Utility to the Nation: An Investment Strategy for our Inland Waterways

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Author Note: The authors would like to thank the United States Army Corps of Engineers' (USACE) Dr. Mark Sudol, Alexandra Schafer, and Bill Chapman for their expertise, resourcing, and overall support on the project. Their help and the continued support from USACE and others at USMA, enabled the team's ability to grow while meeting the research objectives.

Abstract: USACE Institute for Water Resources (IWR) supplies forward-looking research and analysis to the Civil Works program. IWR investigates navigation of inland waterways across the United States and collects data. The data produced by the Navigation Investment Model (NIM) is not extensively used as an institutionally accepted norm to facilitate evaluation and decision making of infrastructure work packages. This research will present a new method for assessing work packages using a Utility to the Region and Nation (U2RN) metric which complements existing heuristic approaches with predictive data analysis techniques. Application of the new methodology will show how prioritization of work packages would significantly change when using data, and when applying a Monte Carlo simulation to determine future states. This paper provides a framework for waterborne investment that can be applied to the entire inland waterway and deep-sea infrastructure.

Keywords: Utility to the Region and Nation, Monte Carlo Analysis, Decision Analysis

1. Introduction and Background

USACE's mission is to deliver engineering services, strengthen our nation's security, energize the economy, and reduce risks from disaster in times of peace and war (USACE 2018). A swim lane diagram in Figure 1 describes findings from stakeholder analysis and captures a mental model for the system's activities or functions beginning with OMB funding for the USACE Civil Works mission provided legislative authorizations. The proposed activity highlighted in yellow describes the point at which a new method described in this research would enhance the current process. The USACE Civil Works business function, which is the focus of this study, includes multiple business lines to include recreation, infrastructure and environmental stewardship, flood risk management, emergency response and navigation among others.

IWR is a branch in the Civil Works program which conducts research to improve the planning of future water resource projects by improving the current and previously implemented methodologies and techniques (Ludwig 1977, pg.348). The fundamental objective of this project is to improve the performance of the USACE water resources program by examining water resource problems and offering practical solutions through a wide variety of technology transfer mechanisms (USACE 2018). IWR leadership has developed earlier models which use collected data to develop investment strategies, but no models have become a regular part of the Division and Headquarters business processes. Furthermore, no current models predict the importance of future work packages. The desire to develop an easy to understand, robust, and data driven model stems from the $194 billion of cargo which navigates through the nation's waterways yearly (GAO 2018, pg.1). If one section of a waterway is damaged, the potential loss of regional or national utility which the cargo represents can be considerable. A 'forward looking' model resulting in a normative metric which uses relevant data to ease decision making for assessment of mission critical work packages. Work packages are requests for funded projects, from basic maintenance and inspections to repairs and proactive corrective maintenance.

