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Priority Risk Index: A Novel Approach to Determining Project Health for the United States Corps of Engineers

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Abstract: This report explores the intricacies of the U.S. Army Corps of Engineers (USACE) business and project management processes, focusing on Military Construction (MILCON) projects. The study examines a methodology for assessing project health through the contingency requirements of CCIR#8, employing value modeling, project metrics, and linear regression analysis on individual projects. The report outlines the process of authorizing and appropriating MILCON projects through the National Defense Authorization Act (NDAA), the standard Project Delivery Business Process (PDBP) of USACE, data collection and validation of aggregate project data, and risk assessment. The methods of data collection involve key stakeholders, critical reports, and CCIR #8 data from within the North Atlantic Division (NAD). Highlighting federal regulations and guidelines, findings include a novel approach to milestone-driven risk-informed decision-making and improved data quality. The report presents a novel Predictive Risk Index model prototype for evaluating MILCON project health and predicting CCIR #8.

Keywords: Systems Decision Process, Military Construction, Risk-Informed Decision Making

1. Introduction

The purpose of this project is to provide a novel approach to determine project health and when to intervene based on a set of indicators over the project lifecycle. Current United States Corps of Engineers (USACE) procedures use the Commanders Critical Information Requirements #8 (CCIR) to inform the Chief of Engineers of projects in poor health. CCIR#8 is defined as "cost or schedule increase on a USACE project exceeding project contingency/float" (USACE, 2022). USACE project managers (PMs) use heuristics-based decision-making, informed by lagging indicator data derived from the Primavera 2 (P2) scheduling and Corps of Engineers Financial Management System (CEFMS) budget management systems, on CCIR #8 reporting for individual projects. In addition, PMs follow guidelines from USACE engineering manuals and regulations on reporting procedures and project management. Throughout the lifecycle of a project, health may be variable, and data-driven tools could re-orient a project when risk begins to manifest to a point where preemptive schedule and budget interventions would assist. By determining project health through leading indicators, determined through evaluation of engineer regulations and meetings with subject matter experts, the developed model may predict when a project is beginning to suffer budget or schedule unhealthy trends indicating poor health. A leading risk indicator might inform adequate measures to better protect project health before a formal CCIR #8 trigger. To validate the novel model developed in this research, three completed NAD military programs projects helped determine model viability and the opportunity for scalability to other business functions and business lines at district and major subordinate commands (MSCs), or Divisions, across USACE.

1.1 Literature Review

The literature review assisted in understanding the structure of USACE's business and project management process, as well as the Federal, Military (Army and Department of Defense), and USACE-specific regulations for managing or acquiring MILCON projects. For authorizations and allocations of MILCON projects, the Department of Defense and subsequently the

Department of the Army receive funding, and authorizations for MILCON projects through the National Defense Funding Act (NDAA) (Department of the Army, 2022). Following acquisition and authorization derived from the NDAA, the following requirements must be met. First is the Department of the Army completes a Department of Defense Form 1391 Military Construction Project Data which includes the cost estimate, description of the proposed construction, specific requirements for the project, and the mission impact if the project is unrealized (Herrera, 2019). Following project acquisition and the completion of DD form 1391, the standard business process USACE follows is known commonly as the Project Management Business Process (PMBP). The PMBP establishes a framework for project delivery from concept to completion. With four phases consisting of 22 processes, it is applicable for all USACE work that is deemed a 'project," (Williams 27). USACE's main business management process is broken down into two engineering regulations. These two engineering regulations are Engineering Regulation 5-1-11 (USACE, 2018) and Engineering Management 5-1-11. ER 5-1-11 describes USACE's main business management process which is the Project Delivery Business Process (PDBP). Within ER 5-1-11 is the project management plan (PMP) which includes the purpose of ensuring project and business leadership has a medium as well as a plan to complete their task. The focus of this research is on PMP development in the Project Planning Phase, and the After-Action Review (AAR)/Lesson Learned in the Project Execution and Control Phase.

