots for Number and Cost 3 based on Cost Growth (%)

There were only two significant combinations within this particular model. First, there was high cost growth in the group of projects that were between \$5M and \$6.9M and had conducted the PDRI twice. Next, there was slightly lower cost growth in the projects that were \$16M and greater and used PDRI twice. The remainder of the factor combinations did not indicate significance within this model. There may be legitimate reasons for the differences within those subsets of projects, but the model as a whole did not show a consistent trend of influence which could be reported as significant. For this reason, the model was discarded as being potentially predictive.

Next, the interaction of Number of PDRIs and Cost 4 yielded p-values of 0.005 and 0.0297 for cost and schedule growth, respectively. Once again, the LS Means Plots were examined for trends and the parameter estimate table was reviewed for significance. The LS Means plots for cost growth (left) and schedule growth (right) are presented in Figure 4.2.

Further analysis indicated that the influence on cost growth from this model was derived from the group of projects greater than or equal to \$8M and conducted the PDRI three times. This slight trend pointed to a significant finding that larger projects performed worse when using the PDRI three times. This trend was similar for both cost and schedule growth metrics in this subsample.

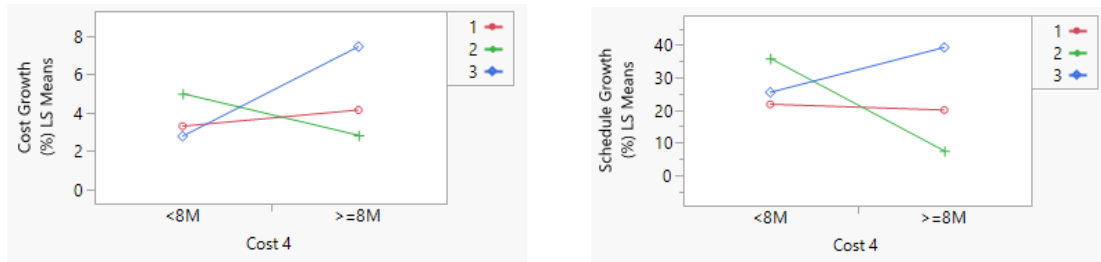


Figure 4.2: LS Means Plots for Number and Cost 4

The influence on schedule growth from this trend was derived from the fact that larger projects with two PDRI performed worse than smaller projects with two PDRI. This can be explained by reviewing the results from Number of PDRI and Cost 3. These results may have pointed to a trend of smaller projects performing better with three PDRI and larger projects performing better with two PDRI. However, there were only a few specific interactions within the model that indicated these trends. Therefore, no conclusion could be made based on this model.

The next set of statistically significant ANOVA models included all four of the Duration factor sets. Their only significance was related to the schedule growth performance metric. This was because the schedule growth metric of a project was dependent on the scheduled duration. Shorter duration projects that experienced a single day of delay indicated higher percentage increase than longer duration projects due to the proportional influence. For this reason, the results of the duration categorical analysis were discarded.

Finally, the three-way ANOVA tests revealed several potential points of significance. However, after review of the detailed report, the significance was not a result of the three way interaction. The significance stemmed from the previously identified two-way interactions of Cost 4 and Duration 4. Based on this finding, the three-way interactions were not considered significant and are discarded.

In summary, although certain tests indicated significance with regard to the Number of PDRI implementations, these results did not show substantial trends. Therefore, the researcher could not statistically determine an optimal number of PDRI implementations based on the available dataset.

4.2.2 Correlation between PDRI implementation phases and success.

The second research question analyzed the PDRI phases labeled as Early, Holistic, Middle, and Late. It asked; Does there exist a combination of PDRI implementation phases which improves project success as compared to another? The hypothesis tested was:

- H_0 : The mean performance of projects which underwent PDRI implementation is not influenced by the combinations of phases of PDRI implementation.
- H_a : The mean performance of projects which underwent PDRI implementation differs for one or more of the combinations of phases of PDRI implementation as compared to the others.