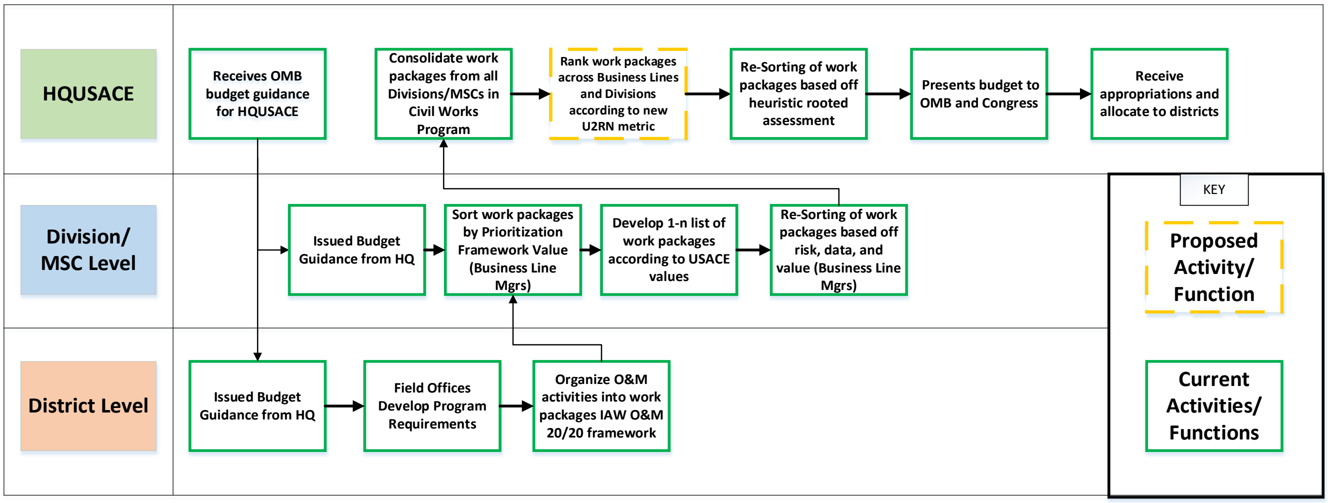

Figure 1. Swim Lane Function Diagram

The geographical scope of this project focused on the Louisville District (LRL) within the Lakes and Rivers Division (LRD). Research examined the current bottom-up approach to programming and budgeting and top-down context so that tools from the domains of value focused thinking and traditional multiple-objective decision analysis might be applied. One component of this was identification that the HQ must set objective guidelines for the leadership allowing the swing weights to be universal across the Divisions. These two domains resulted in a value model and the different value measures will contain social, economic, and environmental factors. The requirement takes these considerations into account when deciding which work package takes priority over another.

Current Process		Future Process
The current process is a heuristic-based decision making tool that ranks work packages two years in advance.	**Distinction (D)**	The new process will be a data driven decision making tool that will still include heuristics and have the ability to project work packages farther than two years.
The current system incorporates 14 business lines to include flood risk management, recreation, infrastructure and environmental stewardship, and navigation. The process is part of USACE HQ and the Lakes and Rivers Division (LRD).	**System (S)**	The future process will continue to incorporate the business lines however, the new process will include the Planning Center of Expertise for Inland Navigation (PCXIN) to ensure the use of data is integrated in future decisions.
In the current process, the seven district commanders order all works packages from 1 to n to determine where O/M dollars will be allocated in the fiscal year based on their heuristics, relationships, and needs.	**Relationship (R)**	In the future process, the data will order the work packages, 1-n, and the district commanders will use their heuristics to check the logic behind the data.
In the current process, the process is highly variable and repetitive in nature. The process does not incorporate key models and resources within USACE to better assess infrastructure investments.	**Perspective (P)**	The future process will use the resources within the organization effectively in order to justify the rankings of the work packages with data.

Figure 2. Current vs. Future Process DSRP Model

The general approach taken in development of the model began with the application of the Systems Decision Process (SDP). The process begins at the problem definition phase with the identification of the problem and stakeholders (Parnell et al. 2011). Within stakeholder analysis, the identification of the specific types of stakeholders is critical. The main stakeholder of this project is IWR with the ultimate decision authority being HQUSACE. Users include the districts of LRD and the consumer of the model is the Civil Works side of USACE. The initial problem statement for USACE IWR was the

USACE is without a decision tool which leverages large amounts of 'Big Data' to determine the location of future trends, and previous efforts to establish a central metric to assess investments has fallen short of acceptance. The proposed method developed in the research intends to challenge and complement an existing heuristic centered decision process and culture. The defined problem emerged as stakeholder insights led the team to the Division as the central integrating command of bottom up data and top down guidance. Figure 2 applies the DSRP systems thinking methodology to capture the mental model of the current, and image a future system which would address the fundamental challenge (Cabrera 2015, pg.7).

Figure 2 illustrates a main difference in the future process as one which is data driven alongside of current heuristic methods. The future process improvement includes Divisions and HQUSACE incorporating the Planning Center of Expertise (PCXIN) data in the overall investment strategy while applying the method described. The future method, when incorporated into the overall process, allows for a system which uses checks and balances on heuristics using predicative data analytics and is described in the methodology section of this paper.

2. Methodology

2.1 Value Modeling

Current budgeting processes rank work packages based on levels of performance established by the O&M 20/20 framework. Data such as the Operational Conditional Assessments (OCA) are relied on during this process. The OCA assess each component of all the infrastructure owned by USACE based on their condition and assign an A-F rating (USACE 2018). Business Line Managers rank work packages at the division level based on expert judgment, risk, value, underlying data, and unique project requirements, which overall is a heuristics-based process. The value model approach effectively integrates heuristics, data, and predictive analytics into an objective process.

2.1.1 Qualitative Value Model

The qualitive value model provides a framework for a value focused assessment of individual work packages for inland waterways. The foundation of the model is the fundamental objective which is to determine the utility/value to the nation for future infrastructure work packages within the inland waterway system. The second level of the model are the functions of the civil works branch of USACE. The objectives for each function are the same – to maximize social, economic, and environmental value to the nation. Value measures, or metrics, allow for the measurement of utility delivered to the region or nation. These value measures allow for an objective comparison between all work packages. Figure 3 focuses on the navigation function which is the only function with a complete set of readily available data.

