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Optimal Design of Inland Waterway System to Enhance Intermodal Transportation: Challenges and Opportunities

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16. Abstract
This study integrates Stakeholder Theory and Grounded Theory to examine challenges and opportunities in the United States inland waterway transport sector through a literature review and stakeholder interviews. Key findings highlight aging infrastructure, rising compliance costs, and demand volatility as significant barriers while emphasizing the sector's role in supply chain resilience. Competition from rail and trucking, limited containerization, and workforce shortages further constrain growth, necessitating infrastructure modernization, digital logistics enhancements, and workforce development. Environmental and seasonal risks threaten service reliability, underscoring the need for contingency planning and targeted investments. These insights inform strategies for improving inland waterway transportation efficiency, resilience, and competitiveness.

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List of Abbreviations

Artificial Intelligence (AI)
Foreign Trade Zone (FTZ)
Grounded Theory (GT)
Inland Waterway Transportation (IWT)
Inland Waterway Container Terminal (IWCT)
Stakeholder Theory (ST)

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Abstract

This study uses a comprehensive methodology that integrates Stakeholder Theory and Grounded Theory to explore the challenges and opportunities within the U.S. inland waterway transport (IWT) sector. Drawing upon an extensive literature review and semi-structured interviews with key stakeholders—including government regulators, barge operators, port authorities, cargo owners, environmental organizations, and advocacy groups—the research provides a holistic view of the barriers confronting IWT operations and identifies potential strategies for improvement.

Findings reveal that aging infrastructure and rising costs remain pressing concerns. Outdated locks, dams, and navigational aids reduce operational efficiency, while stricter environmental regulations compound compliance expenses. Demand volatility further complicates profitability and long-term planning, underscoring a need for flexible operational strategies. Despite these hurdles, the study highlights IWT's pivotal role in bolstering supply chain resilience, particularly when disruptions arise in rail or trucking networks. Expanding integrated logistics systems and fostering intermodal connectivity can improve flexibility and strengthen the sector's position.

The analysis also shows that heightened competition from rail and truck modes and limited containerized options constrain IWT growth. Stakeholders underscore the importance of modernizing infrastructure, improving digital logistics platforms, and expanding intermodal hubs to enhance waterway competitiveness. Additionally, workforce shortages—especially in specialized roles like pilots and engineers—pose significant challenges to operational stability. Addressing these gaps through workforce development programs and accessible digital platforms could streamline shipper-carrier interactions and drive higher adoption.

Lastly, the research identifies environmental and seasonal risks, such as fluctuating water levels, droughts, and extreme weather events, as ongoing threats to service reliability. Strengthening contingency planning and advocating for targeted investments in infrastructure upgrades are crucial steps toward safeguarding IWT's long-term viability. Collectively, these insights inform evidence-based policy decisions and industry strategies aimed at sustaining a more efficient, resilient, and competitive inland waterway transportation system.

Chapter 1 Introduction

Inland waterway transport plays a critical role in the movement of goods across the United States, offering a cost-effective and environmentally friendly alternative to road and rail freight. The United States has an extensive inland waterway system, consisting of more than 36,000 miles of rivers, channels, and canals that serve 41 states (U.S. Department of Transportation, Maritime Administration, 2019). The Mississippi River system, including the Ohio River and the Gulf Intracoastal Waterway, facilitates the movement of bulk commodities such as grain, coal, and petroleum products, particularly in the Midwest and Gulf Coast regions. The Upper Mississippi River is the primary transport channel for grain, corn, and soybeans produced in the United States. Despite its vast network and potential benefits, inland waterway transport remains significantly underutilized compared to other freight modes, accounting for only about 4% to 5% of the nation's total freight volume annually. Various challenges, including aging infrastructure, limited funding, and logistical inefficiencies, hinder its competitiveness and broader adoption within modern supply chains (Congressional Research Service, 2020).