Again, 15 variations of interaction ANOVA tests were conducted for each success metric. The factor set being analyzed was PDRI Phases 2 and the subsequent interactions with other factor sets. A summary of the results from the tests conducted are included in Table 4.3.

Once again, the primary factor set of PDRI Phases 2 was analyzed by itself to determine stand alone trends with the entire dataset of PDRI projects. The PDRI Phases 2 factor set did not show any significance based on the p-values of 0.2897 and 0.3716 for cost and schedule growth, respectively. It should be noted that the Early and Late levels only contained 13 projects each compared to the Middle level which contained 49. Due to this discrepancy, the researcher suggests that additional data is collected to conduct a more thorough analysis of the Early and Late levels.

Table 4.3: PDRI Phases 2 ANOVA Combinations

Category	PDRI Phases 2 x Factor	ANOVA p-value	
		Cost Growth (%)	Schedule Growth (%)
PDRI	Phases 2 only	0.2588	0.5762
Project Type	MAJCOM	0.0714	0.2240
	MAJCOM 2	0.1619	0.1635
	Design Method	0.6543	0.8761
Cost	Cost 1	0.4000	0.3988
	Cost 2	0.5379	0.3330
	Cost 3	0.0406*	0.5116
	Cost 4	0.0088*	0.0559
Duration	Duration 1	0.8044	0.0679
	Duration 2	0.7987	0.0324*
	Duration 3	0.9070	0.0734
	Duration 4	0.4535	0.0390*
3-Way ANOVA	Cost 4 x Duration 4	0.1154	0.0047*
	Cost 4 x Design Method	0.1031	0.1800
	Duration 4 x Design Method	0.8357	0.2854

*Statistically Significant

The first model which identified significance was the two-way interaction of PDRI Phases 2 and Cost 3. Specifically within the cost growth success metric. The researcher first analyzed the effects table to determine the source of significance in the model. The significance was in the interaction of PDRI Phases 2 and Cost 3 and not in the individual factors themselves. The LS Means plot for the interaction in Figure 4.3 was then reviewed.

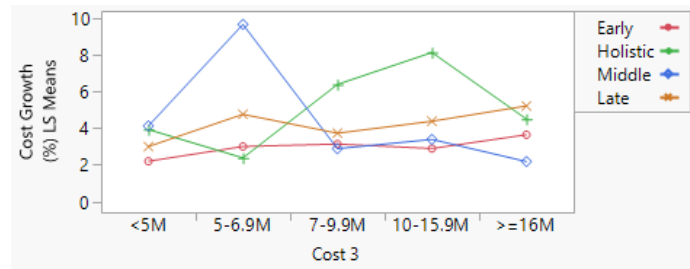


Figure 4.3: Cost Growth (%) LS Means Plots for PDRI Phases and Cost 3

The first noticeable trend is a peak in the \$5-\$6.9M level of Cost 3 for the Middle PDRI phase implementation projects. This coincided with the same peak from research question 1 for projects which underwent two PDRI implementations. This was understandable as the Middle level represented projects which underwent two PDRI implementations in the Design and RTA phases of planning. Therefore, the two factor-level combinations contained roughly the same projects. Once again, although the model identifies a few specific subsets of projects which indicate significance, a majority of the model did not show any trends related to PDRI strategies. The model was then not considered applicable.

Next, PDRI Phases 2 and Cost 4 showed additional significance in the cost growth metric. This significance was consistent with the results presented for the interaction with Cost 3. As depicted in Figure 4.4, the significant factor combinations suggest that a Holistic strategy is more beneficial for the smaller projects than it is for larger projects at a cutoff point of \$8M. Alternatively, implementing the PDRI using the Middle strategy at Design and RTA is more beneficial for the larger projects. This was consistent with results from research question 1. The Holistic level represents projects which underwent three PDRI iterations and the Middle level is largely similar to the level of two PDRI implementations. Therefore, the same conclusion was reached that there were no reportable trends within this model.

