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NAVFAC CEC Graduate Student Project Report

Using Probability Management to Predict Performance on Navy Military Construction Projects

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Table of Contents

List of Figures

1. Abstract

Naval Facilities Engineering Systems Command (NAVFAC) currently has no predictive tool to assess the cost and schedule growth of Military Construction (MILCON) projects. The current NAVFAC assessment of project performance is accomplished by tracking metrics to determine if project performance is degrading. This is a reactive process with lagging indicators and does not allow NAVFAC to proactively manage the performance of projects before degradation occurs. Utilizing historical data of NAVFAC executed MILCON projects, the project team applied statistical analysis techniques developed by Dr. Sam Savage to create a proof-of-concept data analytic tool. Using unique forms of Monte Carlo analysis, the project team developed a model that takes project parameter inputs of total cost and duration and predicts final cost, duration, and probability of meeting original targets. The project team used over 800 clean project data points from NAVFAC's ieFACMAN (Interoperable Enterprise Facilities Management) database to generate probability distributions. These probability distributions were then converted into Stochastic Information Packets (SIP) as inputs into Dr. Savage's Microsoft Excel add-on, ChanceCalc, to generate the project team's data analytic model. The model indicates that for all NAVFAC MILCON, a new project has a 90% likelihood to be over budget and 88% likelihood to be beyond schedule. It is suggested that further analysis and modeling include project parameters with intact relationships (e.g., the relationship between cost and schedule) and expanding available data from other enterprise systems to improve predictive factors and analytic tool capabilities.

2. Introduction

NAVFAC does not currently have a method or tool available to predict performance of its MILCON projects which have a history of finishing behind schedule and/or over budget. This is due to a variety of reasons ranging from errors and fidelity issues during the planning process, poor specifications and designs, customer requested changes, issues with contractors, inadequate construction management, and unforeseen issues during construction.

Currently, NAVFAC uses project delivery Key Performance Indicators (KPI) that were promulgated on October 21, 2019, by Commander, NAVFAC (hereafter referred to as K20-02). This directive was established with the intent to identify earlier in the construction process when projects may become at risk. Each KPI has an associated metric for when they reach certain thresholds, they require leadership engagement. There are currently eight pre-award and 14 post award KPIs in place to track project performance. The KPIs developed provide an adequate management tool; however, it does not provide leading indicators to directly predict future performance and only perform as lagging indicators of project performance.

Undertaking a course entitled “Project Risk Analysis” at Stanford University taught by Dr. Sam Savage, the project team was introduced to the concepts of managing risk using probability management. Dr. Savage presented an introduction to the “Flaw of Averages” and the problems with how data is used to make decisions across much of the business world today. The intent is to go beyond simply relying on the averages of data to perform predictive modeling. Throughout the course, Dr. Savage explained how the use of averages alone will lead you to make decisions that are flawed, hence, the “Flaw of Averages.” The project team learned how to apply the concepts of probability management by using historical data to produce probability distribution curves that can be used with Dr. Savage’s Microsoft Excel software add-on known as “ChanceCalc” to generate a predictive model of project performance based on a set of initial conditions.

To provide a minimum viable product and demonstrate the use of probability management, the team used NAVFAC’s MILCON project data to create distributions to better predict changes in project duration and cost. These parameters were looked at separately without initially considering the possibility of correlation to reduce the complexity of the model; however, analysis of correlation was performed after the model had been built.

3. Purpose of Study

NAVFAC desires to improve project performance by utilizing data analytic tools to predict and assess risk of cost overruns and schedule delays. The purpose of this study is to develop a proof-of-concept data analytic tool that will be able to predict project cost and schedule growth given input data such as project cost and duration from NAVFAC historical data. The tool will utilize this data and probability management tools developed by Dr. Savage.

