Proceedings of the 2020 Annual General Donald R. Keith Memorial Capstone Conference
West Point, New York, USA
April 30, 2020
A Regional Conference of the Society for Industrial and Systems Engineering

Multi-Year Inland Waterway Investment Model and the Value/Consequence Ratio

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Author Note: The authors would like to thank the Department of Systems Engineering at West Point, The United States Army Corps of Engineers (USACE), The Institute for Water Resources (IWR), the USACE New Orleans District team, and personnel at the Mississippi River Valley Division who all supported this research. Specifically, the authors would like to give a special thank you to Dr. Mark Sudol, Dr. Jennifer Olszewski, and COL Dornstauder for their personalized efforts in aiding this project. *This paper was short selected for "Top Paper" of the proceedings.*

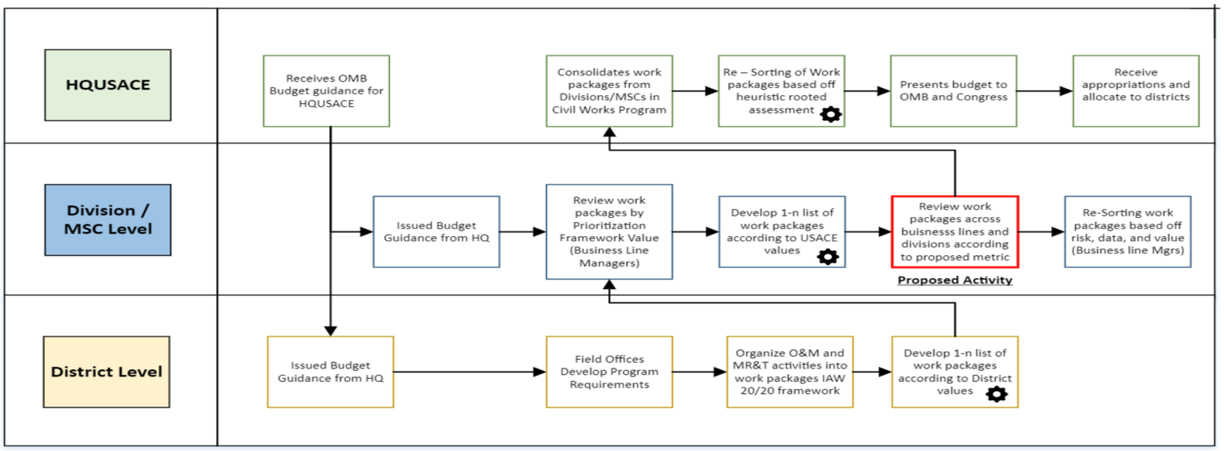
Abstract: USACE's IWR must responsibly manage its work packages through its Operations and Maintenance (O&M) annual budget. IWR has developed several models that use data to inform investment strategies for the prioritization of work packages; however, these strategies are based on old data and not predictive in nature. Because work package ranks significantly change when applying a Value Model and Monte Carlo simulation, this research focuses on the significance of a 3-year predictive budgeting model; a model which is enabled by the National Defense Authorization Act (NDAA, 2020). This research will demonstrate a forward-looking methodology using a Value to Consequence Ratio metric (VCR) for funding work packages through a decision support interface via Microsoft's Power BI. This paper presents the framework for USACE's Civil Works Navigation business line and creates the potential for future work to integrate other business lines utilizing System Dynamics.