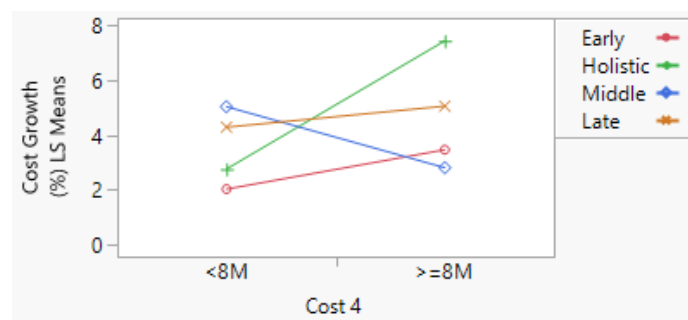


Figure 4.4: LS Means Plots for PDRI Phases and Cost 4 based on Cost Growth (%)

Finally, the Duration category continues the same trend of being statistically predictive of schedule growth. Due to their dependence as described in research question 1, any significant results from the Duration category as they pertain to schedule growth are not valid.

In summary, certain models indicated significance with regard to the PDRI Phases factor set. However, further analysis of these models revealed that there were no trends with respect to PDRI implementation strategies. The researcher could not statistically determine an optimal PDRI Phase implementation strategy based on the available dataset.

4.2.3 Regression of PDRI dates and project success.

The final research question was; Can project success be predicted if the number of days between the latest PDRI implementation date and the project award date is known? It aimed to establish a connection between how early the PDRI was implemented and project performance. As mentioned in Chapter 3, only the dates of the most recent PDRI implementation for each project were available from the previous researcher. Although this made a full investigation more difficult, the analysis was still possible with the data available. The hypothesis for this research question was:

- H_0 : The slope of a linear regression line predicting project performance based on the number of days between latest PDRI implementation and project award equals zero.
- H_a : The slope of a linear regression line predicting project performance based on the number of days between latest PDRI implementation and project award does not equal zero.

The results of the regression analysis indicate a general trend that the earlier the PDRI is conducted, the lower the cost and schedule growth for a project may be. This can be seen in Figure 4.5 which includes the linear regression fit for both cost growth (left) and schedule growth (right). The x-axis represents the number of days between the recorded

implementation date of the latest PDRI and the award date of the project. Higher numbers signify earlier PDRI implementation.

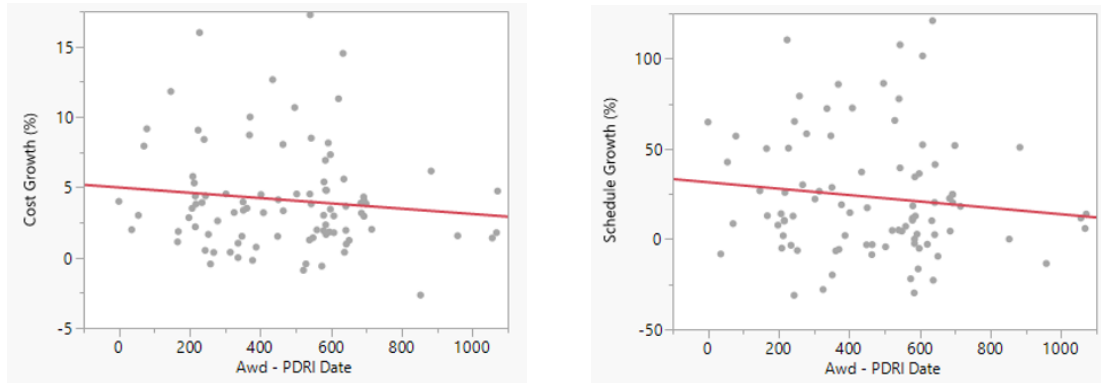


Figure 4.5: Linear Fit for Project Award Date - PDRI Implementation Date

Once again, there is no statistical significance in the results reported. However, a trend does exist indicating that earlier PDRI implementation results in lower cost and schedule growth. This is consistent with the results from research question 2. The highly variable nature of the scatter plot of data suggests that additional data will be required to conduct a full analysis on this particular line of research. Nevertheless, the results for the two regression lines depicted are provided in Table 4.4.

