The Inland Waterway Transportation Systems' Role in Response and Recovery

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Outline

- Introduction
- Waterway Emergency Service Coverage Function
- Case Study Region
- Optimization Approach and Application
- Summary

Introduction
Research Motivation

- Emergency operation planning typically assumes that all standard means of transportation are available
- Including multiple modes of transportation into emergency planning is an obvious contingency measure
- Inland waterways offer an often underutilized, valuable resource
  - United States has more than 26,000 miles of navigable inland waterways
  - Water transportation is a cost effective, fuel efficient, environmentally friendly and safe mode of transportation

Introduction

Research Contributions

- Provide emergency planners with insights into the benefits of inland waterway emergency response
- Provide the first known systematic planning strategy to utilize barges on inland waterways for emergency services
- Develop a decision support methodology to aid emergency planners in designing the most efficient and effective inland waterway-based emergency response system

Waterway Emergency Service (WES) Coverage Function

- Measures the potential benefit of inland waterway emergency response to a given county
- Guides emergency planners in determining the feasibility and benefit of using barge-based emergency services in their emergency response planning

WES Coverage Function

$$WES\ Coverage\ Function = A(PD + V + R + M + LR + T)$$

A Accessibility to Navigable Inland Waterways

PD Population Demands

V Social Vulnerability

R Risk of Disaster

- *Tornado*
- *Earthquake*
- *Flood/Hurricane/Tropical Storm*
- *Terrorist Attack*

M Limited Access to Medical Services

LR Limited Access to Resources

- *Clean Water Supplies*
- *Power Supplies*
- *Temporary Housing*
- *Fuel Supplies*

T Limited Access to Transportation Modes

WES Coverage Function Factors

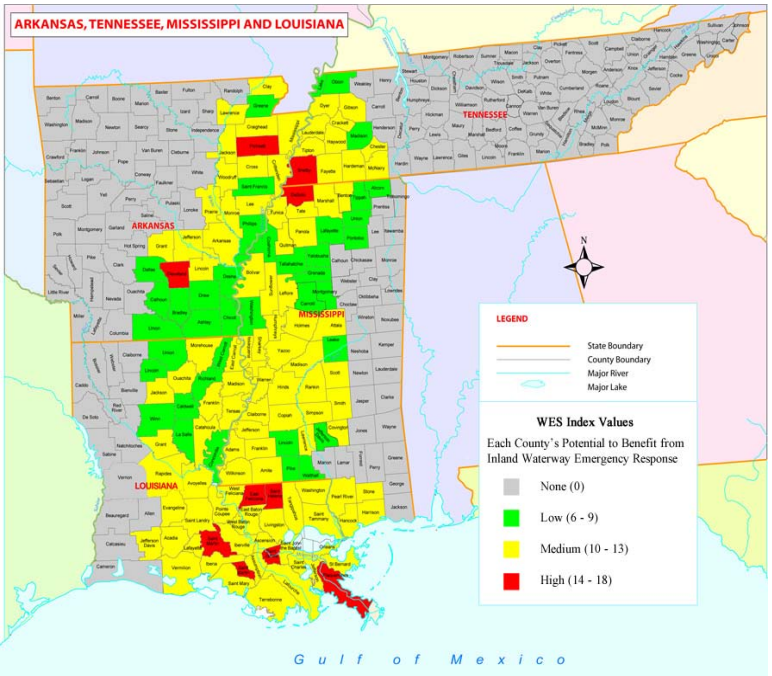
Factor	Description	Metric	Scale			Value
Accessibility to Navigable Inland Waterway	Proximity of a community to a navigable inland waterway. Emergency response is not feasible for communities located too far from a navigable inland waterway.	Distance between county population centroid and closest inland port/terminal	Accessible (≤ 3hr drive @ 35mph) = 1			1
			Inaccessible (> 3hr drive @ 35 mph) = 0			0
Population Demands	Size of population and its proximity to metropolitan areas. Important for identifying the level of services that may be needed during an emergency.	Rural-Urban Continuum Code	Low (7 - 9)			1
			Med (4 - 6)			2
			High (1 - 3)			3
Social Vulnerability	Social, economic, demographic, and housing characteristics that influence a community's ability to respond to, cope with, recover from, and adapt to environmental hazards. Useful for identifying which counties may need the greatest assistance during an emergency.	National percentile ranking of the Social Vulnerability Index (SoVI)	Low (0.01 - 33.33)			1
			Med (33.34 - 66.66)			2
			High (66.67 - 99.99)			3
Risk of Disaster	The risk of tornado, earthquake, flood, or terrorist attack. Useful for identifying which counties are most likely to need inland waterway-based emergency assistance.	Combined risk level of tornado, earthquake, flood, and terrorism	**Tornado**: Low (<2.5), Med (2.5 - 4.99), High (≥5)	**Total**	Low (4 - 6)	1
			Earthquake: Low (<20), Med (20 - 79.9), High (≥80)		Med (7 - 9)	2
			Flood: Low (<3), Med(3 - 4), High (>4)		High (10 - 12)	3
			Terrorism: Low = 1 , Med = 2, High = 3			