Globally, several countries have successfully developed and modernized their inland waterway transport networks, making them integral components of their freight logistics systems. The European Union, for example, has invested heavily in its interconnected inland waterway network, which spans across major rivers such as the Rhine, Danube, and Seine. These waterways are well integrated with rail and road systems, allowing seamless multimodal transport of goods across borders. The European Commission has implemented policies to promote waterway transport, which focus on improving infrastructure, digitalization, and environmental sustainability (Sys, Van de Voorde et al. 2020). As a result, inland waterways in Europe account for a significant share of freight transport, with the Rhine River alone carrying over 300 million tons of cargo annually. The reliability, efficiency, and high level of investment in these networks make them an essential part of Europe's freight logistics.

China has also established itself as a global leader in inland waterway transport, with an extensive and highly utilized river network that plays a crucial role in its economic growth. The Yangtze River, stretching over 3,900 miles, is one of the busiest inland waterways in the world, carrying over 3 billion tons of cargo annually, significantly more than the Mississippi River system (Notteboom, Yang.et al. 2020). The Chinese government has heavily invested in expanding and modernizing its waterways, including deepening river channels, constructing new locks and dams, and integrating smart logistics systems. Advanced vessel traffic management technologies, automated port operations, and extensive multimodal connectivity have made China's inland waterway network highly efficient and capable of handling a diverse range of freight, including containerized cargo. This level of infrastructure investment and policy support has positioned China as a model for how inland waterway transport can be optimized for high-volume freight movement.

In contrast, the United States inland waterway system remains largely underutilized and outdated, despite having one of the most extensive networks in the world. Unlike Europe and China, the U.S. lacks a coordinated national strategy for inland waterway investment and multimodal integration. While other nations have embraced digital tracking systems, real-time freight scheduling, and automated cargo handling, the U.S. still relies on aging infrastructure, outdated locks, and inconsistent dredging efforts. Moreover, while European and Chinese systems facilitate the movement of containerized goods, U.S. inland waterways remain primarily limited to bulk commodities like grain, coal, and petroleum. The success of advanced inland waterway networks worldwide demonstrates that with strategic investment, policy support, and technological adoption, the U.S. could significantly improve the efficiency and competitiveness of its inland waterway transport system.

One of the key advantages of inland waterways is their environmental sustainability compared to road and air freight. Barge transport produces significantly lower greenhouse gas emissions per ton-mile, making it one of the most energy-efficient modes of freight transport. Studies indicate that a barge can move a ton of cargo nearly 647 miles on a single gallon of fuel, while a train can cover approximately 477 miles, and a truck only about 145 miles, with the same fuel consumption (Waterways Council, Inc., 2024). This efficiency translates into lower carbon dioxide (CO_2) emissions, reduced fuel costs, and a decreased reliance on fossil fuels. Additionally, inland waterways help alleviate highway congestion by shifting large volumes of freight off the roads, reducing vehicle miles traveled and cutting down on air pollution caused by heavy-duty trucks. As the global push for sustainability and carbon reduction intensifies, expanding the use of inland waterway transport offers a practical solution for achieving these environmental goals while maintaining an efficient freight network.

Given these sustainability benefits, it is critical to assess the challenges and opportunities for expanding inland waterway transport in the United States. Despite its potential, the system remains underutilized due to aging infrastructure, inconsistent funding, limited multimodal connectivity, and a general lack of awareness among shippers. Understanding these barriers is essential for policymakers, industry leaders, and logistics professionals to make informed decisions about improving the efficiency and competitiveness of the inland waterway network. Identifying opportunities for modernization—such as investing in lock and dam rehabilitation, improving intermodal hubs, and incorporating digital logistics solutions—can help unlock the full potential of this mode of transport. By addressing these challenges, the U.S. can move toward a more resilient, cost-effective, and environmentally sustainable freight transportation system that benefits both the economy and the environment.