2.1.2 Quantitative Value Model

The qualitative value model provides a framework for numerical assessment of specific work packages. Each value measure from the above quantitative value model has a swing weight, which represents relative importance of that measure. Each value measure has a value function, which scales the actual numerical value of a value measure to the level of value the client derives from the numerical value, where value is need for funding. For example, if an OCA for a work package is rated as an F, on an A-F scale, then the value to the customer would be 100 because they would get maximum benefit from the funding of this work package. The swing weights in Table 1 represent only a part of the potential for the entire value model, since it only includes the value measures from the Navigation function. When the assessment includes all value measures from all the functions, the Global Swing Weights sum to one. This assumes all functions have the same utility to the region and nation, which could adjust in future iterations of the model based on HQUSACE senior leader assessment of relative importance.

 ISSN (Online): 2329-0188

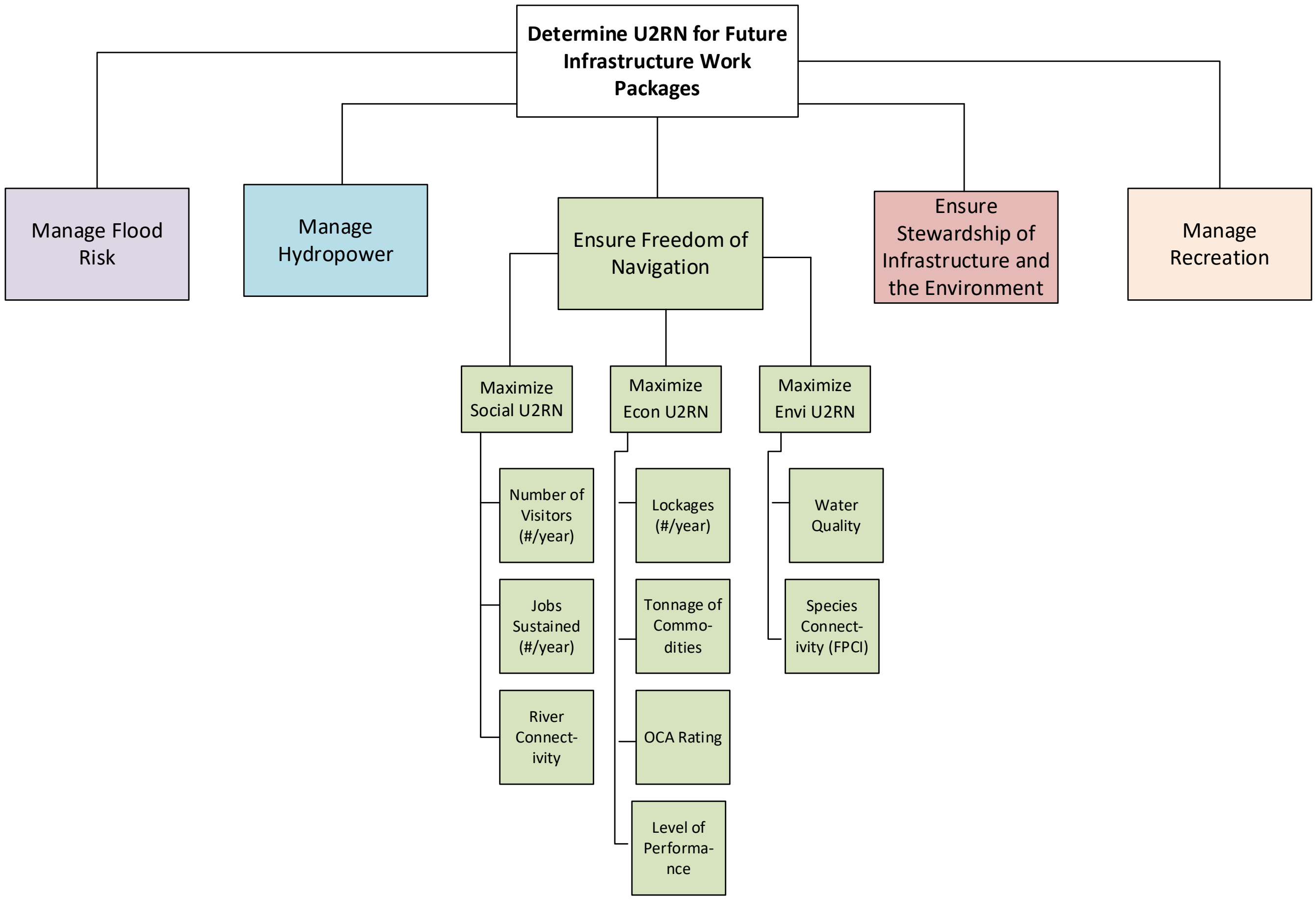

Figure 3. Qualitative Value Model for Inland Waterways

Table 1. Quantitative Value Model Swing Weights

Value Measure	*Global Swing Weight*
Number of Visitors	0.007
Jobs Sustained Per Year	0.034
Lockages per Year	0.034
Tonnage of Commodities	0.055
OCA Rating	0.028
Level of Performance	0.041

2.2 Solution Design

2.2.1 Proof of Concept

The concept of the model applies to any inland waterway system of work packages. For this case study, the area of focus is the Great Lakes and Ohio River Division (LRD), specifically the Louisville District (LRL). The main mission of LRL is navigation, therefore, it is proper to only explore the function "Ensure Freedom of Navigation." Scoping the proof of concept to only one function ensures that the methodology is sound, while limiting the complexity of the scenario. Additionally, all data required as an input to the model is collected by LRD. Part of the proof of concept is showing the value of collecting additional data to make better informed budget decisions. In addition to only looking at the Navigation function, this proof of concept incorporates only fifteen work packages, each of which were LRL work packages from the FY19 budget. Only the top seven out of fifteen projects were allocated funds based on the O&M 20/20 appropriation strategy.

