MARITIME TRANSPORTATION RESEARCH AND EDUCATION CENTER
TIER 1 UNIVERSITY TRANSPORTATION CENTER
U.S. DEPARTMENT OF TRANSPORTATION

Trade-Off Analytics for Infrastructure Preservation

September 1, 2018 – December 31, 2019

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FINAL RESEARCH REPORT
Prepared for:
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1. Project Introduction

U.S. waterborne foreign trade has increased over the past 20 years (MARAD, 2016), and increases in maritime trade and infrastructure utilization are projected in the coming years (Howard, 2019). Maritime managers must be prepared to meet the future demand with a maritime and multimodal infrastructure that is sustainable, resilient, and efficient. Asset management of maritime and multimodal infrastructure involves many stakeholders and difficult trade-offs between operations, monitoring, maintenance, replacement of existing assets and development of new assets with a limited budget. Multiple Objective Decision Analysis (MODA) with Value-Focused Thinking (VFT) combined with Optimization provides a decision support methodology to provide trade-off insights for infrastructure asset management decision makers. However, examination of educational opportunities for practicing professionals reveals a lack of online graduate courses that teach these trade-off analysis techniques. Informing practicing professionals in the use of trade-off analytics will assist them in making infrastructure development, management, and preservation decisions that will provide increased U.S. maritime and multimodal infrastructure capabilities.

2. Project Description

The project objective was to develop an online course to be taught to the maritime and multimodal infrastructure community including: transportation planners, maritime planners, infrastructure managers, Civil Engineers, and Industrial Engineers, on the use of trade-off analytics as a tool to assist them in their infrastructure development, management and preservation decision-making. Modules of this course can also be packaged into online webinars for practicing professionals. This course was developed using existing trade-off analytics resources and maritime case studies developed for the course. The course uses Multiple Objective Decision Analysis (MODA) with Value-Focused Thinking (VFT) and Optimization and to structure complex program asset management decisions requiring trade-offs between conflicting stakeholder objectives. The course focuses on framing decisions, identifying stakeholders, developing objectives and value measures, generating alternatives, developing a value model, developing a cost model, evaluating alternatives, identifying uncertainties, analyzing uncertainties, and making meaningful trade-offs between cost, value, and risk. The case studies and examples focus on maritime and multimodal infrastructures. The course was developed and taught in an online program, the University of Arkansas M.S. in Engineering Management in Fall of 2019. The complete set of course material are available through the MarTREC website for use by instructors at other universities and continuing education programs.

3. Trade-Off Analytics for Asset Management

Any complex asset management program with multiple stakeholders has multiple competing objectives. Before any meaningful evaluation of alternatives, we must first determine the objectives of the infrastructure owners, operators, and stakeholders. Infrastructure assets and preservation projects often have many objectives: obtaining asset condition information, improving capabilities, increasing capacity, increasing resilience, minimizing the adverse impact to the community, minimizing the impact to the environment, and minimizing the costs to users and infrastructure owners. There is also the added difficulty of choosing between multiple projects due to constrained budgets, multiple sources of funds, and complex government approval processes.

Trade-off analytics provides a framework to understand the use of data analytics in asset management. There are three levels in the Trade-off Analytics Hierarchy (figure 1). The first level is descriptive analytics. Descriptive analytics uses asset data that answers the question, "what is?" This describes all of the known information about the assets in the infrastructure system, e.g., location, size, operating characteristics, capability, capacity, age, condition, and maintenance schedule. The second level is predictive analytics. Predictive analytics is the examination of what could be using modeling and simulation. Based on a fundamental understanding of the asset and the infrastructure, the condition of the assets being considered can be predicted under different scenarios (including no action). The sophistication of these predictive methods can vary greatly based on the complexity of the assets, roles of the asset in the infrastructure, and the maturity of the asset. A linear regression model is sometimes sufficient, or multiple integrated simulations using engineering models incorporating uncertainty may be necessary for more complex decisions. Descriptive and predictive analytics provide data to the third level of the trade-off analytics hierarchy which is prescriptive analytics. Prescriptive analytics answers the question "What should be done?" This includes the high level objectives associated with cost, value, and risk of the asset alternatives. This is where the trade-offs become evident: what is the cost of increasing infrastructure capacity? What is the impact on infrastructure capability during an asset upgrade? What is the risk of not properly maintaining an asset? The designers and analysts can use this data to improve the decision options and decision makers can then use the information to choose the alternative that best meets the needs of their stakeholders.

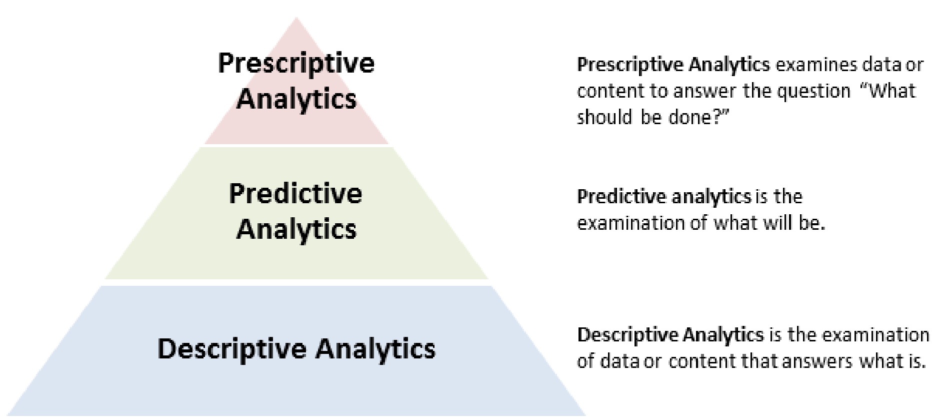

Figure 1: Trade-Off Analytics Hierarchy

4. Methodological Approach

The following sequence of tasks were performed to systematically develop the trade-off analytics course (EMGT 5053) in the Department of Industrial Engineering's Master of Science in Engineering Management program.

Phase 1. We began by assessing stakeholder needs to define course objectives and establish a course outline. While an outline was developed in this phase, later developmental aid from Global Campus at the University of Arkansas resulted in redevelopment and refining of the course objectives and course outline.

Phase 2. Next, we reviewed the available potential textbooks for our course. We conducted a literature review of Multi-criteria Decision Making techniques. While techniques such as the Analytic Hierarchy Process (AHP) and Multiple Objective programming are discussed in current texts, such as *Multi-Criteria Decision Making in Maritime Studies and Logistics* (Lee & Yang, 2017), there was not a focus on Multiple Objective Decision Analysis (MODA) with Value-Focused Thinking and Trade-off Analytics.

Phase 3. We developed the maritime and multimodal infrastructure examples and case studies. These examples were selected to support the course objectives, illustrating trade-off analysis concepts in practical, real-world maritime and multimodal transportation problems. The goal was to develop case studies would feature both regional and national decision perspectives.

Phase 4. Next, we developed the course in Blackboard (a common learning management system). We selected a text, identified reading assignments, prepared PowerPoint presentations, recorded videos explaining the PowerPoints, designed course projects, and developed assessments including reading comprehension, homework, and exams. All materials were posted on the Blackboard course pages. Based on input from Global Campus, the course objectives and course outline were refined to ensure better course content delivery.

Phase 5. In this final phase, the full implementation of the course was completed. The first offering was a three graduate credit offering in the second 8-week session in the Fall of 2019. Course feedback will be used for the next course offering in Spring 2020. This course will be offered online through the Graduate Institute of the U.S. Army Engineering Research and Development Center.

5. Project Deliverables

The project deliverables include the course objectives, the schedule, the syllabus, the case studies, and all of the course materials.

5.1 Course Objectives

This course begins with an introduction to trade-off analytics and decision analysis as well as a brief introduction to maritime and multimodal infrastructure. The course then explores the use of trade-off analytics as a tool to assist with infrastructure development and preservation efforts, with integrated examples of maritime and multimodal infrastructure decision-making. (While the course examples will be on infrastructure, course projects can include any engineering management domain.) Next, the course presents a sound methodology to identify stakeholders, stakeholder objectives, and measures of performance for infrastructure improvement programs. The course uses case studies to demonstrate the application of descriptive, predictive, and prescriptive analytics to evaluate current infrastructure status and identify potential affordable improvements. Development and implementation of an Excel™ based decision support tools to provide trade-off analytics insights and assess best value-per-dollar infrastructure decisions are presented. Required coursework for students includes projects where they apply some of the tools and techniques to an engineering management problem of their choosing (with instructor approval).

The following course objectives were developed. Upon completion of the course the student will be able to:

1. Examine the role of trade-off analyses to support system decisions in each stage of the maritime and multimodal infrastructure life cycle.
2. Identify and define a decision opportunity that requires a trade-off analysis.
3. Explain the advantages and disadvantages of tradespace exploration techniques for trade-off analysis of concepts, architectures, designs, operations, and retirement.
4. Recognize and avoid the mistakes of omission and commission in trade-off analysis.
5. Identify and structure stakeholder objectives and develop single objective and multi-objective decision analysis models to evaluate alternatives.
6. Describe the advantages and disadvantages of common engineering approaches used to generate and evaluate system alternatives.
7. Determine the sources of uncertainty in the life cycle and be able to assess and model uncertainty using probability.
8. Use decision analysis as the mathematical foundation for trade-off analysis.
9. Develop an integrated decision model using Model-Based Engineering that incorporates system performance, value, cost, and risk.
10. Perform a trade-off analysis using both deterministic and probabilistic techniques.
11. Communicate the insights of an analysis and the important trade-offs to senior stakeholders and decision makers.

5.2 Course Schedule

The three credit graduate course was developed and offered in an eight week session. The course was organized into twelve modules. The course also had weekly homework assignments, two class projects, and two exams. The course schedule is provided in figure 2.

October 16 - December 12, 2019 All assessments are due at 11:59pm CST unless otherwise noted.		
Week	**Module - Topic**	**Assessments**
Week 1	Module 1 - Introduction to Trade Off Analytics	Module 1 Quiz
	Module 2 - Conceptual Framework for Trade Off Analytics	Module 2 Quiz
		Week 1 Assignment
Week 2	Module 3 - Identifying Opportunities	Module 3 Quiz
	Module 4 - Identifying Objectives and Value Measures	Module 4 Quiz
		Week 2 Assignment
Week 3	Module 5 - Developing and Evaluating Alternatives	Module 5 Quiz
	Module 6 - Analyzing Resources	Module 6 Quiz
		Week 3 Assignment
Week 4	Module 7 - Integrated Models for Trade Off Analysis	Module 7 Quiz
		Week 4 Assignment
	Exam 1	
Week 5	Module 8 - Benefit Cost Analysis	Module 8 Quiz
		Week 5 Assignment
	Project 1	
Week 6	Module 9 - Exploring Concept Trade Offs	Module 9 Quiz
	Module 10 - Exploring the Design Space	Module 10 Quiz
		Week 6 Assignment
Week 7	Module 11 - Quantifying Uncertainty	Module 11 Quiz
	Module 12 - Sustainment Models	Module 12 Quiz
		Week 7 Assignment
Week 8	**Project 2**	
	Exam 2	
Total		

Figure 2 Three Graduate Credit, Eight Week Course Outline

The objectives of the modules and submodules (lectures) were developed using Bloom's Taxonomy. Bloom's Taxonomy is a hierarchical framework that uses six levels of learning: remembering, understanding, applying, analyzing, evaluating, and creating. Using Bloom's Taxonomy, the coursework was developed to allow students to recall information from their previous work or academic life, integrate this with an understanding of trade-off analytics concepts, apply this knowledge to solve infrastructure related problems, analyze and evaluate the results of these studies, and, finally, to create their own trade-off related study of an engineering management problem.