Keywords: 3-Year Predictive Budgeting Model, Value Modeling, Decision Support Interface, Value to Consequence Ratio

1. Introduction and Background

USACE is an organization that provides vital engineering services and resources for many of the nation's infrastructure and waterborne projects (USACE, 2019). One of these vital services includes maintaining and developing navigation lines. In fact, navigation was the Corps' earliest Civil Works mission, dating to laws implemented in 1824 that authorized funding for the Corps to improve safety on the Ohio and Mississippi Rivers (Home, HQ). One of the two USACE business functions which manages and oversees the upgrades of water resource projects is the Directorate of Civil Works. A field operating activity under the Directorate of Civil Works is the Institute for Water Resources (IWR). IWR focuses on planning analysis, collection, and management of Civil Works and navigation information, including waterborne resource data (USACE, 2019). Additionally, they develop methods and analytical tools to address and improve the requirements of water resources planning and policies (Economic Primer). Figure 1. illustrates the current USACE "1-n list" process of ranking such work packages, beginning with budget guidance from the Office of Management and Budget and ending with a rank ordered list of work packages according to a district's values. The activity highlighted in red is the portion of the IWR process that this report aims to implement a predictive analysis model that builds upon the current process. Additionally, the gears denote the sub-functions, or steps of the process in which the VCR metric and the newly designed Power-BI decision interface can work alongside existing heuristic decision processes to enhance overall decision quality for a multi-year budget.

The initial problem that this research aims to address is the fact that USACE does not clearly utilize predictive analysis tools or predictive data for budget appropriations and the prioritization of work packages. For example, the O&M budget for 2018 was simply based on 2017 data and the desires of decision authorities. Thus, this project will provide Division Level authorities with predictive analysis that will aid in their evaluation, budgeting, and prioritization of work packages. The tool will show how a forward-looking approach changes work package rankings and budgets if USACE analyzed appropriations assigned for projects 3 years in advance. USACE has never had the authority, nor does it currently have a codified decision model to support 3-year O&M work package programming and budgeting. This model will allow USACE to use future forecasted data sets, total values of work packages, and a 3-year budget approach to identify the best course of action for the



- Denotes where the Value/Consequence Metric impacts the current process.

Figure 1. Swim lane diagram for the current processes (Asberry et al, 2019)

execution of their O&M projects. The objective of the predictive model is to develop and implement an investment strategy for managing USACE navigation project portfolios which weighs both values and consequences in accomplishing its mission. The geographical scope of this project initially focused on the New Orleans District of the Mississippi River Division, but due to data availability challenges, it adjusted to the Louisville District in the Great Lakes and Ohio River Division. Figure 2 illustrates the area of interest along the Ohio River for this report. However, the predictive model and decision interface which will be described in this paper are scalable to other Districts, Divisions, and Headquarters levels. The locks used to collect data for this report are Cannelton, Markland, McAlpine, Myers, Newburg, and Smithland.

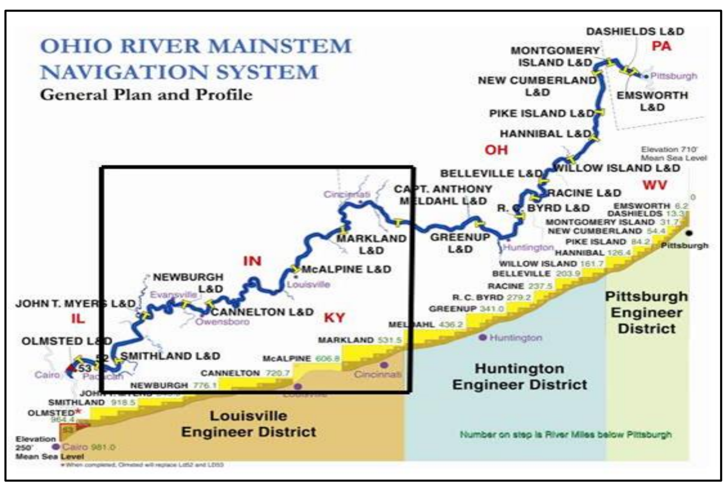


Figure 2. Louisville District Locks and Dams Map (USACE, 2019)

2. Methodology

2.1 Assumptions

This research model includes several key assumptions. First, the predictive analysis assumes the raw data sets fit distributions to forecast data. Second, the extended work package data for the years 2022-2024 is based on proxy data. Additionally, the predicted budget is based on a 3.8% inflation rate (Construction Inflation). Also, it is assumed that there are

15 work packages each year, resulting in 45 total work packages when analyzing the 3-year predictive model. The last assumption is that O&M on the rivers will continue to be under-funded; therefore, the model shows the unrealized value.