In this research, we examine the challenges and opportunities within the U.S. inland waterway transport system by integrating stakeholder perspectives and empirical data. Through an extensive literature review and semi-structured interviews with key stakeholders we identify critical barriers such as aging infrastructure, inconsistent funding, limited intermodal connectivity, and regulatory complexities that hinder inland waterway utilization. Additionally, we explore potential strategies for expansion, including infrastructure modernization, improved policy coordination, digital logistics integration, and sustainability incentives. By providing a comprehensive evaluation of the current inland waterway system, we offer data-driven insights to guide policy decisions, industry investments, and future research aimed at enhancing the efficiency and competitiveness of inland water freight transport.

Chapter 2 Literature Review

This study conducted a literature review to provide a comprehensive analysis of IWT in the context of intermodal transportation systems. Two research questions guided this literature review:

- What are the main challenges facing the integration of IWT in enhancing intermodal transportation systems?
- What strategies and solutions can be implemented to address the challenges in integrating IWT for improved intermodal transportation efficiency and sustainability?

To address these questions, Boolean search strings were developed to identify relevant studies in selected databases. Searches were conducted using Google Scholar and ScienceDirect to identify relevant studies. The Boolean strings included keywords related to inland waterways, barriers, challenges, integration, connectivity, intermodal transportation, and solutions. The search strings used were as follows:

- ("inland waterway") AND ("barriers" OR "challenges" OR "strategies" OR "solution") AND ("integration" OR "connectivity") AND ("intermodal transportation" OR "multimodal logistics")

The search parameters and results are summarized below:

- Google Scholar: Limited to the period 2014–2024, focusing on review articles and research papers, yielding 890 results.
- ScienceDirect: Limited to the period 2014–2024, including all publication types, yielding 146 results.

The filtering and refinement of the selected studies followed a structured process. First, duplicates were removed by consolidating studies identified across both databases. Next, inclusion and exclusion criteria were applied, ensuring that only studies focusing on the challenges, barriers, and solutions for integrating IWT into intermodal systems were retained. Studies that did not directly address these topics or lacked full-text access were excluded. Additionally, a snowballing technique was employed to identify further relevant studies through the references of selected papers. This filtering process ultimately resulted in a final selection of 21 papers.

2.1 Classifications and Research Trends

Different classifications for characterizing challenges, stakeholders, elements, and focus areas in IWT have been discussed extensively in the literature. Nonetheless, to enhance comprehension and organization, this study introduces four overarching categories to consolidate and streamline existing categorizations. These categories are intended to clarify the roles, barriers, and opportunities in IWT while facilitating targeted analysis.

Studies are grouped by their geographic focus to capture regional variations and trends in IWT development. Countries such as the United States, China, India, and European nations exhibit distinct approaches to IWT based on their geographical, economic, and policy contexts.

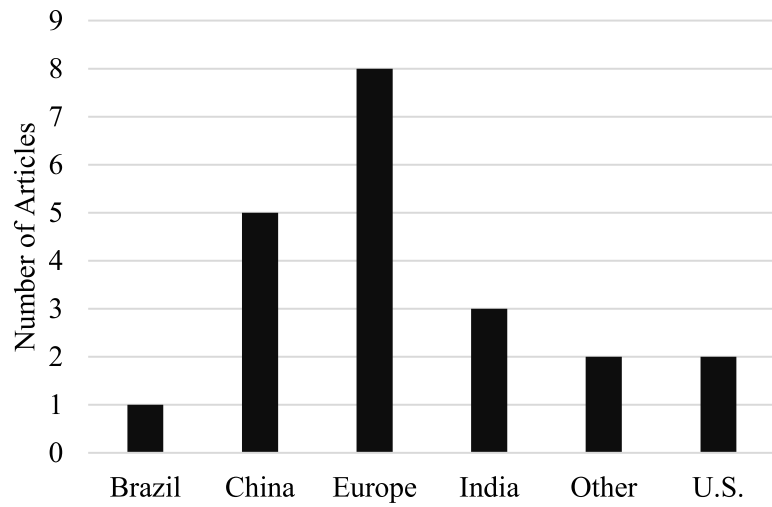

Figure 2.1 Geographic Distribution Research Articles

Figure 2.1 represents the distribution of papers in the literature review by country. It indicates that Europe has the highest representation, with eight papers focusing on its inland waterway transportation systems. This is followed by China, which has five papers, reflecting the country's significant investment and development in IWT. India, the United States, and other regions each have a moderate representation, with two papers each, highlighting emerging research interest in these areas. Brazil has the least representation, with only one paper, suggesting limited research focus or utilization of IWT in the region.

