A Two Stage Stochastic Optimization Model for Port Infrastructure Planning

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Abstract

This research investigates inland port infrastructure investment planning under uncertain commodity demand conditions. A two-stage stochastic optimization is developed to model the impact of demand uncertainty on infrastructure planning and transportation decisions with an objective to minimize the total expected costs, including infrastructure investment cost, and the expected transportation costs. To solve the problem, an accelerated Benders decomposition algorithm is implemented. The Arkansas section of the McCllean-Kerr Arkansas River Navigation System (MKARNS) is used as a testing ground for the model. Results show that commodity volume and, as expected, the percent of that volume that moves via waterways (in ton-miles) increases with increasing investment in port infrastructure. The model is able to identify a cluster of ports that should receive investment in port capacity under any investment scenario.

Background

Inland waterway ports are critical to the nation's inter-modal transportation system. Amount of commodity carried by a 15-barge tow is equivalent to amount of commodity carried by 216 rail cars and 1,050 trucks. Leveraging this efficiency of inland ports requires study on movement of commodity flow through the inland waterway network.Expanding port infrastructure requires large capital investment and tends to target long lifespans, e.g., 25 years or more. Therefore, it is imperative that port capacity expansion investments are neither under nor over invested.Thus, decisions about investments in port infrastructure, as any transportation investment, should be evaluated for different scenarios of freight demand that reflect the unknown nature of economically driven trends seen for freight transport.This calls for an investment model that considers several scenarios and provides optimal inland waterway port infrastructure investment solutions when uncertainty is present.

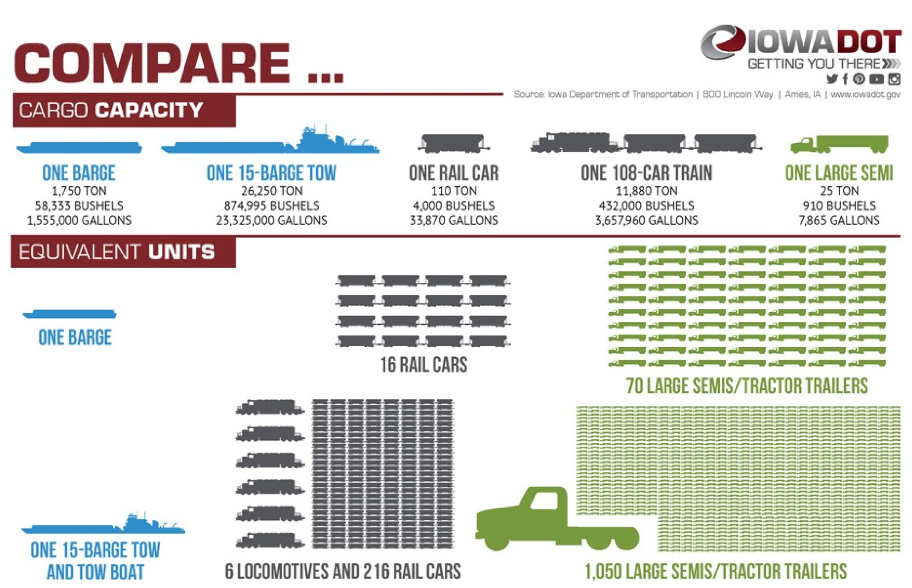


Figure 1. Freight Mode Comparison [1]