Table 4.4: Summary and Lack of Fit Results for Regression

Success Metric	Summary of Fit		Lack of Fit	
	R Square	R Square Adj	F Ratio	Prob > F
Cost Growth	0.0136	0.0026	4.8736	0.0071*
Schedule Growth	0.0149	0.0039	2.314	0.0841

*Statistically Significant

The researcher understands the limitations with regard to conducting this particular test on the dataset available. First, only a small portion of the PDRI data required was

available. Second, the assumption of cost and schedule growth residual normality is not met. Finally, there is a distinct difference between Traditional and Design-Build executions methods which has a substantial influence on the sequence of design and contract award milestones. Therefore, it is recommended that a more complete and accurate dataset be procured. This would allow further analysis which would provide more accurate results.

4.3 Summary

The results shown were products of the methodology outlined in Chapter 3. In total, 60 individual ANOVA tests and two regression tests were conducted. 16 of those 62 tests were significant. However, eight significant tests were the result of the dependence between the duration category and schedule growth metrics. Also, three more significant tests were three-way ANOVAs that were only significant because of previously identified significant two-way interactions. This leaves five significant tests out of 62 tests which were the result of legitimate findings. However, within the five legitimate significant models, none of the models pointed to a conclusive trend related to PDRI implementation strategies. Therefore, based on the tests conducted on the data available, no PDRI implementation strategies have been found to be more or less beneficial for any project type.

The next chapter outlines the overall summary of the research effort. It includes a summary of the key findings from the review of literature as well as the statistical analysis conducted. It includes discussion regarding the validity of the data, the methodology, and the results. Recommendations are then provided based on the findings. Finally, it presents several opportunities for further research to continue improvement on front-end planning within the Air Force Civil Engineer community.

V. Conclusions

This final chapter serves to provide the reader with a brief synopsis of the paper as a whole. First, a summary of the key findings is presented. Then the applicability of the research is discussed by outlining how the effort contributes to the body of knowledge. The scope of the research is also provided with a description of the assumptions, limitations, and validity of the research effort. Recommendations are provided to Air Force Civil Engineer leadership as well as opportunities for future research.

5.1 Consistency with Previous Research

This work aligns well with previous research efforts. There have been several attempts to quantify the effects of proper project planning on project performance. The methods for analyzing project performance based on categorical criteria are consistent with similar previous efforts and the project success metrics of cost and schedule growth are widely used.

Previous research has never analyzed specific PDRI implementation strategies to determine which method may be more beneficial for certain project types. This research effort answered a few specific questions and fills the gap of knowledge within the Air Force MILCON use of PDRI.

5.2 Scope of Research

5.2.1 Assumptions and limitations.

There were a few limitations to the research conducted. First, the originally desired data was not available due to the U.S. Army Corps of Engineers de-funding the website which contained historical PDRI implementation data. For this reason, the researcher relied solely on second hand data. This limited the number of projects that were available for analysis as well as the PDRI implementation dates used for the third research question.

Additionally, the fact that all data collected was pre-recorded and the researcher had no control over the quality of data recording techniques, the researcher had to assume that the data collected was complete and accurate. The researcher also assumed a consistent and adequate level of effort was put into the individual PDRI implementations. Since the researcher was not a part of the facilitation effort to validate its process it was assumed that all PDRI facilitation received the same level of effort and attention. All PDRI facilitations were assumed to be consistent with training and CII guidelines.

With regard to PDRI implementation strategies, it was evident to the researcher that some strategies were more common than others. In particular, the PDRI was implemented two times more often than it was implemented once or three times, and it was implemented later in the planning process more often than it was implemented early. This was the product of a lack of consistent and standardized guidance from AFCEC and the Air Force on how to effectively incorporate PDRI into the MILCON project development process. The lack in guidance left room for interpretation of suggested implementation strategies for individual projects. This created variances in the data which influenced results.

