3-2022

Quantifying Project Complexity to Resource Project Managers

Jereme R. Henrard

QUANTIFYING PROJECT COMPLEXITY TO RESOURCE PROJECT MANAGERS

THESIS

Jereme R. Henrard, Maj, USAF

AFIT-ENV-MS-22-M-211

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

DISTRIBUTION STATEMENT A.
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

AFIT-ENV-MS-22-M-211

QUANTIFYING PROJECT COMPLEXITY
TO RESOURCE PROJECT MANAGERS

THESIS

Presented to the Faculty

Department of Engineering Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Engineering Management

Jereme R. Henrard

Maj, USAF

March 2022

AFIT-ENV-MS-22-M-211

QUANTIFYING PROJECT COMPLEXITY
TO RESOURCE PROJECT MANAGERS

Jereme R. Henrard

Major, USAF

Committee Membership:

Lt Col Justin Delorit
Chair

Lt Col Andrew Hoisington
Member

Maj Brigham Moore
Member

AFIT-ENV-MS-22-M-211

Abstract

The intensified frequency and magnitude of climate-related extreme events have produced devastating disasters for many Air Force installations. A Program Management Office is formed to organize and hasten the recovery of the affected installation; its long-term role is to develop and execute a facility and infrastructure recovery portfolio. Despite the increased frequency of climate-intensified extreme events, there is no formal organizational structure for a program management office. While the Department of Defense has prioritized resiliency to climate change over the last two decades, these initiatives tend to progress slowly due to various operational constraints. The aftermath of Hurricane Michael's devastation of Tyndall Air Force Base in 2018 has identified the need to highlight an event flexible Program Management Office structure that can be applied across disaster types and locations. To inform this organizational structure, i.e., determining how many project managers are needed to execute the installation's portfolio efficiently and effectively, will vary depending on the scale of the subject installation's recovery from the event. This thesis reviews the post-disaster milieu and how it uniquely affects the recovery portfolio by increasing complexity in the projects.

Using an Analytical Hierarchy Process and Multi-Attribute Utility Theory, a complexity index is proposed to weigh each project in the portfolio by its complexity. The project complexity index is vital to formulate a "knapsack packing" problem solved with linear programming. The optimized solution identifies the number of project managers required and assigns an appropriate workload to optimize recovery project oversight to mitigate cost and schedule overruns. This work illustrates that with project inputs such as

cost, period of performance, construction variety, and project interconnectedness, an event and location flexible PMO manning determination tool can be built to determine the right number of project managers to manage recovery.

To my family

Acknowledgments

I would like to express my sincere appreciation to my faculty advisor for his guidance and support throughout the course of this thesis effort. The insight and experience were certainly appreciated. I would also like to thank my sponsor, the Director of the Tyndall Program Management Office, and his staff for the support provided to me in this endeavor. I would also like to thank my peers and other Air Force Civil Engineers who provided feedback and crucial information to the development of this thesis.

JP Henrard

Table of Contents

Page

List of Figures

Page

List of Tables

Page

QUANTIFYING PROJECT COMPLEXITY TO RESOURCE PROJECT MANAGERS

I. Introduction

Climate change is expected to intensify extreme weather events. These weather events include tropical cyclones, which are expected to produce extraordinary facilities and infrastructure damage, tied to intensified flooding from storm surge and precipitation, and increased sustained and peak wind speed. The United States Air Force has many exposed installations on the Gulf and East Coasts and in the Pacific that contain infrastructure and mission assets worth billions of dollars. Air Force stateside installations have suffered catastrophic damage from a hurricane at least once every decade for the past 30 years, with Hurricanes Andrew, Katrina, and Michael devastating Homestead AFB, Keesler AFB, and Tyndall AFB, respectively. Despite this consistent trend, the recovery of affected installations has been approached ad-hoc. The Air Force rarely uses organizational lessons learned from previous disasters to drive decision-making, particularly as it pertains to the staffing of recovery offices to efficiently steer the often large construction portfolios.

Independent of the disaster type, the Air Force historically uses a Program Management Office (PMO) to establish and oversee the installation recovery mission. While each disaster creates a unique workload and road to recovery, the work and fiscal challenges are similar each time. The ad-hoc approach to organizational structuring of the PMO results in suboptimal endowments of total staffing and expertise. Not having a flexible PMO structure based on portfolio requirements established early in the recovery process delays the onset of proper recovery management. Furthermore, it blurs the lines between command and communication concerning what the PMO is supposed to manage

and *how much human capital should be provided to ensure the quality of projects and rapid restoration of key mission-generating functions.* The ad-hoc approach requires that the PMO determine all the organizational structure and staffing in a time-constrained environment. The local installation and Civil Engineer Squadron (CES) rely on the PMO to act as a capacity relief valve across the project process.

Lastly, the post-disaster environment presents unique challenges that further complicate the ability of the PMO to generate and oversee projects. The most pressing of these is demand surge brought about by the post-disaster economy and construction resource constraints, which layers in additional complexity to a high visibility, large and complex project portfolio. Quantifying this complexity would enable decision-makers to more effectively staff PMOs with project managers to oversee the portfolio execution and likely mitigate cost and schedule overruns.

Objectives

The objectives of this study are to (1) conduct a literature review of the post-disaster environment targeting works that address mitigation measures for post-disaster construction demand surge; (2) review project complexity as it applies to construction management and project management as well as ways to quantify complexity and how managing complexity can be optimized to reduce cost, and schedule overruns; and (3) propose a human resourcing solution using optimization techniques, such as the Analytical Hierarchy Process (AHP), Multi-Attribute Utility theory (MAUT), and Linear Programming. This resourcing solution is intended to give PMO decision-makers

quantitative and justifiable support for the request of project managers to execute the PMO portfolio.

Research Approach

The cornerstone of this effort is the quantification of project complexity via an AHP and MAUT-based complexity index. The index shall be used to evaluate a PMO portfolio to direct optimal human resourcing. The complexity index accounts for key parameters inherent in construction projects and captures contextual parameters from the post-disaster environment. It is a critical factor in a linear programming optimization problem, which can be thought of as a permutation of the classic multiple Knapsack Problem, which produces an optimized project manager staffing solution. This model can be implemented by future PMOs to optimize human resources to minimize project cost and schedule overruns.

Subject matter expertise (SME) and stakeholder input were used to define several parameters in the model. The SMEs consisted of several active PMO project managers, as well as other Air Force civil engineers with ten or more years of experience. Their input was received based on the scope of the research problem. Ultimately, considering the SME input and existing body of work, the final parameters, and definitions of the model were finalized by the author.

Research Scope, Assumptions, and Limitations

In this thesis, a fundamental assumption for the PMO is that it will form towards the end of the immediate crisis response to the disaster and represent a transition to the

steady-state recovery operation (Figure 1), which is consistent with the emergence of PMOs following the aforementioned storms for Keesler AFB and Tyndall AFB. However, the transition between initial recovery and sustainment is not always crisp; while the PMO may exist the tail-end of debris removal and roof tarping, most of these crisis mitigations and temporary repair type contracts would be well underway as the PMO approaches initial operating capacity. For example, mold remediation is a lengthy and invasive process and is likely to bridge from the crisis response team oversight into the PMO's oversight. In general, the PMO provides enough capacity to manage the recovery portfolio until the local CES can resume at full capacity and manage the additional recovery portfolio. Alternatively, there may be key metrics to sunset the PMO per the PMO charter or Air Force Civil Engineer Center (AFCEC) guidance.

Furthermore, this thesis intends to inform future PMO missions to jumpstart the recovery by having a human resourcing model available, which can be calibrated to portfolio requirements. The Tyndall PMO, and its portfolio project data, are used to develop the basic framework and calibrate the model. Using the project data is not to assess the Tyndall PMO directly but to create a generalized model and project manager resourcing solution that can be used for any event or any location.

Response Framework Timeline Highlighting PMO Stand Up

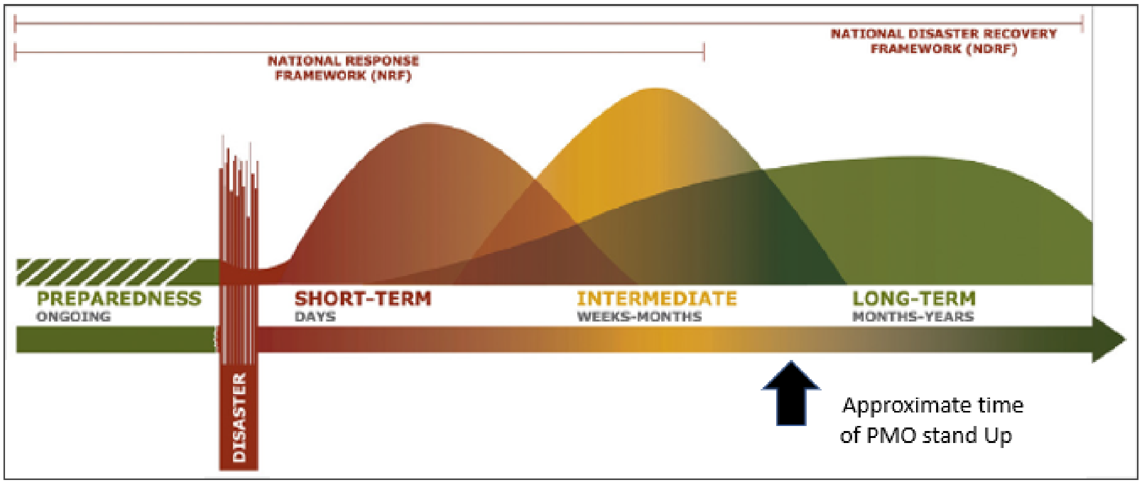

Figure 1. Shows the approximate time after a disaster that a PMO will be formed. Adapted from Haddow (Haddow and Bullock 2020)

II. Literature Review

This literature review covers three primary subjects relevant to the complexity and linear program model, which are presented in Chapter 4. The first part of the review covers the post-disaster environment, demand surge, and how they relate to project management. The second major review area covers project complexity and how it is defined and quantified. Third, a review of relevant optimization techniques that are used in the creation of the model.

Demand Surge

Demand surge is a well-documented but not well-defined phenomenon that commonly occurs after disasters and affects many sectors servicing recovery efforts. Typically demand surge is considered to be the excess cost burden that results from the

failure of local or regional firms to provide labor and materials to support recovery (Hallegatte et al. 2008). From a construction perspective, notionally, demand surge is determined to be active when typical repair and construction costs exceed 20% of normal pre-disaster rates (Olsen and Porter 2011). In simple terms, demand surge is the difference it costs to build post-disaster relative to how much it would have cost prior to the disaster. This difference often termed as capital losses, is relative to the scale of the disaster, with larger, more damaging disasters resulting in a larger demand surge (Döhrmann et al. 2013). Depending on the scale of the disaster, entire transportation, and regional supply chains may be interrupted, which can impose demand surge impacts outside the affected region. The local contractor workforce is hindered because they balance an increased workload with their own need to recover. Like the PMO acting as a relief valve to the local CES, many contractors travel from outside the local region to work in the recovery effort after a large-scale disaster. These contractors do so at a price, as the increased cost of logistics and travel is directly passed onto the customer via increased labor rates or material costs. (Ahmadi and Shahandashti 2018b). This combination of outside contractors and the overall demand for repair and reconstruction leads to the demand surge phenomenon and is the encompassing term used to describe the spike in construction cost during recovery after a disaster.

Historically, records of cost escalation from demand surge as early as 1704, in Britain, when the cost increase for roofing materials approached 500% after a large catastrophic storm hit England, and in 1886 after an earthquake in Charleston, bricklayers

commanded a 67% - 170% wage increase post-disaster (Olsen and Porter 2011). Demand surge has been documented after nearly every major disaster since and is often split into different metrics such as material cost, labor or wage costs, and insurance claims increases or losses. Here the focus is on the material and labor cost escalation, and the analysis ignores insurance claims related to demand surge, as they are not relevant for military applications. The increase in insurance claims can affect the overall post-disaster economy, but reviewing the insurance models is difficult as most of them are proprietary (Olsen and Porter 2011).

Disasters can create a shift in the demand for construction materials as the local supply is either damaged or lost from the disaster itself or is quickly exhausted by the immediate spike generated by post-disaster demand (Apurva et al. 2020). Therefore, demand for construction material reverberates at the local and regional levels. Contractors bringing in material from further away incurs increased logistics and transportation costs (Ahmadi and Shahandashti 2018a). The escalation of material costs has been studied extensively; for example, a forecast demand surge model was built to support recovery in the aftermath of an earthquake in New Zealand (Singh and Wilkinson 2008). Singh and Wilkinson's results suggest that high demand for aggregate and concrete materials create high local and regional costs which are due to their weight. While certain low density-high demand materials may increase in price due to demand surge, the United States is somewhat insulated from the magnitude of price shocks experienced by isolated nations, like New Zealand, due to the stability and size of its supply chain (Arneson et al. 2020).

While material cost escalation should be accounted for, labor cost escalation is generally where the majority of post-disaster project cost increase occurs (Olsen and Porter 2013). After-disaster, variation in labor costs is more extreme than cost escalation for materials due to the need to import labor from the surrounding region, or even further away. While the price increase mechanism is similar to that of material, the labor costs tend to increase further due to not only the logistics of transporting additional laborers into the affected area, but also sustaining them, and providing overtime hours, which are to be expected (Döhrmann et al. 2013). Several studies have shown the effect of demand surge on post-disaster labor cost escalation. Based on a study of 118 metropolitan areas affected by federally declared disasters (2004-2017), the average labor cost increased by 20%, but in one case was reported at 196% (Pradhan and Arneson 2021). These studies also revealed relevant trends in pre-disaster market conditions that may be used to forecast aspects of demand surge.