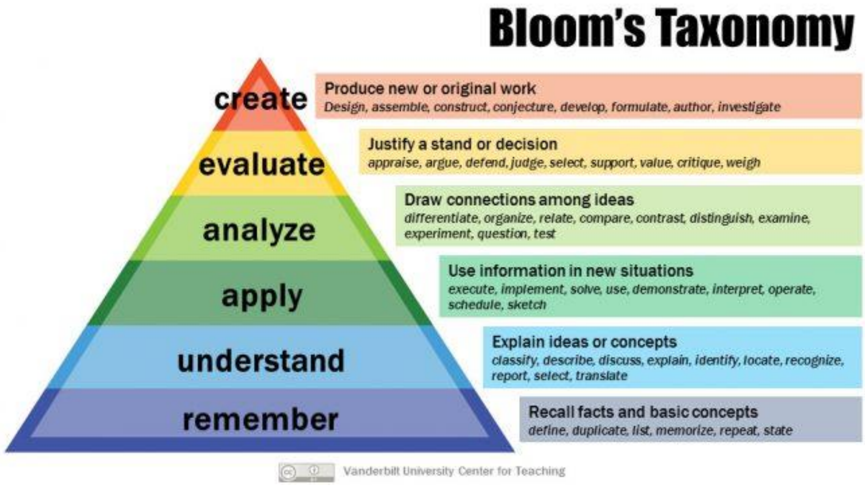

Figure 3 *Vanderbilt University Center for Teaching, "Bloom's Taxonomy". September 6, 2016 via Flickr, Creative Commons Attribution. URL: https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/*

To assess student knowledge, the course integrates cumulative mid-term and final exams as well as two student projects. The first project allows students to perform a trade-off analysis for an engineering management decision problem using deterministic modeling techniques. This project requires the development of either: (1) a net-present value (NPV), (2) a benefit-cost analysis, or (3) a multiple objective decision analysis (MODA) and cost model. Further, each student gives a presentation covering their study's objectives, relevant deterministic modeling techniques, and the recommendations that result from their analysis. The second course project requires the deterministic analysis and an uncertainty analysis, integrating value and cost models. In addition to a presentation, the student must write an executive summary of their project.

5.3 Course Overview: Weekly Content and Assignments

The online course was developed using Blackboard as the Learning Management System. Figure 4 presents a screen shot of the opening page in Blackboard.

Figure 4. Screen Capture of Course Opening Page in Blackboard

Content barriers were used to ensure online students actively engage with the course material. For example, to access the next module the student must first do the reading assignment for the current module and receive a sufficient score on the corresponding reading quiz. The quizzes were developed to be automatically graded for the student, and multiple quiz attempts are allowed since questions are dynamically generated using question pools. The homework assignments are manually graded so only a single attempt is allowed.

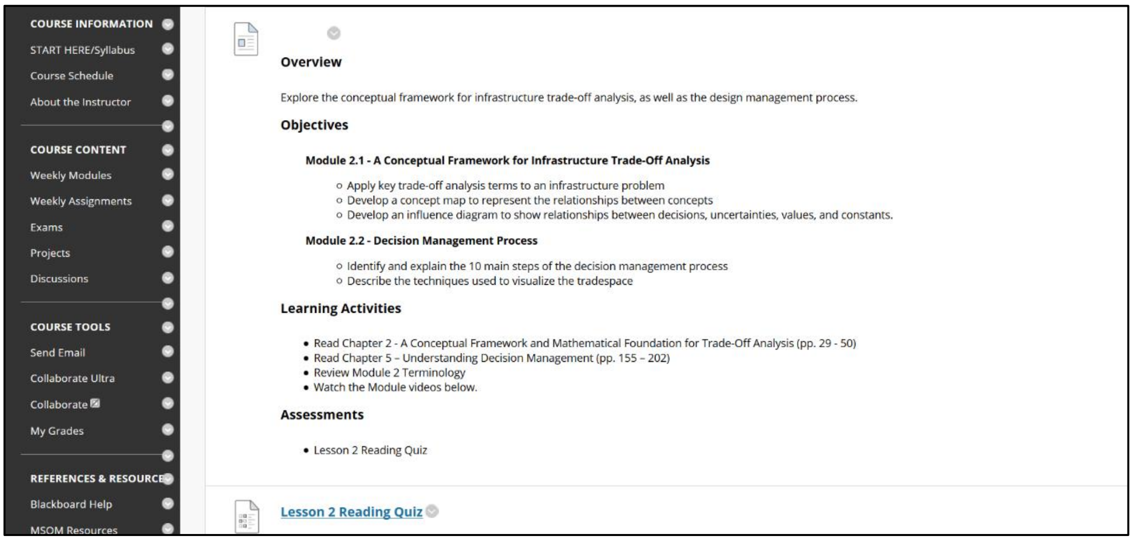

Figure 5. Screen Capture of Module Content Layout in Blackboard

5.4 Case Studies

To provide illustrative examples of trade-off analysis techniques, case studies were developed and integrated into the course. Examples include: an optimization of the United States Army Corps of Engineers (USACE) budget allocations, the Arkansas River navigation study, a benefit-cost analysis of the USACE Mississippi River shipping channel development, a maritime security system, and the design of a lift boat. Brief case study summaries are provided below.

5.4.1 An Optimization of the United States Army Corps of Engineers Budget Allocation

George E. Gallarno (Developed for presentation in this trade-off analytics course)
Project conference presentation included in Appendix C.

This case study describes the use of Multiple Objective Decision Analysis (MODA) with Value-Focused Thinking (VFT) for asset portfolio optimization. First, the organizational values were determined using the U.S. Army Corps of Engineers (USACE) Civil Works Strategic Plan 2014 -2018. This "Gold Standard" document discusses the USACE organizational objectives as well as value measures used to evaluate each objectives progress towards the ideal value. The document was used to develop 29 values measure (and value curves) to assess asset management strategies. The asset management strategies used six budget allocation categories are identified in the USACE strategic plan: navigation, flood risk management, recreation, hydropower, environmental stewardship, and water supply. To generate a specific strategy, each budget category's funds are determined using a percentage of the current fiscal years allocations. Additionally, the budget of each strategy does not exceed what is given for the current fiscal year. The budget strategies were named by their primary emphasis: commerce, civilian, disaster mitigation, conservation, and a balanced.

Two sources of systemic uncertainty were introduced into the MODA model to evaluate their effects on asset management strategy selection: (1) budget reduction and (2) flooding. First, when a budget reduction occurs, the preference ranking of the alternatives remains the same (figure 6). Next, the impact of flooding upon strategy selection was examined with Monte Carlo Simulation. Disaster mitigation achieved the highest expected value, but does not stochastically dominate the other strategies (figure 7). This case study enhances knowledge of how to properly frame asset management models using MODA, optimization, and Monte Carlo Simulation.

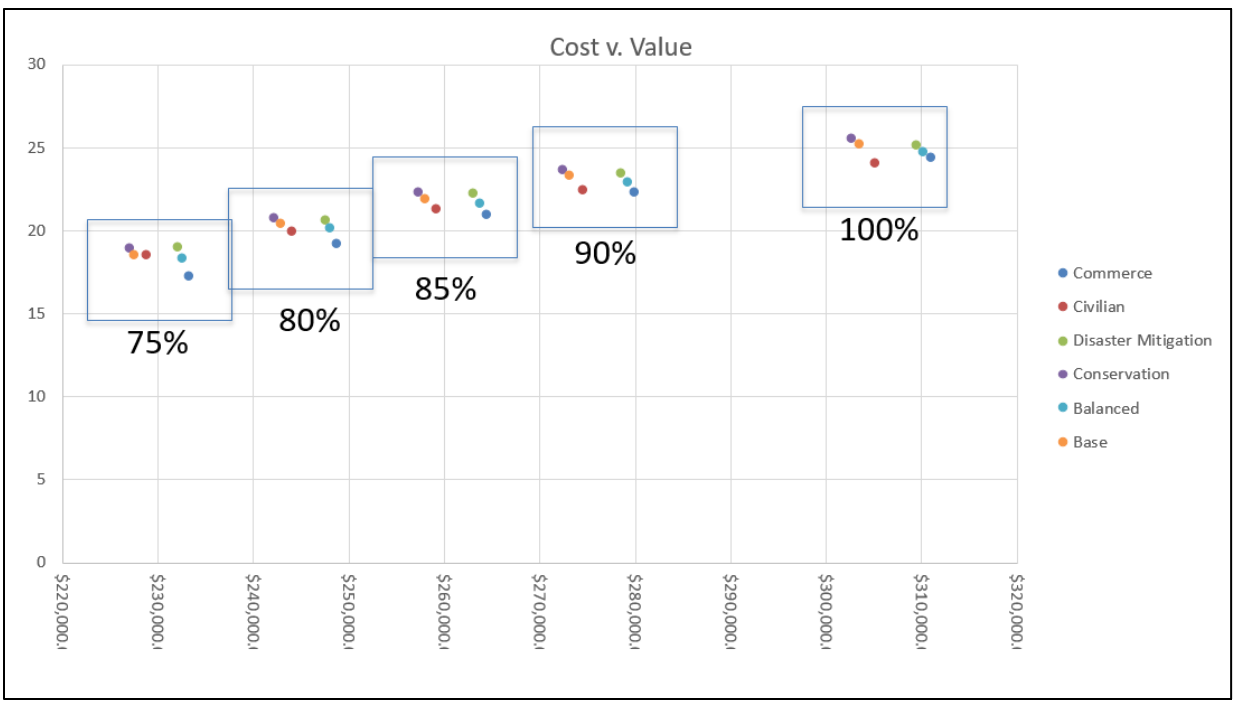

Figure 6. Cost v. Value of Strategies at Percentage of Current Budget

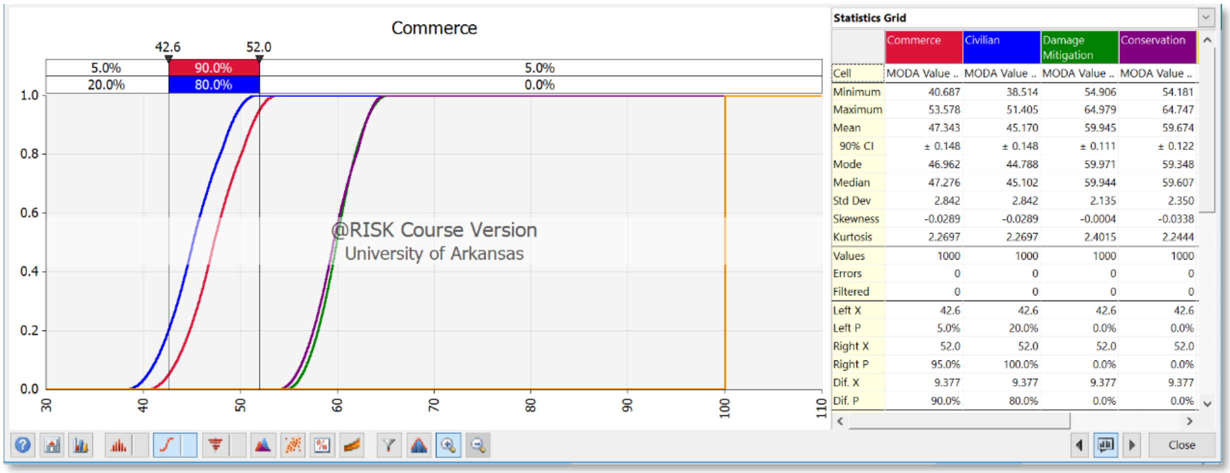

Figure 7. S-curves of Asset Strategies Resulting from Monte Carlo Simulation of Flooding

5.4.2 The Arkansas River Navigation Study

United States Army Corps of Engineers, Little Rock District and Tulsa District. "Final Feasibility Report: Arkansas River Navigation Study - Arkansas and Oklahoma McClellan-Kerr Arkansas River Navigation System." August 2005.

Coal and industrial chemical traffic on the McClellan-Kerr Arkansas River Navigation System (MKARNS) is growing at an annual rate of 1.5% or higher, petroleum products growing 0.6%-0.7% annually, and all other commodities growing at a rate between 0.9% and 1.2%. Due to this increased use, the state of Arkansas must identify valuable alternatives to enhance the navigation system, improve navigation efficiency, and accommodate traffic grow. Three key factors were considered to improve the MKARNS: navigation channel depth maintenance, flow management, and navigation channel deepening. By examining the impacts of minimally and maximally engaging the factors, various strategies were generated and evaluated against each other using benefit-cost analysis. This study increases comprehension of benefit-cost analysis for complex systems with uncertainty.