2.2 Systems Thinking

The foundation of this research's methodology is systems thinking. Systems thinking is an underlying philosophy that examines systems on a holistic level through stakeholder analysis. One way to achieve this scope is through a system-i-gram, shown in Figure 3 (Blair et al, 2007). Based on substantial stakeholder analysis and model analysis with IWR's Dr. Olszweski and HQUSACE COL(Ret) Dornstauder, the focus of this system-i-gram is on the primary USACE business function of Navigation. This system-i-gram describes relationships in the process flowing from national to state and local levels. The system-i-gram begins with Congress who funds Federal Agencies such as the Department of Transportation, the Federal Emergency Management Agency, and the Environmental Protection Agency. They also fund USACE directly through yearly appropriations respective to programs under USACE authority. Within USACE, IWR works with division and district leadership to determine which projects to prioritize. Additionally, Federal Agencies help can help regulate the use of inland waterways and are important stakeholders in Navigation projects. The black star denotes where the predictive model and VCR metric fit into the existing system.

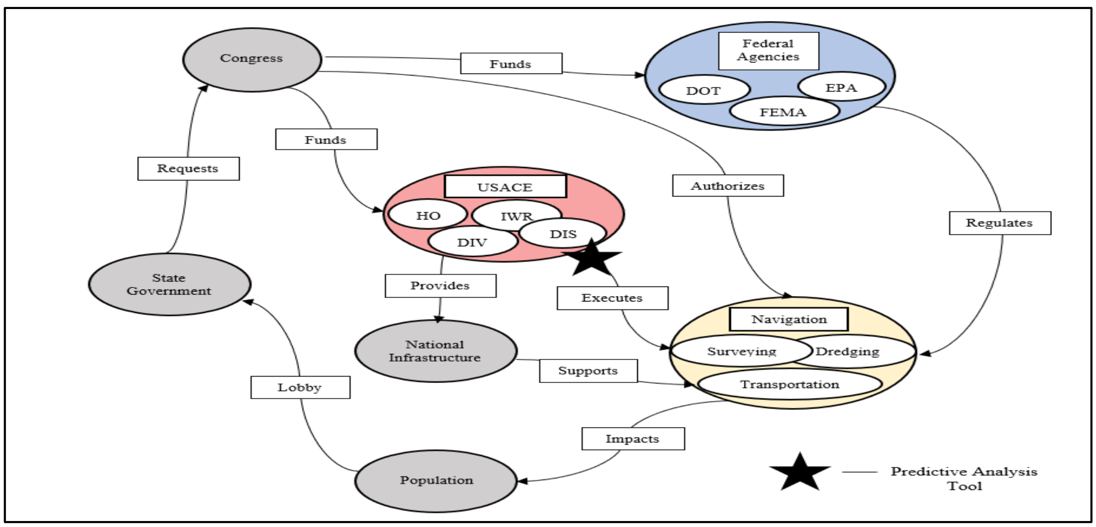


Figure 3. Systemi-gram showing the relationships of the system

2.3 Value Modeling

Value modeling is the process of relating mathematical expressions with the preferences of a stakeholder. Therefore, within the scope of this project, value modeling combines preferences, data, and predictive analysis in order to analyze futuristic budget appropriations and ranks of work packages.