4. Project Background

This project was conceived during a course on probability risk analysis and was executed by looking at data through the lens of probability management. Throughout the course, the project team learned about using probability as a predictive tool. The team became interested in applying the concepts to NAVFAC project performance data to develop a data analytic tool for predicting cost and schedule growth of construction projects. The basis for Dr. Savage’s course was to look beyond utilizing the average as a predictive means due to what he refers to as the “Flaw of Averages.” His methods go beyond traditional statistics, or what Dr. Savage affably refers to as “steam era” statistics. Utilizing advanced forms of Monte Carlo simulations, the tools consider probability distributions to generate models that can be used to predict probable future outcomes along with giving the uncertainty in those predictions.

To generate the predictive model, a Stochastic Information Packet (SIP) was needed. A SIP is a data set containing all the trials based on a specific parameter. In the case of the data analytic tool developed, the SIPs were created based on the most complete historical MILCON data for cost and duration for all NAVFAC executed MILCON projects enterprise wide. These SIPs were a product of the probability distributions of cost and duration from the actual project data and resulted in the creation of a predictive data analytic tool based on historical performance. The next step of the data evaluation process was to take data sets that had inherently linked interdependencies and combine them into Stochastic Library Unit with Relationships Preserved (SLURP). This means interdependences between SIPs are preserved within each trial of the simulation. Trying to simulate cost and schedule overruns, the expectation is to find a correlation between the two parameters. For example, if there is a cost overrun, the expectation is to find a schedule delay, too. In the framework of this study, the project team first looked at cost and schedule separately without one being interrelated with the other. This was done due to time constraints within the course as well as limitations in the data.

The final product of this project was to develop a proof-of-concept data analytic tool to be used as a predictive model for determining cost and schedule growth which may also be used as a risk management tool. The proof-of-concept data analytic tool that was developed was also capable of providing an average final project cost and schedule across all simulations run. This average was based on distributions and was not susceptible to the "Flaw of Averages." Allowing for comparison between originally planned data points and the simulation numbers, it provides the ability to adjust contingency or manage owner expectations on delivery date and total project cost prior to contract award.

5. Actions to Date

Initial Project Scope and Goals: The initial project scope and goals were discussed and developed with Dr. Sam Savage, an adjunct Professor at Stanford University. Dr. Savage is a world-renowned expert in the field of statistics with a focus on modeling uncertainty. The project team confirmed with Dr. Savage the NAVFAC project could be the subject of the course project (CEE 242R-Project Risk Analysis). The project team's initial approach to the project scope was to develop a predictive analysis model to determine the risk of pre and post award Navy MILCON projects and their ability to finish within project budget and construction schedule.

Review of Applicable Literature: The project team reviewed a Center for Naval Analysis (CNA) paper, other graduate student theses, and NAVFAC policies to further develop the project scope and goals. The project team discovered there was an interest within CNA and NAVFAC to use statistical analysis to evaluate the probability of construction projects to complete on time and within budget. This NAVFAC project was aligned with a greater interest being developed within the Department of the Navy to use statistical models to predict the risk of MILCON projects.

Received Comprehensive Data: The project team sorted and cleaned eProjects MILCON data received from the NAVFAC Headquarters Operations (HQ OPS) Department covering fiscal years 2008 – 2022. The project team removed projects that did not have complete data.

Project Scope Sponsor Review and Guidance: The project sponsor, NAVFAC HQ OPS, confirmed the scope of the NAVFAC project and provided further guidance on where to focus the results of the model. The model results would be sorted by NAVFAC regions and a NAVFAC enterprise-wide option. The two parameters of the model would be based on project cost and duration.

Data Analytic Tool Development: The data analytic tool was developed through multiple iterations as explained in the methodology section of this report. The project team consulted Dr. Savage through all iterations of development of the tool. Dr. Savage noted the functionality of the tool was as important as the underlying complex statistical math used. The primary goal during the development of the tool was to develop a predictive tool that would be accessible to a user to evaluate the risk of a project to be over budget or behind schedule.

Tool Use and Application: The model has been completed and is accessible as an interactive dashboard in Microsoft Excel. The model can determine the probability that a particular sized project in a specified NAVFAC region will be over budget and/or behind schedule. Simple adjustments to the tool can be made to minimize risk by increasing budget and/or duration and will show the respective decreases in risk probability. Additionally, the tool shows the underlying correlation of the size of the project with the construction schedule.

