Trade-Off Analytics for Infrastructure Preservation
September 1, 2018 – December 31, 2019
Gregory S. Parnell, gparnell@uark.edu, 479-575-7423
Ed Pohl, epohl@uark.edu, 479-575-6029
Eddie Gallarno, gegallar@uark.edu
December 31, 2019

FINAL RESEARCH REPORT
Prepared for:
Maritime Transportation Research and Education Center

University of Arkansas
4190 Bell Engineering Center
Fayetteville, AR 72701
479-575-6021
ACKNOWLEDGEMENT
This material is based upon work supported by the U.S. Department of Transportation under Grant Award Number 69A3551747130. The work was conducted through the Maritime Transportation Research and Education Center at the University of Arkansas.

DISCLAIMER
The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated in the interest of information exchange. The report is funded, partially or entirely, by a grant from the U.S. Department of Transportation’s University Transportation Centers Program. However, the U.S. Government assumes no liability for the contents or use thereof.
# Table of Contents

1. Project Introduction ........................................................................................................................ 4
2. Project Description ............................................................................................................................ 4
3. Trade-Off Analytics for Asset Management ..................................................................................... 4
4. Methodological Approach ................................................................................................................ 6
5. Project Deliverables ........................................................................................................................ 6
   5.1 Course Objectives .......................................................................................................................... 6
   5.2 Course Schedule ............................................................................................................................ 7
   5.3 Course Overview: Weekly Content and Assignments ..................................................................... 9
   5.4 Case Studies .................................................................................................................................. 10
      5.4.1 An Optimization of the United States Army Corps of Engineers Budget Allocations .......... 10
      5.4.2 The Arkansas River Navigation Study .................................................................................... 12
      5.4.3 Mississippi River Shipping Channel Development ................................................................. 12
      5.4.4 Maritime Security System ....................................................................................................... 13
      5.4.5 Liftboat Design ....................................................................................................................... 13
6. Results ................................................................................................................................................ 13
7. Impacts .............................................................................................................................................. 14
8. Conclusions ....................................................................................................................................... 14
9. References .......................................................................................................................................... 15
Appendices ............................................................................................................................................. 16
   A. Sample Trade-Off Analytics Course Syllabus ............................................................................... 17
   B. Project Presentation Slides ............................................................................................................ 21
   C. IISE 2019 Conference Slides ........................................................................................................ 30
Table of Figures

Figure 1: Trade-Off Analytics Hierarchy .................................................................................................. 5

Figure 2 Three Graduate Credit, Eight Week Course Outline ................................................................. 8

Figure 3 Vanderbilt University Center for Teaching, “Bloom’s Taxonomy” ........................................ 9

Figure 4. Screen Capture of Course Opening Page in Blackboard .......................................................... 9

Figure 5. Screen Capture of Module Content Layout in Blackboard ...................................................... 10

Figure 6. Cost v. Value of Strategies at Percentage of Current Budget .................................................. 11

Figure 7. S-curves of Asset Strategies Resulting from Monte Carlo Simulation of Flooding ................. 12
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](image)
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.
<table>
<thead>
<tr>
<th>Week</th>
<th>Module - Topic</th>
<th>Assessments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1</td>
<td>Module 1 - Introduction to Trade Off Analytics</td>
<td>Module 1 Quiz</td>
</tr>
<tr>
<td></td>
<td>Module 2 - Conceptual Framework for Trade Off Analytics</td>
<td>Module 2 Quiz</td>
</tr>
<tr>
<td>Week 2</td>
<td>Module 3 - Identifying Opportunities</td>
<td>Module 3 Quiz</td>
</tr>
<tr>
<td></td>
<td>Module 4 - Identifying Objectives and Value Measures</td>
<td>Module 4 Quiz</td>
</tr>
<tr>
<td>Week 3</td>
<td>Module 5 - Developing and Evaluating Alternatives</td>
<td>Module 5 Quiz</td>
</tr>
<tr>
<td></td>
<td>Module 6 - Analyzing Resources</td>
<td>Module 6 Quiz</td>
</tr>
<tr>
<td>Week 4</td>
<td>Module 7 - Integrated Models for Trade Off Analysis</td>
<td>Module 7 Quiz</td>
</tr>
<tr>
<td></td>
<td>Exam 1</td>
<td>Week 4 Assignment</td>
</tr>
<tr>
<td>Week 5</td>
<td>Module 8 - Benefit Cost Analysis</td>
<td>Module 8 Quiz</td>
</tr>
<tr>
<td></td>
<td>Project 1</td>
<td>Week 5 Assignment</td>
</tr>
<tr>
<td>Week 6</td>
<td>Module 9 - Exploring Concept Trade Offs</td>
<td>Module 9 Quiz</td>
</tr>
<tr>
<td></td>
<td>Module 10 - Exploring the Design Space</td>
<td>Module 10 Quiz</td>
</tr>
<tr>
<td>Week 7</td>
<td>Module 11 - Quantifying Uncertainty</td>
<td>Module 11 Quiz</td>
</tr>
<tr>
<td></td>
<td>Module 12 - Sustainment Models</td>
<td>Module 12 Quiz</td>
</tr>
<tr>
<td>Week 8</td>
<td>Project 2</td>
<td>Week 7 Assignment</td>
</tr>
<tr>
<td></td>
<td>Exam 2</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*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.
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 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/