Identifying cost forecasting metrics would enable a PMO to predict and estimate cost escalation in the post-disaster economy with a higher degree of accuracy, which would ultimately result in the production of more accurate project cost estimates. Literature has shown that pre-disaster market conditions can signal how the post-disaster cost escalation will occur (Ahmadi and Shahandashti 2018a; Farooghi et al. 2020). The models developed by Ahmadi, Shahandashti and Faroogi were able to skillfully predict percent increase in labor wages, based on quarterly metrics of the local construction sector. Similarly, models focused on residential housing have come to comparable conclusions that pre-disaster

market conditions can be used to create analogous relationships for post-disaster reconstruction capacity and timing, particularly regarding availability and timeliness of permitting. For example, the availability of labor prior to the disaster positively correlates with post-disaster residential construction projects (Arneson et al. 2020). Furthermore, a key forecasting metric is how long demand surge will last. It is documented that Peak Labor Demand Surge typically occurs within *one year* of the disaster (Pradhan and Arneson 2021).

In summary demand surge creates a volatile construction economy, particularly for material and labor. This dynamic environment will constrain resources and typically increase the complexity of the portfolio the PMO manages. Incorporating the increased costs and resource constraints into the complexity model will capture the unique effects of demand surge on project complexity.

Project Complexity

Project complexity is reviewed to understand the nature of complexity, as it relates to stochastic and non-stochastic elements of construction, and to quantify it as a measurable or manageable variable that can be applied project managers who oversee projects during execution. Due to the wide application of project management (PM) in many fields, there is no consensus for what a complex project is, or what makes a project complex (Luo et al. 2017). Through this literature review, a complexity niche is defined in terms of U.S. Air Force program management and the PMO's stated objective of construction planning and oversight in a post-disaster environment. Complexity was used as the primary search

criteria in selection of review material as the research tied to it is comprehensive with respect to what a complicated project is; how its complexity is quantitatively determined; and how it is, or can be, managed (Bosch-Rekveldt et al. 2011).

In general, the more complex the project, the larger and more costly the project will be. However a project's cost is not absolutely analogous with its complexity. Most of the literature regarding the determinants of a project's complexity stems from Baccarini's original two component complexity concept of organizational complexity and technological complexity (Baccarini 1996). This was further developed into more granular concepts such as Bosch-Rekveldt's Technical, Organizational, and Environmental (TOE) framework to capture complexity of engineering projects. The three main components of TOE are further dissolved into subcomponents. Technical complexity is related to scope, goals, tasks, experience and risk; organizational complexity is related to resources, team makeup, team trust, and risk; and environmental complexity is related to stakeholders, market conditions, and risk (Bosch-Rekveldt et al. 2011). Additional frameworks for complexity in construction projects have expanded the components to six areas, such as technology, organization, goal, environmental, cultural, and information complexities (He et al. 2014).

As it relates to government construction projects complexity arises from the scope, as well as risk and uncertainty stemming from multiple stakeholders, significant political pressure or external pressures such as a post-disaster environment (Haas 2009). Having multiple stakeholders and the operational nature of the Air Force, i.e., deliberate and late

to adapt to rapidly changing local environment, may drive uncertainty in project timelines due to mission changes and shifting priorities. The above frameworks lay a foundation for the two-component complexity model of detail complexity and dynamic complexity, in other words there is a duality of complexity. Detail complexity covers elements of the protect that are largely static over time such as project size, stakeholders, relationship between facility components or systems to other infrastructure, variety of trades involved, and overall scope. Conversely dynamic complexity arises from elements that can change over time, often with little predictability. These dynamic elements include internal factors such as human error, resource availability, stakeholder inputs and relations, and changes to scope. The external factors include environment, weather events, economic and social or political issues (Zhu and Mostafavi 2017). Moreover, the post-disaster environment is highly adaptive, and changes rapidly as more stakeholders, and their priorities, are added to the planning process, which adds to the complexity of each project and requires highly skilled project managers (Thomas and Mengel 2008). For example, after Hurricane Michael devastated Tyndall AFB, there was uncertainty with respect to which facilities would be rebuilt, whether new missions would be placed at Tyndall, and old missions would move elsewhere. Ultimately this complexity requires more project management resources, be it time, money, personnel, or expertise (Baccarini 1996). The detail and dynamic complexity framework of Zhu and Mostafavi align well with Air Force construction management processes. The details of complexity can be assessed early on in project development and thus help appropriately allocate resources, such as having

experienced project managers assigned to mitigate the risks associated with dynamic complexity.

Furthermore, the Air Force typically employs a Multiple Project Management or Management of Groups of Multiple Projects (MGMP) model. In many cases, Air Force project managers are responsible for more projects than a typical private-sector project manager would be, likely for reasons associated with business-model differences. That is, private firms may hire project managers to account for a growing portfolio because their revenue potential increases with portfolio size. The literature area around MGMP is small, but one of the key points of success for MGMP is the effective and realistic assignment of projects to project managers. Where realistic assignment is defined by the project manager having both the skills and time, or work capacity and experience to effectively manage the projects tasked to them (Patanakul et al. 2007). The above literature review points to requiring highly skilled project managers to manage a complex portfolio in a highly uncertain environment, such as a post-disaster Air Force Base rebuild.

Despite several standardized metrics of competency measuring the skill of project managers, it is difficult to quantify in terms of project success. The Project Management Professional (PMP) certification and Project Management Book of Knowledge Guide (PMBOK) are well-established indicators of a project manager's knowledge. Nevertheless, it does not capture project execution acumen, and therefore there have not been effective indicators of success for project managers with certifications compared to non-certified project managers (Crawford 2005). As far as methods to balance project manager workload

and assignment, several models have been published in the literature (Patanakul et al. 2007). These models focus on hard skills such as technical competency and soft skills such as managerial, interpersonal, administrative, and business skills. Additionally, there are models using AHP methods to optimize the assignment of specific projects to specific project managers (Mian and Dai 1999). These models complement the proposed methodology in this thesis by aligning the most suitable project manager to a specific project. In this case, correct assignment increases the probability of project success.

Affecting project success is project manager workload. While the literature is not conclusive on what typifies an overburdened project manager, some heuristics have been proposed. The 10% rule says: of a project's planned schedule in labor hours; the project manager should expect to need 10% of the total labor hours to manage the project (Skaik 2009). A program manager can balance the 10% Rule with the expected weekly working hours of the assigned project manager after subtracting framework time such as staff meetings and non-project-related requirements. For example, if a project is scheduled to take 100 labor hours to complete, the project manager is expected to spend 10 hours managing the project over those 100 labor hours. Models based on this 10% heuristic have been developed for optimizing project assignment to projects managers (Patanakul et al. 2007). Additionally, research shows that the efficiency loss of task switching can be up to 40% productive time loss (Meyer et al. 2006). In essence, the more projects a project manager is balancing; the more productive time is lost in switching focus between projects. Some industry averages place the number of projects per project manager at less than eight

for high-performing organizations and greater than eight projects per project manager for underperforming organizations (Cabanis-Brewin 2016). It is unclear if the higher performers simply manage projects better, or if the high performers manage better because they are appropriately assigned work for optimal results. The aforementioned heuristics could be useful when paired with complexity metrics to target a portfolio allocation model.

Optimization Methods Review

Optimization and decision-making methods were reviewed to determine which methods best allow for the quantification of complexity in a manner that enables models to be adapted to a particular situation. The literature has identified some methods for modeling complexity, such as Analytical Hierarchy Process (AHP) (Vidal et al. 2011), Technical, Organizational, and Environmental Framework (TOE) (Bosch-Rekveldt et al. 2011). The analytical hierarchy process is a multi-criteria decision-making method that is well known and documented in the literature. The analytical hierarchy process lends itself to creating a ranked index of distilled values by using networked matrices to develop weighted values for each criterion of the decision. These values allow the index to be weighted according to the user's preferred utility of the selected variables (Saaty 2008).

Linear Programming offers many types of optimization solutions. Looking to the problem statement for motivation—finding the optimal number of human resources, or the number of project managers—one well-known Linear Programming Problem presents as an excellent analog, the Knapsack problem, and its variants. The basic premise of the Knapsack problem is optimizing what the knapsack can carry at some cost or value with

limits on a budget or weight capacity (Salkin and De Kluyver 1975). This problem has many variants, such as the Bin Packing problem, Multiple Bin Packing Problem, and Multiple Knapsack Problem. These variants are largely determined by the constraints imposed on the problem (Gurski et al. 2019). These constraints can be analogously reframed with project portfolio metrics to optimize the number of project managers, just as multiple knapsack problem optimizes the number of knapsacks required for optimal value. Many well-defined algorithms and software solvers exist to solve Multiple Knapsack Problems (Lahyani et al. 2019). These algorithms have been applied in some project management scenarios in the literature as far back as 1975 such as capital project selection (Salkin and De Kluyver 1975).

Literature Review Summary

In summary, for demand surge, the PMO will need to recognize, plan, and be prepared to function in the unique post-disaster environment and understand how it will affect the PMO's ability to program, develop, and execute projects. Demand surge will present a volatile economic milieu with steep cost escalation trends, particularly for construction material and skilled labor rates. Part of that cost escalation will be due to resources having to flow in from outside the local area, which may also present additional logistics complexity into even simple projects. The PMO can leverage several models to help mitigate demand surge. Identifying local market conditions prior to the disaster can help forecast to what extent demand surge may be present post-disaster. Furthermore, understanding demand surge trends such as the local impact of labor and material and

typical temporal trends such as cost escalation usually falling back to norms within one year will allow the PMO to mitigate some of the challenges of the post-disaster environment.

To summarize, project complexity is the combined effects of a project's uncertainty, risk, and technicality. This complexity challenges the management of the project management triangle of cost, time, and quality for each project. As it is applied to the PMO, project complexity increases in the post-disaster environment, where high politicization and frequent ambiguity in project priorities across the portfolio exist. The high complexity of the post-disaster environment demands effective project management, which implies that the right number of project managers with the appropriate skillsets be allocated to the PMO.

AHP, MAUT, and the Multiple-Knap-Sack problem were reviewed as relevant optimization techniques and are cited in the literature as malleable and suitable tools for optimal human resourcing. The AHP allows for complexity criteria to be prioritized in the model to capture contextual factors that increase the complexity, such as increased cost and longer timelines for material. Incorporating a MAUT allows each project to be evaluated for complexity. Finally, the linear programming solutions can be tailored to the decision-maker's risk tolerance to optimize the number of project managers and the skill of project managers to allocate to manage the PMO portfolio.

III. Background & Data

This chapter describes key background information for an Air Force PMO. This ties together the findings from the literature to the complexity score model developed in the next chapter. Additionally, this chapter introduces the raw data from the Tyndall PMO, which is used to construct the model.

As mentioned above, the two-component complexity framework (detail complexity and dynamic complexity) aligns well with the PMO processes. This is because, in government construction, the foundational document for a project—DD Form 1391 (Form 1391)—provides details for the project scope and captures most of the detail complexity elements. As a Department of Defense form this means it is useful for all services and provides a common document in which to draw the complexity information from even though here we are only evaluating a problem for the Air Force. These elements are size, variety, and interconnectedness which are discussed in detail in Chapter IV. These criteria were identified from the Form 1391s for the Tyndall PMO projects and can be seen below (Table 1).

Additionally, it is important to understand the roles and responsibilities expected of the PMO project managers. Referencing the *AFCEC Project Manager Guide for Infrastructure and Facilities*, AFCEC outlines key duties for Military Construction (MILCON) project managers as:

- Manage details involved with meeting the project goals
- Provide information as part of the project delivery team

• Be a key participant in executing and controlling contract changes

• Monitor the project schedule

• Track construction progress in ACES-PM/TRIRIGA (software)

• Manage the inevitable project changes due to changes in customer requirements, unforeseen site conditions, or design errors and omissions.

There is less day-to-day on-site management due to the MILCON process since a construction agent, such as the U.S. Corps of Engineers (USACE), handles the daily management of the project and contractors. Due to the reduced on-site duties per project assigned to a project manager relative to private-sector project managers who cover the typical project manager duties outlined in the PMP or PMBOK ("Project Managers' Guide for Design and Construction" 2008). The above review of the MILCON project manager is important as it will inform the constraints on the number of projects per project manager in the model. Only MILCON procedures are reviewed here, as the PMO data used and modeled for are based on a purely MILCON portfolio. Lastly an Air Force PMO is an operational organization established in the wake of a disaster, and the model developed here intends to maintain a leanness to promote implementation and adaptation across locations and disasters. That is, it intends to inform the PMO decision-makers before major project decisions are made, what human resources should be requested for effective recovery portfolio management.

Data

The data used in the model was obtained from the Tyndall PMO. The raw project data is derived from the Tyndall recovery portfolio, primarily from the Form 1391s (n = 52) detailing the project requirements and portfolio master schedule. The Form 1391s were used because they are the first requirement document for a project to be developed and thus are typically the earliest point at which a complexity score for a project can be calculated (Table 1). The projects are listed in the general order the Form 1391s were listed as originally provided by the PMO, so Project 1: "*Site Development Phase 1*" corresponds with the first Form 1391 in the file and so forth to Project 52, the project order does not correspond to any sort of priority or rank as listed (Table 1). Where available, most projects that have a contract or refined period of performance (PoP) values, in number of days, were used. For four of the projects, current PoP values were unavailable, and the Form 1391 value of 720 days was used, based on all projects given a two fiscal year period in the Form 1391s. The programmed amount (PA) from the Form 1391 is used as the project cost data. The PA is generally a rough estimate and is likely to be refined as the design-charrette process produces detailed drawings from which more accurate estimates can be made. The Form 1391 narratives were reviewed to glean data for the following criteria: the variety of construction to be completed (horizontal, vertical, specialty); the types of systems included in the project: none (n), standard (s), advanced/smart (y); the stakeholders (count); and if there is any phasing of the project (yes/no). This data is captured in (Table 1), and each criterion is fully defined in Chapter IV Methodology.