5.4.3 Mississippi River Shipping Channel Development

United States Army Corps of Engineers, Integrated General Reevaluation Report & Supplement III to the Final Environmental Impact Statement, Mississippi River Ship Channel, Baton Rouge to the Gulf, Louisiana Project. April 2018.

This study examined whether deepening existing channels along the Mississippi river would be in the best interest of the federal government. Existing and future conditions were examined and potential alternatives were generated to address these conditions. Alternatives were evaluated by assessing the feasibility, cost, and benefits of each alternative. Additionally, uncertainty analysis was performed to determine the environmental impact of the alternatives. Multiple constraints were considered to generate initial alternatives. Subsequent alternatives (including hybrid alternatives) were iteratively defined based on feasibility of alternatives under consideration. The suggested alternative was chosen based on net excess benefits. This study enhanced understanding of how benefit-cost analysis can be used to assist in iterative generation of alternatives.

5.4.4 Maritime Security System

Madni, A. and A. Ross, "Exploring Concept Trade-Offs," Trade-off Analytics: Creating and Evaluating the Tradespace, G. Parnell, Editor, Wiley & Sons, 2016.

The goal of this case study was to develop a maritime security system for a particular littoral area of interest (AOI). The system is required to detect suspicious boats, identify suspicious boats, board suspicious boats, and conduct search and rescue missions. Multi-attribute Tradespace Exploration (MATE) is used to explore the design space and generate alternatives. Better alternatives were located along the Pareto frontier, determined by evaluating alternative multi-attribute utility (MAU) versus alternative cost. Next, simulation was used to evaluate the leading alternatives within a stochastic environment. This study illustrated how concept trade-off analysis is a key activity in the conceptual system design phase, and is part of the overall systems engineering trade-offs analysis process.

5.4.5 Lift boat Design

Whitcomb, C. and P. Beery, "Exploring the Design Space," Trade-off Analytics: Creating and Evaluating the Tradespace, G. Parnell, Editor, Wiley & Sons, 2016.

Lift boats are self-elevating, self-propelled vessels - commonly equipped with a crane and an open-space multi-use deck – that are used for oil platform maintenance, fracking, sand blasting, pipe-laying, etc. The deeper that the lift boat can operate, the more profit that can be earned; therefore, longer lift boat legs are needed for increased operator profitability. An issue is that longer legs are heavier, reducing the lifting capacity of the vessels as well as reducing the stability of the vessel during both transport and operation. This case study explores possible design variations using fractional factorial design of experiments. The results of the design of experiments are examined using regression analysis techniques. This case study demonstrates the use of design of experiment techniques to explore the design space.

The above five case studies are provided in the course materials developed for this course and provide to MarTREC.

6. Results

This research developed a trade-off analytics course focused on maritime and intermodal infrastructure asset management. The first offering was in the second 8-week term of the Fall 2019 within the University of Arkansas Engineering Management program. The online course used Blackboard with prerecorded video lectures augmented by reading and content review quizzes. The course development process met all of the project objectives outlined within the original project proposal. First, the coursework provides an overview of a decision analysis methodology used to identify stakeholders, stakeholder objectives, and measures of performance for infrastructure improvement programs. Techniques presented include: vision statements, decision hierarchies, stakeholder issue identification matrix, Value-Focused Thinking, value hierarchies, and value models. Next, descriptive, predictive, and prescriptive analytic techniques are presented in the context of evaluating current infrastructure status and potential improvements. Both deterministic and probabilistic models are introduced, as well as asset management optimization, within the context of single objective and multiple objective decision analysis. Value-Focused Thinking is also used to evaluate alternatives, considering organizational value versus cost. Lastly, Microsoft Excel™ and the Probability Management SIPmath modeling tool are used to help students learn to develop decision support tools to provide trade-off analytics insights to decision makers and stakeholders with the best value per dollar infrastructure improvement programs. Examples of these tools are provided within the course material and students develop their own models, under instructor guidance, in two course projects. All course materials are available thorough MarTREC.

7. Impacts

The course development has resulted in several impacts. First, after discussions with leadership at the United States Army Engineering Research and Development Center (ERDC), they agreed to offer this course in their Graduate Institute. Subsequently, an agreement has been approved by University of Arkansas and ERDC to offer all University of Arkansas M.S. in Operations Management and M.S. in Engineering Management program courses through the ERDC Graduate Institute. Second, continuing work includes pursuing funding for an asset management research proposal with ERDC. Third, using material developed for this project, we have worked with Ms. Patricia J. Gaynor, Marine Structural Engineer, Ports Infrastructure Development Program, Office of Ports and Waterways Planning, U.S. Maritime Administration, to develop a MARAD Decision Support Tool to support their selection of best Port Infrastructure Development Program grants (funded at $278M per year).

8. Conclusions

This project achieved its two objectives: create a trade-off analytics course for the Master of Science in Engineering Management program and provide a course in the ERDC Graduate Institute. While examples for this course come primarily from maritime and multimodal transportation, students who take this course gain an understanding of trade-off analysis techniques and their applications to solving other domain specific problems. Future work includes improving existing techniques and applying them to maritime and multimodal transportation infrastructure asset management for MARAD and ERDC.

9. References

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Maritime Administration, United States Department of Transportation. "U.S. Waterborne Foreign Container Trade by U.S. Customs Ports 2000 – 2017." Source last updated: Tuesday, September 3, 2019. URL: https://www.maritime.dot.gov/data-reports/data-statistics/us-waterborne-foreign-container-trade-us-customs-ports-2000-%E2%80%93-2017

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Whitcomb, C. and P. Beery, "Exploring the Design Space," Trade-off Analytics: Creating and Evaluating the Tradespace, G. Parnell, Editor, Wiley & Sons, 2016.

Appendices

A. Sample Trade-Off Analytics Course Syllabus

B. General Project Presentation Slides (Used for Student Presentations and Poster)

C. Slides from Case Study Presented at the 2019 National Conference of the Institute for Industrial and Systems Engineering (IISE).

A. Sample Trade-Off Analytics Course Syllabus

UNIVERSITY OF ARKANSAS

EMGT 5053: Trade-off Analytics for Engineering Management
Fall 2019 8W2

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Telephone: 479 - 575 - 7423 (Office)
914 - 720 - 3989 (Cell)
Email: gparnell@uark.edu

Course Logistics:
Credit Hours: 3
Days: Online
Time: Online
Location: Online

Prerequisites: None

Required Textbook:
Parnell, Gregory S. Editor, *Trade-off Analytics: Creating and Exploring the System Tradespace*. John Wiley & Sons, 2016.

Course Description:
Explore the use of trade-off analytics as a tool to assist with infrastructure development and preservation efforts, with integrated examples investigating maritime and multimodal infrastructure. (While the course examples will be on infrastructure, course projects can include any engineering management domain.) Learn sound methodology to identify stakeholders, stakeholder objectives, and measures of performance for infrastructure improvement programs. Apply descriptive, predictive, and prescriptive data, models, and analytics to evaluate current infrastructure status and identify potential improvements. Develop and implement an Excel™ based decision support tool to provide trade-off analytics insights and assess best value-per-dollar infrastructure decisions.

Course Topics:

Topics	Hours
Introduction to Trade-Off Analytics and Decision Analysis	3
Introduction to Maritime and Multimodal Infrastructure and Life Cycles	3
Conceptual framework for Infrastructure Trade-Off Analysis	3
Framing the Decision	3
Identifying Improvement Opportunities	2
Developing and Evaluating Alternatives	3
Overview of Benefit Cost Analysis	2
Identifying Benefits and Measures	2
Developing Benefit-Cost Models	2
Developing an Integrated Model for Benefit and Cost Trade-Off Analytics	3
Exploring and Evaluating the Decision Space	3
Understanding Sources of Uncertainty and Analyzing Uncertainty	4
Communicating Analysis Results to Decision-Makers	3
Project Presentations	3
Exams	3

1

Course Outcomes: Upon completion of the course the student will be able to

1. Examine the role of trade-off analyses to support system decisions in each stage of the maritime and multimodal infrastructure life cycle.
2. Identify and define a decision opportunity that requires a trade-off analysis.
3. Explain the advantages and disadvantages of tradespace exploration techniques for trade-off analysis of concepts, architectures, designs, operations, and retirement.
4. Recognize and avoid the mistakes of omission and commission in trade-off analysis.
5. Identify and structure stakeholder objectives and develop single objective and multiobjective decision analysis models to evaluate alternatives.
6. Describe the advantages and disadvantages of common engineering approaches used to generate and evaluate system alternatives.
7. Determine the sources of uncertainty in the life cycle and be able to assess and model uncertainty using probability.
8. Use decision analysis as the mathematical foundation for trade-off analysis.
9. Develop an integrated decision model using Model-Based Engineering that incorporates system performance, value, cost, and risk.
10. Perform a trade-off analysis using both deterministic and probabilistic techniques.
11. Communicate the insights of an analysis and the important trade-offs to senior stakeholders and decision makers.

Grade	
Exam 1:	25%
Exam 2:	25%
Project 1:	15%
Project 2:	25%
Homework & class participation:	10%
TOTAL	100%

Grading Scale	
A:	90% and above
B:	80% to 89%
C:	70% to 79%
D:	60% to 69%
F:	Below 60%

Weekly Assignments: Assignments are due weekly. Your assignments must be submitted to Blackboard. E-mailed assignments will be accepted only for valid reasons (e.g., course web page inaccessible due to down time or software problems).

Exams: Exams will consist of problems, short answer questions and multiple choice. Exams are closed book with one page of notes on both sides. Collaboration is not permitted on exams.

Project 1 (major professional decision): The first project is an individual analysis of a real life engineering decision in any engineering domain that is of interest to you. Project 1 deliverable is a 10 minute presentation and an Excel decision model. Grades will be based on the quality of your problem definition, value model (Net-Present Value model or multiple objective model with 5-10 value measures), life cycle cost model, deterministic analysis, insights, and presentation.

Project 2 (major professional decision): The second project is an individual analysis of a real life engineering decision. Project 2 deliverables are a ten page type-written report (including an executive summary), submission of an integrated (value and cost) Excel decision model that uses Monte Carlo simulation, 10 min presentation. Grades will be based on the quality of your problem definition, decision model, deterministic/probabilistic analysis, insights, and presentation.

Assignments: Please treat the due dates in this class as professional obligations. An assignment will receive a 10% deduction from the total point count for each day it is late.

- Late assignments will not be accepted more than three days after the original due date/time.
- Deviations from this policy will be made only if the student receives approval from me at least 24 hours prior to the homework due date/time.

I understand there are emergencies and extenuating circumstances, which I will certainly consider. I just expect you to plan ahead, if possible.

Grading Questions: All graded material will be returned to students. Once a graded item has been returned, you have 48 hours to challenge the grade. **To challenge a grade, you must submit a typed description of the grading error (attached to the graded item) to me**. Your description must include your name and e-mail address. I will respond to your challenge within 48 hours of its receipt.

Course Policies

Communication:

Students should check their University e-mail on a daily basis. Class announcements including unexpected cancellations will be e-mailed to you. A course web page is located on UA's Blackboard (https://learn.uark.edu/). This web page will be used for course-related email, dissemination of materials and access to on-line grades.

Family Educational Rights and Privacy Act (FERPA):

The *Family Educational Rights and Privacy Act* (FERPA) protects a student's academic and other educational records from unauthorized access. This protection extends to email correspondence between a student and the University of Arkansas faculty and staff.

To provide reasonable assurance that emails are from the student, all university or class related emails must be sent from the student's uark.edu email account. Additionally, university or class related emails must be sent to the student's uark.edu email account.

This means that I cannot acknowledge emails sent from your personal or work email accounts, and I cannot send emails to your personal or work email accounts.