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
5.4.2 The Arkansas River Navigation Study


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


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

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

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 through 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


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

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

Instructor Information:
Name: Gregory S. Parnell, Ph.D.
Office: 313C White Hall
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:

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:

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

<table>
<thead>
<tr>
<th>Grade</th>
<th>Grading Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exam 1:</td>
<td>25%</td>
</tr>
<tr>
<td>Exam 2:</td>
<td>25%</td>
</tr>
<tr>
<td>Project 1:</td>
<td>15%</td>
</tr>
<tr>
<td>Project 2:</td>
<td>25%</td>
</tr>
<tr>
<td>Homework &amp; class participation:</td>
<td>10%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100%</td>
</tr>
</tbody>
</table>

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 479-575-2104 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
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 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

USACE Civil Works Vision
Contribute to the strength of the Nation through innovative and environmentally sustainable solutions to the Nation’s water resources challenges

Strategic Goals

1. Improve the safety and economic well-being of communities and wastewater infrastructure.
2. Facilitate the transportation of commerce goods on the Nation’s coastal channels and inland waterways.
3. Restore, protect, and maintain the aquatic ecosystems to benefit the Nation.
4. Ensure the water and water-related services of the Nation are delivered sustainably.
5. Support the Nation and the Army in achieving and upholding energy security and sustainability goals.

Objective 1.1
Modernize the Civil Works project planning program.
Objective 1.2
Deliver quality solutions and services.
Objective 1.3
Develop a ready and resilient workforce through innovative talent management and career development strategies and programs.

Objective 2.1
Reduce the Nation’s risk and increase resilience to disasters.
Objective 2.2
Support the Department of Homeland Security/Federal Emergency Management Agency to provide lifecycle public works and engineering support in response to disasters.
Objective 2.3
Effectively and efficiently execute responses, recovery, and mitigation.

Objective 3.1
Facilitate commercial navigation by providing safe, reliable, highly cost-effective and environmentally sustainable waterborne transportation systems.

Objective 4.1
Restore aquatic habitat to a more natural condition in ecosystems in which structure, function, and dynamic processes have been degraded.
Objective 4.2
Reduce adverse impacts to the Nation’s wetlands and waterways through an effective, transparent, and efficient regulatory process.
Objective 4.3
Clean up radioactive waste sites.
Objective 4.4
Manage, conserve, and preserve natural resources at USACE projects.
Objective 4.5
Provide opportunities for quality outdoor public recreation.

Objective 5.1
Support the Nation and the Army in achieving and upholding energy security and sustainability goals.
Objective 5.2
Capitalize, recapitalize, operate, and maintain water resources infrastructure to provide maximum value to the Nation.
Objective 5.3
Provide reliable, renewable, hydropower to the Nation.
Objective 5.4
Provide water supply storage in partnership with state and local interests.

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

Source: ARDOT State Freight Plan Oct. 2017
## Course Details

### Textbook

**Trade-off Analytics**


### 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
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.

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

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

[Link to image source: publicradioeast.org/post/public-comment-sought-no-rail-plan]
Illustrative Trade-offs

Value vs Cost Chart

Value Component Chart

Life Cycle Cost ($M) vs Value

- Lock and Dam Repairs on MARDOS
- Replace Locks on Arkansas River
- White River Improvements
- Lock and Dam Repairs on Delaware
First Course Offering in Fall 2019

Master of Science in Engineering Management
Master of Science in Engineering
Master of Science in Operations Management
C. IISE 2019 Conference Slides

Trade-off Analytics to Optimize USACE Civil Works Budget Allocations

George Gallarno
Graduate Research Assistant
Funding Acknowledgements

• 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.
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
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 budgetary 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
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.