Table-1. Raw research data used from Tyndall PMO Form 1391 portfolio and master schedule.

	Criteria	Size		Variety		Interdependencies	
Project No	Project Name	PA (M)	PoP (d)	Stakeholders	horz, vert, specialty	Systems (n,s,y)	Phases (y/n)
1	Site Dvlpmt Phase 1	$ 194.0	1620	1	horz	s	Y
2	Ops AC Mx Hangar 1	$ 78.0	1170	1	specialty	y	n
3	Parking Apron	$ 45.0	1170	1	horz	n	n
4	MXS Complex	$ 48.0	720	1	vert	y	n
5	F35 MUNS Storage Facs	$ 25.0	890	1	vert	y	n
6	CDC	$ 41.0	623	1	vert	y	n
7	Afld Drainage	$ 144.0	1170	1	horz	n	n
8	Aux Ground Equip Fac	$ 22.0	1230	1	vert	y	n
9	Weapons Load trng Hang.	$ 25.0	1470	1	vert	y	n
10	Simulatro Fac	$ 38.0	1170	1	vert	y	n
11	Site Dvlpmt Phase 2	$ 142.0	1620	1	horz	s	y
12	Airey/Tyndall Gate	$ 50.0	890	2	vert	y	n
13	Comm. Gate	$ 25.0	840	2	vert	y	n
14	OSS Radar Approach Fac.	$ 37.0	840	1	vert	y	n
15	AC Mx Fuel Cell Hangar	$ 37.0	1260	1	vert	y	n
16	Areo Physiology Fac.	$ 13.0	720	1	Specialty	y	n
17	Special Purpose VM	$ 20.0	1034	1	vert	y	n
18	AC Wash Rack	$ 10.1	720	1	vert	s	n
19	OG/MXG HQ	$ 24.0	1322	1	specialty	y	n
20	IDRC/Flightline Kitch/Aafes	$ 44.0	720	1	vert	y	n
21	Lodging Facs	$ 179.0	1120	1	vert	y	n
22	Dorm Complex	$ 276.0	1220	1	vert	y	n
23	AC Mx Hanagar 2	$ 75.0	1290	1	specialty	y	n
24	AC Mx Hanagar 3	$ 76.0	1410	1	specialty	y	n
25	FlightLine Muns storage	$ 36.0	890	1	vert	y	n
26	325th FW HQ Fac.	$ 38.0	1040	1	specialty	y	n
27	EM Ops Center/Alt. CP	$ 20.0	785	2	specialty	y	n
28	SFS Mobility Storage Fac.	$ 6.7	673	1	vert	y	n
29	Small Arms Range, indoor	$ 26.0	720	1	speciality	s	n
30	Chapel	$ 26.0	890	1	vert	s	n
31	Community Commons Fac	$ 64.0	865	1	vert	y	n
32	MWR Fields	$ 10.0	690	1	horz	n	n
33	CE/CONS/USACE Complex	$ 104.0	1270	1	vert	y	n
34	LRS Complex	$ 117.0	1270	1	specialty	y	n
35	53 WEG Hangar	$ 133.0	1160	2	specialty	y	n
36	53 WEG HQ Fac	$ 70.0	1160	2	specialty	y	n
37	WEG Subscale Drone Fac.	$ 82.0	1020	2	specialty	y	n
38	MU-2 Hangar/B9310	$ 33.0	601	2	vert	s	n
39	WEG Parking Apron	$ 8.6	1100	2	horz	n	n
40	AFCEC RDT&E Fac & gate	$ 249.0	1120	2	specialty	y	n
41	Silver Flag Facs.	$ 33.0	790	2	vert	s	n
42	Fire Station #4, Silver Flag	$ 8.7	790	2	vert	s	n
43	ABM Simulaotr	$ 16.6	839	2	specialty	y	n
44	Fire Station #2	$ 11.8	984	1	vert	y	n
45	WEG Boat Ramp	$ 3.5	690	2	vert	n	n
46	CarWash/AUtoHobby	$ 7.0	602	1	vert	s	n
47	WEG Lg Drone Facilty	$ 8.5	690	2	vert	s	n
48	Corrosion Control Fac.	$ 9.1	1290	1	specialty	s	n
49	F-35 LRS (part of Mx Fac.)	$ 10.0	1350	1	vert	y	n
50	Dejarnette Gate	$ 25.0	827	1	vert	y	n
51	MWR Marina/Rec Center	$ 40.0	940	1	vert	s	n
52	Fire Station #1	$ 16.5	640	1	vert	s	n

IV. Methodology

Quantifying complexity into a manageable metric is a potential solution for PMOs to assess projects and allocate project managers to oversee the projects. Here, the AHP is the proposed method for quantifying project complexity, by creating a weighted complexity index applied to all projects in the recovery portfolio. The novel use of AHP would not be the selection of projects as it is frequently used in the private sector, but to create a complexity index to inform optimal allocation of resources, namely project managers.

Using AHP to create a complexity index is useful as an indicator in selecting projects to accomplish in a portfolio with multiple project opportunities (Vidal et al. 2011). Proper project management staffing will be required to ensure adequate oversight of the projects based on the project's complexity score. The typical Analytical Hierarchy Process takes four-six steps to accomplish. The steps are listed below in detail. Saaty usually has a four-step process and Karydas extends the four-step method to five steps and includes a sixth, benchmarking step. Here 'checking consistency' is step 5, but 'benchmarking' is included within the fifth step if applicable (Karydas and Gifun 2006; Saaty 2008).

1) First, the problem or decision needs to be established by clearly stating the goal or type of information to be conveyed. *How is Project Complexity determined?*
2) Second, structure the decision hierarchy. Start at the top by stating the decision to be made. Then list the key categories or groups that inform that decision. Next, list the subcategories or criteria that make up each primary group. Lastly,

list any alternatives to be considered. *The primary criteria are Project Size, Project Variety, and Project Interdependence.* They each have two sub-criteria in the model. All the criteria are defined below.

3) Third, construct pairwise comparison matrices for the primary group of decision criteria. Then set up comparison matrices for each group of sub-criteria. Table 2 below outlines the 1-9 rating used for each pairwise comparison. *The AHP model's pairwise comparison matrices are shown below* (Table 4-5).

4) By evaluating the priorities from the pairwise comparisons and then taking the geometric mean of each row in the matrices, an initial weight for the criteria is produced. These weights will then be multiplied by the weight of the respective primary criteria in the hierarchy (Jagoda et al. 2020). *The final calculations of weights are shown in the weight column of the Pairwise Matrix* (Table 6), and example of step four process is shown in the appendix (Figure 12).

5) Check for consistency; repeat steps 3-4 if needed. Once consistency is achieved, benchmark the results if applicable. Consistency ensures that the decision-maker choosing the priority of each pairwise comparison is not breaking the transitive property. That criterion A is preferred to criterion B, and criterion B is preferred to criterion C; therefore, criterion A must be preferred to criterion C. There is some tolerance in the method if the exact pairwise multiplication is not perfectly transitive. The generally accepted tolerance is a consistency ratio

(C.R.) less than 0.01(Ishizaka and Labib 2011). An example process is shown in the appendix (Figure 13). *The model's consistency rating is C.R. = 0.0029*

Having more criteria in an individual pairwise matrix makes consistency among all pairwise comparisons within the matrix very difficult to achieve. Consistency among each pairwise matrix is crucial for the resulting weighted index to be meaningful for real-world application (Ishizaka and Labib 2011).

Table - 2. Shows the 1-9 rating levels to use during the pairwise comparison adapted from (Ishizaka and Labib 2011).

Pairwise Comparison Rating Values

Intensity of Importance	**Definition**
1	Equal importance
2	Weak
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong or demonstrated importance
8	Very, very strong
9	Extreme importance

Creating the Framework

The analytical hierarchy process framework proposed is based on the framework developed by (Vidal et al. 2011) (Table 3), which is rooted in Baccarini's original project

complexity dichotomy of organizational structure complexity and technological complexity (Baccarini 1996), but the criteria ultimately are used to capture the detail complexity (Zhu and Mostafavi 2017). Keeping the process lean is important as the PMO will have many tasks to accomplish as the organization is formed and begins managing the recovery effort. To keep the AHP lean, the technology criteria used in other models are not used here. It has been incorporated into system interconnectedness criteria. For example, if truly novel technology is being used for projects in the recovery portfolio such as 3-D printing, a separate technology primary criterion may be warranted. It could be included in the AHP framework by the PMO leadership since the demonstration of the technology is a priority focus in such a case.

The selected criteria and sub-criteria presented below (Table 3) is a proposed minimum criteria solution. Keeping the process lean increases usability but does come with a small risk of being less accurate in capturing complexity. This distinction is important as decision-makers for the PMO require some level of accuracy, but less comprehensive metrics to gauge its organizational size and requests for project managers. This is contrary to the private sector and contractor perspective, where more accuracy can be correlated to more profits and lower risk or uncertainty in evaluating alternatives. The risk here is marginal and takes the form of requesting an extra or too few project managers, which can easily be rectified by shifting human capital. The PMO can gain better complexity resolution by adding additional criteria. Some of these are discussed in the future research section in the conclusions.

Table 3. Primary criteria and sub-criteria of project complexity of the analytical hierarchy process model.

Project Complexity Hierarchy

Primary Criteria	***Project Size***	***Project Variety***	***Project Interdependencies***
Sub-Criteria	Project Cost ($M) Period of Performance (# days)	Construction Variety Number of Stakeholders	Project Phases System Interconnectedness

Next, each selected primary criteria and sub-criteria are defined within the context of the PMO and government construction.

1) Project Size: These are easy to see descriptors that are most associated with any project and are composed of Cost and Period of Performance (PoP) typically measured in the number of days:
   a) Period of Performance: Specified in the contract, this is the number of days it is expected to take the contractor to complete the project. While the period of performance alone is not a great indicator of complexity itself, it can be a useful forecasting tool. Preliminary studies (Teston et.al, 2021) show that the longer a project lasts, the more likely a cost or schedule overrun will occur.
   b) Cost: Usually the most visible or well-known aspect of any project. It is not a great indicator of complexity itself, but high-cost projects tend to attract attention and publicity which can add to the complexity.
2) Project Variety: This category covers the more technical portions of the project such as how many skill sets are required to understand the statement of work and execute. It

also covers the number of stakeholders. These types of subcategories make a project more complicated and increase complexity:

a) Variety of construction: This sub-criterion evaluates the number of skillsets required. Horizontal dominate projects such as roads or utilities rate low, full vertical construction rates higher, and specialty construction such as SCIFs or other unique or less common requirements rate highest.

b) Number of Stakeholders: Individual stakeholders are defined as mission owners for the model, typically the O-6 level commander. When multiple stakeholders are involved with one project or multiple projects, the complexity increases significantly. Often this is one of the largest contributors to complexity in a project. A stakeholder is defined as the mission owner, which is straightforward if the owner is co-located with the project. If the mission owner is geographically separated, then a second stakeholder, namely the local Wing Commander or their delegate, is automatically a second stakeholder due to "influence via jurisdiction" since the local wing can easily affect the project's progress. Additional stakeholders will come into play if multiple mission owners or jurisdictions are in play. For the Tyndall PMO, most projects have 1 or 2 stakeholders as defined in this model.

3) Project Interdependencies: This category captures parts of the project that are reliant on other factors within the project itself or other projects in the portfolio:

a) System interconnectedness: This sub-criterion captures the technology that may be new or novel in construction, such as sensors or alarms. Additionally, if the new

systems being installed are standard technology, they need to tie into an existing network. Some standard systems are facility alarms, fire suppression, and wastewater removal system. The new smart technology or the more systems are linked together, the higher the complexity rating.

b) Project Phases: Straight forward, if there are phased projects where one or more projects depend on the completion of an earlier phase, there is a higher complexity due to the dependency on other active projects in the portfolio.

With criteria defined, four pairwise comparison matrices were created to evaluate the proposed framework. The first matrix compares the three *primary* criteria of project size, project variety, and project interdependence (Table 4). The following three matrices compare each sub-criterion (Table 5). Each criterion is compared to the other criteria in the matrix. When a criterion compares to itself, the result is always one, which is shown down the diagonal of each matrix. The preferred or prioritized criterion is given a whole number value based on the one to nine scale (Table 2). The alternative criterion is assigned the reciprocal of the whole number given to the prioritized criterion. For example, if *PoP* is preferred over *cost* with a value of three, then the score for *cost* is one-third. The pairwise comparisons were obtained from SME input and adjusted to ensure consistency. Once the pairwise comparisons are completed in each matrix, a geometric mean is used to calculate the weight of each criterion. Next, the weights from the primary criteria are multiplied by the weights in their respective sub-criteria to produce the final complexity index weight values for each sub-criterion (Table 6).

Table 4. Shows the Primary Criteria pairwise comparison matrix for the AHP model and resulting primary criteria weights

Pair-Wise Comparison Matrix for the Primary Criteria

Primary Criteria	Project Size	Project Variety	Project Interdependence	Weight (%)
Project Size	1	1/2	3	31%
Project Variety	2	1	5	58%
Project Interdependence	1/3	1/5	1	11%

Table 5. Shows the Sub - Criteria pairwise comparison matrix for the AHP model and resulting sub-criteria weights

Sub-Criteria Pair-Wise Comparison Matrix

Size Sub-Criteria	Period of Performance	Cost	Weight (%)
Period of Performance	1	3	75%
Cost	1/3	1	25%
Variety Sub-Criteria	Variety of Construction	Stakeholders	Weight (%)
Variety of Construction	1	3	75%
Stakeholders	1/3	1	25%
Interconnectedness Sub-Criteria	Phases	Systems	Weight (%)
Phases	1	1/2	33%
Systems	2	1	67%

Before moving to the MAUT portion of the methodology, let us see how a few projects look using the Form 1391 data (Table 1) broken out into the defined sub-criteria (Table 7). These sample projects are taken from throughout the portfolio, they are not projects numbers 1 through 4. They were chosen to highlight the diversity of the Tyndall portfolio and how seemingly large projects may not always be the most complex. These

example projects are shown later as we transmute the raw data into utility values (Table 8), and finally complexity scores (Table 9). With the AHP complete the resulting consistent weighted decision variables can inform what criteria weigh the most on the decision at hand.