6. Methodology

Research in the field of probability management is nothing new; however, the application of statistics, chance, uncertainty, and risk under the guise of probability management is. This project sought to apply probability management techniques to a common risk within NAVFAC construction contracts which is cost and schedule growth. To achieve the goals of this study required four main steps. These steps included data collection, data organization, data analysis, and development of a proof-of-concept data analytic tool.

The first step was data collection. NAVFAC utilizes ieFACMAN with two intranet software programs, eProjects and eContracts. These two programs were identified as the most complete data source to gather viable construction project data to best meet the objectives of this study. The data was downloaded, and it included 10,327 NAVFAC construction projects between Fiscal Years 2008 and 2022. However, not all data was complete, and some was unusable. Cleaning the data was required to filter subsets of the data that could skew the study. The minimum advisable amount of data that would be adequate to perform the study was 100 projects. The study focused on Navy MILCON projects that had been completed (i.e., built and contract closed). After filtering the data to those projects that had all required data points such as Contract Award Date, Contract Completion Date (CCD), Contract Award Amount, and Current Contract Amount, 832 projects remained.

The second step was data organization. To make the data more workable and avoid unnecessary delay due to the significant amount of source data. Unnecessary project tag data was expunged from the main data file. These items were duplicate or extraneous information that was not helpful to organize the data or did not create value to perform the data analysis. The items removed were carefully reviewed, justified, and documented. This source data can be made available by request to the authors on an as needed basis and for official use only. The intent of the data remaining was to support organizing the data by location, responsible team, total value, total duration, and type.

The third step was data analysis. Analysis was performed using Microsoft Power BI. Power BI is a software tool, like Salesforce's Tableau, which provides visual representation of data to better identify trends. Using the cleanest data available to best provide a proof-of-concept, the project team determined that the responsible team tag would be a good baseline grouping of the data to first analyze. Responsible teams are more commonly referred to as the NAVFAC region. Figures 1 and 2 exhibit how the data for percent late and percent over, respectively, were represented visually in Power BI. Percent late refers to the percent late that a project was completed past their original CCD. Percent over refers to the percent over that a project's cost was when compared to its Contract Award Amount. A donut chart was used to showcase the data broken down by region. A histogram of the data was also created to visualize the percent late and percent over. Each histogram was organized into bins to better visualize the distribution of data. This visualization enabled outliers to be identified and associated with the region it was located, made capable by the Power BI tools employed. It was determined that the data selected provided insights into the distribution of cost and schedule growth for NAVFAC projects by region which met the study's objectives.