Supply Chain Network

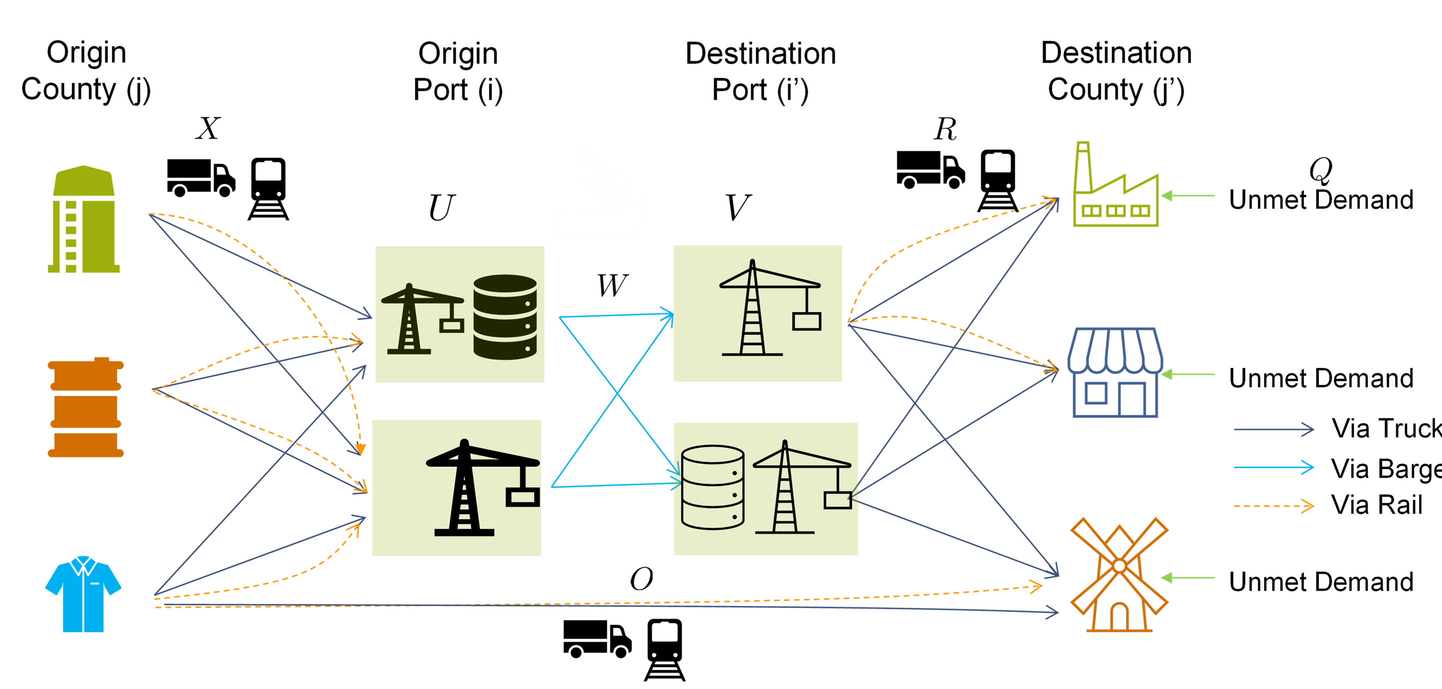


Figure 2. Inland Waterway Supply Chain Network

Method

- Objective: Minimize Equipment cost + Storage facility cost + Supply chain cost + Penalty cost
  - Equipment cost includes cost of commodity processing equipments (crane, forklift, hopper, conveyor)
  - Supply chain cost includes cost of moving commodities via rail, truck and barges
  - Penalty cost includes cost of fulfilling unmet demand via external sources
- Constraints: Flow balance, Capacity, Supply, Demand
- Stochastic Parameter: Commodity demand
- Algorithm: Accelerated Benders decomposition algorithm with Knapsack inequalities and Pareto-optimal cuts

Case Study

Arkansas section of the MKARNS:

- 308 miles
- Contributes to the national economy with $4,535M in sales, $168m in business tax, and 33,695 jobs [2]

Case Study Size:

- 75 counties
- 30 ports
- 12 months
- 11 commodity groups
- 10 demand scenarios

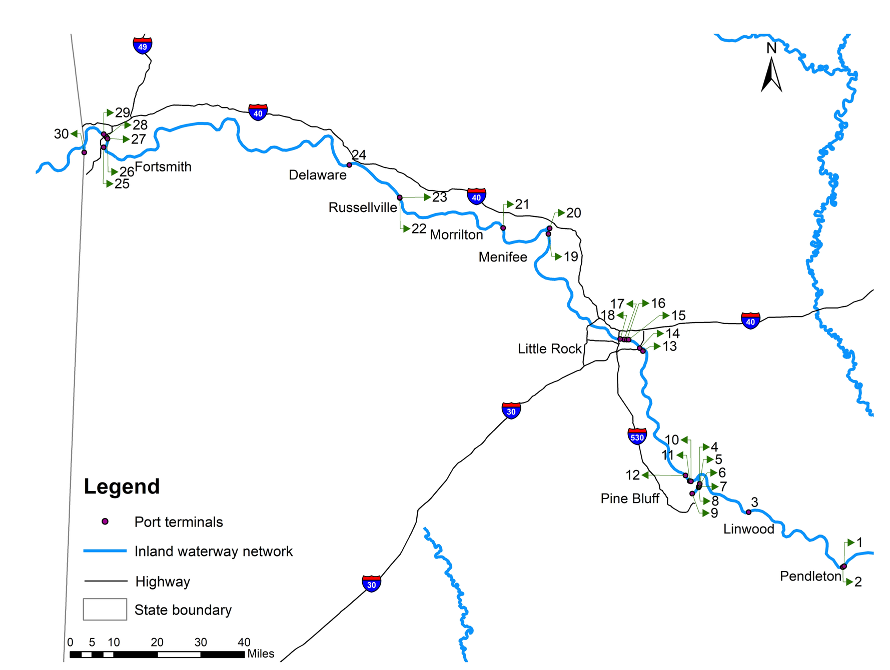
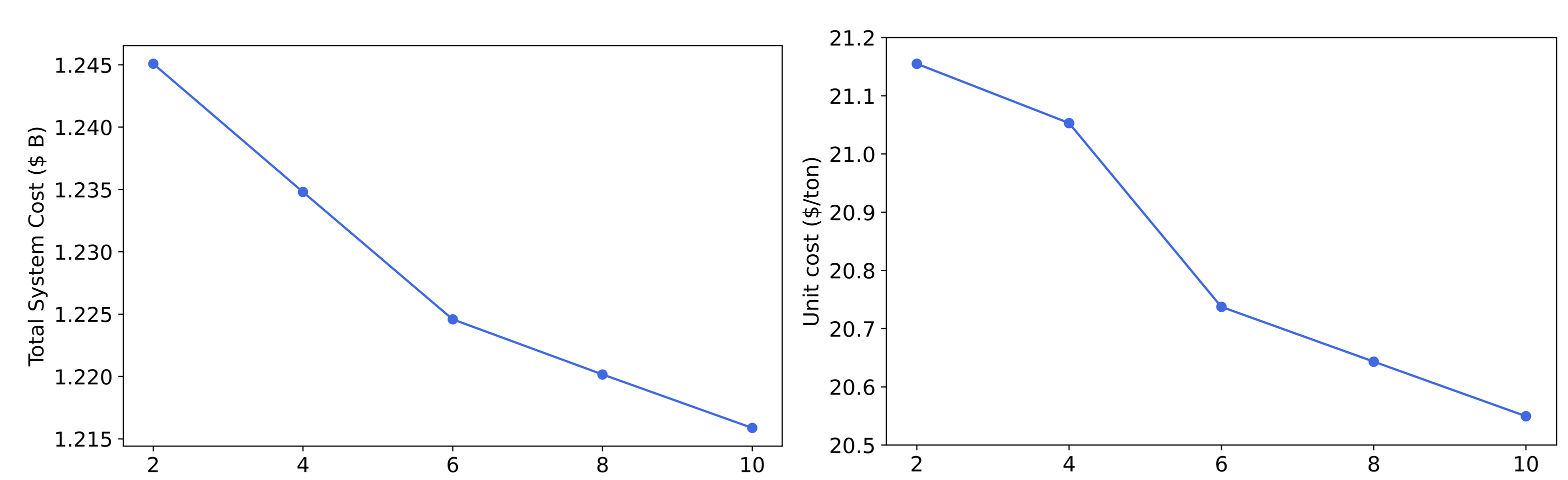


Figure 3. Arkansas Section of MKARNS [1]