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.
Decision Hierarchy

**GIVENS**
- Current Infrastructure
- Budget Decisions, Policy

**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

# Stakeholder Issue Matrix

<table>
<thead>
<tr>
<th>Environmental Factors</th>
<th>Decision Makers/Stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Decision Authority</td>
</tr>
<tr>
<td></td>
<td>Budget</td>
</tr>
<tr>
<td>Cultural</td>
<td></td>
</tr>
<tr>
<td>Economic</td>
<td></td>
</tr>
<tr>
<td>Historical</td>
<td>Past Cost Overruns</td>
</tr>
<tr>
<td>Legal</td>
<td>Fed. Law/Permit compliance</td>
</tr>
<tr>
<td>Moral/Ethical</td>
<td></td>
</tr>
<tr>
<td>Natural Environment</td>
<td></td>
</tr>
<tr>
<td>Political</td>
<td>Defend budget decision</td>
</tr>
<tr>
<td>Security</td>
<td></td>
</tr>
<tr>
<td>Social</td>
<td></td>
</tr>
<tr>
<td>Technological</td>
<td>project equipment requirements</td>
</tr>
</tbody>
</table>
Influence Diagram

Legend

- Constant
- Decision
- Uncertainty
- Compound Uncertainty
- Value

Time
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)

<table>
<thead>
<tr>
<th>Division</th>
<th>Region</th>
<th>Project</th>
<th>Mile</th>
<th>Project Description</th>
<th>Budget</th>
<th>Budget Breakdown for Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Arkansas River</td>
<td>151.7</td>
<td>Hydro-electric Dam and Reservoirs</td>
<td>$6,000,000</td>
<td>$6,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Broken Bow Lake</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$7,000,000</td>
<td>$7,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Bull Shoals Lake</td>
<td>151.7</td>
<td>Navigation and Flood Risk Management</td>
<td>$8,000,000</td>
<td>$8,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Buffalo River</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$9,000,000</td>
<td>$9,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Cadillac Dam</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$10,000,000</td>
<td>$10,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Delaware Lake</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$11,000,000</td>
<td>$11,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Delaware River</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$12,000,000</td>
<td>$12,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Devil's River</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$13,000,000</td>
<td>$13,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Einstein Lake</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$14,000,000</td>
<td>$14,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Horseshoe Lake</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$15,000,000</td>
<td>$15,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Lake Jackson</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$16,000,000</td>
<td>$16,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>McAlpine Dam</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$17,000,000</td>
<td>$17,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>McKenzie River</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$18,000,000</td>
<td>$18,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Ouachita River</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$19,000,000</td>
<td>$19,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Roborizer Dam</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$20,000,000</td>
<td>$20,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Standing Bear Lake</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$21,000,000</td>
<td>$21,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>St. Francis River</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$22,000,000</td>
<td>$22,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>South Fork River</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$23,000,000</td>
<td>$23,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Spring River</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$24,000,000</td>
<td>$24,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Talledega Lake</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$25,000,000</td>
<td>$25,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Tippit Dam</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$26,000,000</td>
<td>$26,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Tucumcari River</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$27,000,000</td>
<td>$27,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Upper Arkansas River</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$28,000,000</td>
<td>$28,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>White River</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$29,000,000</td>
<td>$29,000,000</td>
</tr>
<tr>
<td>Southark</td>
<td>Upper N.W.</td>
<td>Wolf Creek</td>
<td>151.7</td>
<td>Flood Risk Management</td>
<td>$30,000,000</td>
<td>$30,000,000</td>
</tr>
</tbody>
</table>
Methodology: Value Model

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

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

- Total additive value of alternative

- 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
Methodology: Fundamental Objectives

USACE Civil Works Vision
Contribute to the strength of the Nation through innovative and environmentally sustainable solutions to the Nation’s water resources challenges

Strategic Goals

1. Improve the safety and resilience of communities and water resources infrastructure.

2. Facilitate the transportation of commerce goods on the Nation’s coastal channels and inland waterways.

3. Restore, protect, and manage the Nation’s coastal and wetland resources to maintain coastal habitats.

4. Restore, protect, and manage the Nation’s wetlands and waterways to maintain ecosystem and water resource infrastructure.