Table 6. Final weight calculation for each Sub-Criteria, the final weights are also shown and discussed in Results, note values have been rounded to two decimals.

Final Complexity Index Weight Table

Primary Criteria	Weight	Sub Criteria	Sub-weight X Primary-weight	Final Weight (%)
Size	31%	PoP	0.75 × 0.31	23%
		Cost	0.25 × 0 .31	8%
Variety	58%	Construction Variety	0.75 × 0.58	43%
		# Stakeholders	0.25 × 0.58	15%
Interdependency	11%	Phases	0.33 × 0.11	4%
		Systems	0.67 × 0.11	7%

Table 7. Example projects display the raw data gleaned from the Form 1391s.

Sample Projects Raw Data Values for AHP Criteria

	Criteria	**Size**		**Variety**		**Interconnectedness**	
Project Number	Project Name	Cost ($M)	PoP (days)	Stake-holders	Construction variety	Systems	Phases
1	Site Development Phase 1	194	1620	1	Horizontal	None	Yes
33	Civil Engineer, Contracting, USACE Complex	104	1270	1	Vertical	Advanced	No
36	WEG Headquarters	70	1160	2	Specialty	Advanced	No
51	MWR Marina & Rec. Center	40	940	1	Vertical	Standard	No

Applying Multi-Attribute Utility Theory to the AHP

The next step in the process draws upon Multi-Attribute Utility Theory (MAUT). MAUT effectively applies a perceived ranking or utility of each of the complexity criteria

for each project; it allows each project's sub-criteria to be evaluated independently (Karydas and Gifun 2006). In the model, each sub-criterion utility is evaluated on a percentage scale. The least complex projects have the lowest values while the most complex projects have the highest values. Using a zero-to-one-hundred percent scale normalizes the values, used in decimal zero-to-one form, and allows utility curves to be drawn for each sub-criterion for each project in the portfolio (Figure 2).

Additionally, each utility table was determined to have a stepwise rise in utility, or complexity, as used here. These stepwise buckets were chosen to be mostly linear steps, with larger steps indicating more uncertainty, and thus more complexity, for the categorical criteria. For example, smart technology is still in development of how it will be implemented, and thus has a lot of uncertainty associated with it. The stepwise buckets were based on natural breaks in the real data for the continuous criteria of PoP, and an example of cost is shown (Figure 3). These utility charts were then reviewed by SMEs for general concurrence of the values.

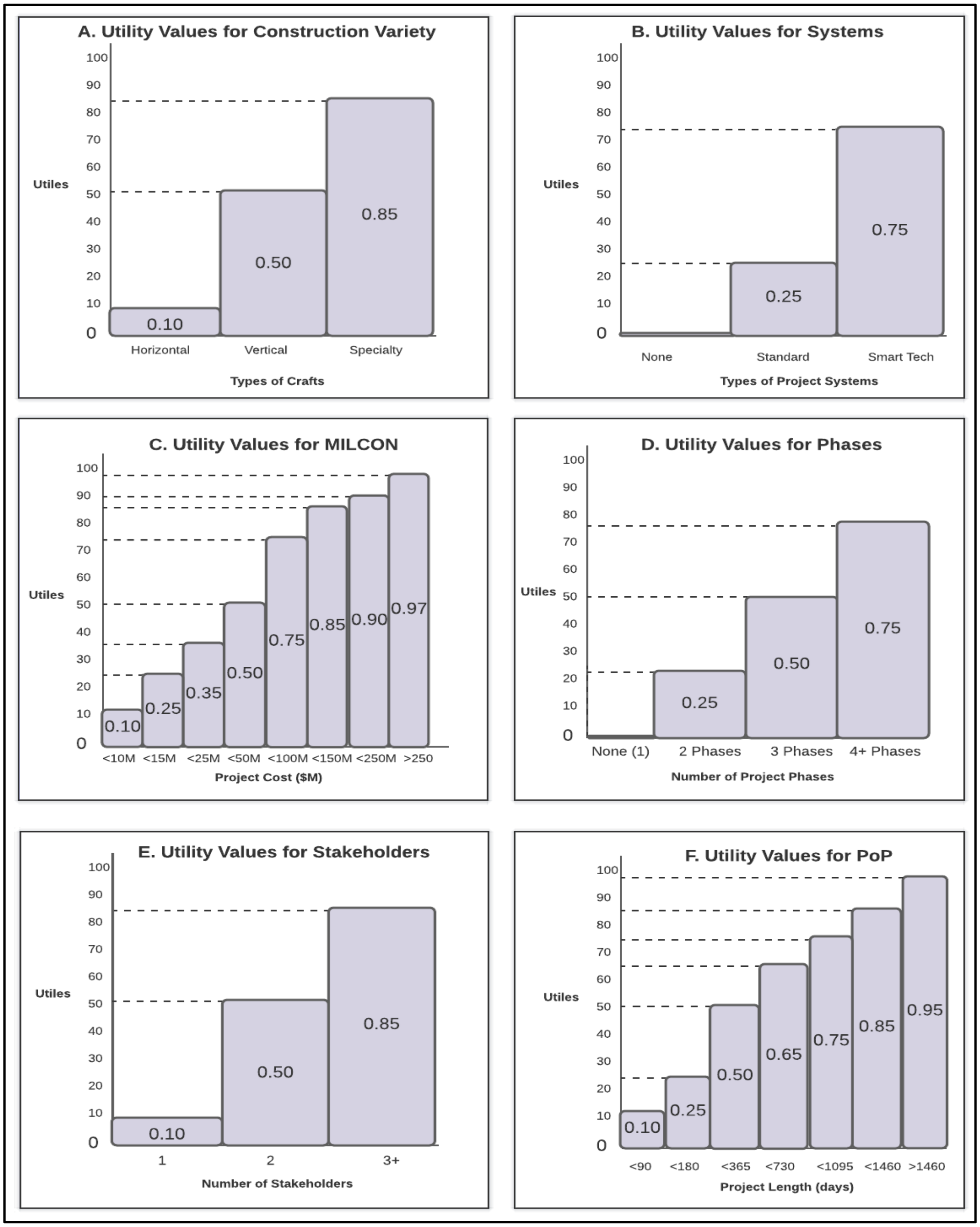

Figure 2. MAUT utility scores for each sub-criterion in the AHP. Chart A details the utility values for construction variety. Chart B details the utility values for systems. Chart C details the utility values for the cost ($M). Chart D details the utility values for phases. Chart E details the utility values for stakeholders. Chart F details the utility values for PoP in days.

Tracking Project Cost to Corresponding Utility Value

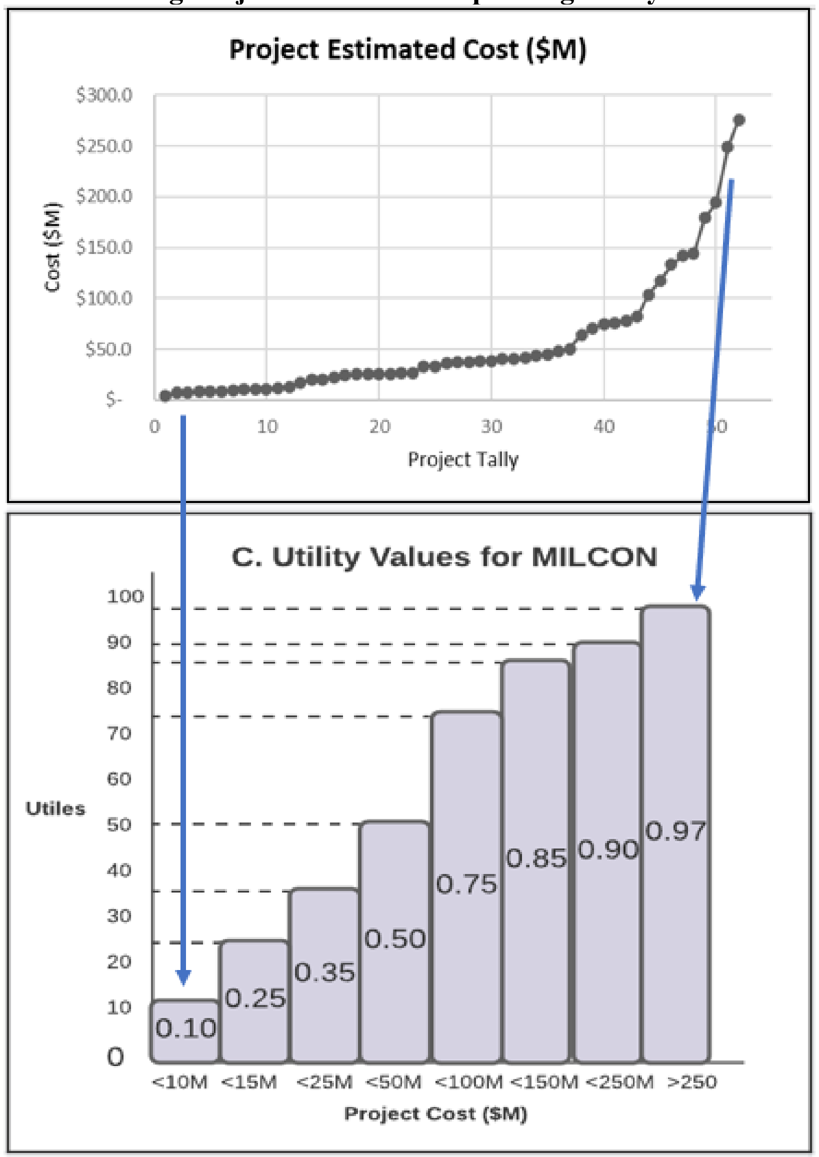

Figure 3. Tracking of breaks in the portfolio cost data to utility value.

Table 8. Example projects display the utility data converted from the Form 1391s raw data.

Sample Projects Utility Values for AHP Criteria

Project Number	Criteria	**Size**		**Variety**		**Interconnectedness**	
	Project Name	Cost ($M)	PoP (days)	Stake-holders	Construction variety	Systems	Phases
1	Site Development Phase 1	0.9	0.95	0.1	0.1	0.25	0.25
33	Civil Engineer, Contracting, USACE Complex	0.75	0.85	0.1	0.5	0.75	0
36	WEG Headquarters	0.75	0.85	0.5	0.85	0.75	0
51	MWR Marina & Rec. Center	0.35	0.75	.01	0.5	.025	0

As an example, we revisit the example projects (Table 8) and see that the raw data scores have been transmuted into their associated utility scores. Once each project has been evaluated with MAUT, the utility value is multiplied by the corresponding weighted criteria from the AHP. Lastly, the weighted utility of each criterion is summed to produce a complexity score for each project. An example of the process for the first five projects is shown, note these are different projects from the four sample projects shown earlier (Figure 4). This provides the decision-maker a complete list of weighted projects ranked by complexity. This process is repeated for all projects in the recovery portfolio to produce a list of 1-n projects from the most complex to least complex. The final list of 52 projects complexity ratings is shown in the Appendix (Table 18).

	Project Complexity Index	Project Utility Score				
Criteria	Criterion Weight	Project 1	Project 2	Project 3	Project 4	Project 5
Cost	0.08	0.90	0.75	0.50	0.50	0.35
PoP	0.23	0.95	0.85	0.85	0.65	0.75
Variety	0.44	0.1	0.85	0.1	0.5	0.5
Phases	0.04	0.25	0	0	0	0
Systems	0.07	0.25	0.75	0	0.75	0.75
Stakeholder	0.15	0.1	0.1	0.1	0.1	0.1
Total	100%	38	69	29	48	49

Individual Project utility Scores transposed from Table 9.

Complexity Index derived From AHP Final Weights

Final project Complexity ratings calculated by taking the sum product of the project's utility scores with the Criterion weights

Figure 4. Example of final complexity rating process combining the AHP and MAUT portions of the model for projects 1 through 5 in the portfolio.

It is worth reviewing the example projects, recall the example projects are not all represented in Figure 4, and seeing how the final complexity score shakes out for those projects (Table 9). Note that even with extremely high project size scores in *cost* and *PoP,* as well as having a *phase* input the site development project is not that complex. Conversely the WEG headquarters is middle of the road in size and no phase, but rates high in the *construction variety*, and *systems* as well as having two *stakeholders* result in this being one of the most complex projects in the portfolio. The Civil Engineer, Contracting, and USACE complex end up rating slightly above average in the portfolio, and the MWR Marina and Recreation Center are simple, and are at the bottom of the portfolio's complexity. These results are generally expected from the information available in the Form 1391. However, one may be inclined to think the Site Development project to be

more complex than it really is compared to the WEG Headquarters. The MWR project includes a restaurant a few other straightforward facilities, but the bulk of the work is simple horizontal construction of recreational fields and simple marina. These summarize what we expect to see when one really considers the complexity criteria, and realize the complexity scores being modeled are realistic.

Table 9. Shows the final steps of the Complexity score process by taking the sum-product of each project's utility values with the AHP criterion weights. Recall these projects are not all represented in Figure 4.