Another key category focuses on the fundamental components of inland IWT and their specific roles within the system. The literature primarily highlights four main elements: Fleet, which examines vessel design, fleet size, and operational efficiency; Port, which explores inland container terminals, dry ports, and their intermodal functions; Waterway, which addresses channel navigability, water level management, and dredging; and Integration, which investigates the connectivity of IWT with rail, road, and maritime systems to create efficient intermodal networks.

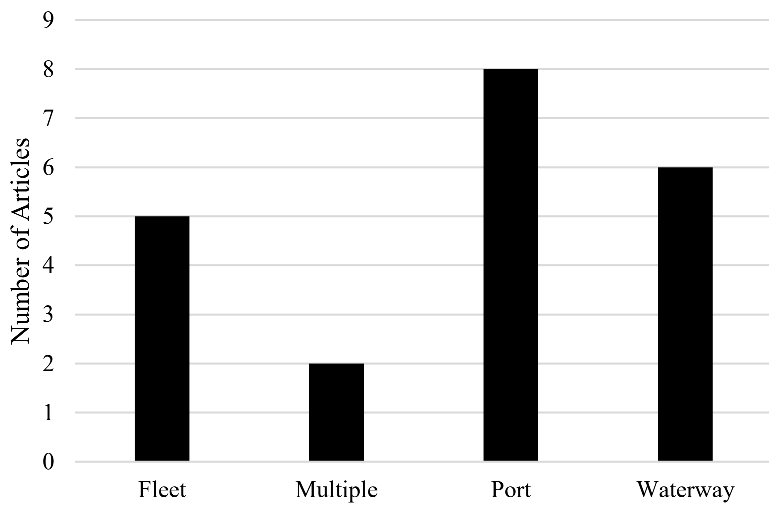

Figure 2.2 Distribution of Research Papers by Key Components

Figure 2.2 illustrates the distribution of papers by elements of IWT studied in the literature review. Among the elements, integration is the most frequently addressed, with eight papers focusing on the connectivity of IWT with other transport modes such as rail and road. Ports and waterways are also significant areas of research, with six and five papers respectively, emphasizing their roles in infrastructure and navigability. Fleet has the least representation, with only two papers, indicating a lower emphasis on vessel-specific studies in the reviewed literature.

IWT involves various stakeholders, including carriers (shippers), policy makers (government bodies, regulatory authorities, and international organizations), and multiple stakeholders (cargo owners or businesses). These groups play essential roles in shaping IWT operations, regulatory frameworks, and supply chain efficiency.