5. Support the Nation and the Army in achieving our energy security and sustainability goals.

Objective 1.1
Modemize the Civil Works project planning program.

Objective 1.2
Deliver quality solutions and services.

Objective 1.3
Develop a ready and resilient workforce through innovative talent management and leader development strategies and programs.

Objective 2.1
Reduce the Nation’s risk and increase resilience to disasters.

Objective 2.2
Support the Department of Homeland Security/FEMA Emergency Management Agency to provide lifecycle public works and engineering support in response to disasters.

Objective 2.3
Efficiently and effectively execute response, recovery, and mitigation.

Objective 3.1
Facilitate commercial navigation by providing safe, reliable, highly cost-effective and environmentally sustainable waterborne transportation systems.

Objective 4.1
Restore aquatic habitat to a more natural condition in ecosystems in which structural function, and dynamic processes have been degraded.

Objective 4.2
Reduce adverse impacts to the Nation’s wetlands and waterways through an effective, transparent, and efficient Regulatory process.

Objective 4.3
Clean up radiactive waste sites.

Objective 4.4
Manage, conserve, and preserve natural resources at USACE projects.

Objective 4.5
Provide opportunities for quality outdoor public recreation.

Objective 5.1
Support the Nation and the Army in achieving energy security and sustainability goals.

Objective 5.2
Capitalize, establish, coordinate, and maintain water resources infrastructure to provide maximum value to the Nation.

Objective 5.3
Provide reliable, renewable, hydroelectric power to the Nation.

Objective 5.4
Provide water supply/storage in partnership with states and local interests.

A gold standard document for elicitation of fundamental organizational objectives
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.

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Objective 2.3: Facilitate the transportation of commerce goods on the nation's coastal channels and inland waterways.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY 14 Target - 100%</td>
<td>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.</td>
</tr>
<tr>
<td>FY 15 Target - 100%</td>
<td></td>
</tr>
<tr>
<td>FY 16 Target - 100%</td>
<td></td>
</tr>
<tr>
<td>FY 17 Target - 100%</td>
<td></td>
</tr>
<tr>
<td>FY 18 Target - 100%</td>
<td></td>
</tr>
<tr>
<td>Monthly 20%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Objective 3.1</th>
<th>Facilitate commercial navigation by providing safe, reliable, highly cost-effective, and environmentally sustainable waterborne transportation systems.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure 3.1.a</td>
<td>The number of instances where mechanically driven failures at locks results in delays of more than 24 hours.</td>
</tr>
<tr>
<td>Measure 3.1.b</td>
<td>The number of instances where mechanically driven failures at locks results in delays of more than one week.</td>
</tr>
<tr>
<td>Performance Measures</td>
<td></td>
</tr>
<tr>
<td>Target: FY 14</td>
<td>FY 15</td>
</tr>
<tr>
<td>1-Day 46</td>
<td>44</td>
</tr>
<tr>
<td>1-Week 26</td>
<td>25</td>
</tr>
</tbody>
</table>

Sustainable Solutions to America's Water Resource Needs
Methodology: Value Functions