Example Complexity Score Calculation Table

	Complexity Index	**Project Utility Scores**			
Sub-Criteria	Criterion Weight	Site Development Phase 1	Civil Engineer, Contracting, USACE Complex	WEG Headquarters	MWR Marina & Rec. Center
Cost	8%	0.90	0.75	0.75	0.35
PoP	23%	0.95	0.85	0.85	0.65
Variety	43%	0.1	0.5	0.85	0.5
Stakeholder	15%	0.1	0.1	0.5	0.1
Phases	4%	0.25	0	0	0
Systems	7%	0.25	0.75	0.75	0.25
Total	**100%**	**38**	**54**	**75**	**43**

Project Manager Assignment

Following the determination of project complexity, the next step is to determine the optimal number of project managers. Project manager assignment can be parameterized in government project management terms analogous to a multiple knapsack or bin packing problem. Instead of knapsacks holding a certain capacity of items of some value, there are project managers "holding" a certain number of projects of some complexity.

Here, two types of project managers are identified, by experience level, to manage risk in the portfolio management, though any number of experience levels and project

manager endowments are possible. The first type of project manager is inexperienced and referred to hereafter as a *novice*. Novice project managers are included in this analysis for two reasons: 1) to meet a need put forth by Air Force Civil Engineer leadership to use PMOs as low-threat environments to allow inexperienced, company-grade officers to gain operational experience; and 2) to illustrate how the model reacts to extremes in experience level. The second category of project managers is defined as experienced, *expert* managers. These are typically contractors or mid-level government civilian (GS-12 or 13) or military (field grade officer) employees. An objective function is proposed to minimize the number of project managers, which is seen as a worthy objective considering each project manager must be paid. The constraints on this objective function are detailed below (Table 10) and defined algebraically (Table 11).

Table 10. Lists the model constraints and associated details or assumptions.

Optimization Constraint Details

Constraint	Details & Assumptions
Every project is assigned to a project manager	Based on all projects getting funded, and thus must be managed
No more than 8 projects per project manager.	Based on the literature that 8 projects are the tipping point from high to low performance
Novice managers may not manage projects with greater than 50 complexity	Based on the average complexity of the portfolio is 51.
Experts may manage a project of any complexity.	The assumption that the hired experts are qualified for the most complex projects
At least four novice project managers must be used	The assumption is that a minimum novice footprint will be required.

Table 11. Shows the variable definitions and functions for the constraints

Algebraic Constraint Definitions

Variable/Function	Definition
Where n projects indexed by j, where j = {1,…,n} Where m project managers indexed by i, where i = {1,…,m}	
x_{ij}	Whether a project manager i, is assigned project j
w_j	Project complexity rating for project j
W_i	The allowable complexity for a given project manager
p_i	Cost of hiring/utilizing project manager i
$\min Z = \sum_j \sum_i p_i x_{ij}$	Objective Function
$\sum_{j}^{n} x_{ij} \leq 8, \forall\, i \in \{1, \dots, m\}$	Workload constraint of no more than 8 projects per project manager
$w_j x_{ij} \leq W_i, \forall\, j \in \{1, \dots, n\}, \forall\, i \in \{1, \dots, m\}$	Allowable Complexity Constraint
$\sum_{i}^{m} x_{ij} = 1, \forall\, j \in \{1, \dots, n\}$	All projects must be assigned to one and only one project manager
$x_{ij} \in \{0,1\}, \forall\, i, j$	Binary restriction of project manager assigned or not assigned

The linear optimization was executed using an open-source bin packing methodology template in Microsoft Excel. The cost data for using or hiring an expert project manager was found on the Bureau of Labor and Statistics. The salary of an Architectural & Engineering manager with at least five years of experience was used for the expert salary. These costs (Table 12) are notional and meant to represent the likely cost of hiring contractor employees to manage PMO projects, which was the case in the Post-Katrina PMO at Keesler AFB. The cost for novice project managers is based on the annual salary of a 3-year Lieutenant, as CGOs are intended to fill this role in the model.

Table 12. Lists the estimated annual costs for project managers of varying skill levels

used in the model.

Estimated Annual Cost Per Project Manager	
Expert Project Manager	Novice Project Manager
$150,000 per year	$90,000 per year

V. Results

The following section shows the results of the model, beginning with the outputs of the AHP complexity index. Next, the utility scores for the example projects are shown. The full utility scores and final complexity scores for the portfolio can be found in the appendix (Tables 17-18, respectively). Finally, a presentation of the number of project managers required based on the model's constraints is discussed in the methodology section.

Table 13. Shows the final AHP Complexity index weight per sub-criteria

Final Complexity Index Weight Table	
Sub-Criteria	Final Weight (%)
PoP	23%
Cost	8%
Construction Variety	43%
Stakeholders	15%
Phases	4%
Systems	7%

The finalized sub-criteria weights of the AHP (Table 13) show that *construction variety*, which captures the technical scope, is the prioritized criterion in the model, but the other criteria are of measurable weight to the overall complexity score. The lowest being *phases* at 4%. Without more data points to support phasing being weighted higher in the model for the Tyndall portfolio, this may be a low-end prioritization of phases as a

complexity indicator for government projects. Finally, note that the criteria weights sum to 100%, so the sub-criteria fully define complexity in the model.

Table 14. Summary Statistics of the portfolio's complexity, cost, and PoP sub-criteria.

Summary Statistics

	Average	Standard Deviation
Portfolio Complexity Score	51.76	12.40
Portfolio Raw Cost ($M)	53.08	61.8
Portfolio Raw PoP (days)	1004	267

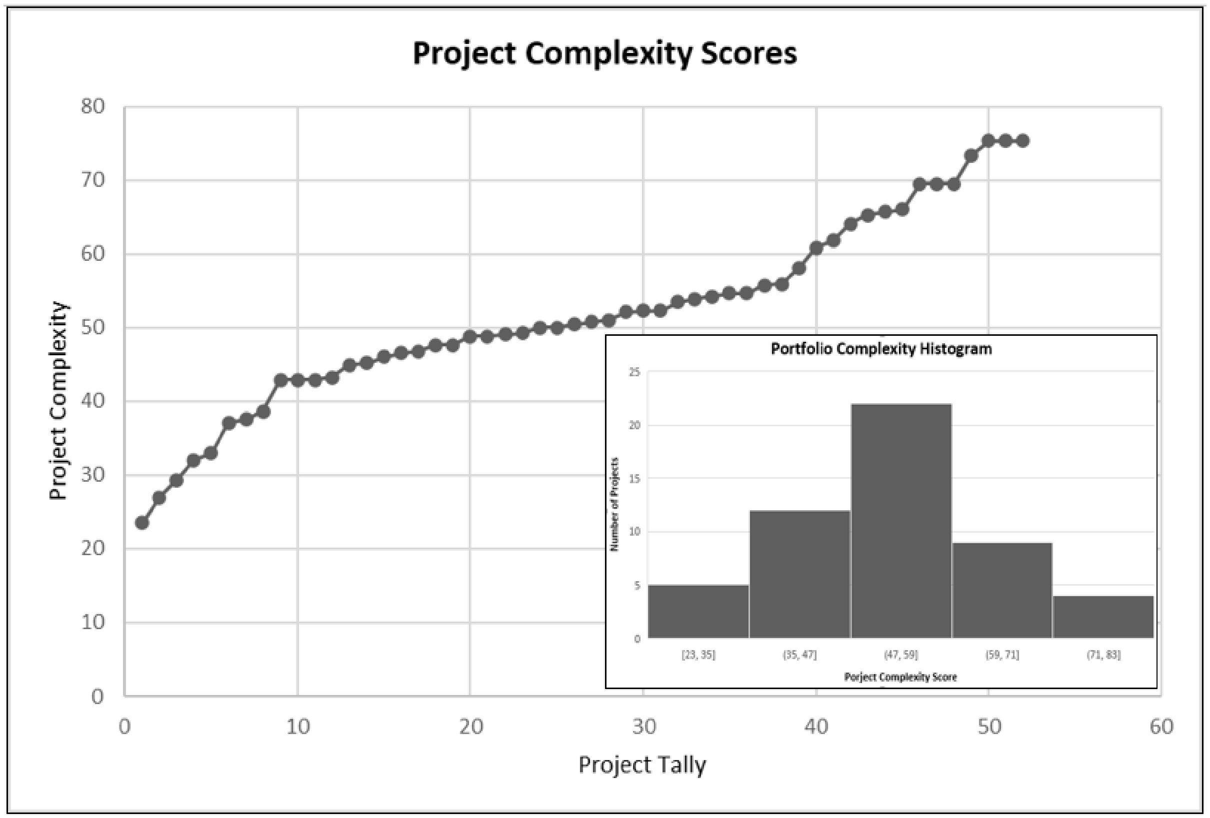

Figure 5 - Line graph showing the range of complexity across the Tyndall portfolio, with inset histogram showing the approximately normal distribution of complexity scores.

The distribution of the recovery portfolio is pseudo normal (Figure 6), and the spread of complexity from the lowest of 24 to the highest at 75. This variance across the

portfolio allows for a broad spectrum of projects, non-complex and complex, in which project managers of varying skill levels can be assigned. The summary statistics show useful data that can also support decisions in risk tolerance (Table 14). Knowing the average complexity and the standard deviation allows informed decisions regarding where to create boundaries between complex and non-complex projects. This will not only mitigate risk but allow the managers to be assigned well according to their skill. If the distribution had been severely clumped or very flat, then it would be the case that a consistent level of skill would be required across the portfolio.

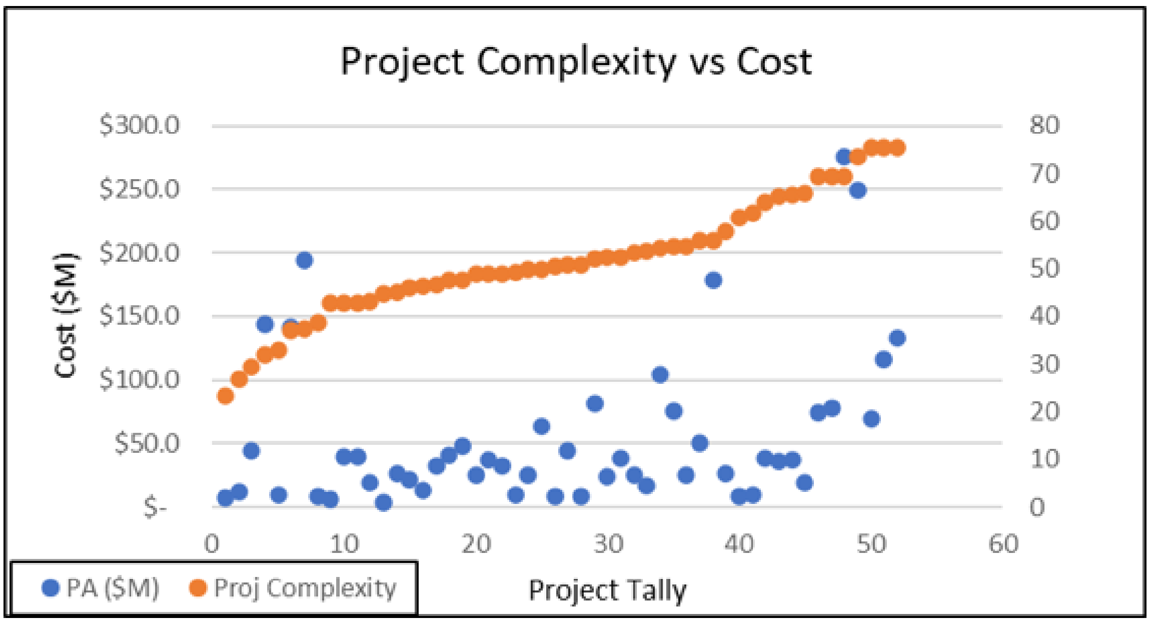

Figure 6. Plot comparing complexity Scores and the project's cost. This shows the portfolio organized by increasing complexity, in orange, compared to the projects respective cost in blue.

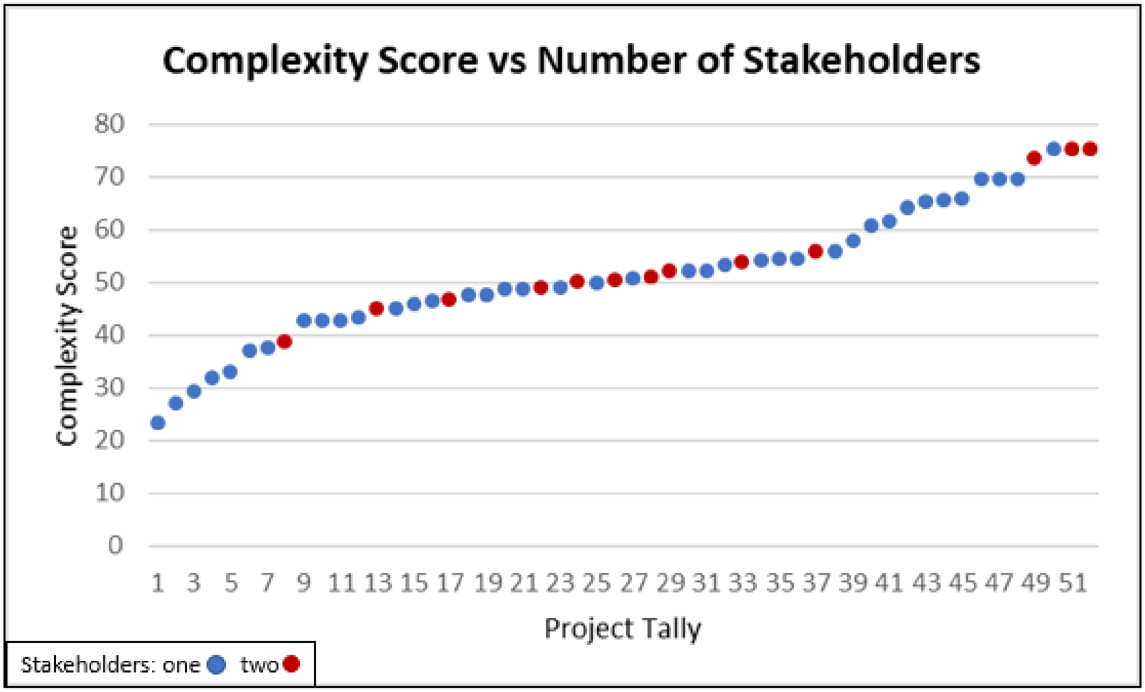

Figure 7. Shows complexity relative to the number of stakeholders in the project. Note that having multiple stakeholders, while indicative of complexity, does not dominate the complexity scores.