2. Methodology

2.1 Systems Thinking and Value Modeling

The Systems Decision Process, utilized in this modeling effort involves the creation of a qualitative and quantitative value model which include value functions, additive value model, and weighting associated with taking qualitative attributes and assigning a final numerical value for a project. Through value-focused thinking and the development of the qualitative value model, the group determined value measures based on key functions the final model needed to accomplish. From this modeling process, key quantitative measures apply to the phases and milestones of the USACE project life cycle to develop a final value in which to compare projects of different scopes, schedules, and budgets. The quantitative value model takes the qualitative value measures and applies a numerical system to evaluate projects. This begins with value functions (Driscoll, Parnell, & Henderson, 2022). For each value function, a 0 through 100 score was determined based on an allowable range of each metric. For example, the number of charrettes ranges is 0 to 15 with 0 assigned a score of 100 and 15 assigned a score of 0 as having more charrettes results in a less risky project. The value model's methodology is consistent, but in this research application, it is used to quantify risk for each project. For all 16-risk metrics used in the project, a risk score was gleaned from a function using the raw data input of each project. To normalize each score on the same scale and utilize weighting to determine an overall project risk score per phase and milestone, both linear regression and additive risk equations, which are identical in their construction to a value model, aided the team in the analysis (equation 1). The output of this novel model prototype is a 'by phase and milestone' final risk score, termed the Priority Risk Index (PRI).

$$v(x) = \Sigma_{i=1}^{n} w_i v_i(x_i) \tag{1}$$

The PRI is a risk-informed and predictive model that takes the inputs of a project and outputs a graphical index that depicts the future status from the current calculated risk index of the project. The SDP identified that there are three major functional requirements in the qualitative model. The functional requirements are that the model must predict risky MILCON projects in the project initiation, planning & design, and construction phases. Each phase or objective is analyzed into two main parts, the objective and risk measure. For example, the objective of the initiation phase has a set of activated metrics during the phase: Charrettes (CHR), Awarded in Same as Programmed Amount (APP), 0-30% Design Development (36D), 60-90% Design Development (69D), 90-100% Design Development (9FD), and Value Engineering Study (VE). The risk measures for the initiation phase consist of the number of CHRs, VEs, 36D, 69D, and 9FD completed and the number of weeks before or after the APP. These metrics are traceable to stakeholder inputs and regulation milestones for project health and thus enhance any traditional risk priority number (RPN) descriptive and heuristic-based analysis using likelihood, severity, and detectability.

2.2 Novel Modeling Approach

The Predictive Risk Index model is a milestone and phase-based model. The milestones for this model refer to consistent and more documented milestones that occur in all USACE MILCON Projects. The team determined these milestones through stakeholder analysis with high-level leadership from USACE's NAD. Each milestone occurs in a phase derived in USACE's ER 5-1-11 PMBP. Utilizing milestones and phases that occur consistently throughout most USACE MILCON projects the team created a standardized timeline to define, evaluate, and determine important metrics that affect the risk level associated with MILCON project health. However, the uniqueness of this model comes from only evaluating metrics that are activated at certain milestones which allows the team to determine which metrics are leading indicators, monitoring indicators, and lagging indicators of risk concerning project health. The team compiled this into a PRI Metric Matrix located below in FIGURE 1. For example, Milestone 1: 0-30% Design Development Milestone, Initiation Phase only has two metrics activated when determining its PRI, which are the number of charrettes that have occurred and the difference in weeks between the project's Awarding Date and the project's Programming Date.

Phase	Milestone Number	Project Life Cycle (Milestone)	Metrics Activated	CHR (# of meetings)	APP (weeks)	3D(# of modifications)	6D (# of modifications)	VE (# of modifications)
Initiation	1	0-30% Design Development	CHR, APP	14	10	X	X	X
Initiation	2	60-90% Design Development	CHR,3D, APP,VE	4	6	5	X	2
Initiation	3	90-final% Design development	CHR, 6D, VE, APP	9	3	X	2	12