5.2.2 Validity and strengths of scope.

Although a similar dataset was analyzed by Dicks et al. (2017), this research effort delved deeper into the PDRI projects to determine the best implementation strategy of the PDRI on Air Force MILCON projects. To the researchers knowledge, this level of analysis has not been conducted on a set of PDRI projects within the DOD. Additionally, the list of PDRI projects analyzed was an exhaustive list of the available dataset. Constraints were applied to ensure accurate reporting of results without extrapolation. These constraints covered a wide range of projects, creating an expansive scope of analysis. The results from this research effort should provide critical insight into the project planning strategies employed by the Air Force and the Department of Defense.

5.3 Summary of Key Findings

In total, only five of the 62 statistical tests conducted yielded significant results. However, within the five significant models, none of the models pointed to a conclusive trend related to PDRI implementation strategies. Therefore, based on the tests conducted on the data available, no PDRI implementation strategies have been found to be more or less beneficial for any project type. Although the analysis was inconclusive, it is suggested that additional data be collected to analyze further. Based on the review of literature, it is suggested that the Air Force start planning projects earlier using the PDRI in accordance with the Construction Industry Institute (CII) recommendations. Additional data should be collected and analyzed from the earlier planned projects.

5.4 Literature Review

To develop a sufficient background of knowledge prior to data analysis, the researcher reviewed a large amount of peer reviewed literature. The review began with the general knowledge of front-end planning and its benefits. This lead to an in-depth review of the Project Definition Rating Index (PDRI) including how it was created, how it is used, and its benefits to project performance. Then, the unique requirements of the MILCON program were outlined. This included an explanation of how the Air Force is currently implementing a front-end planning strategy while incorporating the use of PDRI.

The findings from the review of front-end planning practices differ from the Air Force MILCON project development strategy. The development strategy suggested by CII and other industry experts points to an in-depth scope definition process prior to design. The Air Force MILCON strategy attempts to produce a planning process, but this process is much later than is suggested by CII and the PDRI documentation.

5.5 Implications and Recommendations

There are several recommendations for the Air Force Civil Engineer community that came from this research effort. First and foremost, the front-end planning process for MILCON projects needs to be more defined and strictly enforced. Without a defined process for project management teams to follow, the level of planning will vary greatly between each project. It is recommended to follow the PDRI implementation guidelines more closely by shifting the planning process to left.

Based on the review of literature and the inconclusive results presented, the PDRI is not being implemented early enough in the planning process to provide sufficient results. Figure 5.1 compares the CII recommended PDRI implementation strategy to the current Air Force MILCON implementation strategy. The Air Force phases for PDRI implementation of Planning, Design, and RTA do not match the CII recommended phases of Feasibility, Concept, and Detailed Scope. In fact, the first Air Force phase of Planning seems to contain the entire front-end planning process. As a result, the first PDRI implemented in Air Force MILCON projects is currently the only one which is implemented within the proper time-frame, but is much later than intended. This means the Air Force is not receiving the full benefit of the proven CII strategy.

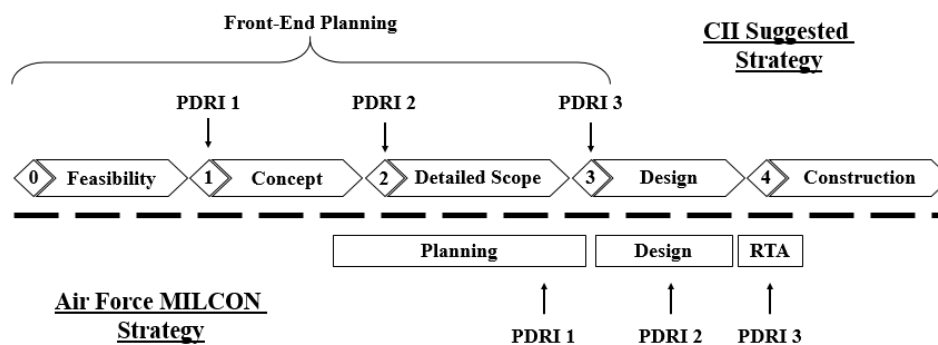


Figure 5.1: CII PDRI Implementation Strategy vs. Air Force MILCON Strategy

Additionally, since the Design and RTA PDRI phases are implemented so late in the project approval phases, they are not measuring what they are intended to measure. By the time a project is in design or is ready to be advertised for construction execution, the requirements list and scope should have already been solidified, as suggested by CII. The PDRI is a tool to help define requirements prior to design, not confirm that they have not changed through the design process.