Academic Honesty Policy:

- As a core part of its mission, the University of Arkansas provides students with the opportunity to further their educational goals through programs of study and research in an environment that promotes freedom of inquiry and academic responsibility. Accomplishing this mission is only possible when intellectual honesty and individual integrity prevail. Each University of Arkansas student is required to be familiar with and abide by the University's 'Academic Integrity Policy' at honesty.uark.edu. Students with questions about how these policies apply to a particular course or assignment should immediately contact their instructor

- Plagiarism is often misunderstood. It can be defined as submitting someone else's work as your own. It is not permissible to "cut and paste" and then just cite another's work. In writing for homework or projects, you should read and learn, process through your mind, relate ideas, and then express what you learned **in your own words**. Cite the references where you found your information. If you do use someone else's words, you must use quotation marks **and** cite. You should not overuse quotes – save them for a rare occurrence.

A complete statement of the U of A's Academic Honesty Policy is available in the UA Student Handbook and the UA Graduate Catalog.

University of Arkansas Academic Policy Series 1520.10

University of Arkansas Academic Policy Series 1520.10 requires that students with disabilities are provided reasonable accommodations to ensure their equal access to course content. If you have a documented disability and require accommodations, please contact me privately at the beginning of the semester to make arrangements for necessary classroom adjustments. Please note, you must first verify your eligibility for these through the Center for Educational Access (contact 479–575–3104 or visit http://cea.uark.edu *for more information on registration procedures).*

B. Project Presentation Slides

Trade-off Analytics for Infrastructure Preservation

Ashley Johnson, George Gallarno, Dr. Gregory Parnell, Dr. Ed Pohl

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MarTREC
Maritime Transportation Research & Education Center

Arkansas Waterways Commission
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ARDOT
ARKANSAS DEPARTMENT OF TRANSPORTATION

ERDC
Engineer Research and Development Center

Introduction

Key Infrastructure Types

Ports (Coastal and Inland)

Channels

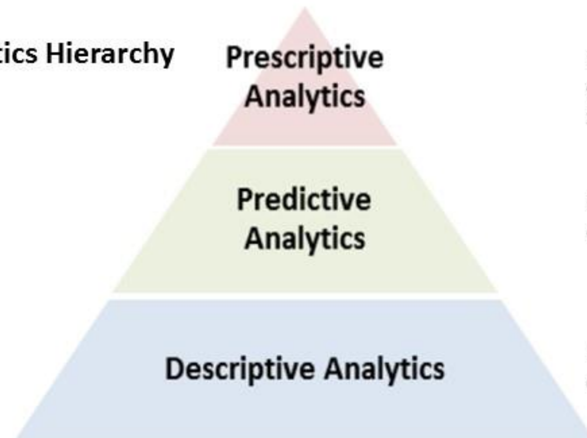
Dams and Locks

Intermodal Connectors

- Rapidly growing demands on maritime and multimodal transportation network
- Transportation agencies require a sound methodology to make appropriate decisions considering the trade-offs between objectives and cost.

Introduction

Trade-off Analytics Hierarchy



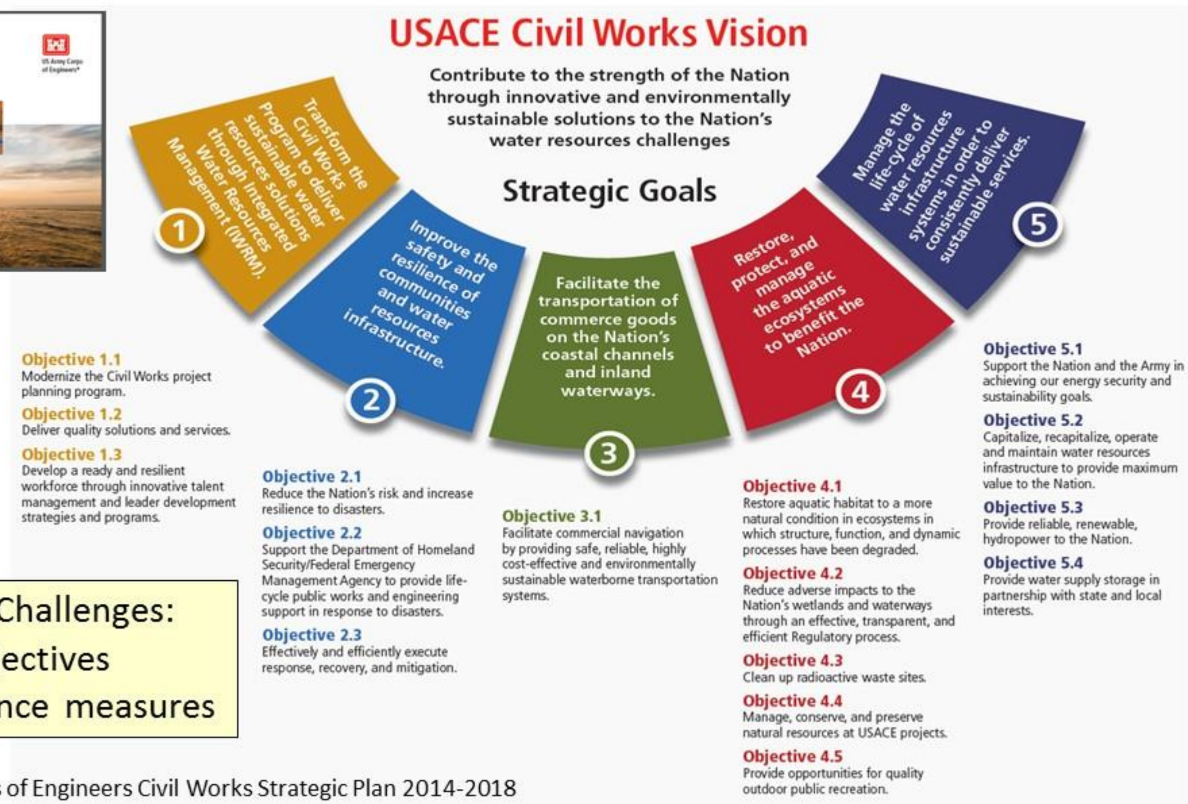
Prescriptive Analytics examines data or content to answer the question "What should be done?"

Predictive analytics is the examination of what will be.

Descriptive Analytics is the examination of data or content that answers what is.

- Trade-Off Analytics is a systems engineering technique that uses Model-Based Engineering and descriptive, predictive, and prescriptive analytics to balance trade-offs between objectives.

National Level Trade-offs



Trade-off Challenges:
16 objectives
29 performance measures

Source: US Army Corps of Engineers Civil Works Strategic Plan 2014-2018

State Level Trade-offs

Trade-off Challenges:

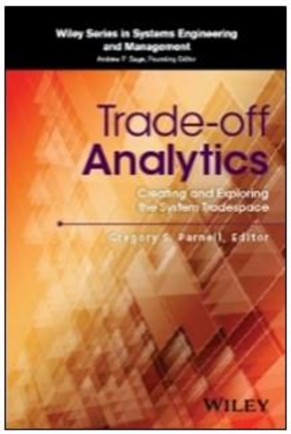
- Prioritize project portfolios given a limited budget
- Balance values and objectives between in-state and national level transportation agencies
- Ensure future viability and sustainability of infrastructure by balancing O&M and development

TRANSPORTATION 2040
WE MOVE
ARKANSAS FREIGHT

Source: ARDOT State Freight Plan Oct. 2017

Course Details

Textbook



Parnell, Gregory S. Editor, Trade-off Analytics: Creating and Exploring the System Tradespace. John Wiley & Sons, 2017.

Course Topics
Introduction to trade-off analytics and decision analysis
Introduction to maritime and multimodal infrastructure life cycles
Conceptual framework of infrastructure trade-off analysis
Framing the infrastructure decision
Identifying infrastructure improvement opportunities
Overview of Benefit Cost Analysis
Identifying infrastructure benefits and measures
Developing infrastructure benefit models
Developing infrastructure cost models
Developing an integrated model for benefit and cost trade-off analytics
Developing and evaluating alternatives
Exploring and evaluating the decision space
Developing an asset portfolio decision model
Understanding sources of uncertainty and analyzing uncertainty
Communicating analysis results to decision-makers

Projects and Assessment
2 x Infrastructure related student projects
2 x Comprehensive exams

Course Details

Maritime Examples are Included in Trade-Off Analytics Course

- Provide insight into both national and regional project decisions.
- Establish a consistent project decision methodology that aligns with organizational values and objectives.

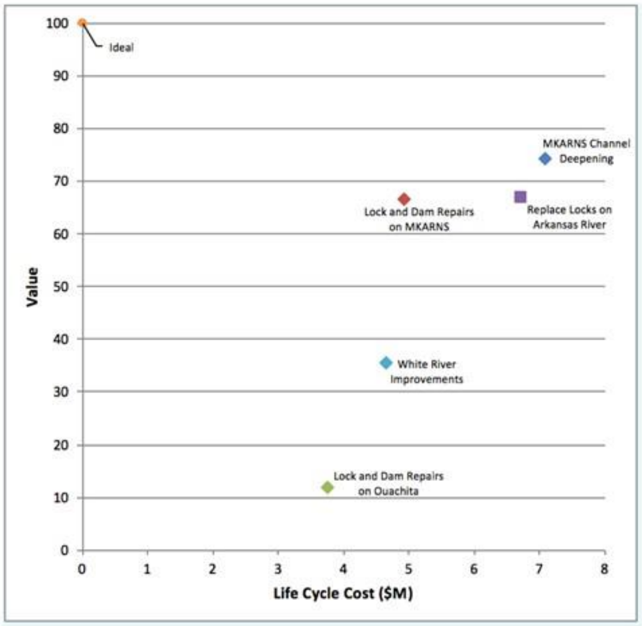
publicradioeast.org/post/public-comment-sought-nc-rail-plan

Photo by USACE in the article "Newt Graham Lock and Dam18 Open for Traffic" 2013

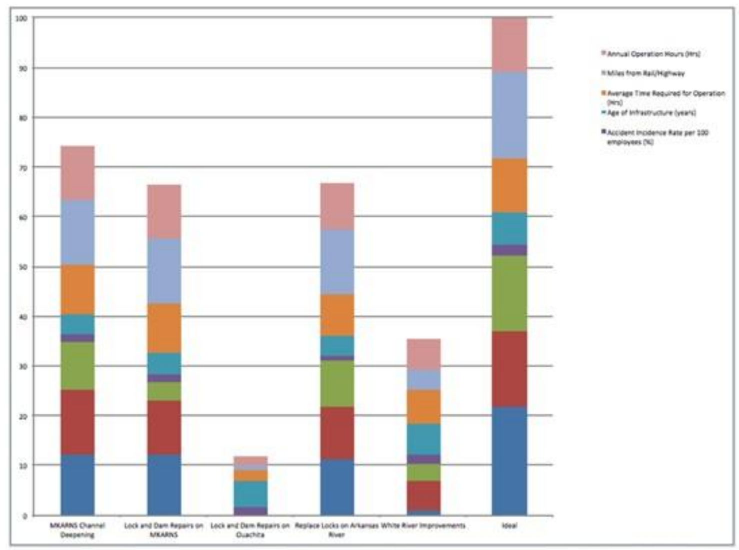
- Use real data, demand forecasts, and organizational values to build portfolio models.
- Provide understanding of the trade-offs for decision-makers and stakeholders.

Illustrative Trade-offs

Value vs Cost Chart



Value Component Chart



First Course Offering in Fall 2019

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ERDC University

Master of Science in Engineering Management

Master of Science in Engineering

Master of Science in Operations Management

ERDC Graduate Institute

C. IISE 2019 Conference Slides

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Funding Acknowledgements

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- This material is based upon work supported by the U.S. Department of Transportation under Grant Award Number DTRT13-G-UTC50/69A3551747130. The work was conducted through the Maritime Transportation Research and Education Center at the University of Arkansas.
- *This material is based upon work supported by the Arkansas State Highway and Transportation Department. The work was conducted through Mack-Blackwell Transportation Center.*

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Bottom Line Up Front

OVERVIEW

Maritime and multimodal infrastructure needs:

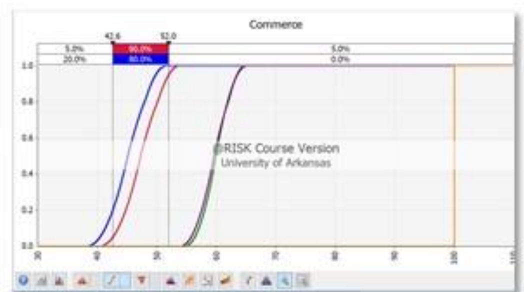
- Increased Cost-Efficiency
- Increased Resilience
- Increased Sustainability

PURPOSE

Use an objective and transparent method to prioritize asset management budget decisions to improve infrastructure resilience and increase infrastructure sustainability.