Figure 1. PRI Metric Matric for the Initiation Phase

The team developed and utilized value functions to convert the raw metric scores in the PRI Metric Matrix into values we could aggregate into a PRI value for each milestone. In Figure 2, the team also determined the weights for each metric. Weights refer to the importance or significance of the metric on the milestone's PRI. The weights were determined by utilizing linear regression techniques on a dataset in which the independent variables were raw values of each of our metrics and the dependent variable was a Cost Schedule Index (CSI) value. This value quantifies how much a project was over or under its originally planned CSI value. A higher CSI value indicates more risk as a project that goes over its allocated budget or schedule will have a higher CSI value (Meredith, Shafer, & Mantel, 2021). The team took the P-values, attained from the linear regression analysis, for each of our metrics and binned them into ten separate bins with bin 10 being P-values less than 0.1 as P-values closer to 0 indicate more importance and therefore should be allocated more weight. The team then normalized the P-values based on the number of metrics activated per milestone to determine the weight for each metric at each milestone. After this, the team aggregated the values per milestone by utilizing the Additive Value Equation. The results were thirteen PRI values: one for each milestone, an average PRI for each phase, and a total average PRI value for the entire project.

Determining Weight Values for Metrics in Initiation Phase							
Metric	Pvalue	Noramlized Pvalue	Bins	Noramlized Bin Value	Milestone 1	Milestone 2	Milestone 3
X Variable 1 (CHR1)	0.568727	0.353	7	0.085	0.412		
X Variable 2 (CHR2)	0.003277	0.002	10	0.122		0.256	
X Variable 3 (CHR3)	0.161271	0.100	9	0.110			0.250
X Variable 4 (APP1)	0.020172	0.013	10	0.122	0.588		
X Variable 5 (APP2)	0.192679	0.120	9	0.110		0.231	
X Variable 6 (APP3)	0.008456	0.005	10	0.122			0.278
X Variable 7 (36D)	0.04438	0.028	10	0.122		0.256	
X Variable 8 (69D)	0.608255	0.378	7	0.085			0.194
X Variable 9 (VE)	0.001838	0.001	10	0.122		0.256	0.278
Total	1.609054	1	82	1			

Figure 2. Weighting and Binning Process for Metrics

A key aspect of applying leading indicators to the project includes forecasting of project health from each phase. Utilizing nine milestones and four phases, in conjunction with calculated PRI values, forecasting methodology allows PMs to see the long-term effects of their project risk. The phase first system allows PMs to evaluate the effects of a project 's previous phases and the lasting project health effects. Without using direct cost and scheduling metrics, the leading indicators dictate future project health if PMs are unable to prioritize additional resources for risky projects.

$$WMA_n = \Sigma_{i=1}^{n} W_i D_i \tag{2}$$

$$F_{t+1} = \alpha D_t + (1 - \alpha) F_t \tag{3}$$

$$\frac{1}{n} \Sigma_{i=1}^{n} |x_i - m(X)| \tag{4}$$

This project utilized two main forecasting methods, exponential smoothing (equation 2), and weighted moving average (equation 3). As shown in the yellow and green lines, respectively in Figure 2, the forecasting allows managers to see the effects of risk on their project per the district and division thresholds. To determine the best forecasting method, equation 4, mean

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absolute deviation, was used to compare methods based on error (Russell & Taylor, 2019). Overall, the novel process created to create the leading indicator of PRI is seen in Figure 3. One keynote is that the research identified multiple milestones which could be added in time, but that would require enterprise data protocols for collection and clarity. Feedback at district and MSC levels reinforced the need for enhanced and consistent data management.