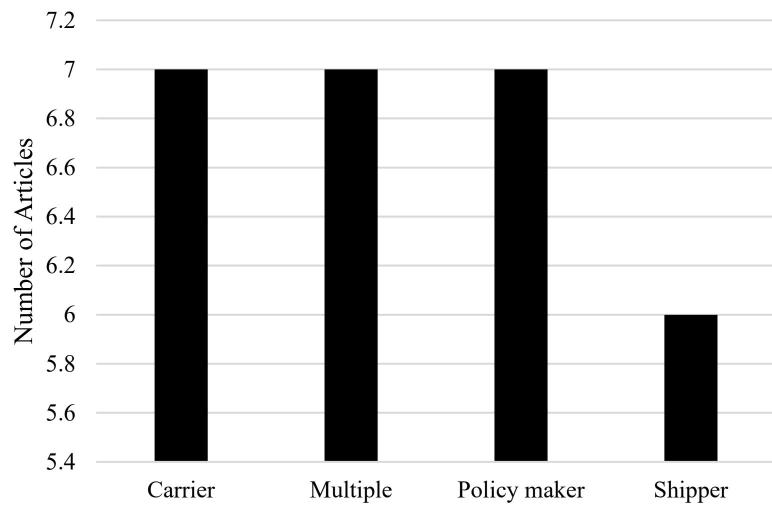

Figure 2.3 Distribution of Research Papers by Decision-Making Stakeholders

Figure 2.3 illustrates the distribution of research papers in the literature by decision-makers. Policy makers and multiple stakeholders dominate the focus, with eight papers each, emphasizing governance, regulations, and collaborative efforts in improving IWT. Carriers are also well-represented, with seven papers highlighting their operational and logistical roles. However, shippers receive the least attention, with only three papers, indicating a gap in research on cargo owners' perspectives and contributions within the IWT framework.

Different classifications for characterizing focus areas in IWT are expected as Calderón-Rivera, Bartusevičienė et al. (2024) addressed the multidimensional challenges and opportunities within this mode of transportation. To enhance clarity and facilitate analysis, this study introduces four overarching categories that consolidate existing classifications. Governance and policy encompass aspects related to the regulatory frameworks, governance systems, and policy initiatives that guide decision-making processes, ensuring sustainable development of IWT. These include policies aimed at reducing environmental impacts and fostering socio-economic benefits for regions relying on waterways. Addressing managerial and operational policies requires a clear distinction based on the temporal nature of activities proposed by Tako and Robinson (2012). Management involves strategic, long-term actions that often take two to five years to implement, such as fleet expansion planning or infrastructure investment decisions. In contrast, operations focus on short-term, day-to-day activities like scheduling, tracking shipments, and coordinating intermodal transfers. Infrastructure and technology combine considerations of physical assets, such as ports and waterways, with technological advancements like real-time tracking systems, blockchain, and automation, aimed at addressing infrastructural gaps and enhancing overall efficiency. Together, these categories provide a comprehensive framework for analyzing the diverse factors shaping the performance and integration of IWT into intermodal logistics networks.

Figure 2.4 illustrates the distribution of papers by focus area in the literature review. Governance and policy and infrastructure and technology are the most represented categories, with eight papers each, reflecting significant interest in regulatory frameworks and the development of physical and technological infrastructure for IWT. Management and operational aspects are moderately covered, with six and four papers respectively, highlighting strategic and day-to-day challenges and solutions. This distribution highlights the priority given to systemic and infrastructural improvements in IWT research.