DECISION FRAMING

CONCLUSION: Disaster Mitigation Focus



Value-Focused thinking can inform infrastructure asset management decisions

Icons: (top left) https://thenounproject.com/term/history/11223/, (top right) https://www.shareicon.net/looking-seeing-binocular-697177 (bottom left) USACE Civil Works Strategic Plan 2014-2018

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Decision Frame

OPPORTUNITY OVERVIEW

An aging maritime infrastructure is responsible for:

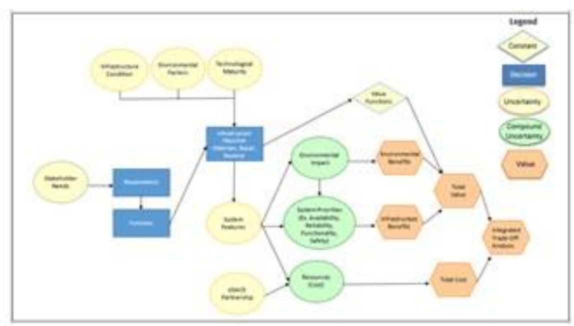
1. Supporting U.S. domestic and national security interests,
2. Meeting the navigational needs of domestic and foreign commercial ventures through safe, efficient, reliable, and environmentally sustainable waterways (both inland and coastal,
3. Contributing to America's power grid through hydroelectric power plants located within USACE dams, and
4. Mitigation of disaster through flood risk management.

VISION STATEMENT

We will decide how to **prioritize budget**ary approval for U.S. Army Corps of Engineers **maritime infrastructure construction, maintenance, and operations** in the most cost-efficient way. This is needed to better utilize yearly budget as well **as improve infrastructure resilience and** increase infrastructure **sustainability**. We will know that we have succeeded if the decision makers are satisfied and the decision is unbiased, transparent, and defensible.

DECISION HIERARCHY

INFLUENCE DIAGRAM



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Opportunity Overview

OPPORTUNITY OVERVIEW

An aging maritime infrastructure is responsible for:

1. Supporting U.S. domestic and national security interests,
2. Meeting the navigational needs of domestic and foreign commercial ventures through safe, efficient, reliable, and environmentally sustainable waterways (both inland and coastal,
3. Contributing to America's power grid through hydroelectric power plants located within USACE dams, and
4. Mitigation of disaster through flood risk management.

Image Source: https://www.wsp.com/en-AU/sectors/maritime

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Vision Statement

We will decide how to ***prioritize budget*** decisions for U.S. Army Corps of Engineers ***maritime infrastructure construction, maintenance, and operations*** in the most cost-efficient way. This is needed to better utilize yearly budget as well as ***improve infrastructure resilience and*** increase infrastructure ***sustainability***. We will know that we have succeeded if the decision makers are satisfied and the decision is objective, transparent, and defensible.

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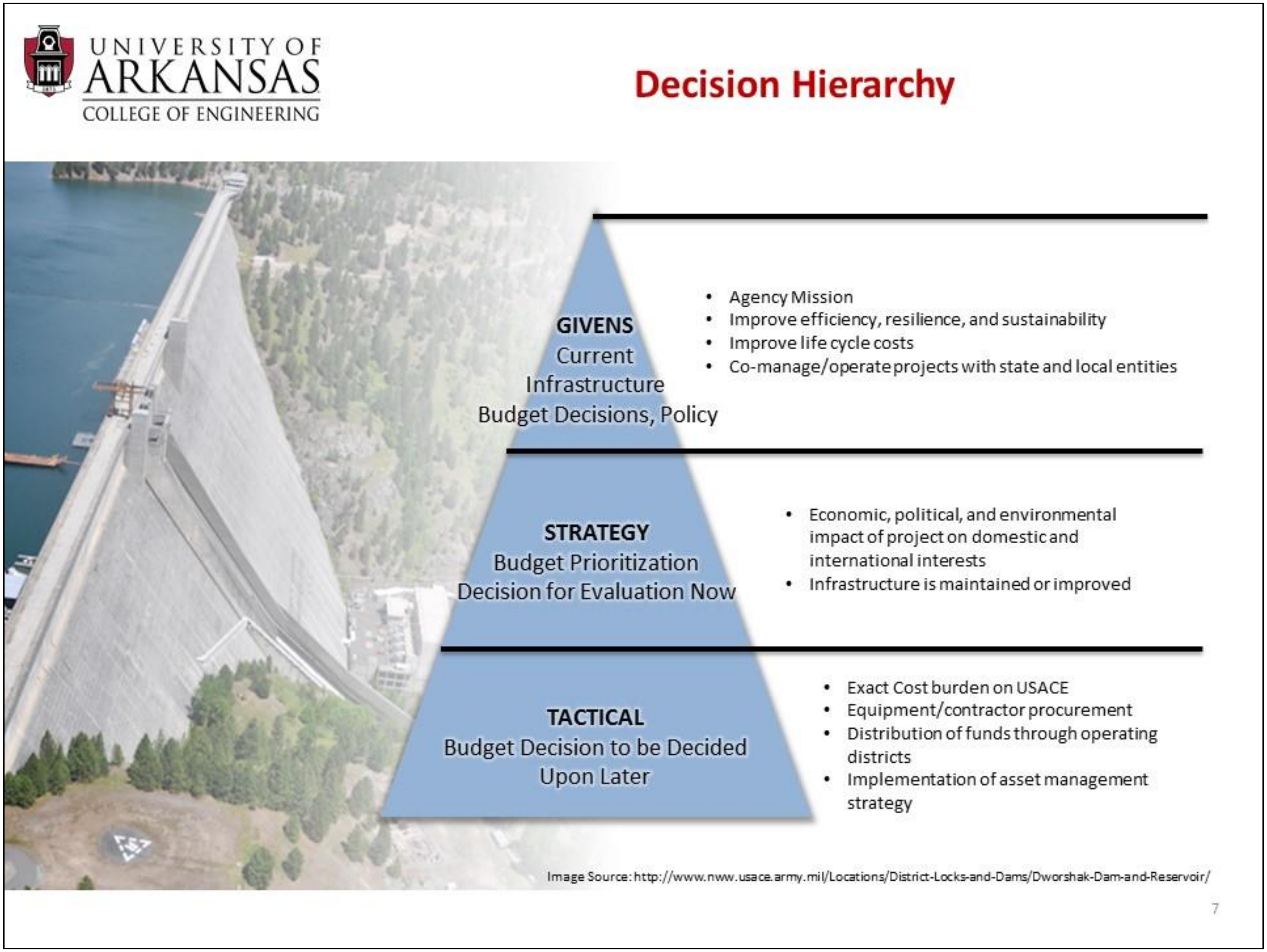
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Decision Hierarchy
GIVENS
Current Infrastructure
Budget Decisions, Policy
• Agency Mission
• Improve efficiency, resilience, and sustainability
• Improve life cycle costs
• Co-manage/operate projects with state and local entities
STRATEGY
Budget Prioritization
Decision for Evaluation Now
• Economic, political, and environmental impact of project on domestic and international interests
• Infrastructure is maintained or improved
TACTICAL
Budget Decision to be Decided Upon Later
• Exact Cost burden on USACE
• Equipment/contractor procurement
• Distribution of funds through operating districts
• Implementation of asset management strategy
Image Source: http://www.nww.usace.army.mil/Locations/District-Locks-and-Dams/Dworshak-Dam-and-Reservoir/
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Stakeholder Issue Matrix

Environmental Factors	Decision Makers/Stakeholders: Decision Authority	Client (state/local govt)	Infrastructure Owner (Budgeter)	Users (Shipping/ Transport Companies)	Local Communities
Cultural					Acceptance of project
Economic	Budget	Cost overrun Schedule Slips Skilled Labor	Construction/ Repair costs	Waterway inaccessibility	
Historical	Past Cost Overruns	Past Cost Overruns			
Legal	Fed. law/ Permit compliance	Fed. Law/ Permit compliance		Infrastructure loses operational permit	
Moral/Ethical		Acquisition ethics			
Natural Environment		Environmental requirements	Disaster readiness natural hazards	Infrastructure deterioration	Preservation of communal and sport areas/ natural wildlife
Political	Defend budget decision	Budget approval			Political protests due to mission
Security		User Security Terrorist Attack	Civilian security/safety		public facilities
Social				Accidents	
Technological	project equipment requirements	Meets project needs	Future project needs	Infrastructure deterioration	

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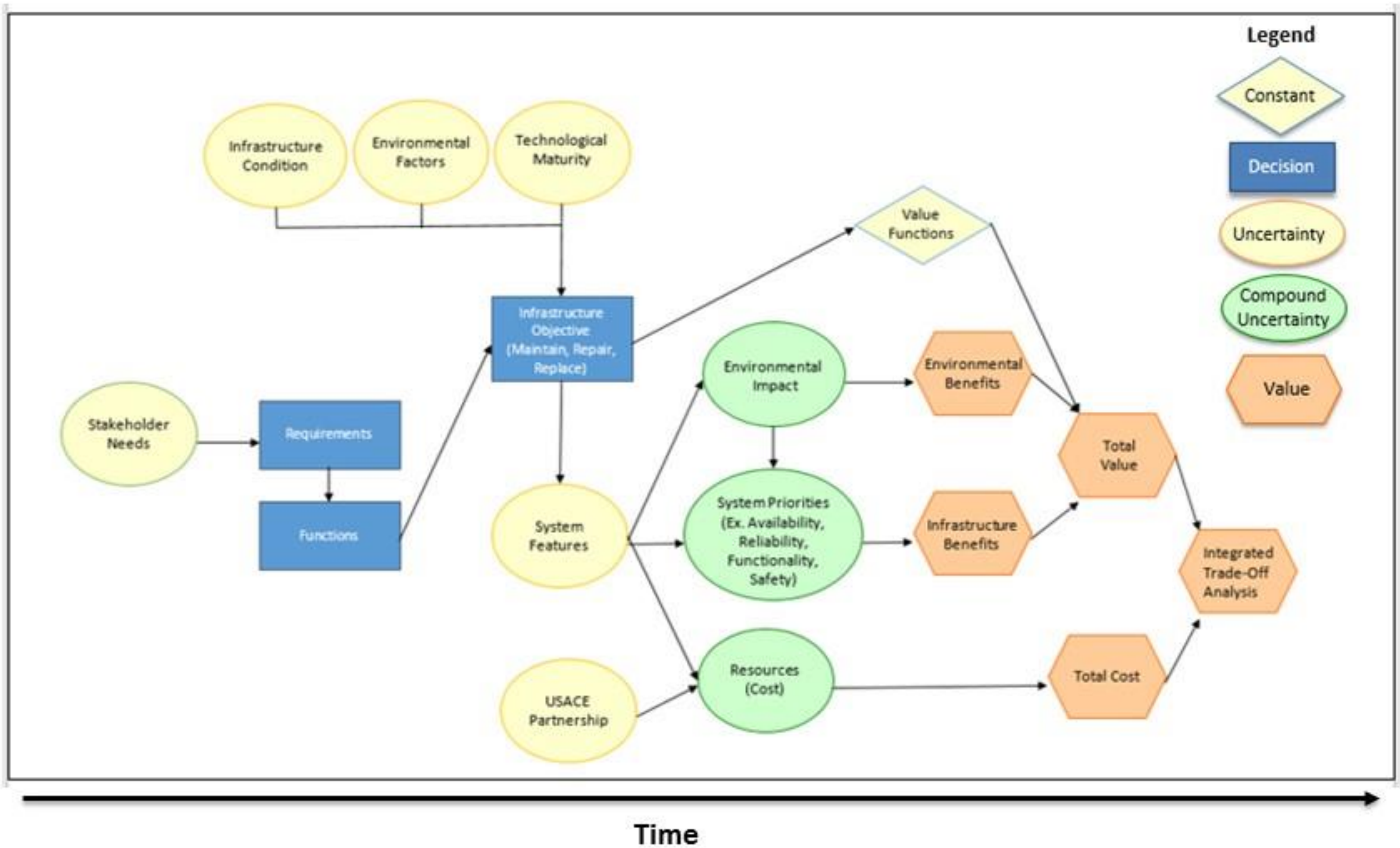
Influence Diagram