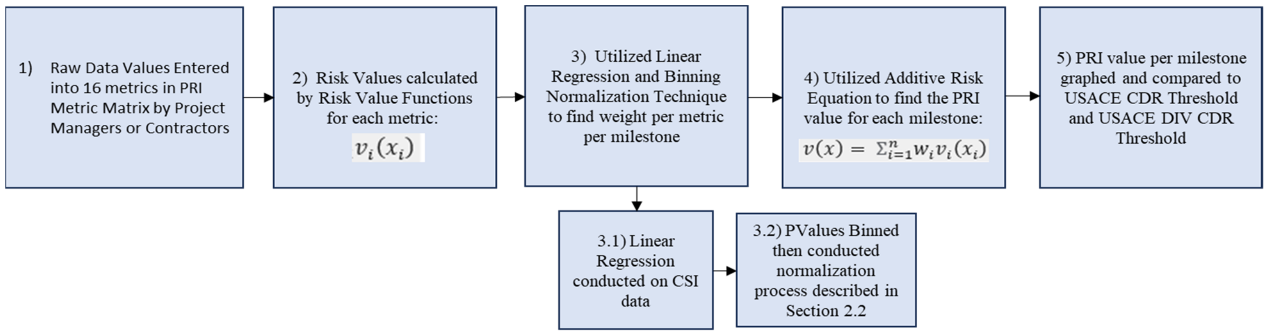

Figure 3. A scalable novel process for determining the Priority Risk Index

2.3 Model Application

This PRI model's managerial application is to determine leading indicators of project risk associated with MILCON project health. It indicates which milestones and which phases of MILCON projects are most vulnerable to risk. This application is to aid senior leaders within USACE in estimating MILCON project health for each project within their project portfolio to create a cohesive understanding between PMs, Senior USACE leadership, and Congress. It also provides USACE PMs and USACE Senior leadership a predictive and monitoring capability to forecast and predict risk through a MILCON project lifecycle. Below FIGURE 4, illustrates Project X (in purple) with proxy-generated data created during the first Model Sprint.

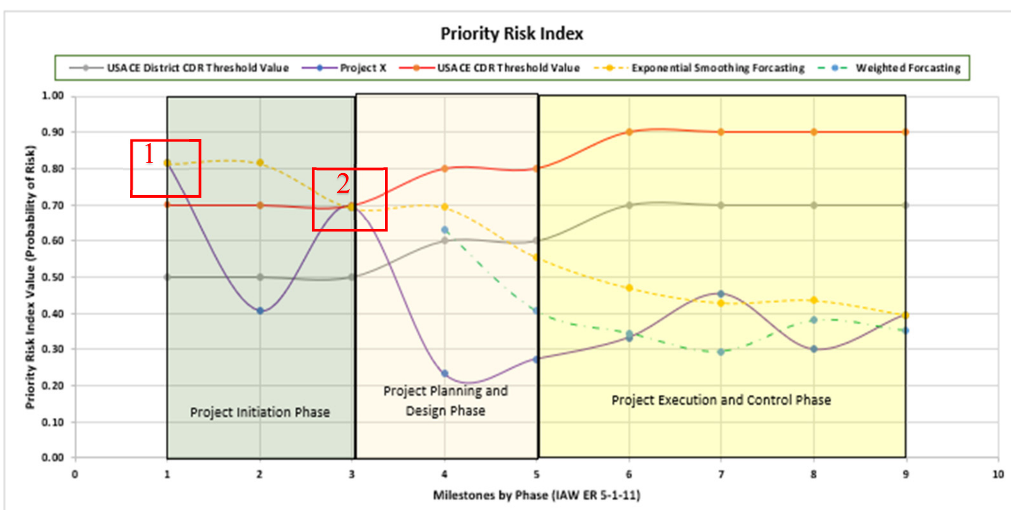

Figure 4. Priority Risk Index with Forecasting

Project X illustrates PRI fluctuation throughout the first three phases of the PDBP. The Orange Line indicates the USACE Commander's (CDR) threshold where a CCIR#8 may trigger a preemptive notification for intervention and alignment of resources toward an at-risk project. For example, the first red box labeled 1 in Figure 4 exceeds the USACE CDR's threshold and therefore a CCIR#8 would occur. The grey line indicates the Division or MSC CDR's threshold for preemptive intervention and action. The red box labeled 2 which occurs at Milestone 3 exceeds the District CDR threshold and therefore the District CDR might choose to implement risk mitigation techniques for reducing the PRI value thus re-establishing project health.

Interventions could include additional direct costs including labor, equipment, or material. It could also include the application of intellectual capital, research and development, or best practice coordination with similar project team members internal to the command, or across the USACE enterprise. This process and PRI project health interface seek to increase project health transparency between PMs, Division CDRs, and the USACE CDR for preemptive action. Its purpose is ultimately to provide input for early corrective measures throughout the project lifecycle to reorient the project back on course to reduce the project's PRI value below both thresholds.