To do this, it is suggested that AFIMSC and AFCEC implement a mandated policy which requires early PDRI implementation consistent with the CII recommendations. A concept of this strategy is presented in Figure 5.2. To help the Civil Engineer community implement the PDRIs, the researcher suggests standing up a dedicated team of project managers who are trained in PDRI facilitation. This team can then assist base level personnel with developing the scope of their requested MILCON project prior to cost estimation and DD1391 validation. This would be a formalized process which would replace the current suggestion to implement Planning Charrette Reports.

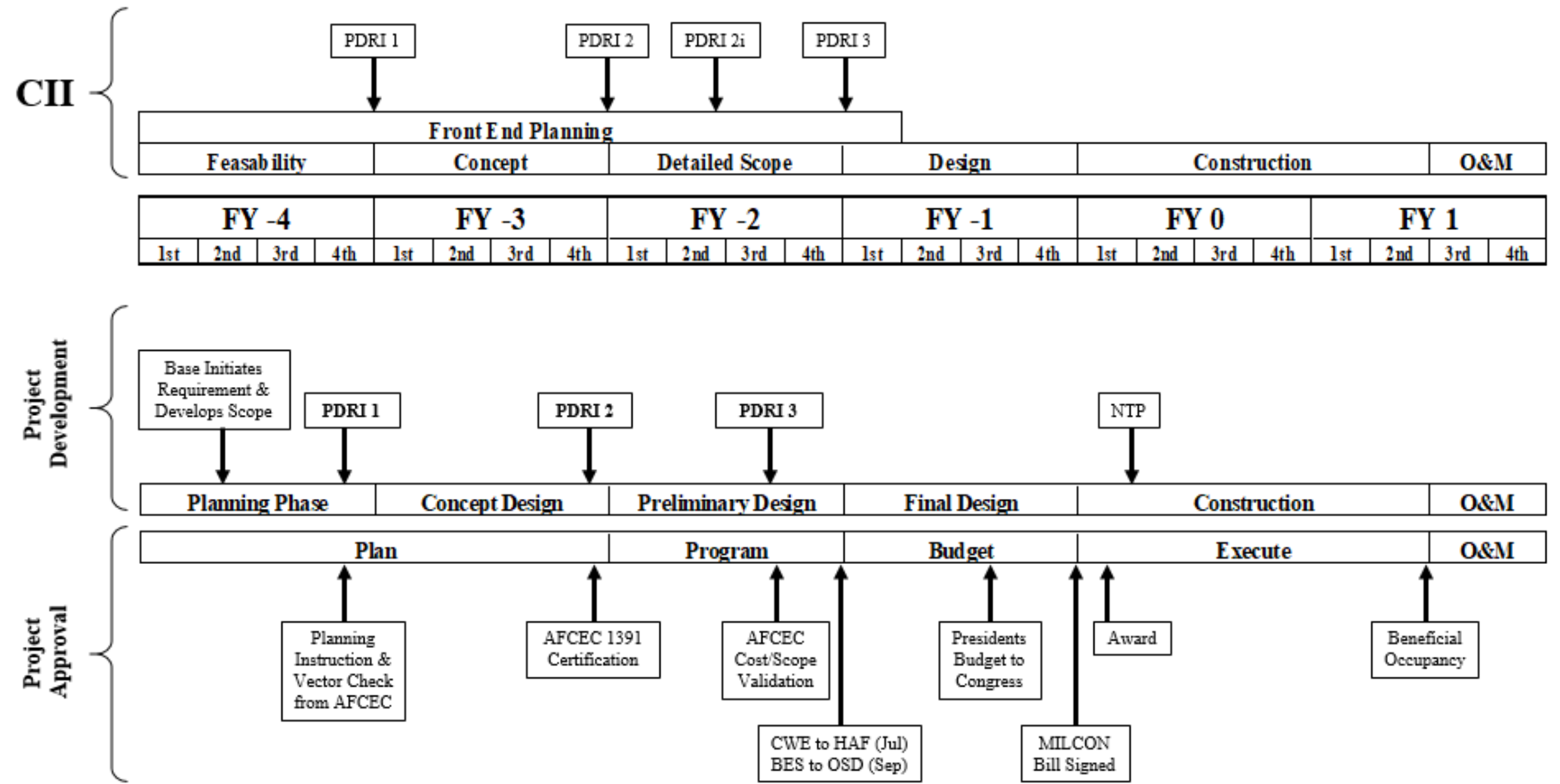


Figure 5.2: Suggested Air Force MILCON Project Development Timeline

The researcher also understands that there is a difference between the planning process for Design-Build versus Traditional Design-Bid-Build projects. It is suggested that the approval process be adjusted so these two types of projects undergo the same front-end planning process and guidelines. Specifically, for Traditional execution projects, it is suggested that the year of execution is related to the year the design is awarded rather than the construction contract. If proper planning is conducted using PDRI, the projects will be much better scoped for the design effort. Additionally, this would mean there would be fewer projects which undergo design and never receive funding for execution.

This suggestion is based on the fact that the PDRI contains an element within the Execution Approach section that is specifically tied to the execution method. This is generally not identified until later in the planning process. The Air Force should be using the scope of the project to determine the best execution method. Using PDRI earlier in the planning process will improve the scope definition upon which those decisions are made.

Based on the issues the researcher experienced with data collection, one other recommendation is to incorporate an Air Force managed PDRI database which can be tied to the MILCON tracking and reporting database. The Air Force Civil Engineer community is currently transitioning to the IBM TRIRIGA interface for much of its data tracking needs. This system is designed to replace ACES-PM and be a more user friendly and comprehensive system for data tracking. If the Air Force can include a PDRI data tracking system within the scope of TRIRIGA, it would enable Air Force leadership to pull reports and run analytics on project performance. The goal would be to use the project data to conduct trend analysis on various types of projects or based on PDRI score thresholds. Trend analysis would enable the Air Force to adjust strategies for project planning to optimize our resources.