2.2.2 Value Scoring

For each work package, a total value score is calculated based on the quantitative and qualitative value models. From the value functions, derived is a score for each value measure for each work package. These scores capture the delivery of 'utility to both the region and nation,' or a U2RN metric based on the swing weights associated with each value measure. For every individual work package, the scores from each value measure multiplied by the swing weight associated with that value measure give the individual value score, then those values summed give the total value score. The value scores for each work package are in Figure 4. The higher the U2RN metric of the work package, the higher ranked it should be in the budget. This U2RN metrics could be compared with the cost of each work package to deliver a utility-cost curve. The metric alongside current heuristic decision processes will allow USACE to blend both the science and the art of their unique decision culture.

2.2.3 Predictive Analytics

Forecasting and trend analysis can account for future changes in the value measures. Looking at the data for a value measure over time can show how it will behave into the future. For example, Figure 5 illustrates the available data, in blue, and the predicted trend, in orange, of tons of commodities that will flow through the McAlpine locks. The prediction formulation occurs by aligning known data to a distribution with a standard error. Each value measure for each work package has a unique distribution fitted to the particular data set associated with it. Since each distribution has error built into it, the predicted value for the value measure is not deterministic. Therefore, to populate the forecasted years, a simulation must follow. So, using a Monte Carlo simulation, random sampling of the distribution occurs and populates the forecasted years. Each value measure, for each work package repeats this process. The model specifically includes years 2025 and 2040, but the model can forecast any desired year.