WES Coverage Function Factors (cont.)

Factor	Description	Metric	Scale			Value
Limited Access to Medical Services	Number of community hospital beds per 100,000 people, available in the areas. Important for identifying the neccessity of medical services that may be brought to the area during an emergency.	Number of community hospital beds per 100,000 people	Low (>317)			1
			Med (1 - 317)			2
			High (0)			3
Limited Access to Resources	Availability of resources including clean water supply, power supply, temporary housing, and fuel supplies. This factor is important in identifying the neccessity of providing resources via barge.	Combined availability level of water supply and irrigation systems; electric power generation, transmission, & distribution; number of hotels, motels, B&B, other travel accommodation, RV parks and camps, rooming and boarding houses; number of gasoline station establishments. To be consistent, all the metrics are measured per 100,000 people.	**Clean Water**: Low (>8), Med (1 - 8), High(0)	**Total**	Low (4 - 6)	1
			Power: Low (>7), Med (1 - 7), High(0)		Med (7 - 9)	2
			Temporary Housing: Low (>23), Med (1 - 23), High(0)		High (10 - 12)	3
			Fuel: Low (>67), Med (1 - 67), High(0)			
Limited Access to Transportation Modes	Accessibility to railroad system or airports. If a county does not have easy access to other modes of transportation it has higher potential to benefit from waterway-based transportation.	Railroad passes through the county and/or at least on public airport is located in the county	Both railroad and airport(s) are accessible			1
			Railroad or airport is accessible			2
			Neither railroad nor airport is accessible			3

Case Study Region

- Lower Mississippi River region
- Four states
  - Arkansas (75 counties)
  - Louisiana (64 parishes)
  - Mississippi (82 counties)
  - Tennessee (95 counties)



- WES coverage function results

WES Coverage Function Results

- In the case study region,
  - Thirty nine (12%) counties have low
  - Ninety seven counties (31%) counties have medium
  - Nine counties (3%) have high

  potential to benefit from water-based emergency response
- 171 counties do not have feasible access to Mississippi River (54%)
- 73% of the counties in the four state region with access to the Mississippi River have at least medium potential to benefit

Optimization Approach

1. Minimize Number of Required Barges Model
   - Formulated a set covering model to help emergency planners to determine the minimum number of barges required
2. Maximize WES Coverage Model
   - Considering the resource limitations, formulated a maximal covering model to determine the optimal starting location for the available barges in order to provide maximum WES coverage
3. Goal Programming Approach
   - Developed a multi-objective optimization model that combines the objectives of models 1 and 2

Notation

- Sets
  - C Set of counties, indexed by i
  - P Set of ports, indexed by j and k
- Parameters
  - A_{ij} 1 if county i has access to port j (less than 3 hours drive), 0 otherwise
  - d_{jk} 1 if port j is in the barge coverage range of port k (12 hrs), 0 otherwise
  - n Number of available barges
  - w_i WES coverage function value for county i
  - R_i Value of risk of disaster factor for county i
  - S_i Value of social vulnerability factor for county i
  - m Number of ports
- Decision variables
  - x_i 1 if county i is covered, 0 otherwise
  - y_j 1 if there is a barge at port j, 0 otherwise