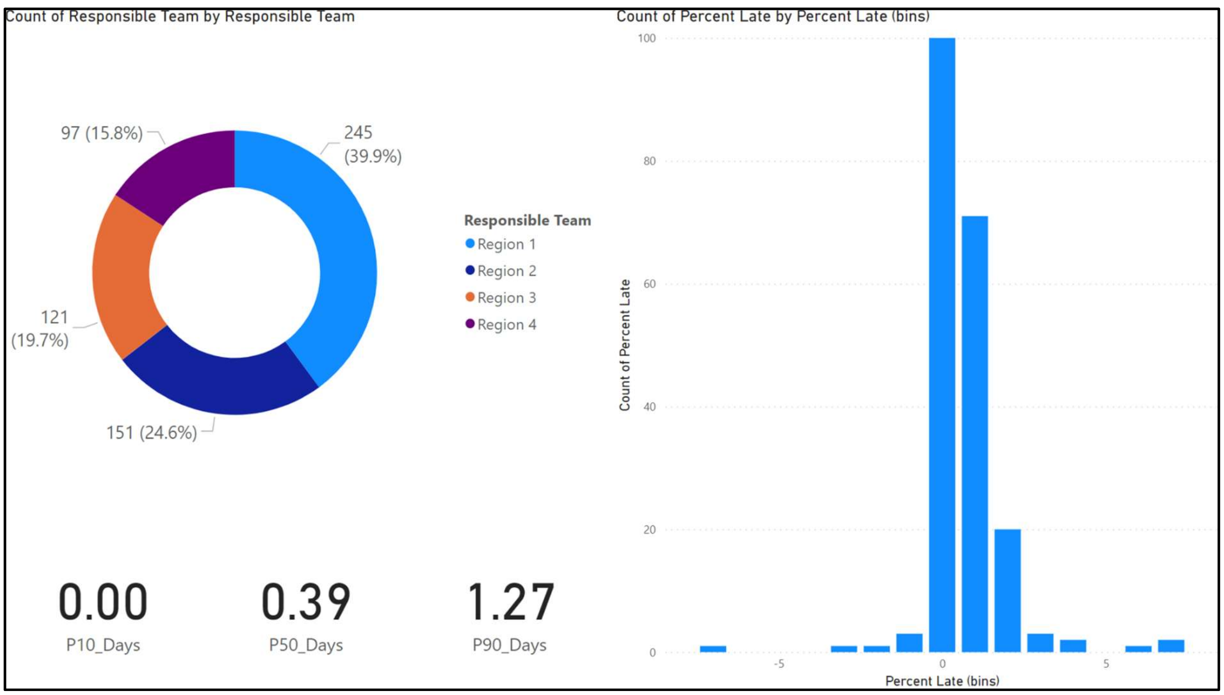

Figure 1: Power BI Data Analysis of Percent Late Data

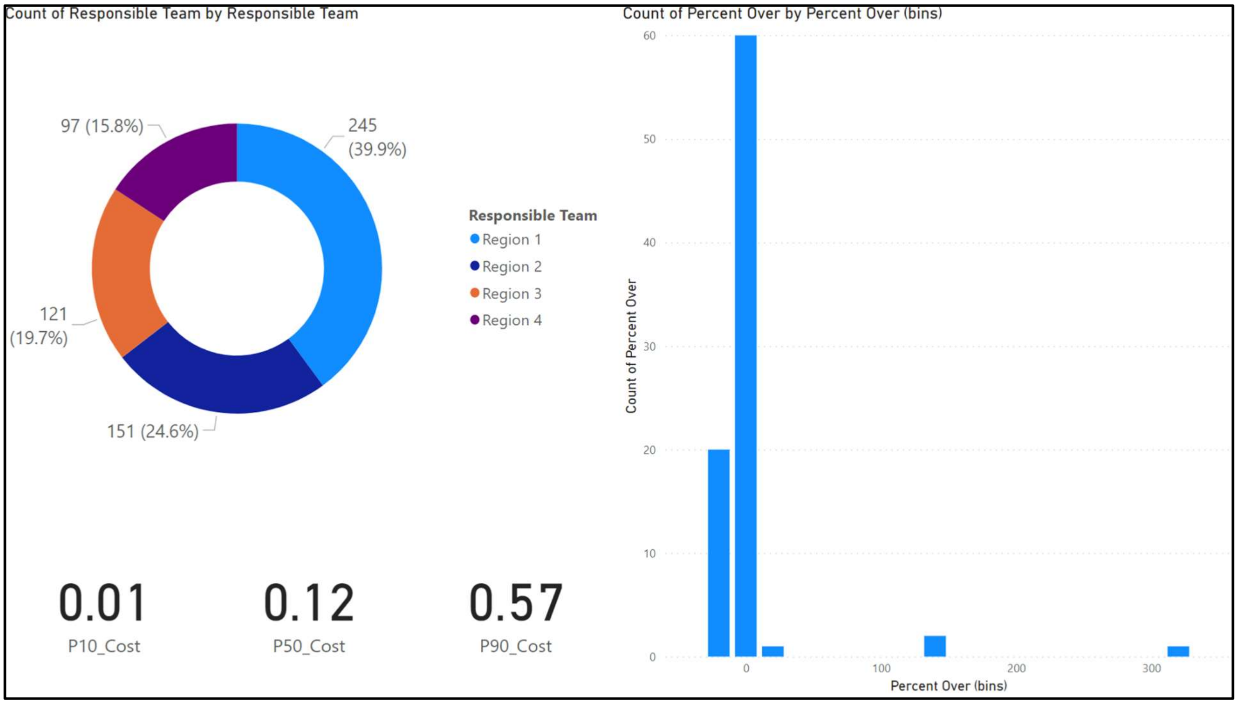

Figure 2: Power BI Data Analysis of Percent Over Data

The next aspect of the data analysis was to identify percentiles of data that could be input into a number of different coding or software applications to create metalogs that fit the project data distributions. With Power BI, percentiles of data were able to be automatically calculated for percent late and percent over for each region. These are in the bottom left-hand corner of both Figures 1 and 2. For each instance they are representing the distribution of all regions observed in the chart. These percentiles associated with each region could be manually inputted into ChanceCalc, Python, or other online open source or proprietary coding software applications to produce metalogs. These metalogs could then be translated into transmittable code to be used as SIPs. These SIPs enable the data points to be used more readily when combined with other data that may not have the same exact amount of data points.

Once the data was in SIPs, the last step of creating a proof-of-concept data analytic tool was possible. The tool was created in Microsoft Excel using free downloadable software from Probability Management known as “ChanceCalc.” The dashboard of the data analytic tool is shown in Figure 3. Python and other online, open-source coding applications can also perform the same functions if performed by a skilled programmer. ChanceCalc provides tools for a relative novice to create the data analytic tools and take advantage of the data analysis already performed. In Excel, the SIP libraries were loaded into ChanceCalc and then input into the spreadsheet. The tools available within ChanceCalc further enabled the data distributions to be used to demonstrate the probability that projects would go over their estimated costs or schedule durations. These probabilities were then translated into values based on planned estimated costs and/or durations which met the objectives. This also provided a proof-of-concept data analytic tool to determine project risk for cost and schedule growth based on the historical distribution of data. Figure 3 showcases an example project with a cost of $2.5M and 730 days to complete. The tool's predictive output produces a result that projects the total cost of over $3M and not finishing for more than 1,000 days based on the historical data used to develop the SIPs.