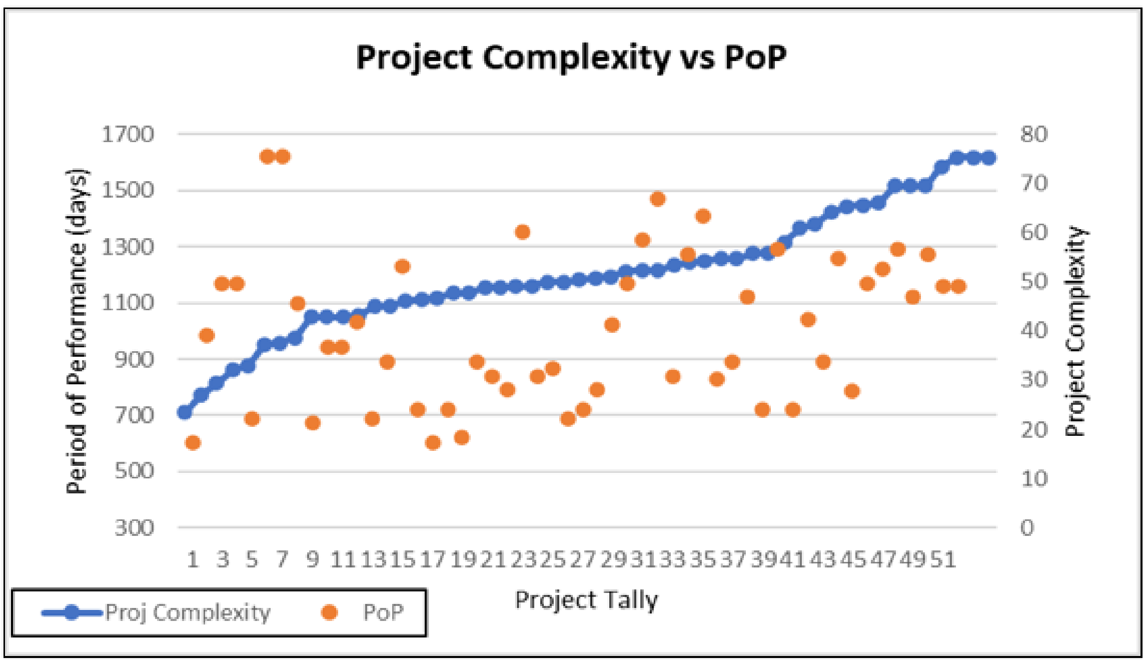

Figure 8. Shows project complexity compared to the respective PoP. Note that the PoP does not dominate the complexity score.

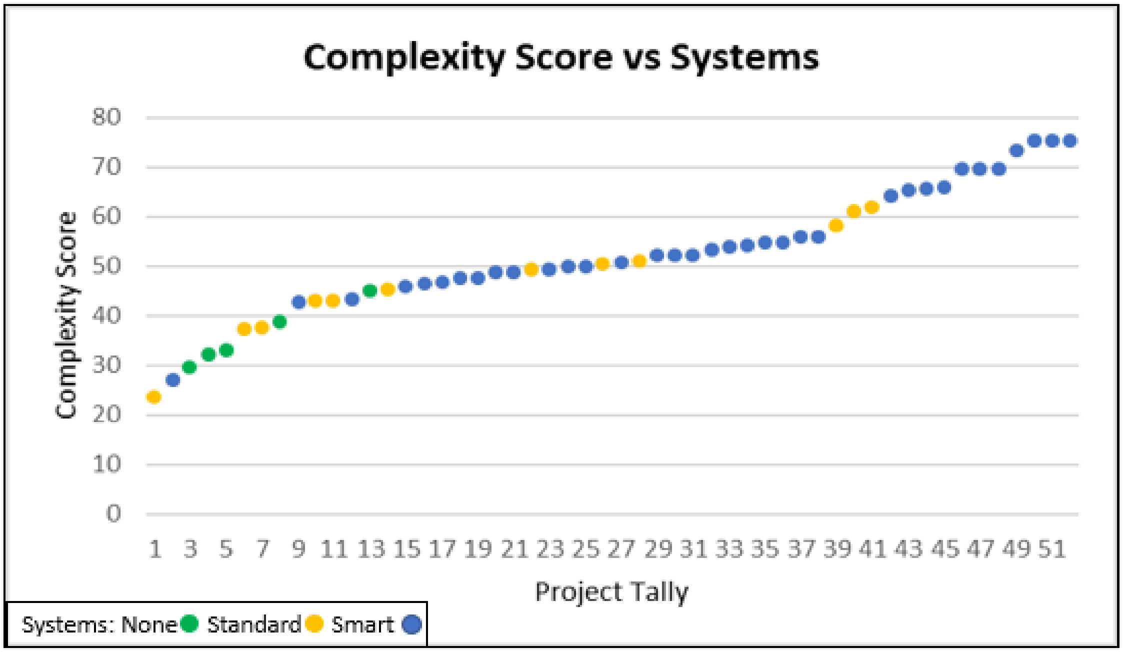

Figure 9. Shows the complexity scores compared to the systems included in the project. Note that smart systems appear across the most complex projects; they are also spread throughout the portfolio.

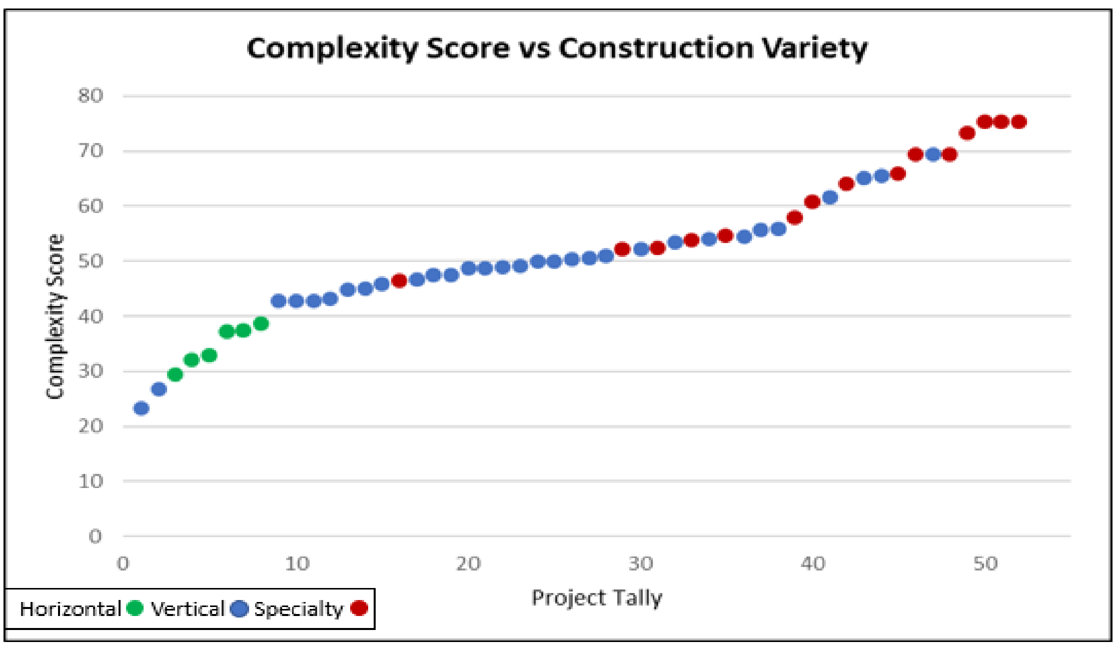

Figure 10. Shows the complexity scores compared to the project's construction variety. Note that this criterion captures the scope of the project and is the most dominant of the criteria.

One key result is checking whether one criterion dominates the resulting complexity score to the point that the other criteria are not useful. Visually (Figure 6) shows that cost is not dominant, though one may assume that a more costly project is larger in scope and thus higher in complexity, it is clearly not always the case. Notably, the three most complex projects have middle-of-the-road project costs relative to the portfolio. Similarly, comparing complexity to PoP, there is not a trend among projects with the largest PoP also being the highest in complexity (Figure 8). Though it may seem intuitive that the longer a project lasts the more opportunity that some dynamic complexity may arise and cause some sort of delay or overrun, the PoP itself does not dominate the complexity score. Notably, the number of stakeholders does not dominate either (Figure 7). The literature often depicts stakeholders as the single largest factor in a project's complexity, but the narrow definition used in the model may mute the traditional power associated with multiple stakeholders. Next, look at the complexity score compared to systems (Figure 9). With systems, we see Smart systems heavy at the top, but it appears across the portfolio. Standard systems also cover a large swath of the portfolio, while projects with no real systems included tending to be low complexity. Due to the lower weighting of the system's criteria in the AHP and the general spread of the systems across complexity scores, this would not be considered a dominating criterion. Finally, look at complexity compared to construction variety. We see most, but not all the specialty construction projects towards the high complexity scores. In fact, only one project with specialty construction was below average relative to the portfolio. Conversely, the projects

that are horizontal in nature do tend to be low complexity and can be seen as a clump in green toward the lower end of the complexity (Figure 10). While not completely dominant, this skew towards specialty construction having greater complexity scores is expected as the AHP weights the construction variety highest among all the criteria in the complexity index. Construction variety is the biggest indicator of complexity in the model, as it is the criteria that capture most of the scope of a project, but it does not paint the whole picture. The other criteria are critical to getting accurate and usable results from the complexity scores.

Finally, below (Table 15) are the results of the linear programming solver showing the number of novice and expert project managers required to manage the portfolio. These results are based on the input constraints of the model as written in the methodology (Tables 10-11) and the cost estimates used in the model (Table 12). These results show that the PMO would need approximately $1M per annum to fund their project manager element if fully contracted. Below is a visual representation of the solver output (Figure 11).

Table 15. Results of the excel solver for the optimal number of project managers

Optimal Number of Project Managers

Project Manager Level	Number Required	Annual Cost ($K)
Novice	4	360
Expert	4	600
Total	**8**	**960**

While this results in a minimum number of project managers based on the skill and workload constraints, the solver output is not the most efficiently balanced in complexity. Most decision-makers would probably reduce the cost of the fourth expert managing only

one project by accepting some risk to give a lower-level expert complexity project (51-55 Complexity) to the unburdened fourth novice. Alternatively, the workload could be balanced among all four experts in a more risk-averse scenario. Likewise, the constraints can be adjusted to produce different risk tolerance scenarios. Reducing the work capacity constraint to 5 projects per project manager or increasing risk tolerance by allowing novice managers to work on higher complexity projects, up to 60 perhaps.

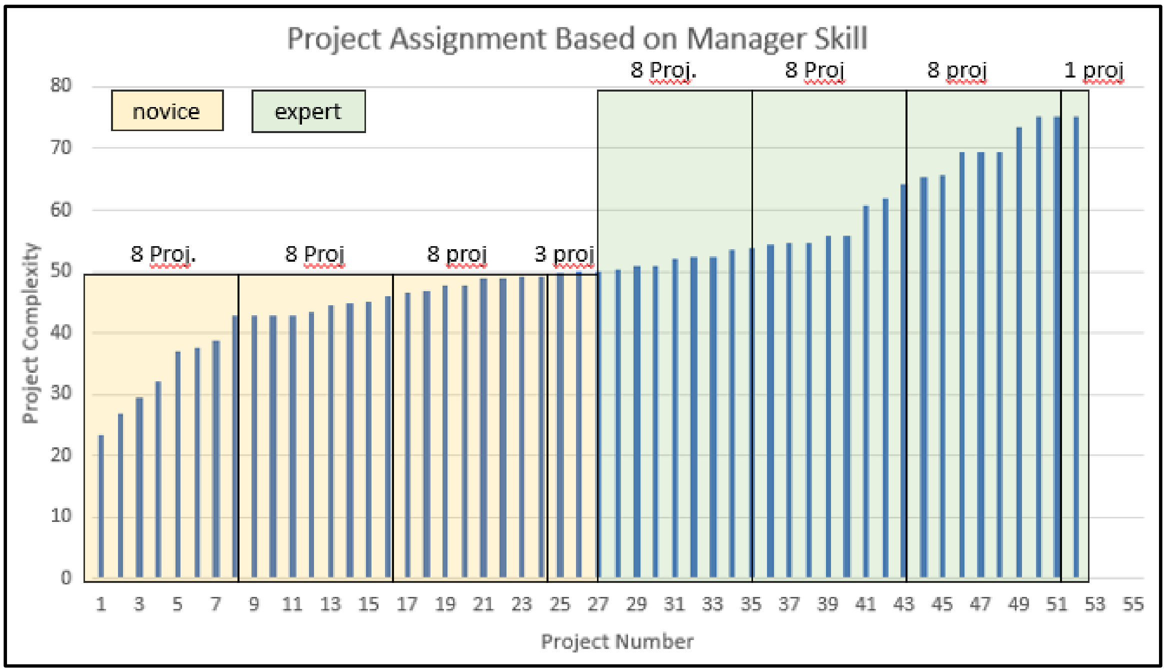

Figure 11. Visually shows the allocation of projects to project managers from the solver output.

VI. Discussion

The results show that the AHP and MAUT methods employed can be used to develop a project complexity index and individual complexity scores. Notably, most of the data is available from a project's Form 1391, which can be accomplished in the initial planning phases of the portfolio development shortly after the PMO initially forms. The

one criterion used that needs extra scrutiny beyond the Form 1391 is the Period of Performance. This tends to have a large variance from Form 1391 to the project's contract bidding and awards phase.