The first step in the value modeling approach was constructing a qualitative value model. The qualitative value model illustrates the conceptual framework of the Inland Waterway Investment Strategy predictive model. This framework represents a top-down approach from the fundamental objective of the project to the functions of the model, and finally, to its value measures, which are derived from stakeholder analysis. The fundamental objective of the model, motivated by Dr. Olszewski's and COL Dornstauder's previous work, is to provide a 3-year predictive model that assists USACE in budgeting and prioritizing Operations and Maintenance (O&M) navigation work packages. The value measures were derived from the system's functions and are used to evaluate the total value that each work package provides for the USACE Civil Works mission. This allowed for the comparison of work packages based on the ranked values. The value measures include total vessels, population, GDP, lockages per year, tonnage of commodities, and OCA rating. Figure 4 depicts the qualitative value model.

A quantitative value model transforms the qualitative value model into measurable and normalized value scores. The quantitative value model illustrates how the value measures are related to the numerical values of work packages. Each of the value measures in Table 1 carries a swing weight that signifies the metric's relative significance to work packages amongst the

ISBN: 97819384961-8-9

pool of value measures. Interviews and previous metrics from other models informed the weights. For this project, significance is defined as how much a value measure affects a lock's operation. The swing weights were assigned values between 0 and 1 and may change to account for preferences over time. A larger value correlates to a larger significance. Additionally, each value measure was associated with a value function that scales raw data values to values between 0 and 100, where 0 is the minimum value and 100 is the ideal value. These values provide the information needed for value scoring.

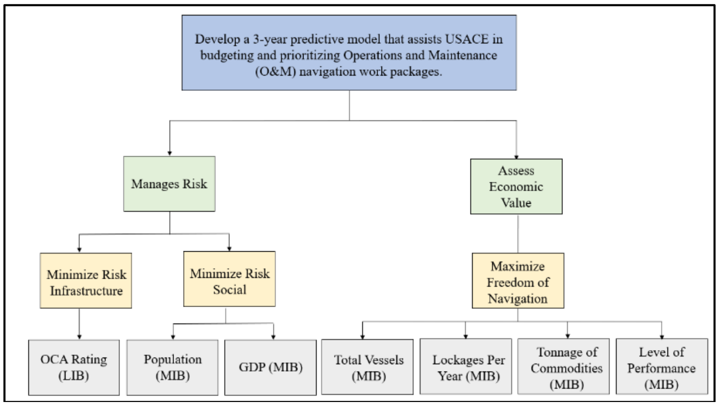


Table 1. Quantitative Value Model Swing Weights

Value Measure	Global Swing Weight
GDP of Impacted City	0.05
Total Vessels	0.15
Lockages per Year	0.25
Tonnage of Commodities	0.30
OCA Rating	0.10
Level of Performance	0.10
Population of Impacted City	0.05

Figure 4. Qualitative and Quantitative Value Models

2.2 Value Scoring

Value scores were calculated by combining the qualitative and quantitative value models. After the raw data for each value measure was converted into a number between 0 and 100, the resulting value was multiplied by the swing weight of the respected measure. This resulted in a value for each value measure that was associated with a specific work package. The addition of each resulting value from the value measures is the total value of the work package. The total value represents the importance of funding the work package, thus allowing the team to rank the work packages over time. Equation (1) represents how total system value for each work package is calculated (Parnell, 2009) and Figure 5 respresents total value scores for each.