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

<table>
<thead>
<tr>
<th>Significant Impact on Infrastructure</th>
<th>Affects States</th>
<th>Municipal Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of preventive maintenance completed on critical components</td>
<td>Number of Dam Safety Action Classification Rejected</td>
<td>Number of License Expires</td>
</tr>
<tr>
<td>100 0.07</td>
<td>75 0.05</td>
<td>55 0.04</td>
</tr>
<tr>
<td>Percent Scheduled and Executed Assigned and Funded Missions and Programs</td>
<td>Number of Active State- and Federal Interagency Flood Risk Management Teams</td>
<td>Number of License Delays of More than One Week</td>
</tr>
<tr>
<td>90 0.06</td>
<td>70 0.05</td>
<td>50 0.05</td>
</tr>
<tr>
<td>Percent of Trained and Certified Emergency Response</td>
<td>Peak Unit Availability</td>
<td>Number of License Delays of More than 24 Hours</td>
</tr>
<tr>
<td>85 0.06</td>
<td>65 0.04</td>
<td>48 0.05</td>
</tr>
<tr>
<td>Percent progress towards National Flood Characterization Tool</td>
<td>Percentage of time units are out of service due to organized outage</td>
<td></td>
</tr>
<tr>
<td>80 0.05</td>
<td>45 0.05</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Moderate Impact on Infrastructure</th>
<th>Affects States</th>
<th>Municipal Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent of Projects on Schedule</td>
<td>Percent of general permit discussions made within 60 days</td>
<td>Percent of PSA compliance in health and safety standards</td>
</tr>
<tr>
<td>70 0.05</td>
<td>46 0.03</td>
<td>35 0.05</td>
</tr>
<tr>
<td>Percent Increase of Technical Competencies for USACE/WMD That Meet or Exceed Army DAM Targets</td>
<td>Percent of USACE lands and waters that have achieved desired natural resource conditions</td>
<td>Percent of PSA Compliance in facility condition standards</td>
</tr>
<tr>
<td>90 0.04</td>
<td>45 0.03</td>
<td>34 0.02</td>
</tr>
<tr>
<td>Percent Completion and Deployment of Command Training Plans</td>
<td>Percent of acres of storage under contract versus acres feet available</td>
<td>Percent of PSA Compliance in efficiency standards</td>
</tr>
<tr>
<td>50 0.03</td>
<td>45 0.03</td>
<td>33 0.05</td>
</tr>
<tr>
<td>Percentage of USACE Customer Satisfaction</td>
<td>Percent of investment costs recovered versus the total investment costs available for recovery</td>
<td></td>
</tr>
<tr>
<td>48 0.03</td>
<td>45 0.03</td>
<td>0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Minor Impact on Infrastructure</th>
<th>Affects States</th>
<th>Municipal Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent of Current Annual Updated All- Parked Contingency Plans Across USACE</td>
<td>Percent of Planners Trained</td>
<td>Area of habitat restored, created, improved, or protected</td>
</tr>
<tr>
<td>45 0.03</td>
<td>58 0.03</td>
<td>20 0.05</td>
</tr>
<tr>
<td>(a) Percentage reduction in NTU petroleum use</td>
<td>Percent of Planners Achieving Certification</td>
<td>Number of individual properties restored to beneficial use</td>
</tr>
<tr>
<td>42 0.03</td>
<td>30 0.02</td>
<td>10 0.01</td>
</tr>
<tr>
<td>(b) Percent reduction in goal subject energy intensity by 2030/2007</td>
<td></td>
<td>0.00</td>
</tr>
</tbody>
</table>
Asset Management Strategies

<table>
<thead>
<tr>
<th>PORTFOLIO EMPHASIS</th>
<th>N</th>
<th>FRM</th>
<th>RC</th>
<th>H</th>
<th>EN</th>
<th>WS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commerce</td>
<td>1.2</td>
<td>1.1</td>
<td>0.7</td>
<td>1.2</td>
<td>0.8</td>
<td>1</td>
</tr>
<tr>
<td>(N, FRM, and H promoted)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Civilian</td>
<td>0.8</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>(RC, H, and EN promoted)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disaster Mitigation</td>
<td>1.1</td>
<td>1.3</td>
<td>0.5</td>
<td>1</td>
<td>1.1</td>
<td>1</td>
</tr>
<tr>
<td>(N, FRM, and EN promoted)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conservation</td>
<td>1</td>
<td>1.125</td>
<td>0.75</td>
<td>1</td>
<td>1.125</td>
<td>1</td>
</tr>
<tr>
<td>(FRM, EN, and WS promoted)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balanced</td>
<td>1</td>
<td>1.181</td>
<td>0.788</td>
<td>1.1</td>
<td>0.956</td>
<td>0.95</td>
</tr>
<tr>
<td>(Average of others)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

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

Strategy generation table to develop asset management strategies
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)
Portfolio Value v. Cost

How would introduction of uncertainty impact portfolio choice?
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
Sources of Uncertainty

One-Way Sensitivity to Percentage of Projects on Schedule

Percentage of Projects on Schedule impacts sensitivity for the second preferred alternatives.
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

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

Cost v. Value

75%  80%  85%  90%  100%

- Commerce
- Civilian
- Disaster Mitigation
- Conservation
- Balanced
- Base
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.
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-97177 (bottom left) USACE Civil Works Strategic Plan 2014-2018