In implementation the AHP portion of this process only needs to be accomplished once at the is beginning of the PMO standup. In fact, the model presented captures the input from many SMEs and active PMO stakeholders. Meaning the presented AHP weights can be used, as is, for any organization managing a diverse portfolio. Through benchmarking future PMOs can choose to adjust the AHP weights via adjustment of the pairwise comparisons or the addition of the criteria in the model. Otherwise, as new projects are developed, the PMO only needs to accomplish the utility values for the new projects and weight with the Complexity Index then file into the portfolio depending on its final complexity rating ready to be assigned to a project manager.

Furthermore, the optimization constraints are easily and highly adaptable to the risk tolerance of the PMO director or decision-maker. As shown the rote output will minimize the costs associated with the project managers, but it evenly spreads the projects based on the skill and capacity constraints. While the goal and result of gaining the number of project managers required to manage the portfolio are achieved, the even spread of assignments is not a realistic assignment of projects. There will be engagement by the decision-makers to assign the projects according to their risk tolerance and the skillset of each unique project manager once onboard the PMO.

Table 16. Summary statistics of the Tyndall PMO staffing and metrics

Tyndall PMO Statistics

Project Managers Assigned	Average Projects per PM	Range of Projects Assigned	Average Value of Projects to a PM ($M)	Range of Value ($M)
5	10	7-13	610.7	454 - 876

Comparing the results of the research with the Tyndall PMO’s project manager staffing, we can compare some of the Tyndall PMO's statistics (Table 16) with constraints applied in the model and the results of requiring eight project managers per the research. We see that Tyndall has fewer employed project managers, and most of the managers are at, or above the eight project limit used in the model. Additionally, the only work capacity metric available was the sum of the value of the projects assigned to each manager. These values were also based on the cost data from each project’s Form 1391. A few notable and distinct differences must be addressed in the Tyndall PMO's employment of project managers compared to the results of the research. First, the Tyndall PMO is only using expert project managers as defined in the model. There are young CGOs, or novices in the Tyndall PMO. However, the CGOs are used in supporting and assistant roles to the MILCON project managers. This helps lift some burden from the project managers and is shown to be an effective way to mitigate the risk associated with having more than eight projects assigned to the project managers. It is not possible to compare the complexity scores developed directly to the current portfolio being managed because the MILCON projects are developing in real-time and certain projects have contractually been split or combined so the current real-world portfolio is similar but not the same as the data used in

the model. Discussion with several of the Tyndal PMO project managers has shown the complexity scores based on the Form 1391s and early master schedule are close to what they perceive in managing the design phases and entering into construction execution of the projects.

The research is designed to answer the question of how many project managers are needed early in the standup of the PMO. The Tyndall PMO is going on four years at this point and has had some cycles of manning increase or decrease based on discussions with the Tyndall PMO. The proposed model would allow quantifiable justification to request adequate or additional staffing based on workload and establish an effective baseline to stand up future PMOs once the Form 1391s are built.

As well, it is worth noting that the portfolio only has two phased projects. As discussed in the results, this is not enough data to validate whether the phases sub-criteria is appropriately weighted within the AHP. The nature of government portfolios is tied to fiscal years and phases are often by design spread over different fiscal years. This spreading of the phases forces the “next phase” to be delayed artificially from a contracting perspective and can mitigate some of the risk of previous phases delaying the next phase. This is often seen when constructing or repairing a taxiway or parking apron where the whole area will be repaired, but in phases over several fiscal years. Additionally, some of these large paving projects have hard boundaries that will not prevent the next phase from beginning in some cases and thus phasing is really a fiscal constraint not a true dependency on the previous phase. More research on this criterion is needed to clarify how to better

capture this information from a Form 1391 or another source to use in the complexity criteria properly.

Finally, there is one outlier project that based on discussions with the Tyndall PMO project managers, has a severe mismatch complexity with its real-world perceived complexity. The *Airfield Drainage* project has become one of the most demanding projects in the portfolio. With a complexity score of 32, it should be a very straightforward project. There are a few things to note about the discrepancy based on discussions with the project manager. First, it seems the Form 1391 for the Airfield drainage project did not truly capture the scope of what was needed to accomplish the project. This highlights a potential weakness in relying heavily on the Form 1391 for most of the data used in the model. Second, it rather bluntly confirms the dynamic complexity at play, as expressed by Zhu, of MILCON and government construction in general (Zhu and Mostafavi 2017). In this case, the dynamic complexity manifests as changes to the project scope, interjecting uncertainty into the project. Lastly, only the Airfield Drainage project was highlighted during discussions as having the issue of extreme discrepancy of effort compared to the complexity score. In rough terms, this translates to a 98% "success" rate on the complexity scores.

VII. Conclusions

This chapter provides concluding remarks on the research. Including closing thoughts on the expected contribution to the body of knowledge and highlighting areas of future research and development of the methodology presented. Finally, the chapter finishes with a summary of the research.

Expected Contribution

The novel use of the Analytical Hierarchy Process to create a complexity index and apply it to a project portfolio to inform decision-makers on the optimal allocation of human capital resources broadens the scope of the analytical hierarchy process and multi-attribute utility theory. The proposed model increases the application of multi-criteria decision methods in the construction and project management fields and the human resources field. Additionally, it is hopeful that this model would be readily usable for any project management entity, such as an Air Force Civil Engineering Squadron's Engineering Flight, MILCON management across installation, and not only a PMO in a post-disaster environment.

Future Research & Development

The methodology presented shows the promise of a new way to evaluate a government construction portfolio for optimal management aligned with the decision-maker's risk tolerance. Two ways the existing methodology could be adapted in the future is to apply the model to a Facilities Sustainment, Restoration, and Maintenance (FSRM) portfolio. These portfolios are the standard portfolios managed by Civil Engineer

Squadrons at every Air Force Installation. The model would allow the base engineers to produce quantifying arguments to evaluate their project manager resourcing and request more human resources via contractors or government employees.

As the current model did not evaluate FSRM processes a couple things would need to be done to update the model for an FSRM Portfolio. First, FSRM typically have much lower cost thresholds and a new cost utility chart should be employed to capture the range of costs being managed. It is recommended to use the same method described of developing stepwise buckets based on natural breaks in the data. Secondly the constraints on the project managers and definitions of skill levels should be evaluated as to what resources are expected or being requested. FSRM project managers typically provide more daily contract oversite and mirror more closely industry standards for a project manager compared to the MILCON project managers duties. The constraint of eight or less projects per project manager is probably more relevant to the FSRM project manager.

Additionally, the model could be used to inform some contracting decisions to help mitigate risk. As the knowledge of which projects are complex or less complex can be leveraged to help in the bundling of projects under one larger contract or conversely phasing a solicitation to reduce complexity. An example of bundling may be to combine solicitations from projects that share stakeholders in order to consolidate the number of project managers interacting with the stakeholders would allow more streamlined communication and oversight.

Lastly, there some limitations in the model and future research would help to clarify or correct these limitations. There was not enough data to make any informed conclusions regarding the weight of phases as a criterion. Also, the definition used for stakeholders is quite narrow and should be evaluated to incorporate a more robust cohort of possible and frequently seen stakeholders in government construction.

A portfolio with more phased projects would help further develop the Interconnectedness primary criteria and phases sub-criteria. The nature of phasing in government projects is not always a true linear dependency on another project, so the weight for this criterion really needs a more robust study. It is also possible it is infrequent enough to generally be removed from the model as portfolios with many phased projects may be the exception and not the norm.

Regarding stakeholders it is suggested for future research to identify a few more critical and frequent stakeholders seen in government projects. Upon reviewing the results this criterion is a little too narrow as defined in the model relative to what is expected from the output. To suggest a way forward it is recommended to review stakeholders as internal and external in general. I think the model captures the internal Air Force stakeholders well but does not readily capture external stakeholders. Some frequent external stakeholders are environmental authorities, and local utility companies. Environmental authorities are almost always involved in construction on airfields, which is of course frequent in Air Force projects. Additionally local utility companies will be heavily involved in a portfolio developed for post-disaster recovery.

Finally, some suggested future criteria to explore are contractor burden, non-disaster contexts, and unique technology use such as 3-D printing. Specifically, further research into mixed context portfolios would allow a criterion to capture some of the dynamic complexity that is not captured in the current model. Capturing contractor burden would require a good understanding of the contractor's resource constraints, which typically will not be available until much later in the project process as compared to the information available on the Form 1391.

Summary

Post-disaster projects tend to be numerous, extraordinarily complex, involving multiple stakeholders, higher cost, and aggressive timelines. These condensed timelines are driven by Air Force installations' national security capabilities and perception. The need to show credible, tangible recovery as fast as possible is driven as much by local and economic drivers as it is to show internationally that the U.S. has not lost any defense capability. This visible fast recovery adds contextual complexity to the recovery portfolio. As such, it is critical that the PMO formed to develop and execute the recovery portfolio be prepared and adequately resourced to contend with this environment. Having a lean, easy-to-use framework to quantify project complexity will allow the Project Management Office leadership to compare and assign project managers to the projects at the earliest point in developing the portfolio. Using analytical hierarchy and multi-attribute utility theory allows each project to have a complexity rating that will inform the project manager work demand for each project assigned. Leveraging the project complexity score to ensure

the appropriate project managers are assigned and no project managers are overloaded allows proper oversight and better management of the projects. The project management office can program, develop, and execute the recovery portfolio to reduce cost and scheduling overruns. The framework developed in this paper is intended to solve the Air Force's need to have an event flexible PMO structure. However, it could be applied to any organization looking to streamline its recovery process by promoting quality of construction and managing complexity, while balancing resource constraints.

APPENDIX

Table 17. Sub-Criteria Utility Scores per Project. Based on the Data from (Table1) the utility scores were figured using the Utile Charts presented in Chapter IV Methodology.

Portfolio Utility Scores per Sub-Criteria						
Project No.	Cost	PoP	Variety	Stakeholder	Phases	Systems
1	0.9	0.95	0.1	0.1	0.25	0.25
2	0.75	0.85	0.85	0.1	0	0.75
3	0.5	0.85	0.1	0.1	0	0
4	0.5	0.65	0.5	0.1	0	0.75
5	0.35	0.75	0.5	0.1	0	0.75
6	0.5	0.65	0.5	0.1	0	0.75
7	0.85	0.85	0.1	0.1	0	0
8	0.25	0.85	0.5	0.1	0	0.15
9	0.35	0.95	0.5	0.1	0	0.75
10	0.5	0.85	0.5	0.1	0	0.75
11	0.85	0.95	0.1	0.1	0.25	0.25
12	0.5	0.75	0.5	0.5	0	0.75
13	0.5	0.75	0.5	0.1	0	0.75
14	0.35	0.75	0.5	0.1	0	0.75
15	0.25	0.85	0.85	0.1	0	0.75
16	0.35	0.65	0.5	0.1	0	0.75
17	0.1	0.75	0.5	0.1	0	0.25

18	0.35	0.65	0.85	0.1	0	0.75
19	0.5	0.85	0.5	0.1	0	0.75
20	0.9	0.65	0.5	0.1	0	0.75
21	0.97	0.85	0.5	0.1	0	0.75
22	0.75	0.85	0.85	0.1	0	0.75
23	0.75	0.85	0.85	0.1	0	0.75
24	0.5	0.95	0.5	0.1	0	0.75
25	0.5	0.75	0.85	0.1	0	0.75
26	0.35	0.75	0.85	0.1	0	0.75
27	0.1	0.65	0.5	0.1	0	0.75
28	0.35	0.65	0.5	0.1	0	0.25
29	0.35	0.65	0.5	0.1	0	0.25
30	0.35	0.75	0.5	0.1	0	0.25
31	0.5	0.75	0.5	0.1	0	0.75
32	0.75	0.65	0.5	0.1	0	0.75
33	0.75	0.85	0.5	0.1	0	0.75
34	0.75	0.85	0.85	0.5	0	0.75
35	0.75	0.85	0.85	0.5	0	0.75
36	0.75	0.85	0.85	0.5	0	0.75
37	0.5	0.75	0.5	0.5	0	0.25
38	0.1	0.65	0.5	0.5	0	0.25
39	0.95	0.85	0.1	0.5	0	0
40	0.5	0.85	0.85	0.5	0	0.75
41	0.1	0.75	0.5	0.5	0	0.25
42	0.35	0.75	0.5	0.5	0	0.25
43	0.25	0.75	0.5	0.5	0	0.75
44	0.25	0.75	0.1	0.1	0	0.25
45	0.1	0.65	0.5	0.5	0	0
46	0.1	0.65	0.1	0.1	0	0.25
47	0.1	0.65	0.5	0.5	0	0.75
48	0.1	0.85	0.85	0.1	0	0.25
49	0.1	0.85	0.5	0.1	0	0.75
50	0.35	0.75	0.5	0.5	0	0.75
51	0.35	0.75	0.5	0.1	0	0.25
52	0.35	0.65	0.5	0.1	0	0.25

Table 18. Shows the final complexity score for each project calculated from the AHP process.