3. Findings

3.1 Model Validation, Data Quality, and Limitations

The prototype risk model is scalable to all USACE command echelons, but another requirement was whether it could predict future health within each phase and across milestones. The research evaluated two forecasting techniques to predict PRI values that will populate for ongoing projects. Key leader visualization via Project Review Briefs of forecasted progress could provide early warning for action. In Figure 4, the forecasted techniques are illustrated by dotted lines. The blue dashed line represents a weighted moving average technique, and the yellow dashed line is an exponential smoothing forecast. A Mean Absolute Deviation as previously introduced in equation 4 was conducted for three NAD completed projects, and it was determined that the weighted moving average approach outperformed the exponential smoothing approach with respective MAD scores of 0.0864 and 0.1433 for the PRI prototype. Continuous evaluation of forecasting methods would be required to validate this predictive component of the model and could be accomplished through additional database access. Other forecasting methods for consideration in future prototypes might include linear regression and adjusted exponential smoothing.

To validate the model, NAD provided three completed projects for evaluation. Through discussions with subject matter experts, leaders within NAD, and PMs at construction sites, the group established acceptable ranges for each project's metrics. The model validation underscores the limitations within which the proponents of the model can provide values and predictive assessments. However, the importance of accurate data collection within the set boundaries of modeling components is highlighted by the validation of the model. The downside of the model validation is the bounds of each function as stakeholder analysis and research yielded each metric, but not the corresponding bounds of each. Therefore, the function bounds are not perfect for calculating PRI and future work must be conducted to identify more accurate bounds to better compare projects of varying length, duration, and scope. Overall, the model validation yielded a functioning model with an accurate PRI number for comparison and use of leading indicators of the risk for a CCIR#8 report.

The final test to validate the model was the Pearson Correlation Test (Schober, Boer, Schwarte, 2018). The result of this test is a value between -1 to 1 with values closer to 1 indicating the two datasets are positively correlated, values closer to -1 indicating the two datasets are negatively correlated, and values closer to 0 indicating there is no correlation at all. The Pearson correlation of the three validation datasets the team utilized was: NAP had a Pearson value of 0.33, NAB had a value of 0.20, and NAO had a Pearson value of 0.20. These values indicate the low correlation of the model and validation datasets, indicating that there were data voids in the data collection of USACE for the metrics the team was utilizing. For example, the team assumed Material Equipment Specifications as recorded. metrics however, the validation datasets illustrated otherwise.

Model validation illustrated model inflexibility with inaccurate, and unstructured data. The PRI model requires a large magnitude of data not formally collected from PMs and therefore if the data required to make the model accurate is not well documented it results in our model calculating inaccurate PRI values from assumptions about the data. For example, one iteration of the data validation illustrated that the Beneficiary Occupancy Date (BOD) was the same amount as the Total Timeline of the project, but the BOD is usually utilized as a time reserve in case the PM needs more time to execute the completion of the project. The BOD is not the total timeline of the project therefore assumptions were made about the project's timeline. Another example is the overall cost of the project did not align with the given NAD data in the PRI Matrix. These examples illustrate the necessity of accurate and consistent data. With further data collection and model validation, the System Usability Scale (SUS), developed by John Brooke, will be used to assess whether the model is durable and usable to assess risks in projects. This will provide the group with valuable information to rework the data input dashboard for easier use by PMs, to prevent data input challenges.

3.2 Model Sensitivity and Project Health Comparisons

The model sensitivity analysis for this paper measured the effects of changing metric values. The team determined that adjusting metrics weight effected the PRI. For example, in Figure 5 the team changed the weight of the APP metric in the initiation phase and compared the results of the NAP and NAB validation set. The team concluded that if the weight of the APP metric is less than 0.8 then the NAB validation project has more risk than the NAP validation project. Therefore,

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USACE should focus efforts on the NAB project; however, if the APP metric weight is greater than .8 then the NAP validation project has more risk than the NAB validation project. The point of indifference in which USACE should focus all its efforts on both projects is when the APP metric weight is equal to 0.8, with respect to the initiation phase. Sensitivity could be conducted for all phases of all projects by USACE CDRs to prioritize projects and determine lines of effort.