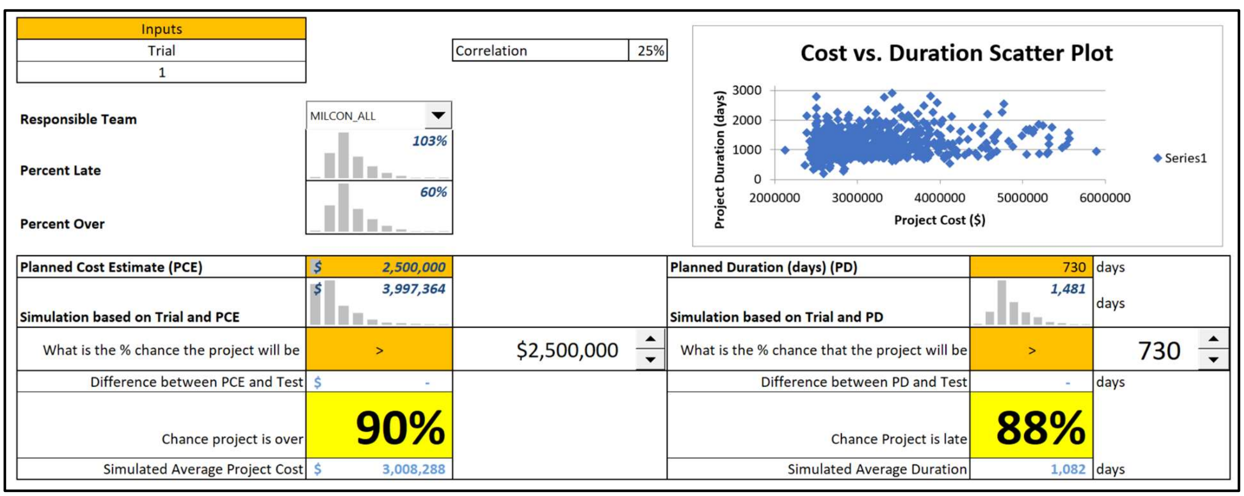

Figure 3: Proof-of-Concept Data Analytic Tool Excel Dashboard

The final piece of functionality delivered in the proof-of-concept data analytic tool was to determine the interdependence of data sets. To do this, data sets that had inherently linked interdependencies were to be combined into a Stochastic Library Unit with Relationships Preserved (SLURP). This means interdependences between SIPs are preserved within each trial of the simulation. Trying to simulate cost and schedule overruns, the expectation is to find a correlation between the two parameters. For example, if there is a cost overrun, the expectation is to find a schedule delay, too. In the framework of this study, the project team first looked at cost and schedule separately without one being interrelated with the other. This was done due to time constraints within the course as well as limitations in the data. While a SLURP of the data was not generated, an analysis of correlation was performed, and it was found that there was a 25% correlation between cost and schedule growth.

7. Limitations of Research

The scope of this project was to apply probability management to construction cost and schedule risk. The project team proposed to develop a risk analysis technique to create leading indicators in the form of KPIs. The intent was to reduce the difference between actual construction contract award cost and final construction contract cost as well as reduce the difference between initial construction CCD and final CCD. Upon achieving a proof-of-concept, we sought to identify other project KPIs that these predictive risk analysis techniques or data analytical tools could be applied to. Finally, the project team pursued developing a data analytical tool to reduce risk consistently and dynamically for construction cost estimating and scheduling. The objective was to use a statistical analysis tool that will narrow a list of projects to the projects which have the highest predictive risk for leadership to proactively mitigate project cost overruns and project schedule in advance. In the performance of the study, the project team identified several limitations to fully develop a data analytical tool; however, a proof-of-concept was completed successfully.

At the outset, viable sources of datasets were identified to use for the study. The ieFACMAN software, to include eProjects and eContracts, was identified as the best source of datasets for the information required. Throughout the process of data collection, the largest, clean set of data to utilize for the study was sought. The information input into eProjects and/or eContracts by NAVFAC contract specialists and construction managers were found to be the most complete data sets available. The data sets available that are used for KPIs within NAVFAC included Contract Award Date, CCD, Contract Award Amount, and Current Contract Amount. The data for dates associated with Beneficial Occupancy Date (BOD), Required Beneficial Occupancy Date (RBOD), and Mission Need Date only recently begun tracking after release of K20-02 in 2019. Due to this, the data was incomplete for many of the projects and did not provide enough usable data to perform our research. The study only used completed projects due to the need to assess CCD and other end state metrics. This meant most projects that were completed or closed did not have KPIs fully incorporated from K20-02.

As the study proceeded to reviewing the number of projects that were completed late, there were a considerable number of projects that finished exactly on time, i.e., not early, and not late. Upon further analysis, it was recognized that CCD is not a date for construction to be complete, but the date that contract final payment was made and the contract closed. This date is rarely the same date as true construction completion. BOD is a more accurate metric for this. The BOD is associated with the customer being cleared to occupy the building. RBOD is when the customer needs to occupy the building. Mission Need Date is when the customer needs to be fully operational in the building. While the BOD will inform when construction is complete enough for occupation, the RBOD will inform if construction was completed on time. The BOD and RBOD would be better data points to use instead of CCD. Although this study was not able to use the ideal set of data points, it was able to proceed with adequate data to functionally provide a proof-of-concept for how the analysis tool may work.

Moving forward with the data, it was organized by the responsible team. In eProjects, the responsible team is the heading associated with the NAVFAC Region. This organization strategy was helpful to highlight responsibility for teams that were delivering projects that were behind schedule or over budget and it accounted for all MILCON projects up to $700M+. It is understood that the larger budget a project has, the more likely that a project carries more risk for being delivered late or requiring change orders that can grow the cost and duration of a project. The distributions created could have been improved for predicting the chance of cost or schedule overruns had the projects been divided up by dollar value or type of project instead of by region alone. However, despite total contract cost (dollar value) being well recorded, the type of project or facility type was often not recorded in the data available. Associating facility type or type of project would provide additional opportunity to focus the risk of projects beyond just dollar value and/or region.