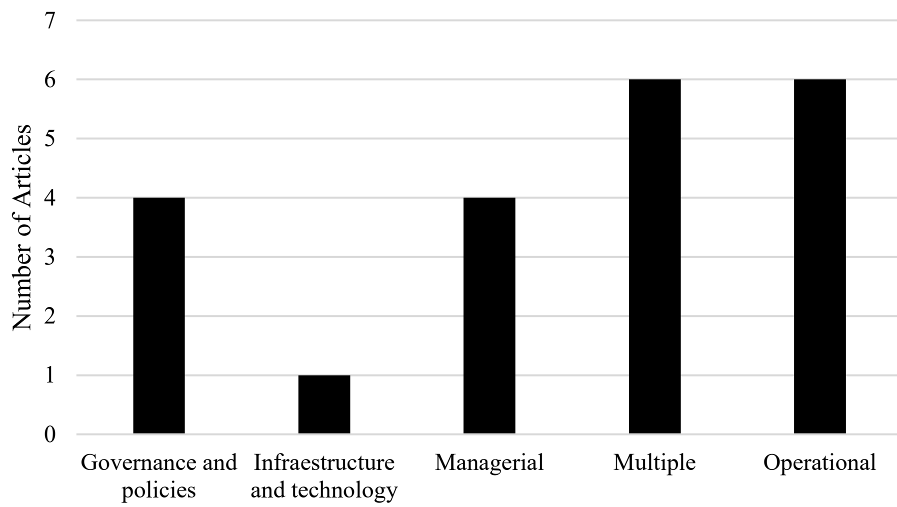

Figure 2.4 Distribution of Research Papers by Focus Area

2.2 Analysis of Relevant Research

A key objective of the literature review was to identify the barriers limiting IWT integration and the potential solutions or benefits that can be achieved through strategic interventions. To provide a clear and comprehensive overview, the following sections summarize each study, outlining the specific challenges identified and the corresponding opportunities or solutions proposed. Additionally, detailed paragraphs for each study offer contextualized findings, ensuring a structured presentation of insights. This approach facilitates a deeper analysis of the complexities associated with IWT integration and the strategies needed to effectively address its multifaceted challenges.

2.2.1 Sun Lu et al. (2023) Challenges and Opportunities

There are several challenges faced by river shipping in container port access transportation, including the low operating frequency of liners, which diminishes their competitiveness against trucking. The paper highlights the generally low grades of Chinese river channels and the poor condition of locks, which create barriers for companies to operate larger ships. Additionally, the lack of systematic design in river shipping routes and the absence of a carbon tax further hinder the growth of river shipping as a viable alternative to trucking. These factors collectively contribute to the stagnation of river shipping's mode share in port access transportation.

Upgrading river channels and locks is a key opportunity to enhance the operational capacity of river shipping, allowing larger ships to be utilized, which can lead to economies of scale. Implementing a carbon tax is proposed as a strategy to increase the cost of trucking, thereby making river shipping more competitive for container port access transportation. The bi-level programming model developed in the study aims to optimize river channel upgrades, ship size, and operating frequency, which can serve as a solution to improve the efficiency of inland waterway transportation. The case study suggests that with the proposed upgrades, the mode share of river shipping is projected to increase significantly, indicating a strategic opportunity for stakeholders to invest in infrastructure improvements. The study emphasizes the importance of systematic design of river shipping routes to enhance integration and coordination within the transportation network, which can lead to improved service quality and efficiency.

The challenge of incomplete port regionalization in the Yangtze River Delta indicates the logistics supply chain terminalization in inland areas is relatively low. It highlights the need for synergy between spatial and network developments, which has not yet been fully achieved in the region. Additionally, the paper notes the fluctuation in container volume growth rates and the growth rates of port and shipping service enterprises, which complicates the evolution of the port system. The authors suggest that future research should address the economic, social, and environmental impacts of port system evolution.

Enhancing the logistics service supply capacity of inland ports and non-hub areas is a key opportunity for improving inland waterway transportation. This can help reduce the cost of element transmission between provincial and municipal regions. Policy guidance can attract enterprises to establish operations in inland and non-hub areas, promoting the development of port and shipping services while meeting current needs. This can lead to growth in local freight containers. Attention should be given to areas around seaport hubs, such as Suzhou, Jiaxing, and Nantong, which are important for port expansion and can alleviate logistics pressure on hub ports. Improving service capabilities in non-riverine inland hubs is essential, as good services are a significant factor for customers when selecting carriers and starting nodes. The integration of logistics service functions in inland areas can be enhanced through the establishment of better cargo organization and accessibility, driven by the shift of some supply chain segments of multinational production towards inland areas.

2.2.2 Liu, Cao et al. (2024) Challenge and Opportunities

Weak infrastructure and cross border systems could hinder the economic growth of the South Asia Subregional Economic Cooperation area. This paper highlights the logistics bottleneck in northeast India, particularly the Siliguri corridor, which isolates inland regions from global markets. Additionally, the study points out the limited connectivity of these regions to seaports and maritime shipping, which affects intra and inter regional trade. The paper also notes the difficulty for the Bangladeshi government to implement border facilitation due to the shifting of cargo to Indian ports.