Results



(a) System Cost (b) Unit Cost

Figure 4. (a) investment vs. total system cost, (b) investment vs. unit cost

- Total system cost and unit supply chain cost decreases with increase in investment in port infrastructure (Figure 4)
- This decrease can be attributed to the increased volume of commodity shipped via waterways (Figure 6a)

Results

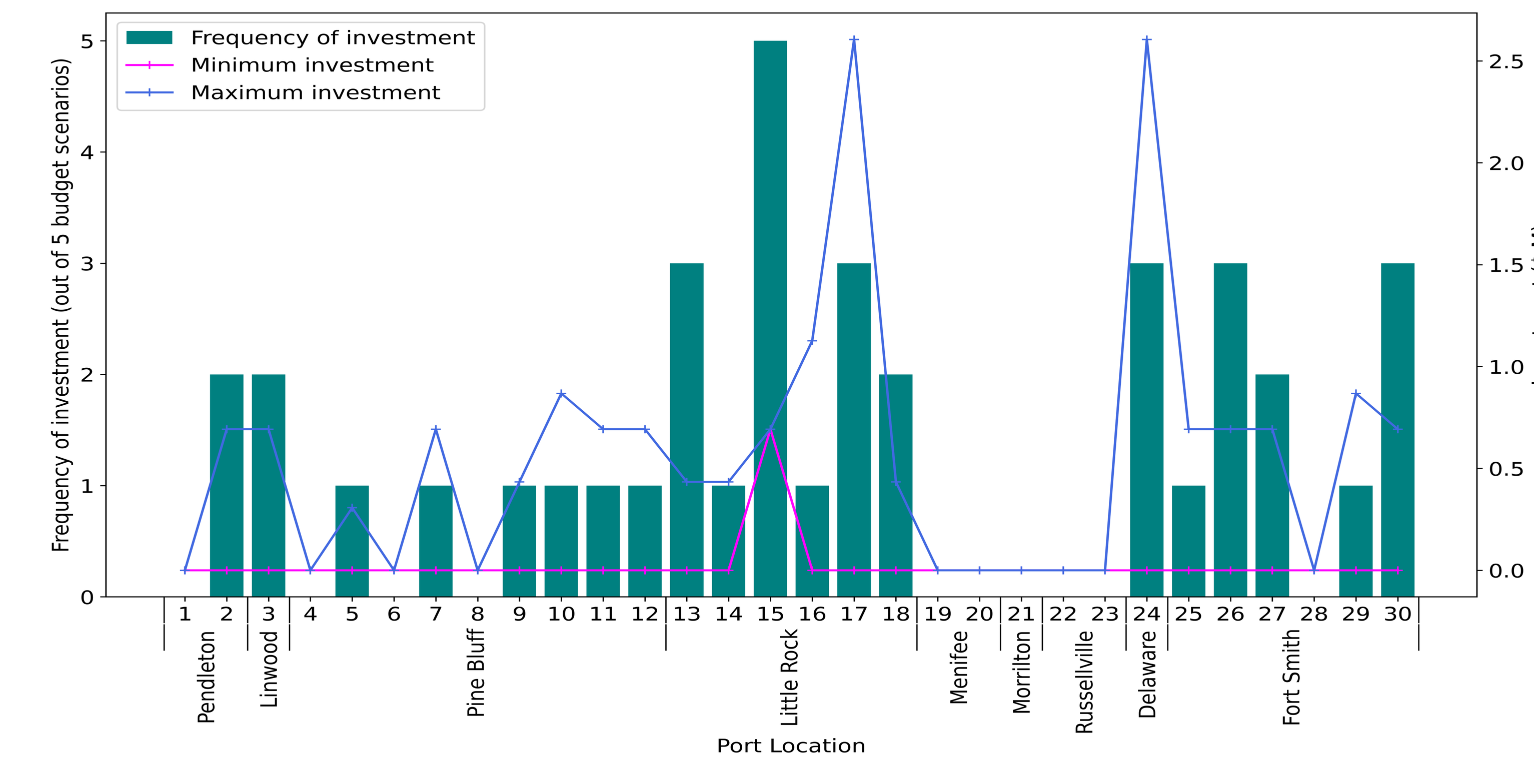
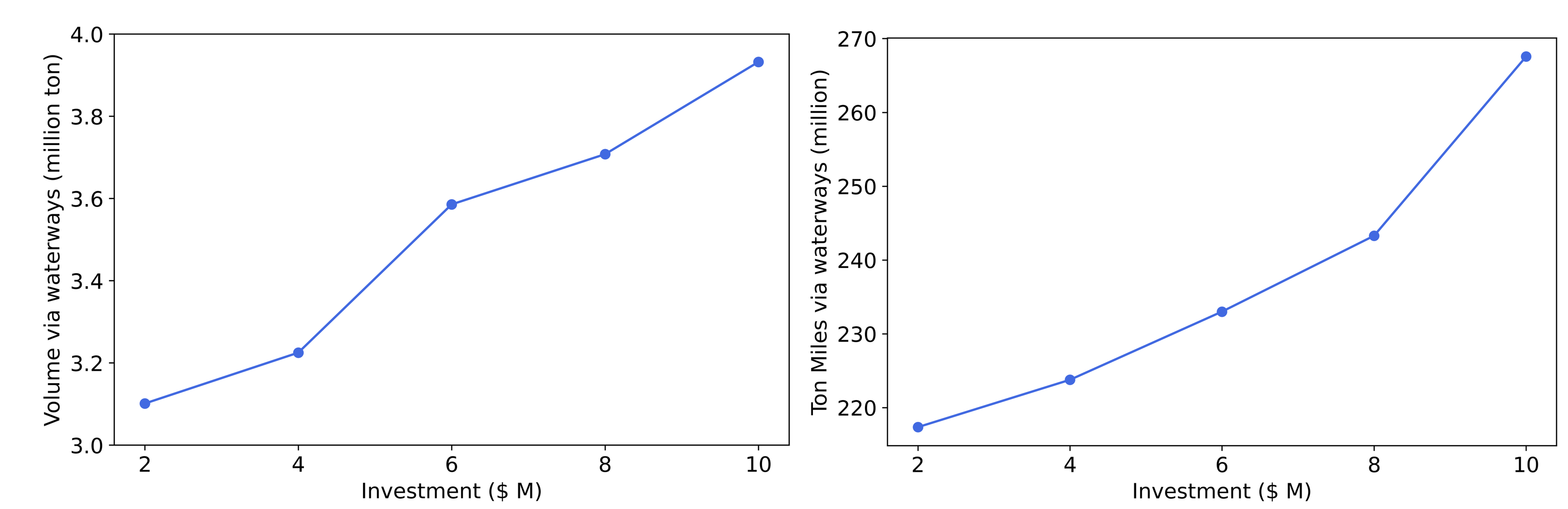


Figure 5. Port investment

- In most of these scenarios, the model determines that investments should be made on ports located at Little Rock, Delaware, andFort Smith(Figure 5)



(a) Volume (b) Ton-miles

Figure 6. (a) investment vs. total volume, (b) investment vs. total ton-miles

- The volume and ton-miles of commodities shipped via the waterways increases as the investment in port infrastructure increases (Figure 6)
- Since barges have the least amount of carbon emission, the finding can be used to advocate for more funding of inland port capacity expansion

Conclusion

- Developed an optimization model to guide strategic investments in inland waterway port infrastructure investments
- Results reveal that with increasing investment, there is decrease in unit supply chain cost and increase in volume of commodities moved via waterway
- Model identifies cluster of ports (Little Rock, Fort Smith) that needs investment for port capacity expansion

References

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[2] Heather Nachtmann, Othman Boudhoum, Furkan Oztanriseven, et al. Regional economic impact study for the mcclellan kerr arkansas river navigation system. 2015.

ACKNOWLEDGMENT: This work is supported by a research grant (Grant number 69A3551747130) from the Maritime Transportation Research and Education Center (MarTREC).