Finally, training personnel on scope definition strategies and providing tools to develop requirements is a key recommendation to Air Force leadership. In 2016, there was a large

effort to develop a course for Air Force Civil Engineers to attend and become proficient at cost estimation of projects. Although this is a critical skill to ensure an accurate budget, the researcher believes that the first step in creating accurate estimates is developing accurate project scopes. If the cost estimator has little information with which to estimate, the estimate will be inaccurate and not representative of the actual requirements for the project.

It is suggested that AFCEC develops a course to teach the Civil Engineer community the best practices of developing project scopes and requirements lists. This course can coincide with the cost estimation courses and provide a solid foundation of the level of project development which is required prior to estimation.

5.6 Future Research

There is a substantial amount of future research that could be conducted as a result of this research effort. Due to the limited availability of originally desired data, the analysis for research question 3 was not as robust as it could have been. The researcher would recommend a deeper investigation into the dates of PDRI implementations and how they correlate to project success. It is hypothesized that there exists an optimal point when PDRI should be conducted for Air Force MILCON projects. Conducting PDRI too early means there will be too much time between project definition and execution, leaving time for changes to occur. Conducting PDRI too late means the benefits from PDRI implementation would not be realized because the project scope development process would already be too far along. This analysis could provide critical insight into a suggested strategy for implementation.

Further research should also be conducted on PDRI effectiveness for other construction programs. It is the researchers belief that the PDRI could help not only the MILCON program, but also the Facilities Restoration and Modernization (FSRM) program. The PDRI tool has specific sections which are tailored to restoration type projects (Construction Industry Institute, 2013). After the MILCON PDRI process is improved, the next focus for

AFCEC should be the implementation of PDRI on the FSRM program. A simple research effort could first explore the FSRM planning and approval process to identify the most opportune PDRI implementation point using lessons learned from the MILCON program and this research effort.