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O&M Cost Data

- Used approved budget for the 2020 fiscal year. Data scraped includes:
  - Operations Budget
  - Maintenance Budget
  - Budget Request by Category (Navigation, Flood Risk Management, Recreation, Hydropower, Environmental Stewardship, and Water Supply)

Division	District	Project	Stat	Project Description	Budget			Budget Breakdown by Category					
					Operations	Maintenance	Total	N	FRM	RC	H	EN	WS
Southwestern	Little Rock	Beaver Lake	AR	Hydro-Electric Dam and Recreation Area; Budget includes joint activities across multiple business lines	7,161,000	3,938,000	11,099,000	-	1,644,000	2,000,000	2,268,000	3,272,000	25,000
Southwestern	Little Rock	Blue Mountain Lake	AR	Dam used to create artificial lake. Primary purpose is flood control and flood related damage mitigation.	1,541,000	221,000	1,762,000	-	1,009,000	456,000	-	287,000	10,000
Southwestern	Little Rock	Bull Shoals Lake	AR	Hydropower and flood risk management. Benefit of recreation.	5,756,000	1,710,000	7,466,000	-	1,042,000	1,695,000	3,449,000	423,000	13,000
Southwestern	Little Rock	DeQueen Lake	AR	Flood Risk Management, Water Supply, Recreation, environmental stewardship	1,147,000	432,000	1,579,000	-	956,000	425,000	-	188,000	10,000
Southwestern	Little Rock	Dierks Lake	AR	Flood Risk Management, Water Supply, Recreation, environmental stewardship	1,110,000	300,000	1,410,000	-	873,000	476,000	-	51,000	10,000
Southwestern	Little Rock	Gillham Lake	AR	Flood Risk Management, Water Supply, Recreation, environmental stewardship	992,000	1,553,000	2,545,000	-	2,007,000	383,000	-	143,000	12,000
Southwestern	Little Rock	Greers Ferry Lake	AR	Hydropower and flood risk management. Benefit of recreation.	7,200,000	1,843,000	9,043,000	-	869,000	3,303,000	2,255,000	1,654,000	28,000
Southwestern	Little Rock	McClellan-Kerr Arkansas River Navigation System	AR	Inland navigation, Environmental stewardship, and recreation	30,087,000	22,388,000	52,475,000	36,177,000	-	6,991,000	5,938,000	1,441,000	10,000
Southwestern	Little Rock	Millwood Lake	AR	Primary Flood Risk Management, Secondary Water Supply, Recreation, environmental stewardship	2,400,000	845,000	3,245,000	-	1,656,000	762,000	-	802,000	25,000
Southwestern	Little Rock	Nimrod Lake	AR	Primary Flood Risk Management, Secondary Recreation	1,703,000	306,000	2,009,000	-	1,199,000	507,000	-	293,000	10,000
Southwestern	Little Rock	Norfork Lake	AR	Primary Flood Risk Management and Hydropower; Secondary Recreation	4,827,000	2,515,000	7,342,000	-	1,620,000	1,967,000	2,727,000	867,000	10,000
Southwestern	Tulsa	Council Grove Lake	KS	Flood Risk Management, Water Supply, Water Quality Control, and Recreation	1,529,000	654,000	2,183,000	-	1,145,000	599,000	-	424,000	15,000
Southwestern	Tulsa	El Dorado Lake	KS	Flood Risk Management, Water Supply, Water Quality Control, and Recreation	804,000	144,000	948,000	-	483,000	31,000	-	419,000	15,000
Southwestern	Tulsa	Elk City Lake	KS	Flood Risk Management, Water Supply, Water Quality Control, Recreation, and Environmental Stewardship	1,272,000	236,000	1,508,000	-	822,000	215,000	-	456,000	15,000
Southwestern	Tulsa	Fall River Lake	KS	Flood Risk Management, Water Quality, Fish and Wildlife, and Supplementary Water Supply	941,000	361,000	1,302,000	-	832,000	300,000	-	170,000	-
Southwestern	Tulsa	John Redmond Dam and Reservoir	KS	Flood Risk Management, Water Supply, Water Quality Control, Recreation, and Fish and Wildlife	1,489,000	390,000	1,879,000	-	1,198,000	319,000	-	347,000	15,000
Southwestern	Tulsa	Marion Lake	KS	Flood Risk Management, Water Supply, Water Quality, and Recreation	1,372,000	918,000	2,290,000	-	1,091,000	720,000	-	464,000	15,000
Southwestern	Tulsa	Pearson-Skubitz Big Hill Lake	KS	Flood Risk Management, Water Supply, Recreation, and Fish and Wildlife	1,232,000	225,000	1,457,000	-	820,000	597,000	-	25,000	15,000
Southwestern	Tulsa	Toronto Lake	KS	Flood Risk Management, Water Supply, Water Quality, Fish and Wildlife, and Recreation	604,000	125,000	729,000	-	594,000	23,000	-	97,000	15,000
Southwestern	Tulsa	Arcadia Lake	OK	Flood Risk Management, Water Supply, and Recreation	425,000	82,000	507,000	-	343,000	36,000	-	113,000	15,000
Southwestern	Tulsa	Birch Lake	OK	Flood Risk Management, Water Supply, Water Quality Control, Recreation, and Fish and Wildlife	971,000	140,000	1,111,000	-	762,000	280,000	-	69,000	-
Southwestern	Tulsa	Broken Bow Lake	OK	Flood Risk Management, Hydropower, Water Supply, Recreation, and Fish and Wildlife	3,210,000	687,000	3,897,000	-	62,000	74,000	2,280,000	113,000	15,000
Southwestern	Tulsa	Canton Lake	OK	Flood Risk Management, Water Supply, and Irrigation Outputs	1,464,000	296,000	1,760,000	-	664,000	959,000	-	122,000	15,000
Southwestern	Tulsa	Copan Lake	OK	Flood Risk Management, Water Supply, Water Quality Control, Recreation, and Fis and Wildlife	930,000	242,000	1,172,000	-	759,000	255,000	-	143,000	15,000
Southwestern	Tulsa	Eufaula Lake	OK	Flood Risk Management, Hydropower, Navigation and Water Supply	5,065,000	2,158,000	7,223,000	-	1,024,000	1,990,000	2,141,000	1,135,000	50,000
Southwestern	Tulsa	Fort Gibson Lake	OK	Primary Flood Risk Management and Hydropower, Secondary Recreation, Environment	4,715,000	773,000	5,488,000	-	421,000	1,538,000	1,842,000	970,000	-
Southwestern	Tulsa	Fort Supply Lake	OK	Flood Risk Management and Water Supply	804,000	456,000	1,260,000	-	720,000	454,000	-	86,000	-
Southwestern	Tulsa	Great Salt Plains Lake	OK	Flood Risk Management, Conservation (environment), Recreation, and Fish and Wildlife	277,000	66,000	343,000	-	257,000	25,000	-	61,000	-
Southwestern	Tulsa	Heyburn Lake	OK	Flood Risk Management, Water Supply, Recreation, and Fish and Wildlife	695,000	129,000	824,000	-	435,000	295,000	-	89,000	15,000
Southwestern	Tulsa	Hugo Lake	OK	Flood Risk Management, Water Supply, Water Quality Control, Recreation, and Fish and Wildlife	1,716,000	223,000	1,939,000	-	981,000	775,000	-	168,000	15,000
Southwestern	Tulsa	Hulah Lake	OK	Flood Risk Management, Water Supply, Low Flow Regulation, and Conservation (environment)	542,000	468,000	1,010,000	-	775,000	45,000	-	175,000	15,000
Southwestern	Tulsa	Kaw Lake	OK	Flood Risk Management, Water Supply, Water Quality Control, Hydropower, Recreation, and Fish and Wildlife	2,103,000	285,000	2,388,000	-	1,161,000	880,000	-	332,000	15,000
Southwestern	Tulsa	Keystone Lake	OK	Flood Risk Management, Water Supply, Hydropower, Navigation, and Fish and Wildlife	3,917,000	1,126,000	5,043,000	-	481,000	1,063,000	1,894,000	460,000	30,000
Southwestern	Tulsa	McClellan-Kerr Arkansas River Navigation System	OK	Navigation (including Locks)	11,989,000	7,198,000	19,187,000	11,816,000	-	1,426,000	4,052,000	385,000	-
Southwestern	Tulsa	Oologah Lake	OK	Flood Risk Management, Water Supply, Navigation, Recreation, and Fish and Wildlife	2,624,000	480,000	3,104,000	-	1,416,000	868,000	-	805,000	15,000
Southwestern	Tulsa	Optima Lake	OK	Flood Risk Management, Water Supply, Recreation, and Fish and Wildlife	91,000	4,000	95,000	-	95,000	-	-	-	-
Southwestern	Tulsa	Penzacola Reservoir, Lake of the Cherokees	OK	Hydropower and flood risk management	153,000	7,000	160,000	-	160,000	-	-	-	-
Southwestern	Tulsa	Pine Creek Lake	OK	Flood Risk Management, Water Supply, Water Quality Control, Fish and Wildlife, and Recreation	1,337,000	118,000	1,455,000	-	702,000	516,000	-	202,000	35,000
Southwestern	Tulsa	Sardis Lake	OK	Flood Risk Management, Water Supply, Recreation, and Fish and Wildlife	1,130,000	1,390,000	2,520,000	-	1,798,000	530,000	-	170,000	30,000
Southwestern	Tulsa	Skiatook Lake	OK	Flood Risk Management, Water Supply, Water Quality Control, Recreation, and Fish and Wildlife	1,170,000	312,000	1,482,000	-	539,000	685,000	-	223,000	35,000
Southwestern	Tulsa	Tenkiller Ferry Lake	OK	Flood Risk Management and Hydropower	4,036,000	733,000	4,769,000	-	299,000	1,606,000	1,647,000	473,000	50,000
Southwestern	Tulsa	Waurika Lake	OK	Flood Risk Management, Water Supply, Water Quality Control, Recreation, and Fish and Wildlife	1,203,000	400,000	1,604,000	-	821,000	610,000	-	148,000	25,000
Southwestern	Tulsa	Wister Lake	OK	Flood Risk Management, Water Supply, Low Flow Augmentation, Water Conservation, and Sedimentation Control	729,000	171,300	900,300	-	637,000	52,000	-	196,300	15,000
Southwestern	Fort Worth	Aquilla Lake	TX	Flood Risk Management, Water Supply, and Sediment	989,000	222,000	1,211,000	-	363,000	109,000	-	125,000	14,000
Southwestern	Tulsa	Arkansas-Red River Basins Chloride Control - Area VIII	TX		1,772,000	25,000	1,797,000	-	-	-	-	1,797,000	-
Southwestern	Fort Worth	Bardwell Lake	TX	Dam for Flood Risk Management and Recreation	1,740,000	453,000	2,193,000	-	1,425,000	504,000	-	170,000	14,000

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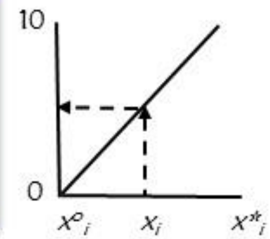
Methodology: Value Model

- Additive Value Model for Value Tradeoffs (Keeney and Raiffa, 1976)

Total additive value of alternative

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

Value function for measure i, a function of the score of measure i

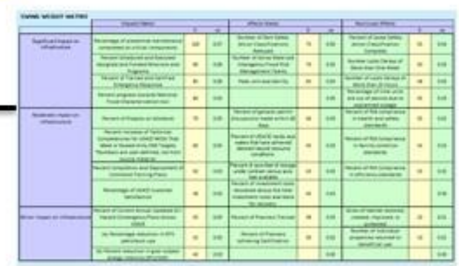


$$\sum_{i=1}^{n} w_i = 1$$

Normalize swing weights

Swing weight of value measure i

Value functions developed from U.S. Army Corps of Engineers Civil Works Strategic Plan, 2014 - 2018



Keeney, R.L. and Raiffa H. *Decision Making with Multiple Objectives Preferences and Value Tradeoffs.* New York: Wiley, 1976.