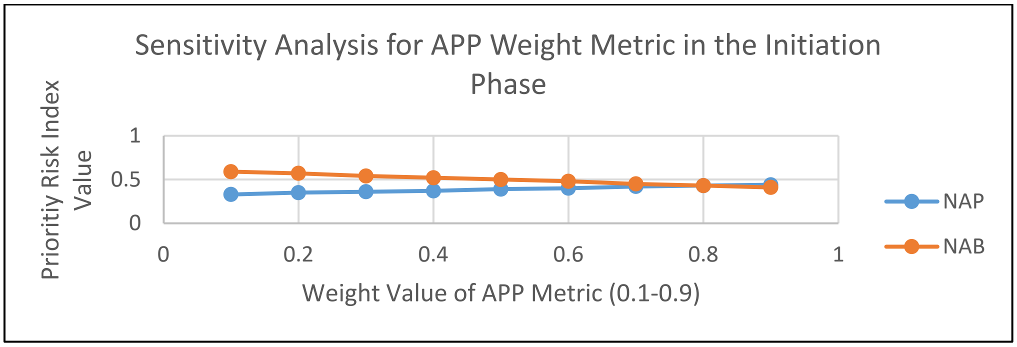

Figure 5. Sensitivity Analysis of APP Metric

4. Conclusions and Future Work

The development of the PRI has created the framework for a novel approach to determine project health and when to intervene based on a set of indicators over the lifecycle of the project. By using systems thinking methodology, such as weighted scoring, the team was able to apply quantitatively derived weights to key milestone-based metrics in project health. The evaluated metrics seek to enable USACE to minimize risk by assessing leading indicators and ensuring compliance with project requirements and milestones outlined in the PDMP. The application of PRI not only enables PMs to assess project health but also fosters a cohesive understanding of project health among PMs, senior leaders, and Congress by providing access to predictive monitoring. However, the team was only able to validate the model by applying it to three projects, and while initial findings are that the PRI is a feasible asset for USACE, a larger project data set is required to statistically validate the model as a representation of real-world project health. Data quality is key in this endeavor. Future work will likely require a review of data collection strategies and architecture for USACE enterprise systems and an expansion of this model to validate and adjust risk metrics for civil works projects. Tying the PRI model to generative artificial intelligence large-language models (LLM) could become critical for rapid 'best practice' interventions across the construction and project management industries, and internally, as USACE after action reviews of completed projects are often locally filed free-text pdf files.

5. References

Department of the Army. (2022). *Fiscal Year (FY) 2023 Budget Estimations.* Retrieved from https://www.asafm.army.mil/Portals/72/Documents/BudgetMaterial/2023/Base%20Budget/Operation%20and%20Maintenance/OMA_Volume_1.pdf

Driscoll, P. J., Parnell, G. S., & Henderson, D. L. (2022). *Decision Making in Systems Engineering and Management* . Wiley.

Herrera, J. G. (2019). Military Construction: Authorities, Process, and Frequently Asked Questions. *Congressional Research Service*.

Marthy, S., & Bolton, P. (2024, November 14). Microsoft Teams Interview. (U. C. Group, Interviewer)

Meredith, J. R., Shafer, S. M., & Mantel, S. J. (2021). *Project Managment: A Managerial Approach.* Wiley.

Russell, R. S., & Taylor, B. W. (2019). *Operations & Supply Chain Management.* Wiley.

Schober, P., Christa, B., & Schwarte, L. (2018). Correlation Coefficients: Appropriate Use and Interpretation. *Anesthesia & Analgesia*, 1763-1768.

System Usability Scale. (1986). Retrieved from Usablity.gov: https://www.usability.gov/how-to-and-tools/methods/system-usability-scale.html

USACE. (2018, July 31). *Managemnet: USACE Business process*. Retrieved from United States Army Corps of Engineers: https://www.publications.usace.army.mil/Portals/76/Users/227/19/2019/ER_5-1-11.pdf?ver=2018-09-27-142333-540

USACE. (2022). *USACE CCIR Requirements Instructions*. Annex D. Retrieved from United States Army Corps of Engineers.