Minimize Number of Required Barges Model

$$Min \sum_{j \in P} y_j \qquad (1)$$

$$x_i \leq \sum_{j \in P} \sum_{k \in P} y_j d_{jk} a_{ik} \qquad \forall i \in C \qquad (2)$$

$$\sum_{j \in P} \sum_{k \in P} y_j d_{jk} a_{ik} \leq m x_i \qquad \forall i \in C \qquad (3)$$

$$x_i = 1 \qquad \forall i \in C \qquad (4)$$

$$R_i \leq 2(x_i + 1/2) \qquad \forall i \in C \qquad (5)$$

$$S_i \leq 2(x_i + 1) \qquad \forall i \in C \qquad (6)$$

Example Performance Constraints

$$x_i, y_j \in \{0,1\} \qquad \forall i \in C, \forall j \in P \qquad (7)$$

Minimize Number of Required Barges Results

Barge Coverage Range (hours)	Min Number of Required Barges	Origin Ports
3	8	2,5,6,8,9,12,15,16
6	7	2,5,6,8,12,15,16
12	**5**	**1,5,7,12,15**
24	3	3,9,15
48	2	4,13

Port Number	Port Name	State
16	Osceola	AR
15	Memphis	TN
14	Helena	AR
13	Rosedale	MS
12	Yellow Bend	AR
11	Greenville	MS
10	Lake Providence	LA
9	Madison Parish	LA
8	Vicksburg	MS
7	Claiborne County	MS
6	Natchez	MS
5	Greater Baton Rouge	LA
4	South Louisiana	LA
3	New Orleans	LA
2	St. Bernard	LA
1	Plaquemine	LA

Maximize WES Coverage Model

$$Max \ \sum_{i \in C} w_i x_i \qquad (1)$$

$$x_i \leq \sum_{j \in P} \sum_{k \in P} y_j \, d_{jk} \, a_{ik} \qquad \forall i \in C \qquad (2)$$

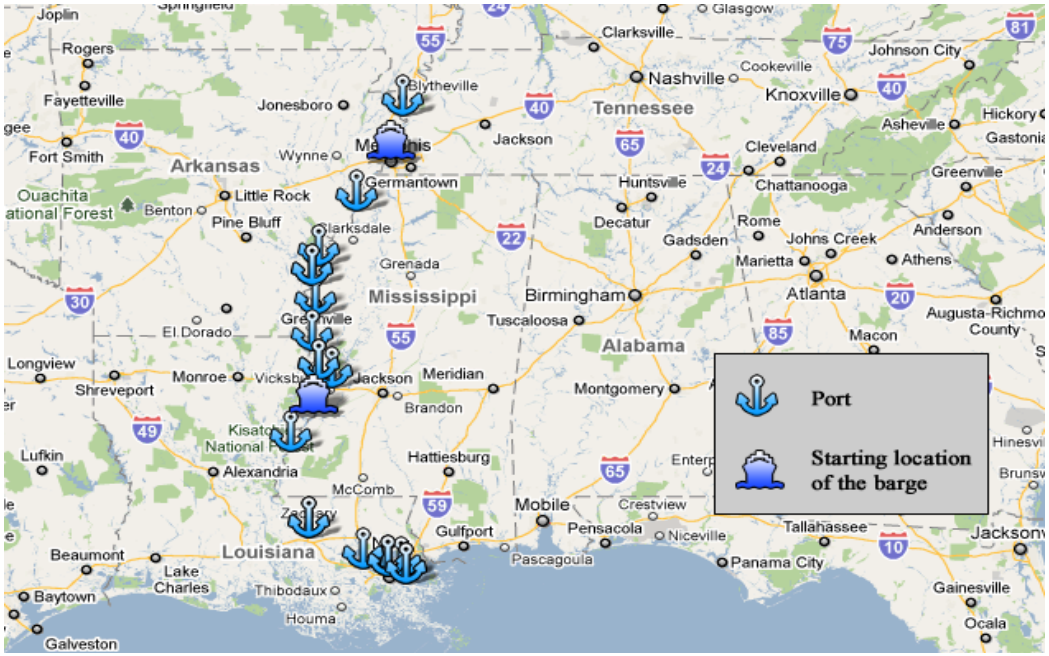
$$\sum_{j \in P} \sum_{k \in P} y_j \, d_{jk} \, a_{ik} \leq m x_i \qquad \forall i \in C \qquad (3)$$

$$\sum_{j \in P} y_j \leq n \qquad (4)$$

$$x_i, y_j \in \{0,1\} \qquad \forall i \in C, \forall j \in P \qquad (5)$$

Maximize WES Coverage Results

Number of Available Barges	Origin Ports	Number of Covered Counties (% covered)	Coverage Scores (Objective Function Values)
1	7	69 (48%)	712
2	**7,15**	**110 (76%)**	**1148**
3	5,7,15	133 (92%)	1423
4	1,5,7,15	139 (96%)	1494