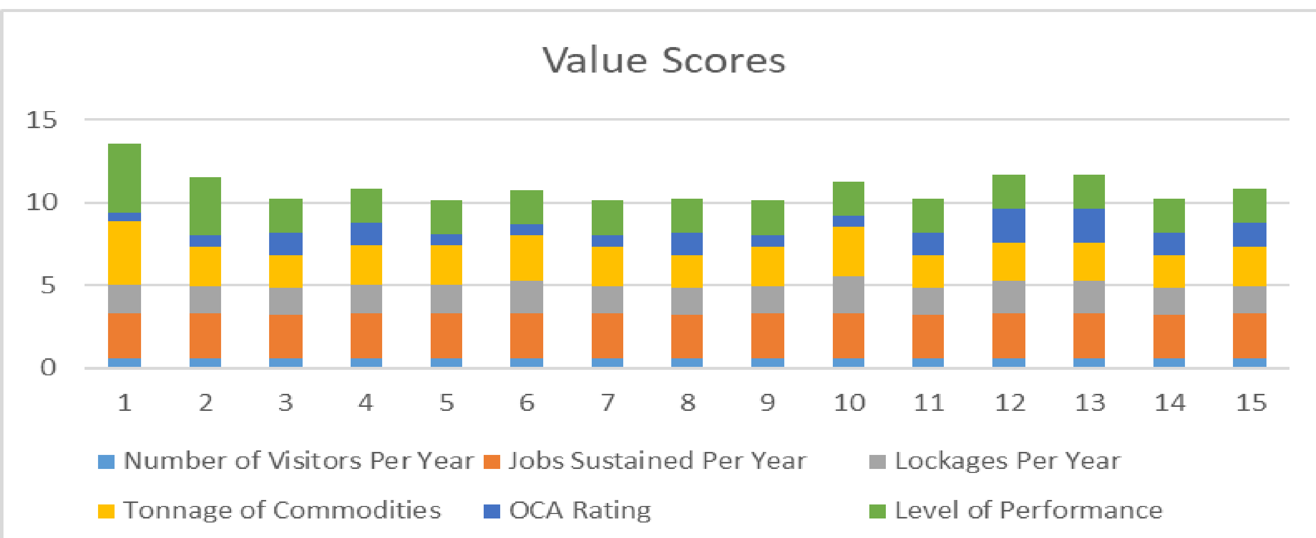

Figure 4. Utility to the Region/Nation (U2RN) Scores for Example Work Packages

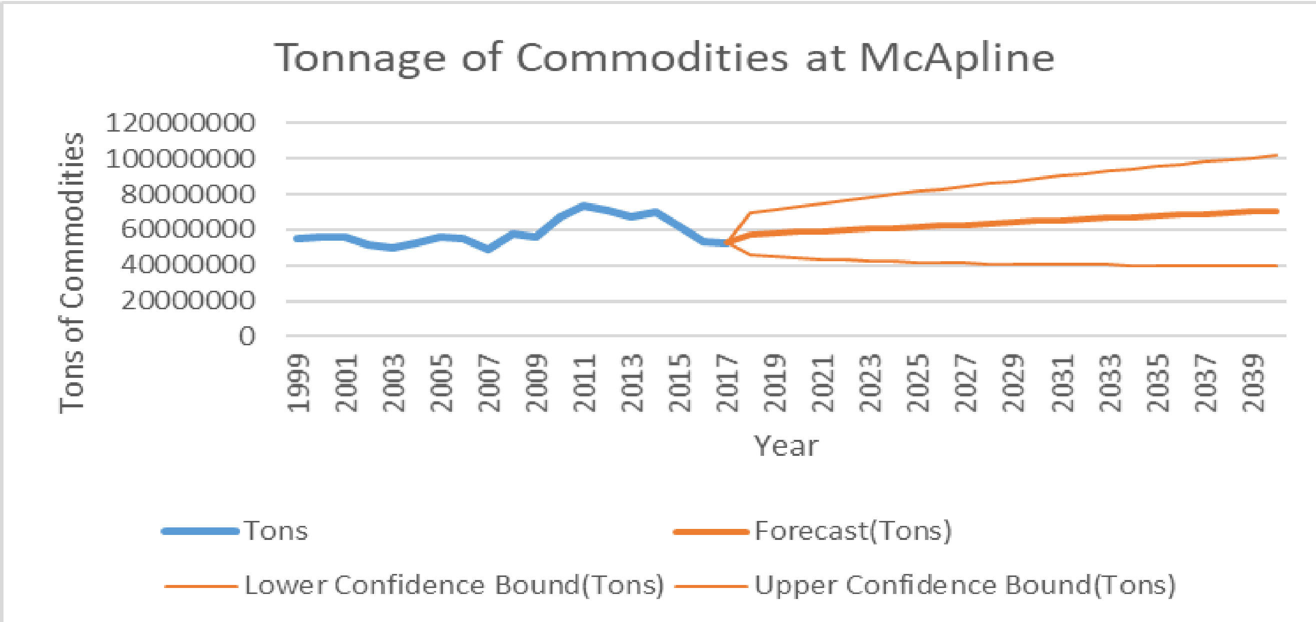

Figure 5. Example of Predictive Analysis

2.2.4 Comparison

A paired t-test compared the original order of the list of the 15 work packages to the re-ordered list based on the calculated value scores. The null hypothesis states that there is no significant difference between the order of the original work package list and the reordered list, therefore the delta value for each work package in the list would be zero. The alternate hypothesis states that there is a significant difference between the order of the original work package list and the reordered list. The null delta and actual delta are the inputs to the t-test. The results of the t-test indicate that there is a significant difference between the ordering of the lists based on the p-value of 0.00235.

3. Findings

Based on the t-test, the current investment strategy employed would be significantly different than the proposed investment strategy when using the value-focused methodology. The proposed investment strategy with the U2RN metric is more effective because it better aligns work projects based on social, economic, and environmental value to the nation. Predictive analytics reveal that project importance changes over time.