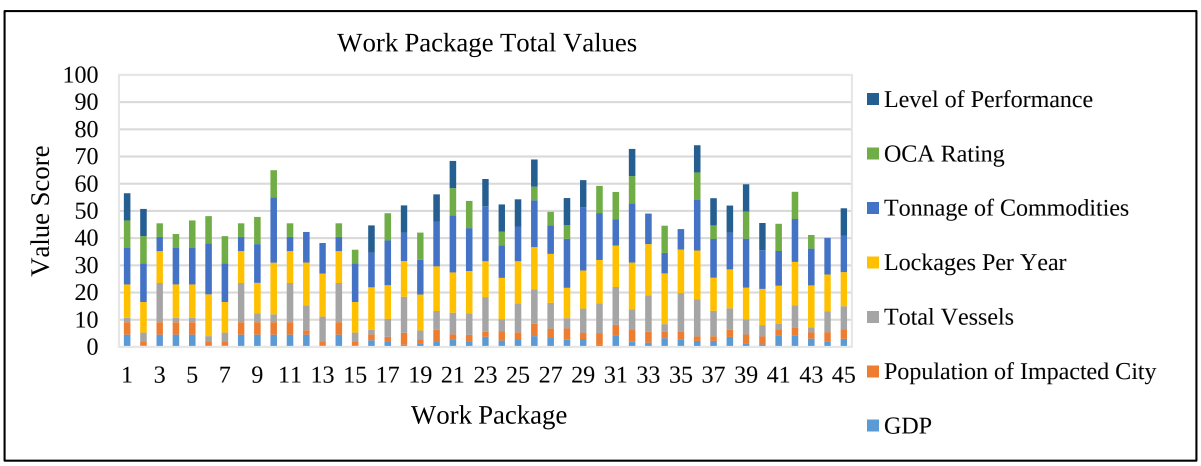


Figure 5. Value Scores of each Work Package

$$V(x) = \sum_{i=1}^{n} w_i v_i(x_i) \quad (1)$$

$v(x)$ is the total value
i = 1 to n is the number of the value measure
x_i is the value score on the i^{th} value measure

$v_i(x_i)$ is the single dimensional value of a score of x_i
w_i is the weight of the i^{th} value measure
and $\sum_{i=1}^{n} w_i = 1$ (all weights sum to one)

2.2.1 Predictive Analytics

The data that the value scoring takes into consideration is based on predicted data sets. The calculation of the predicted data utilizes the excel "forecast.ets" function in excel. This function uses an exponential smoothing algorithm to predict future data based on the 20 years of data that the team had access to. The function includes an upper and lower confidence interval to show the range of possible predicted values. The importance of using predicted data rests in how relevant the data is with respect to time. For example, by using predictive data, the model ranks the work packages for 2019 and 2022 based on 2019 and 2022 predicted data. This is substantially different than the current process of using 2017 data to predict the 2018 work package ranks and budget. The extended work packages are based on predicted proxy data for 45 work packages. The proxy work packages were split into 3 categories, small, medium, and large, based on their total cost. The total cost utilizes the "randbetween" function to assign random cost values to work packages for the years 2022-2024. Then, the predicted cost values were converted into present values. This way, the work packages are also randomized by year and reflect present day budgeting. This also allowed the team to analyze the work packages based on value versus cost in the model.

2.2.2 Model Design

The structure of the model is based in Excel. After the work packages are assigned total values, they are placed in a "1-n" list from the highest total value to the lowest total value. This is the order that the work packages are expected to be funded. Then, the total cost of all 45 work packages is calculated in present value. This represents the ideal fully funded budget if each work package could be funded. The realistic budget ask is calculated based on inflation and material construction cost trends. Then, each work package is funded or not funded, designated with a "Y" or "N" based on the realistic budget ask. The work packages are funded in order until the funding exceeds the realistic budget ask. The resulting list of funded work packages illustrates the amount of work packages that USACE could fund within a 3-year predictive budget, resulting in the VCR metric.