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Methodology: Fundamental Objectives

*A **gold standard document** for elicitation of fundamental organizational objectives*

USACE Civil Works Vision, USACE Civil Works Strategic Plan 2014-2018

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Methodology: Value Functions

Objective 2.3

Effectively and efficiently execute response, recovery and mitigation.

Under Presidential Policy Directive #8 (PPD #8) USACE exercises roles and responsibilities and executes assigned response, recovery, and mitigation missions within its own specific authorities and those under the National Response, Disaster Recovery, and Mitigation Frameworks.

Performance Measures
Measure 2.3.a: Percent scheduled and executed assigned and funded missions and programs.
FY 14 Target – 100%
FY 15 Target – 100%
FY 16 Target – 100%
FY 17 Target – 100%
FY 18 Target – 100%

Measure 2.3.b: Number of active state-led interagency flood risk management teams (Silver Jackets)
FY 14 Target – 42
FY 15 Target – 45
FY 16 Target – 48
FY 17 Target – 50
FY 18 Target – 50

CW STRATEGIC GOAL 3

FACILITATE THE TRANSPORTATION OF COMMERCE GOODS ON THE NATION'S COASTAL CHANNELS AND INLAND WATERWAYS.

Goal 3 involves the USACE navigation business line, whose objective is to provide safe, reliable, highly cost-effective, and environmentally sustainable waterborne transportation systems for the movement of commercial goods. Many shippers move their goods by water, where that is the most profitable way for them to transport these materials. Through a combination of capital improvements and the operation and maintenance of existing infrastructure, this business line facilitates that commerce.

Objective 3.1

Facilitate commercial navigation by providing safe, reliable, highly cost-effective, and environmentally sustainable waterborne transportation systems.

The Nation's infrastructure to support the transportation of commercial goods by water involves a network of navigable coastal channels, inland waterways and related features maintained by the USACE, as well as publicly- and privately-owned marine terminals, intermodal connections, shipyards and repair facilities. The USACE maintains approximately 25,000 miles of coastal channels and inland waterways, including 926 coastal, Great Lakes, and inland harbors; and 241 river locks at 197 sites.

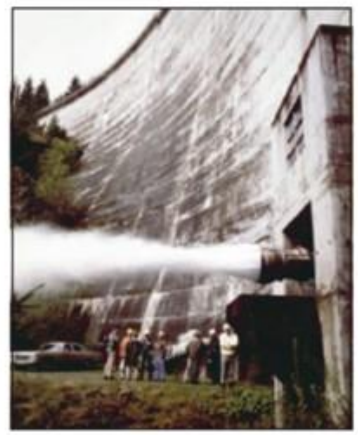
Performance Measures

Measure 3.1.a: The number of instances where mechanically driven failure at locks results in delays of more than 24 hours.

Targets:	FY 14	FY 15	FY 16	FY 17	FY 18
1- Day	46	44	42	40	38

Measure 3.1.b: The number of instances where mechanically driven failure at locks results in delays of more than one week.

Targets:	FY 14	FY 15	FY 16	FY 17	FY 18
1-Week	26	25	24	23	22



Sustainable Solutions to America's Water Resources Needs 21

USACE Civil Works Vision, USACE Civil Works Strategic Plan 2014-2018

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Methodology: Value Functions

CW STRATEGIC GOAL 3

FACILITATE THE TRANSPORTATION OF COMMERCE GOODS ON THE NATION'S COASTAL CHANNELS AND INLAND WATERWAYS.

Objective 3.1

Facilitate commercial navigation by providing safe, reliable, highly cost-effective, and environmentally sustainable waterborne transportation systems.

Performance Measures

Measure 3.1.a: The number of instances where mechanically driven failure at locks results in delays of more than 24 hours.

Targets:	FY 14	FY 15	FY 16	FY 17	FY 18
1- Day	46	44	42	40	38

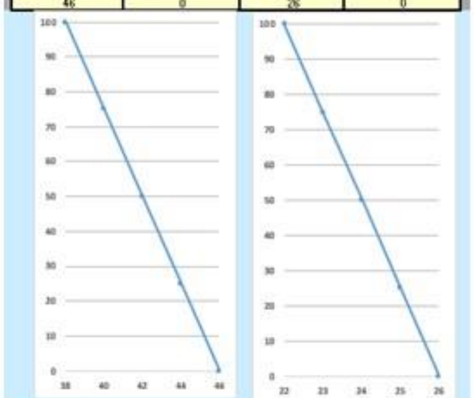
Measure 3.1.b: The number of instances where mechanically driven failure at locks results in delays of more than one week.

Targets:	FY 14	FY 15	FY 16	FY 17	FY 18
1-Week	26	25	24	23	22

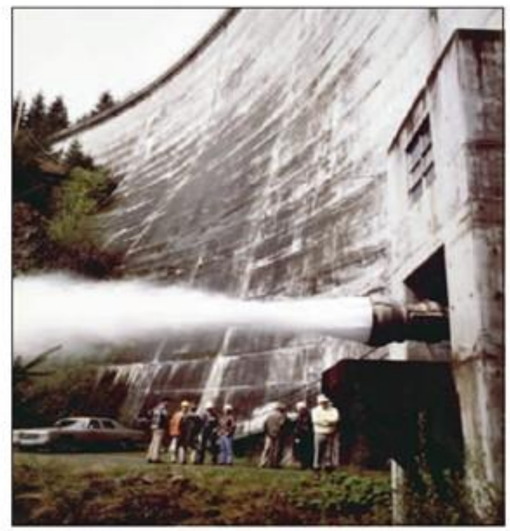
3. Ensure the Movement of the Nation's Vaterbourne Transportation

Facilitate Commercial Navigation by Providing Safe, Reliable, Highly Cost Effective, and Environmentally Sustainable Vaterbourne Transportation System

Objective 3a		Objective 3b	
Minimize number of 24 hours delays due to lock failure		Minimize number of one week (or more) delays due to lock failure	
Number of Locks Delays of More than 24 Hours		Number Locks Delays of More than One Week	
x	v(x)	x	v(x)
38	100	22	100
40	75	23	75
42	50	24	50
44	25	25	25
46	0	26	0



Each Objective had its value measure(s) defined by the U.S.A.C.E.; Value function determined notionally



USACE Civil Works Vision, USACE Civil Works Strategic Plan 2014-2018

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Methodology: Swing Weight Matrix

- Values for matrix derived notionally from USACE Civil Works Strategic Plan as well as from readings of civil works project reports and interviews with USACE personnel.

SWING WEIGHT MATRIX

	Impacts Nation			Affects States			Municipal Effects		
		fi	wi		fi	wi		fi	wi
Significant Impact on infrastructure	Percentage of preventive maintenance completed on critical components	100	0.07	Number of Dam Safety Action Classifications Reduced	75	0.05	Percent of Levee Safety Action Classification Complete	55	0.04
	Percent Scheduled and Executed Assigned and Funded Missions and Programs	90	0.06	Number of Active State-Led Interagency Flood Risk Management Teams	70	0.05	Number Locks Delays of More than One Week	50	0.03
	Percent of Trained and Certified Emergency Response	85	0.06	Peak unit availability	65	0.04	Number of Locks Delays of More than 24 Hours	48	0.03
	Percent progress towards National Flood Characterization tool	80	0.05			0.00	Percentage of time units are out of service due to unplanned outage.	45	0.03
Moderate impact on infrastructure	Percent of Projects on Schedule	70	0.05	Percent of general permit discussions made within 60 days	46	0.03	Percent of PSA compliance in health and safety standards	35	0.02
	Percent Increase of Technical Competencies for USACE MCOs That Meet or Exceed Army CMS Targets *Numbers are user-defined, not from source material	60	0.04	Percent of USACE lands and waters that have achieved desired natural resource conditions.	45	0.03	Percent of PSA Compliance in facility condition standards	34	0.02
	Percent Completion and Deployment of Command Training Plans	50	0.03	Percent of acre-feet of storage under contract versus acre-feet available	43	0.03	Percent of PSA Compliance in efficiency standards	33	0.02
	Percentage of USACE Customer Satisfaction	48	0.03	Percent of investment costs recovered versus the total investment costs available for recovery.	40	0.03			0.00
Minor impact on infrastructure	Percent of Current Annual Updated All-Hazard Contengency Plans Across USACE	45	0.03	Percent of Planners Trained	38	0.03	Acres of habitat restored, created, improved, or protected	20	0.01
	(a) Percentage reduction in NTV petroleum use	42	0.03	Percent of Planners Achieving Certification	30	0.02	Number of individual properties returned to beneficial use	10	0.01
	(b) Percent reduction in goal subject energy intensity (BTU/GSP)	40	0.03			0.00			0.00

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Asset Management Strategies

PORTFOLIO EMPHASIS	N	FRM	RC	H	EN	WS
Commerce (N, FRM, and H promoted)	1.2	1.1	0.7	1.2	0.8	1
Civilian (RC, H, and EN promoted)	0.8	1.2	1.2	1.2	0.8	0.8
Disaster Mitigation (N, FRM, and EN promoted)	1.1	1.3	0.5	1	1.1	1
Conservation (FRM, EN, and WS promoted)	1	1.125	0.75	1	1.125	1
Balanced (Average of others)	1.025	1.181	0.788	1.1	0.956	0.95
Base	1	1	1	1	1	1

N – Navigation
FRM – Flood Risk Management
RC – Recreation
H – Hydropower
EN – Environment
WS – Water Supply

Strategy generation table to develop asset management strategies

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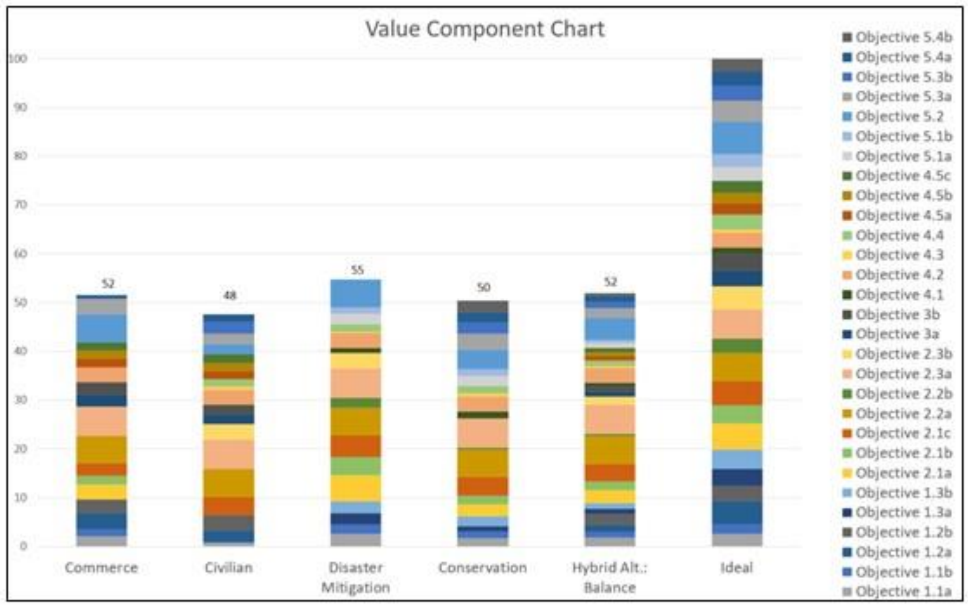
Analysis: Comparison of Management Strategies