Assessing cost growth with the data provided also produced a substantial number of projects that were completed at the original contract award amount. Most projects in the database were firm fixed price (FFP) or lump sum contracts. As FFP or lump sum contracts, cost growth is information not shared by the contractor unless it was at fault of the owner, in this case, NAVFAC. This is a limitation to determining at a more granular level the effectiveness of contract estimating within NAVFAC. Contract change orders that increase the cost of a contract are only processed once responsibility of the additional cost is determined and a final cost is agreed to by both parties. As a result, the true cost of a project may not be represented by the final contract amount, although it may be the realized cost to NAVFAC.

The final objective of the study was to use a statistical analysis tool that would narrow a list of projects which have the highest predictive risk for leadership to proactively mitigate project cost overruns and project schedule in advance. This could be done for both pre-award program management as well as post-award. In the performance of the study, it was several limitations were identified to fully develop a data analytical tool; however, a proof-of-concept was successful. In its current iteration as a pre-award tool, it does an effective job of visualizing the chance for a project to be delivered on time or within budget. Due to limited time and experience in developing the tool, it currently does not allow an associated dollar value, contract period, or other data to be correlated. Other data that could be incorporated as inputs to further develop a post-award tool include other post-award KPIs as listed in K20-02. Additional inputs would better determine the risk of construction cost and schedule in the field. To make a more robust tool, additional data, as noted, will be required, as well as time to build the tool for the additional functions that would make it more useful for deployment in the field.

8. Benefit to NAVFAC

The objective of this project was to develop an analytical tool to be used enterprise-wide to evaluate the objective risk of the Navy's MILCON portfolio of pre and post award projects. This data analytical tool has three potential benefits to NAVFAC. First, this dashboard can be used as a NAVFAC planning tool during the development of DD 1391s. Second, this dashboard can be used to predictively evaluate the risk of current MILCON projects to employ NAVFAC resources to mitigate risk proactively before larger issues develop. Third, this dashboard has potential to be further developed to analyze individual projects using real-time data.

The first use of the dashboard as a planning tool will assist NAVFAC in the development of DD 1391s. The current process of developing MILCON initial project costs and schedules are based on RS Means and Unified Facilities Criteria pricing guides. Typically, projects are given large contingency factors in the initial stages to capture uncertainty of initial planning. Using an analytical tool to make an informed decision based on historical data to assess an initial project cost and schedule will provide an objective parameter for planners to use when developing DD 1391s. This process will continue to get better as the feedback loop of actual project award cost and schedule are compared to initial planning estimates based on the model.

The second use of the dashboard provides NAVFAC the ability to predictively evaluate the risk of current MILCON projects and provides NAVFAC Regions and NAVFAC HQ OPS, a tool that brings attention to projects that need additional resources. The employment of resources to projects which have high risk of project cost and schedule growth will actively mitigate risk. This tool can be used as an additional feature of the current Operations dashboard or KPI tracker to oversee the performance of NAVFAC's MILCON execution.

The third potential use of the dashboard is to analyze individual projects in real-time. The ability to use the model at the field office level would be a fully encapsulated end-stage version of this tool. The benefit of a Facility Engineering Acquisition Division or local field office to monitor the progress of individual projects in real-time with predictive analysis of risk to schedule and budget growth throughout the performance of a project would be beneficial to NAVFAC. This would provide an objective benchmark for the construction management team to assess risk and better prevent projects from growing in cost or schedule unwittingly.

All three versions of the dashboard and their benefits would be paramount to NAVFAC supporting the objective of using an analytical tool to mitigate risk to execution of MILCON projects. The further development of this model would be critical to enterprise-wide oversight of the MILCON portfolio and potentially be used as a pre-award planning tool, a post award regional tracking tool, and a real-time field office level construction management tool.