Table 2 within Figure 6 shows how the ranking of work packages change from 2019 to 2025 to 2040. Time horizon should be a factor in investment strategies. The ranking of projects changes over time because the inputs to the value measures change, which affect the value scores and the rank, as illustrated in Figure 6. Overall the proposed investment strategy is not only different, but it is more effective at aligning the values of USACE than their current investment methods.

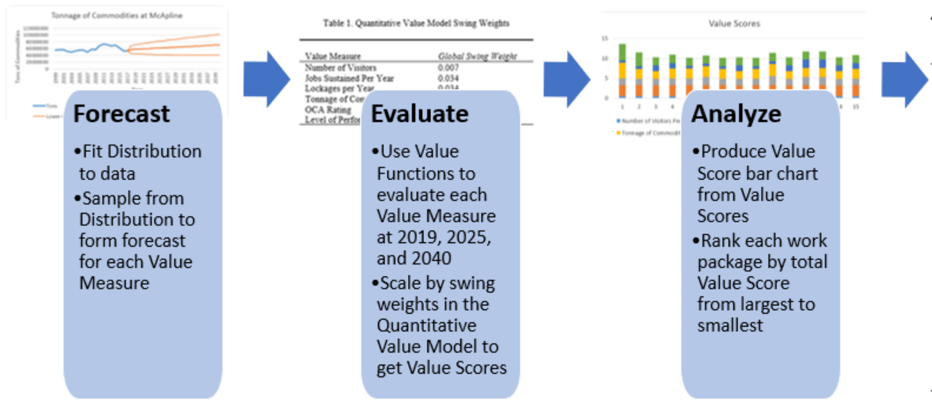

Table 2. Value Score Ranking Overtime

2019 Ranking	2025 Ranking	2040 Ranking
1	10	10
2	1	1
10	13	4
12	6	5
13	4	6
6	5	14
4	12	13
15	14	12
5	2	3
7	3	8
9	8	11
3	11	2
8	9	9
11	15	15
14	7	7

Figure 6. Flow of Methodology to Results

4. Conclusions and Future Work

For future considerations, the project to just one district along the main stem of the Ohio River. Applying value-focused thinking with an associated value model will encourage a new way of thinking about how to invest operations and maintenance dollars across the portfolio of work packages. Using the data collected by the lock masters and PCXIN, USACE can build their decisions based not only on heuristics, but data. This proof of concept would benefit from two enhancements including collection and assessment of data to enable the use of the full qualitative value model thus enabling a 'entire watershed assessment across all possible functions or civil works business lines.

A second area where this methodology could be applied is in deep water ports. The value-focused thinking approach would be applicable to deep water ports such as the New York/New Jersey Port, but would require a reassessment of the qualitative value model since the value measures are likely to change. The nature of work packages would also include very different infrastructure and equipment for shoreline protection, significant and regular dredging, and support of intermodal transfer points. Examining the contributions that the ports provide for the region or nation via value-focused thinking will allow USACE to assess areas requiring improvement based using unique value measures. However, the 'fit' of the data analytic method prescribed in the recommended process improvement from Figure 1 would remain unchanged.

This study can fill in some gaps within USACE as an organization and provide a new innovative way of thinking. Infrastructure maintenance on the locks, dams, and levees across the country are important for public and private economic stewardship and are important at the national level. As such, investment in operations research and systems analysis human and IT capabilities should be examined for reform of organizational design. The development of a value-focused mindset across the Corps of Engineers can enable how data analytics are internally valued as better investment strategies and decision processes will ultimately result in the enhancement of USACE's ability to deliver value and utility to the region and nation.

5. References

Ludwig, D.D. (1977)"The Institute for Water Resources." *The Military Engineer no 69.* 451: 348-49.
Parnell, G.S. (2011). *Decision Making in Systems Engineering and Management*. Wiley Publishing
USACE. (2018). Institute for Water Resources. Retrieved from https://www.iwr.usace.army.mil/About/
USACE. (2018). O&M 20/20. Retrieved from https://intranet.usace.army.mil/hq/cecw/Pages/OM2020.aspx
USACE. (2018). Our Mission. Retrieved from https://www.usace.army.mil/
United States Government Accountability Office. (2018). *Inland Waterways: Actions Needed to Increase Budget Transparency and Contracting Efficiency*. Retrieved from https://www.gao.gov/assets/700/695255.pdf