Portfolio Project Complexity Scores

Project No.	Complexity Score	Project No.	Complexity Score	Project No.	Complexity Score	Project No.	Complexity Score
1	38	14	49	27	45	40	73
2	69	15	66	28	43	41	49
3	29	16	47	29	43	42	51
4	48	17	43	30	45	43	54
5	49	18	62	31	50	44	27
6	48	19	52	32	50	45	45
7	32	20	51	33	54	46	23
8	46	21	56	34	75	47	50
9	53	22	69	35	75	48	61
10	52	23	69	36	75	49	49
11	37	24	55	37	52	50	55
12	56	25	65	38	47	51	43
13	50	26	64	39	39	52	43

Pairwise Comparison of Primary Criteria with Weight Calculation

Pair-Wise Comparison Matrix for the Primary Criteria					
Primary Criteria	Project Size	Project Variety	Project Interdependence	Column Vector	Weight W (%)
Project Size	1	1/2	3	1.145	31%
Project Variety	2	1	5	2.150	58%
Project Interdependence	1/3	1/5	1	0.405	11%
			Summation	3.7	100%

"Very Good Method" W vector Weight Calculation

Column Vector= $\sqrt[n]{n_1 \times n_2 \times \cdots \times n_n}$ e.g., Project Size = $\sqrt[3]{1 \times 0.5 \times 3}$ = **1.145**

W = $Column\ Vector / \sum W_i$ e.g., **W** Variety = 2.15/3.7 = **0.581**

Figure 12. Shows an example of the "Very Good Method" weight calculation accomplished after completing the pairwise comparisons.

Detailed Steps to check AHP Consistency

- Calculate maximum eigenvalue: λ_{max}, for the comparison matrix
- Calculate the weighted sum vector **[W']** : $[W'] = [A] \times [W]$
- Calculate the consistency vector **[W'']** by dividing each element in the **[W']** vector by its corresponding element in the **[W]** vector.
- $W_i'' = W_i'/W_i$ for each element in the vector from i = 1 to n

	[A]				[W]	[A]X[W]	[W']/[W]
Primary Criteria	Project Size	Project Variety	Project Interdependence	Column Vector	Weight W (%)	W'	W''
Project Size	1	0.5	3	1.145	31%	0.928	3.00334
Project Variety	2	1	5	2.150	58%	1.747	3.00338
Project Interdependence	0.333	0.2	1	0.405	11%	0.328	3.00342
			Summation	3.7	100%	λmax = 3.003338	

- Calculate Consistency Index (CI) = $(\lambda_{max} - n)/ (n - 1)$
- λ_{max} = 3.00338; CI = (3.00338 – 3) / 2 = **0.00169**
- Check the Consistency Rating (CR) = CI/RI
- If CR ≤ 0.1Then consistency of matrix **[A]** is acceptable
- RI is the random consistency index. These are known values from the body of knowledge.
- The table of RI based on a matrix A of size n:

n	1	2	3	4	5	6	7
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32

- Therefore CR = 0.00169/0.58 = **0.0029**
  - Which is < 0.1 so matrix A for the primary criteria is very consistent

Figure 13. Details step five of the AHP to check for consistency.

Snap shots of the Excel solver template used in the analysis.

Sequence	Parameter	Value	Remarks
0.Interface	Language	English	Please refer to the manual for modifying the interface.
1.Items	Number of Projects/items	52	[1,100] number of projects
2.Bins	Number of types of bins	2	[1,10] novice and expert
3.Solution	Guillotine cuts?	No	Not used for this
4.Optional - Visualization	Item labels	Yes	project number
	Bin labels	Yes	numerical bin1, bin2 etc..
	Zoom	Automatic	default
5.Solver	First-Fit-Decreasing based on:	Area	area defined as 1 x complexity score
	Show progress on status bar?	Yes	default
	CPU time limit (seconds)	60	At least one second per item. Default

Figure 14. Shows the Excel Bin Packer Template as set up for the project manager constraints. The visualization was not used in this thesis. The figures used in the thesis were developed manually or cited of form another source.

Bin Type ID	Name	Width (x)	Height (y)	Area	May be used?	Cost	Estimated number of bins	Number of bins
1	Bin type 1	8.00	50.00	400.00	May be used	1.00	7	7
			Total area:	2800.00				

Bin Type ID	Name	Width (x)	Height (y)	Area	May be used?	Cost	Estimated number of bins	Number of bins
1	Bin type 2	8.00	100.00	800.00	May be used	1.00	4	7
			Total area:	5600.00				

Figure 15. Shows the Bin Packer Template bins set up for Novice and Expert manger constraints. The width is the number of allowed projects, workload, and the area captures the allowed complexity constraint. Note that not all the information on the template was used for the analysis, such as total area.

Bin 1 of Bin type 1					Max number of items	Area utilization	Net profit
		Bottom left corner			8	49.14%	-1.00
Item count	Item type name	x coordinate	y coordinate	Rotated?	Can be rotated?	Area	Profit
1	Item type 13	0.00	0.00	No	No	49.98	0.00
2	Item type 31	1.00	0.00	No	No	49.98	0.00
3	Item type 32	2.00	0.00	No	No	49.59	0.00
4	Item type 49	3.00	0.00	No	No	49.21	0.00
5	Item type 41	4.00	0.00	No	No	49.06	0.00
6	Item type 5	5.00	0.00	No	No	48.82	0.00
7	Item type 14	6.00	0.00	No	No	48.82	0.00
8	Item type 4	7.00	0.00	No	No	47.66	0.00
9							
Bin 2 of Bin type 2					Max number of items	Area utilization	Net profit
		Bottom left corner			8	60.97%	-1.00
Item count	Item type name	x coordinate	y coordinate	Rotated?	Can be rotated?	Area	Profit
1	Item type 22	0.00	0.00	No	No	69.49	0.00
2	Item type 25	1.00	0.00	No	No	65.25	0.00
3	Item type 26	2.00	0.00	No	No	64.09	0.00
4	Item type 48	3.00	0.00	No	No	60.83	0.00
5	Item type 21	4.00	0.00	No	No	55.93	0.00
6	Item type 24	5.00	0.00	No	No	54.61	0.00
7	Item type 12	6.00	0.00	No	No	55.79	0.00
8	Item type 18	7.00	0.00	No	No	61.77	0.00
9							

Figure 16. Shows a sample of the solution output for each used project manager from the Bin Packer template. Item type corresponds to project number (Table 1), and area is the calculated project complexity. Not all information was used in the analysis for this thesis such as area utilization or profit. The cost of the project managers was calculated manually from the estimated annual cost for each type of project manager and the number of bins output by the software.

Bibliography

Air Force Civil Engineer Center (2017). " Air Force Civil Engineer Center Project Manager Guide to Infrastructure and Facilities." https://afcec-portal.lackland.af.mil/cf/cft/SitePages/Home.aspx

Ahmadi, N., and Shahandashti, S. M. (2018a). "Assessing the Vulnerability of Building Exterior Construction's Labor Wages to Weather-Related Disasters in the United States." *Construction Research Congress 2018*, American Society of Civil Engineers, New Orleans, Louisiana, 594–603.

Ahmadi, N., and Shahandashti, S. M. (2018b). "Role of Predisaster Construction Market Conditions in Influencing Postdisaster Demand Surge." *Natural Hazards Review*, American Society of Civil Engineers, 19(3), 04018010.

Apurva, P., Sharareh, K., and Sanjgna, K. (2020). "Impact of Natural Disasters on Construction Projects: Strategies to Prevent Cost and Schedule Overruns in Reconstruction Projects." *Proceedings of the Creative Construction e-Conference 2020*, Budapest University of Technology and Economics, Online, 49–57.

Arneson, E., Javernick-Will, A., Hallowell, M., and Corotis, R. (2020). "Predicting Post-disaster Residential Housing Reconstruction Based on Market Resources." *Natural Hazards Review*, 21(1), 04019010.

Baccarini, D. (1996). "The concept of project complexity – a review." *International Journal of Project Management*.

Bosch-Rekveldt, M., Jongkind, Y., Mooi, H., Bakker, H., and Verbraeck, A. (2011). "Grasping project complexity in large engineering projects: The TOE (Technical, Organizational and Environmental) framework." *International Journal of Project Management*, 29(6), 728–739.

Cabanis-Brewin, J. (2016). "Optimal Project Manager Load." <https://www.pmsolutions.com/blog/view/optimal-project-manager-load> (Jan. 26, 2022).

Crawford, L. (2005). "Senior management perceptions of project management competence." *International Journal of Project Management*, 23(1), 7–16.

Döhrmann, D., Gürtler, M., and Hibbeln, M. (2013). "An Econometric Analysis of the Demand Surge Effect." *SSRN Electronic Journal*.

Farooghi, F., Ahmadi, N., and Shahandashti, M. (2020). "Quantifying Relationship between Pre-Disaster Construction Market Conditions and Post-Disaster Construction Labor Wage Fluctuations in the Gulf Coast Construction Industry." *Construction Research Congress 2020*, American Society of Civil Engineers, Tempe, Arizona, 812–822.

Gurski, F., Rehs, C., and Rethmann, J. (2019). "Knapsack problems: A parameterized point of view." *Theoretical Computer Science*, 775, 93–108.

Haas, K. (2009). "Managing Complex Projects. Part 1." *Project Times*, <https://www.projecttimes.com/articles/managing-complex-projects-part-1.html?Itemid> (Mar. 8, 2021).

Haddow, G., and Bullock, J. (2020). *Introduction to emergency management*. Elsevier, Inc, Philadelphia.
Hallegatte, S., Boissonnade, A., Schlumberger, M.-E., and Muir-Wood, R. (2008). “Demand Surge and Worker Migrations in Disaster Aftermaths: Application to Florida in 2004 and 2005.” 25.
He, Q., Luo, L., Hu, Y., and Chan, A. (2014). “Measuring the complexity of mega construction projects in China—A fuzzy analytic network process analysis.” *International Journal of Project Management*, 33.
Ishizaka, A., and Labib, A. (2011). “Review of the main developments in the analytic hierarchy process.” *Expert Systems with Applications*, S0957417411006701.
Jagoda, J. A., Schuldt, S. J., and Hoisington, A. J. (2020). “What to Do? Let’s Think It Through! Using the Analytic Hierarchy Process to Make Decisions.” *Frontiers for Young Minds*, 8, 78.
Karydas, D. M., and Gifun, J. F. (2006). “A method for the efficient prioritization of infrastructure renewal projects.” 16.
Lahyani, R., Chebil, K., Khemakhem, M., and Coelho, L. C. (2019). “Matheuristics for solving the Multiple Knapsack Problem with Setup.” *Computers & Industrial Engineering*, 129, 76–89.
Luo, L., He, Q., Jaselskis, E. J., and Xie, J. (2017). “Construction Project Complexity: Research Trends and Implications.” *Journal of Construction Engineering and Management*, 143(7), 04017019.
Meyer, D. E., Rubinstein, J. S., and Evans, J. E. (2006). “Multitasking: Switching costs.” *https://www.apa.org*, <https://www.apa.org/research/action/multitask> (Mar. 10, 2021).
Mian, S. A., and Dai, C. X. (1999). “Decision-Making Over the Project Life Cycle: An Analytical Hierarchy Approach.” *Project Management Journal*, Sage Publications Inc., 30(1), 40.
Olsen, A. H., and Porter, K. A. (2011). “What We Know about Demand Surge: Brief Summary.” *Natural Hazards Review*, 12(2), 62–71.
Olsen, A. H., and Porter, K. A. (2013). “Storm Surge to Demand Surge: Exploratory Study of Hurricanes, Labor Wages, and Material Prices.” *Natural Hazards Review*, 14(4), 247–257.
Patanakul, P., Milošević, D., and Anderson, T. R. (2007). “A Decision Support Model for Project Manager Assignments.” 56.
Pradhan, S., and Arneson, E. (2021). "Postdisaster Labor-Demand Surge in the U.S. Highways, Roads, and Bridges Construction Sector." *J. Manage. Eng.*, 10.
Saaty, T. L. (2008). “Decision making with the analytic hierarchy process.” 16.
Salkin, H. M., and De Kluyver, C. A. (1975). “The knapsack problem: A survey.” *Naval Research Logistics Quarterly*, 22(1), 127–144.
Singh, B., and Wilkinson, S. (2008). “Post-disaster Resource Availability following a Wellington Earthquake: Aggregates, Concrete and Cement.” 12.

Skaik, S. (2009). “Determine How Many Projects One Project Manager Can Manage.” *Construction Management Guide*.

Thomas, J., and Mengel, T. (2008). “Preparing project managers to deal with complexity–Advanced project management education.” *International Journal of Project Management - INT J PROJ MANAG*, 26.

Vidal, L.-A., Marle, F., and Bocquet, J.-C. (2011). “Measuring project complexity using the Analytic Hierarchy Process.” *International Journal of Project Management*, 29(6), 718–727.

Zhu, J., and Mostafavi, A. (2017). “Discovering complexity and emergent properties in project systems: A new approach to understanding project performance.” *International Journal of Project Management*, 35(1), 1–12.

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 074-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From-To)*
25-03-2022	Master's Thesis	September 2020 – March 2022

TITLE AND SUBTITLE	
Quantifying Project Complexity to Resource Project Managers	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	**5d. PROJECT NUMBER**
Henrard, Jereme, R., Major, USAF	**5e. TASK NUMBER**
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/ENY) 2950 Hobson Way, Building 640 WPAFB OH 45433-8865	AFIT-ENV-MS-22-M-211
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(E.S.)	**10. SPONSOR/MONITOR'S ACRONYM(S)** **Tyndall PMO**
Tyndall Program Management Office 540 Mississippi Rd Tyndall AFB, FL 32403 afimsc.pa.workflow@us.af.mil	**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A. APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This research develops a multi-criteria decision analysis model to quantify project complexity and inform decision-makers in resource-constrained organizations with the Tyndall Program Management Office (PMO) as a case study. The complexity score is used as a risk metric to determine the appropriate number of skilled or novice project managers to effectively manage the PMO portfolio to mitigate cost and schedule overruns. The research provides an innovative approach to consider manning levels at the PMO and other project management-focused organizations/sections.

15. SUBJECT TERMS

Complexity, Project Management, Multi-Criteria Decision Making, Post-Disaster

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					Lt Col Justin D. Delorit, AFIT/ENV
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(Include area code)*
U	U	U	UU	75	(937) 255-3636, ext. 4826 (justin.delorit@afit.edu)

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18