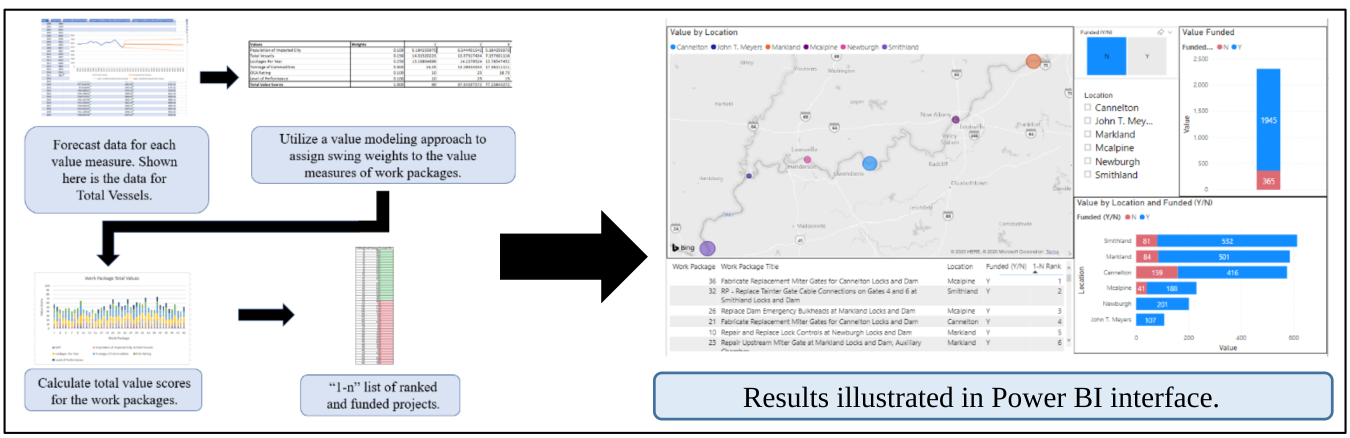


Figure 6. Illustration of Methodology

3. Findings

The fully funded budget ask amounted to $85,287,248, while the realistic budget ask amounted to $75,625,047. This resulted in the funding of 36 out of the 45 work packages. Additionally, the Value-Consequence Ratio (VCR) metric showed that the total value of the work package portfolio summed to 2310 and the total value of work packages funded summed to 1940. The ratio of funded projects to the total value of the project portfolio, or the VCR, was .84, meaning the realistic budget ask funded 84% of the fully funded budget's value. The model can be used to determine what work packages to fund if it is impossible to fund all the work packages, and how much money to request on a 3-year budget versus a 1-year budget. The differences in ranking and budget when considering a 3-year versus a 1-year budget illustrates the importance of predictive analysis when budgeting appropriations.

ISBN: 97819384961-8-9

4. Conclusions and Future Work

There are several benefits to using a 3-year budgeting system and VCR metric in combination with the current system. First, the predictive analysis model displays the amount of value lost for the work packages not funded in a 3-year predictive budget. This allows decision makers to analyze the loopholes in their budgets and alleviate the amount of value lost. By doing this, decision makers receive the resources to fund project portfolios in advance, instead of looking at each year as an independent case. Second, the 3-year budget system allows for increased autonomy within a district. Decision makers have more resources to handle problems within their districts, which will also allow them to manage larger portfolios.

One possible extension to the model could be the ability for the stakeholders to change the values of the swing weights. For example, if a decision maker valued expert opinion over all other value measures, then decision makers would increase the global weight of the OCA rating. When those values are changed, decision makers can see the changes of the new ranking of the individual packages while looking at a 3-year block. Researchers will also investigate the option of using a System Dynamics approach to develop a VCR model. This model will perhaps handle the complexity of the real-world situation better than the predictive analysis used here by creating a more flexible approach for USACE decision authorities.

Because no model specific to this predictive analysis exists at USACE, it is difficult to validate the model. However, the model validation rests in its comparison to similar models. Specifically, the U2RN Metric model proved that the ranking of work packages will change over time (Asberry, Griffith-James, Houle, Wilby, Schreiner, 2019). The new model builds upon this notion by adding a predictive budget assessment to this finding. Additionally, the 3-year budget considers the existing 1-year budgeting process at USACE, demonstrating a representation of the actual system. In addition, experts who have served in USACE executive positions have validated the model's approach. The ability to validate this model using analytic techniques will come available as data sets are made accessible from the USACE Civil Works Information Financial Database (CW-IFD), and represents the future work.

Ultimately, looking into 3 years will change how congress appropriates money to USACE. Each district will be responsible for planning 3 years out and funding projects that their districts decide. Instead of completely replacing the current method of ranking work packages, the model created through this study can be used to supplement decision making in the future.

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