5.7 Conclusions

This research effort focused on the implementation of the PDRI on Air Force MILCON projects. Specifically, the researcher sought to identify a strategy of PDRI implementation that yielded higher project performance than other strategies. After a thorough review of literature related to project planning and scope development, the researcher collected and analyzed a dataset of 96 projects that underwent PDRI implementation. The researcher analyzed the dataset based on several criteria. The two primary criteria were the number of times the PDRI was implemented, and the specific phases of project development in which the PDRI was implemented.

First, the researcher conducted ANOVA analysis of PDRI projects. There were some specific subsamples of projects which yield significant results with regard to the PDRI implementation strategy, but there were no specific trends relating PDRI implementation strategies to project success. Therefore, conclusive trends were not identified within the available data.

Based on the findings throughout this paper, the researcher suggests the continuation of PDRI implementation on Air Force MILCON projects. Literature suggests that PDRI implementation should be earlier in the project planning process and be mandated by AFIMSC and AFCEC. The facilitations should be done by a specially trained team of AFCEC project managers and at least one PDRI should be conducted prior to approval of the Programmed Amount listed on the DD 1391. This measure will ensure an accurate cost estimate to be submitted for budgeting purposes as well as define requirements and establish scope early in the process with all key stakeholders. Finally, a standard front-end

planning process should be developed for use on both Design-Build and Design-Bid-Build contracts. This process should be mandated and trained to Air Force personnel.

Appendix A: Blank DD Form 1391

1. COMPONENT	FY _____ MILITARY CONSTRUCTION PROJECT DATA		2. DATE (YYYYMMDD)	REPORT CONTROL SYMBOL DD-A&T(A)1610	
3. INSTALLATION AND LOCATION			4. PROJECT TITLE		
5. PROGRAM ELEMENT	6. CATEGORY CODE	7. PROJECT NUMBER	8. PROJECT COST (\$000)		
9. COST ESTIMATES					
ITEM		U/M	QUANTITY	UNIT COST	COST (\$000)
10. DESCRIPTION OF PROPOSED CONSTRUCTION					

Appendix B: Air Force MILCON Timeline

- AFCEC: Air Force Civil Engineer Center
- PCR 1: Base executes the Air Force Planning Charrette Report to develop project scope and requirements
- DD 1391: Military Construction Project Data sheet
- Planning Instruction: Air Force issues planning funds and guidance to begin project development process. First indication that project may be funded in the coming years.
- PCR 2: AFCEC executes Planning Charrette Report to validate scope and requirements
- DI 2: Design Instruction Code 2 (initiate 35% Design effort)
- DI 3: Design Instruction Code 3 (initiate 15% Design effort)
- DI 6: Design Instruction Code 6 (initiate 100% Design effort)
- DI 7: Design Instruction Code 7 (initiate Design-Build RFP package)
- Smart Start: AFCEC Pre-project Planning tool adapted from PDRI
- CWE to HAF: Current Working Estimate for project cost submitted for approval by Headquarters Air Force
- BES to OSD: Budget Estimate Submission by HAF to the Office of the Secretary of Defense
- NTP: Notice to Proceed with construction activities

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14. ABSTRACT The \$1.3B Air Force Military Construction (MILCON) program has shown a trend of 6% cost growth and 12% schedule growth in the construction phases of its projects. Air Force leadership has attributed this to a shortfall in the standardized processes for requirements definition and scope development. The Project Definition Rating Index (PDRI) has been in use on Air Force MILCON projects for almost a decade, but the development and approval process for these projects does not lend itself to direct PDRI implementation. 96 PDRI MILCON projects executed from 2009 to 2016 were analyzed for trends in project development implementation strategies using Analysis of Variance and Regression. It is suggested that the Air Force provides clear, mandated guidance for earlier project development and improve data collection, storage, and analysis methods to aid additional research efforts.						
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