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Goal Programming Approach

- Additional Notation
  - Parameters

    t_1 Target value for minimum number of required barges *(1)*

    t_2 Target value for maximum WES coverage *(1553)*

    v_1 Scaling factor for minimum number of required barges objective *(0.9934)*

    v_2 Scaling factor for maximum WES coverage objective *(0.0066)*

    α Weight assigned to minimum number of required barges objective *(0.5)*
  - Decision variables

    d_1 Deficiency variable for the minimum number of required barges

    d_2 Deficiency variable for the maximum WES coverage

Goal Programming Formulation

$$Min\ \alpha v_1 d_1 + (1-\alpha) v_2\, d_2 \qquad (1)$$

$$x_i \leq \sum_{j \in P} \sum_{k \in P} y_j\, d_{jk}\, a_{ik} \qquad \forall i \in C \qquad (2)$$

$$\sum_{j \in P} \sum_{k \in P} y_j\, d_{jk}\, a_{ik} \leq m x_i \qquad \forall i \in C \qquad (3)$$

$$\sum_{j \in P} y_j - d_1 \leq t_1 \qquad (4)$$

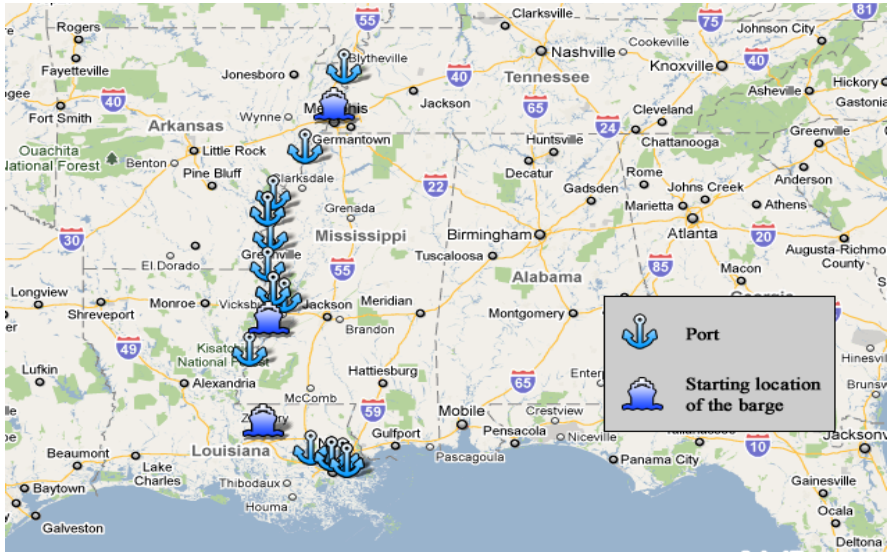
$$\sum_{i \in C} w_i x_i + d_2 \geq t_2 \qquad (5)$$

$$x_i, y_j \in \{0,1\} \qquad \forall i \in C, \forall j \in P \qquad (6)$$

$$d_1, d_2 \geq 0 \qquad (7)$$

Goal Programming Results

Barge Coverage Range (hours)	Number of Available Barges	Origin Ports	Number of Covered Counties (% covered)	Coverage Scores (Objective Function Values)
3	3	5,9,15	122 (84%)	1312
6	3	5,8,15	127 (88%)	1362
12	**3**	**5,7,15**	**133 (92%)**	**1423**
24	3	3,9,15	145 (100%)	1553
48	2	1,13	145 (100%)	1553



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1	Plaquemine	LA

Summary

- Developed WES coverage function to help planners assess the feasibility of using inland waterways to provide emergency assistance to their communities
- Developed a decision support methodology to aid emergency planners in designing the most efficient and effective inland waterway-based emergency response system
- Conducted case study
  - Assuming 12 hour coverage range, three barges are required to provide emergency response coverage to 92% of the counties in the four state region
- Future work
  - Heuristic development
  - Explore resource allocation on barges
  - Consider the use of watercrafts other than barge