A lack of political interest and investment in infrastructure hinders development. There is a shortage of skilled labor and insufficient training for crew members, exacerbated by the aging workforce and declining interest in nautical education. Operational challenges arise from climate change, leading to extreme weather events that affect reliability and performance. Additionally, cost-related factors, such as handling fees and competition pricing, pose significant barriers to modal shift towards IWT. The underdevelopment of information systems and navigation aids further complicates IWT operations.

The study highlights the potential for improving inland waterway transport by increasing the frequency of services, with assumptions of one, three, and seven services per week, which could enhance connectivity and efficiency in cargo transport. Speed improvements for inland waterway transport are also considered, with assumptions of increasing speeds to 20 km/h and 40 km/h, which could further optimize transport times. The development of transport corridors, including inland waterways, is essential for reducing cross border costs and enhancing regional connectivity, particularly for landlocked regions like Bhutan and Nepal. Institutional arrangements and border facility enhancements, such as digitalization of customs clearance, are critical for facilitating smoother operations in inland waterway transportation. The integration of inland waterway transport into the broader logistics network can provide a more comprehensive approach to cargo movement, potentially alleviating congestion in other transport modes.

The development of policies that stimulate IWT growth aligned with environmental requirements is a significant opportunity for enhancing IWT. Encouraging private sector participation in seeking alternatives for IWT development can lead to innovative solutions and improvements. Implementing River Information Systems can optimize connectivity, improve communication among stakeholders, and enhance operational efficiency in IWT. The adoption of cleaner energy alternatives, such as Liquefied Natural Gas, hybrid electric systems, and hydrogen, presents opportunities for reducing emissions and improving energy efficiency in IWT. The modernization of the fleet and vessel design, focusing on efficiency and greener technologies, is essential for ensuring the safety of crew and cargo while enhancing competitiveness. The establishment of public private partnerships can leverage investments in inland infrastructure, facilitating the development of IWT networks. The integration of IWT into co-modal transportation systems at national and regional levels can enhance its role in the supply chain and improve overall transport efficiency. Developing hydrological forecasts to provide information about water levels and stream velocities can improve operational decision making and reduce costs in IWT.

2.2.3 Kawachi and Shibasaki (2024) Challenges and Opportunities

The paper discusses the impact of climate change as a significant challenge, particularly the consequences of low water levels affecting IWT reliability, leading to modal shifts towards road transport. Another challenge is the declining trend in the IWT workforce, attributed to socioeconomic factors such as low wages and aging, which negatively impacts regional employment and spillover effects. The need for new business models is emphasized to attract stakeholders for innovative developments, particularly in densely populated areas.

There is an opportunity to improve conditions of navigability through the development of technological resources, which can address challenges such as low water levels. Higher population density can enhance the competitiveness of container IWT by responding to freight transport demand with greater economies of scale. Cross border collaboration among member countries and stakeholders is essential to leverage new market opportunities and improve container IWT performance. The findings suggest the need for spatially oriented policies to tackle issues like low water levels and workforce decline, which could foster innovative business models in the IWT sector.

The transportation of goods between Joinville and Itapoá Port is currently limited to road transport, despite the potential benefits of a waterway network. This indicates a lack of existing infrastructure to support IWT in the region. There is an absence of local facilities, and companies in Joinville must rely on depots and multimodal terminals in seaport cities. This adds complexity and cost to the supply chain, hindering the integration of IWT.

The study highlights the potential of integrating existing logistics operations to enhance intermodal transportation efficiency. This integration can reduce reliance on road transport, thereby alleviating road congestion and lowering greenhouse gas emissions by 65%. Implementing an IWCT in Joinville is proposed as a strategy to facilitate containerized cargo transportation by barge, which can significantly improve operational efficiency and sustainability. The use of self-propelled barges with attached cranes for loading and unloading containers at the IWCT can enhance operational flexibility and efficiency, making IWT a more viable option for regional cargo transportation. The proposed IWCT-waterway model is positioned as a competitive and cost-effective alternative to traditional road transport, offering a 2% cost reduction for end customers while promoting sustainable logistics practices. The study emphasizes the importance of capitalizing on underutilized waterways to establish a benchmark for sustainable and economically viable logistics solutions in Brazil, which can serve as a model for other regions.