- Asset Management Strategies considered:
  - Commercial (Navigation, Flood Risk Management and Hydropower Emphasis)
  - Civilian (Recreation, Hydropower, and Environmental Emphasis)
  - Disaster Mitigation (Navigation, Flood Risk Management, and Environmental Emphasis)
  - Conservation (Flood Risk Management, Environmental, and Water Supply)
  - Hybrid (Averages aforementioned budget decision across all categories)



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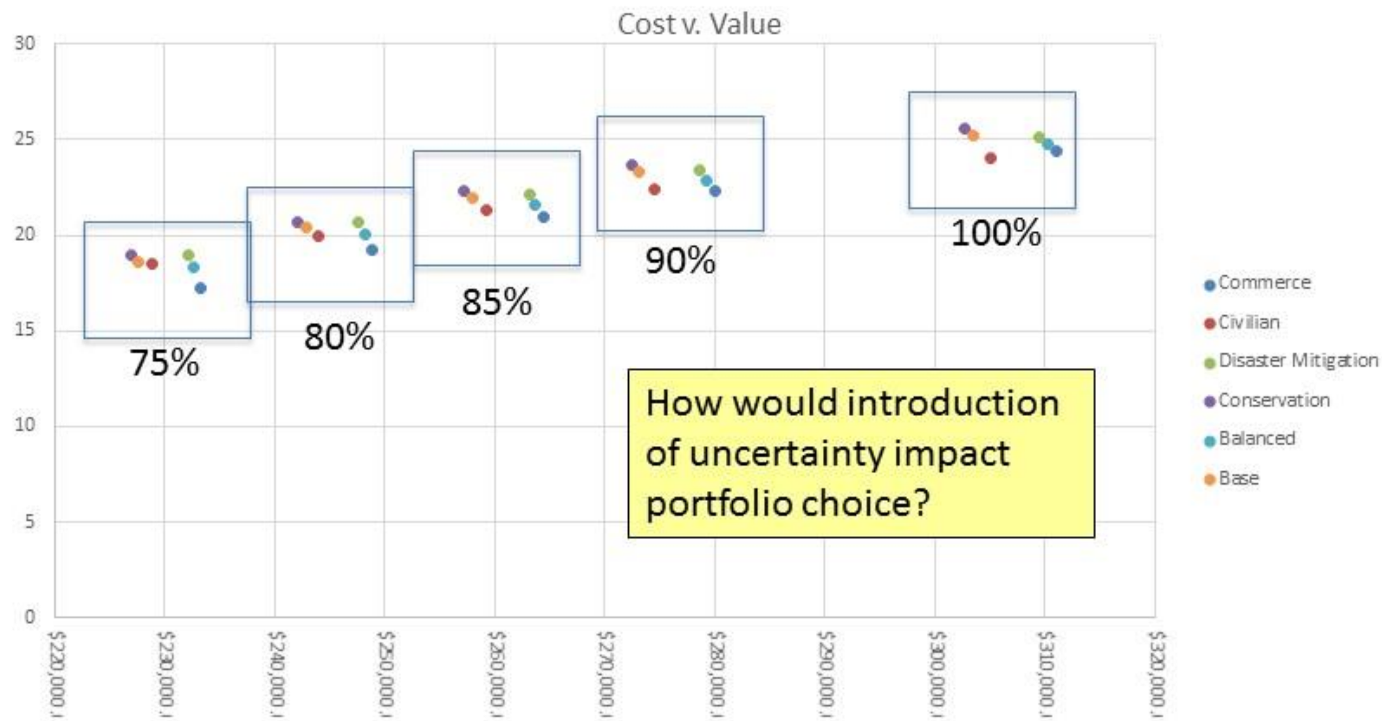
Portfolio Value v. Cost



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Systemic Uncertainty: Flooding

Impacts:

- Percentage of projects on schedule
- Percentage of USACE customer satisfaction
- Number of lock delays greater-than 24 hours
- Number of lock delays greater-than or equal to 1 week

Source: ABC 7, Chicago – Flooding on Illinois River, Apr. 2013
http://cdn.abclocal.go.com/images/wls/cms_exf_2007/news/local/AP433827475512.jpg

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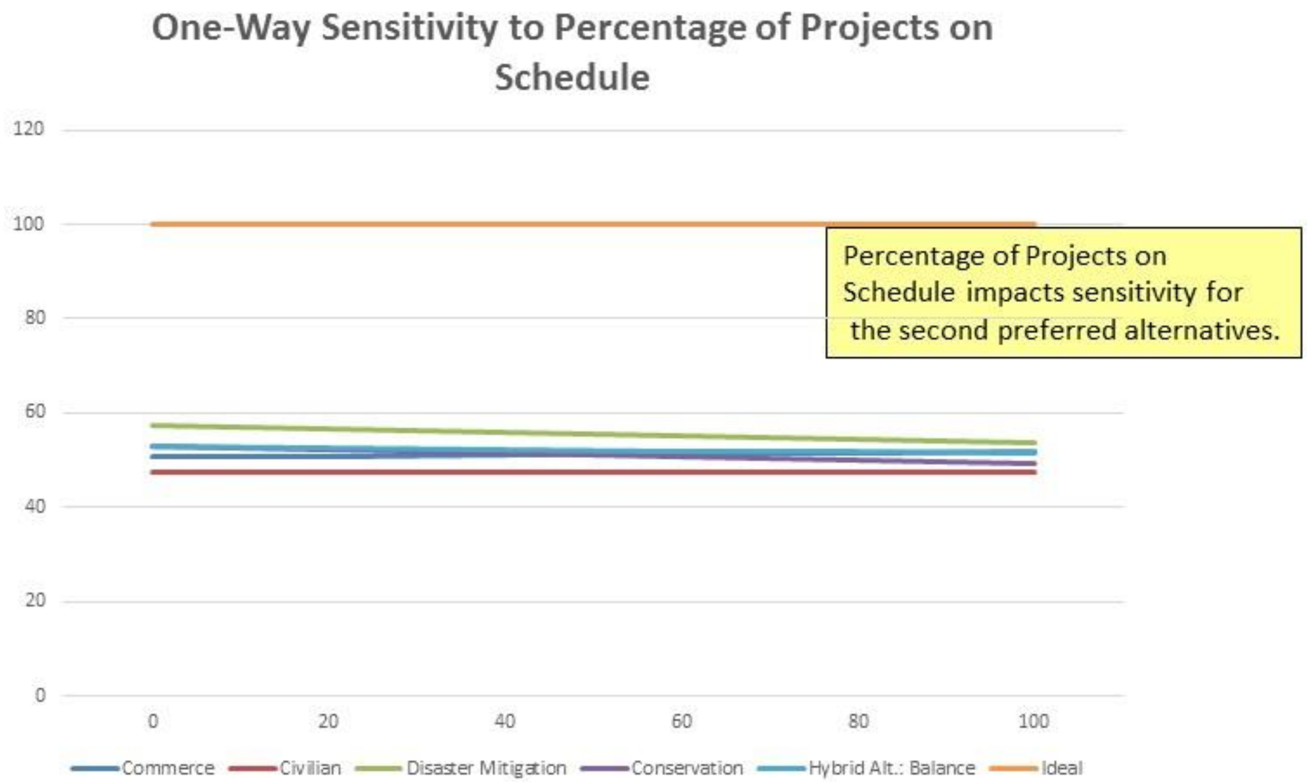
Sources of Uncertainty



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Sources of Uncertainty

Independent variables:

(1) Percent of Projects on Schedule

(2) Number of Locks Delays of More than 24 Hours

(3) Number of Locks Delays of More than One Week

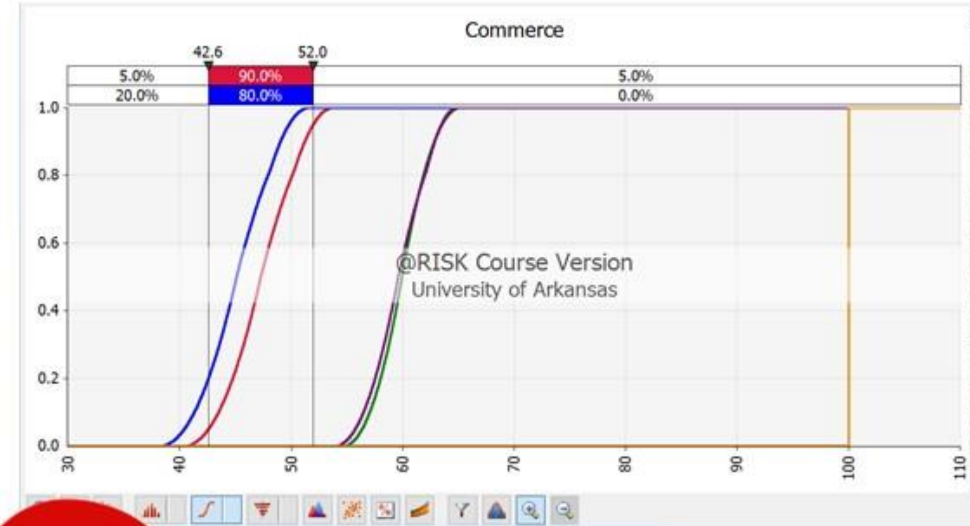
(4) Percent of PSA Compliance in Facility Condition Standards

(5) Percent of PSA Compliance in Efficiency Standards

(6) Percent of PSA Compliance in Health and Safety Standards

(7) Percentage of Preventive Maintenance Completed on Critical Components

Uncertainty Analysis: Monte Carlo Simulation



Statistics Grid

	Commerce	Civilian	Damage Mitigation	Conservation
Cell	MODA Value ..	MODA Value ..	MODA Value ..	MODA Value ..
Minimum	40.687	38.514	54.906	54.181
Maximum	53.578	51.405	64.979	64.747
Mean	47.343	45.170	59.945	59.674
90% CI	± 0.148	± 0.148	± 0.111	± 0.122
Mode	46.962	44.788	59.971	59.348
Median	47.276	45.102	59.944	59.607
Std Dev	2.842	2.842	2.135	2.350
Skewness	-0.0289	-0.0289	-0.0004	-0.0338
Kurtosis	2.2697	2.2697	2.4015	2.2444
Values	1000	1000	1000	1000
Errors	0	0	0	0
Filtered	0	0	0	0
Left X	42.6	42.6	42.6	42.6
Left P	5.0%	20.0%	0.0%	0.0%
Right X	52.0	52.0	52.0	52.0
Right P	95.0%	100.0%	0.0%	0.0%
Dif. X	9.377	9.377	9.377	9.377
Dif. P	90.0%	80.0%	0.0%	0.0%

Close

Disaster Mitigation strategy achieves a higher EV, though it does not stochastically dominate the Conservation Strategy. This was anticipated though...

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Uncertainty Analysis: Monte Carlo

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Results

- USACE can benefit from Value-Focused asset management.
- This project reveals how a decision support tool can be constructed that helps determine value for projects and portfolios alike using similar framework.
- Easily integrates with existing practice in USACE, using Monte Carlo simulation for uncertainty analysis.
- Offers decision-makers the ability to check asset portfolios management decisions against organizational values

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Bottom Line Up Front

OVERVIEW

Maritime and multimodal infrastructure needs:

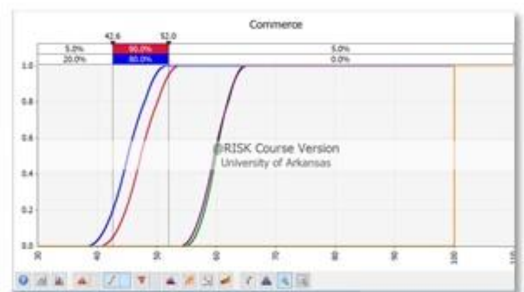
- Increased Cost-Efficiency
- Increased Resilience
- Increased Sustainability

PURPOSE

Use an objective and transparent method to prioritize asset management budget decisions to improve infrastructure resilience and increase infrastructure sustainability.

DECISION FRAMING

CONCLUSION: Disaster Mitigation Focus



Value-Focused thinking can inform infrastructure asset management decisions

Icons: (top left) https://thenounproject.com/term/history/11223/, (top right) https://www.shareicon.net/looking-seeing-binocular-697177
(bottom left) USACE Civil Works Strategic Plan 2014-2018

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