9. Recommendations

Throughout the completion of our research, limitations and unexpected findings were identified that would be subject for additional research, study, or analysis. Overall, the limitations primarily stemmed from incomplete data. The types of data that were incomplete were eProjects and eContracts contract milestone dates, facility type data associated with each project, and actual cost data from contractors after project completion. Unexpected findings that were discovered encompassed the significant amount of indifferent project data surrounding on time completion of projects.

A major limitation for the project was the project milestone data from eProjects and eContracts including categories such as BOD, RBOD, and Mission Need Date; however, these only began tracking after release of K20-02 in 2019. Due to this, the data was incomplete for many of the projects and did not provide enough usable data to perform the study respective to these recent updates. Only completed projects were also able to be used due to the need to assess CCD and other end state metrics. This meant most projects did not have KPIs fully incorporated from K20-02. The continued effort to improve on the proof-of-concept analytical tool would be most benefited from complete data within these categories. Ascertaining data that more closely aligns with actual construction completion instead of contract completion, will also provide more accurate data to develop distributions to support the model.

A second dataset that would provide further granularity and basis for comparison is complete data associated with facility type. This data is entered as a code associated to facility type but was incomplete for most data points. The final significant limitation was the inability to access contractor cost data for NAVFAC projects. As most projects in the database were Firm Fixed Price (FFP) or lump sum contracts, cost growth is information not shared by contractors unless it was at fault of the owner, in this case, NAVFAC. This is a limitation to determining at a more granular level the effectiveness of contract estimating within NAVFAC. Contract change orders that increase the cost of a contract are only processed once responsibility of the additional cost is determined and a final cost is agreed to by both parties. As a result, the true cost of a project may not be represented by the final contract amount, although it may be the realized cost to NAVFAC. The overall recommendation to address the limitations identified here is to improve "data hygiene" which is the completeness of data collected from the field in NAVFAC's enterprise systems.

While performing analysis of the data to identify trends prior to establishing the representative distributions, it was discovered that there were a remarkable number of projects that finished exactly at CCD. This meant the project was neither completed early or late. For data entry purposes, it is believed that the CCD date is only loosely associated with the actual end date of a contract and not an accurate assessment of when the contract or construction is truly complete. As discussed in the methodology section, it was recognized that CCD is not a date for construction to be complete. Instead, it should be the date that contract final payment was made and the contract closed. This date is rarely the same date as true construction completion. It is recommended to create distributions for use within the analytical tool using BOD as a more accurate metric for this. The BOD is associated with the customer being cleared to occupy the building and RBOD is when the customer needs to occupy the building. While the BOD will tell us when construction is complete enough for occupation, the RBOD will tell us if construction was completed on time. It is recommended for further research to utilize the BOD and RBOD as better data points to use instead of CCD.

With additional KPI data being gathered because of K20-02, it is believed that more accurate and complete data will be available to incorporate into the proof-of-concept data analytic tool that was developed with this study and in conjunction with Dr. Savage. It is recommended that this data, once available in substantial quantity, be incorporated to fully develop the three different tools identified in the Benefit to NAVFAC section which include a pre-award analytic tool to improve DD1391 estimate development, a post-award analytic tool to better identify cost and schedule risk of underway projects at the NAVFAC Region level, and as a cost management tool for the field office level.

10. Conclusion

It is understood that there is a need for NAVFAC to be able to better predict project performance and risk to ensure project success. This project shows that using probability management with past project cost and schedule performance data can be used to generate probability distributions to better predict future project performance. While there have been strides made in data quality within NAVFAC project management systems, there is still room for improvement including potential fidelity gains from additional data collected due to K20-02 that will improve accuracy within the model. The most significant data set for accurate schedule prediction would be the use of RBOD vice CCD. With better data quality, more data analysis can be done to correlate cost, schedule, and other KPIs into a robust tool for use at any echelon within NAVFAC. The accuracy of the model would be further honed by adding correlations that would link all the inputs appropriately ensuring effects of each input generate the appropriate response increasing predictive accuracy. A fully functioning predictive data analytic tool based on the proof-of-concept data analytic tool developed with this project should be pursued by

NAVFAC to ensure the continued future success of its construction programs and the missions they support.

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