2.2.4 Calderón-Rivera, Bartusevičienė et al. (2024) Challenges and Opportunities

Market overcapacity, uncontrollable costs, and fluctuating freight prices hinder the efficiency of IWT systems. Insufficient modal and nodal infrastructure, including seaports and hinterland waterways, limits accessibility and operational efficiency. Weak collaboration among stakeholders in logistics chains impedes the development of effective transport solutions and greening supply chains. The high emissions of nitrogen oxides and particulate matter from IWT compared to road transport contribute to a decline in its environmentally friendly image.

A modal shift from road transport to inland waterway and rail transport can enhance the sustainability of the transport system. This shift is crucial for achieving the EU's targets for increasing waterborne transport by 2030 and 2050. Investments in infrastructure, such as the construction of new railway bridges and the restoration of inland waterways, are essential for facilitating this modal shift and improving transport efficiency. The study indicates that enhancing the capacity of transport infrastructure can lead to significant economic benefits, including reduced transit times and lower transport costs for shippers and consumers. Environmental opportunities arise from the potential reductions in air pollution and greenhouse gas emissions associated with increased use of inland waterway transport, which is generally more energy efficient than road transport. The research suggests that coordinated efforts among stakeholders, including policymakers, transport operators, and infrastructure developers, are necessary to effectively leverage these opportunities.

Operational inefficiencies in IWT diminish its competitive edge compared to road and rail transport. These inefficiencies include poor container barge handling, low call sizes, barge congestion, and high waiting times in terminals, exacerbated by extreme water levels that limit payload capacity. It highlights the lack of comprehensive models that capture dynamic interactions between IWT and other transport modes, often focusing solely on singular innovative solutions without integrating multiple innovations. Additionally, regional differences in infrastructure and market maturity pose challenges in applying the model across various contexts.

There are opportunities to improve container IWT by developing innovative solutions that enhance the use of inland IWT fleets and infrastructures by focusing on effective and cost-efficient transport qualities. Strategies aimed at maximizing load factors, better scheduling, and handling of vessels are essential for improving IWT performance. Innovations such as cargo consolidation, mobile terminals, and smart navigation systems could significantly increase the attractiveness and efficiency of container IWT. Policymakers can support these innovations through targeted interventions, such as optimizing lock operations and reducing waiting times at terminals, which would enhance the integration of container IWT with other transport modes. The establishment of multimodal transport hubs is crucial for facilitating seamless transitions between IWT, rail, and road transport, thereby improving overall efficiency in the container logistics system. There is a need for a comprehensive dynamic model that captures the interactions between different transport modes and the impact of various innovations on IWT performance, which could lead to better decision making and policy formulation.

2.2.5 Bedoya-Maya, Beckers et al. (2023) Challenges and Opportunities

There is limited availability of vehicles and barges, which can impact the efficiency of IWT operations. This paper discusses the effects of weather conditions, such as water level fluctuations, which restrict the use of barges' full capacity and affect port operations. The issue of commodity mixing is addressed, as the model restricts vehicles carrying only one type of commodity to maintain purity, complicating logistics. Additionally, the paper notes the challenges posed by seasonal variations in agricultural products and the need for effective dredging management.

Incorporating shallow draft inland waterways into multimodal transportation networks can enhance freight distribution efficiency. It emphasizes the importance of mode sharing with

IWT to achieve significant monetary savings and societal benefits, suggesting a strategic approach to freight movement. The research identifies the need for tactical and operational planning decisions, such as capacity allocation and route optimization, which can improve the overall effectiveness of the transportation network. The model developed in the study considers environmental and social costs, indicating an opportunity to enhance sustainability in transportation practices. The case study of National Waterways demonstrates practical applications of the model, providing insights into effective management of dredging, vehicle availability, and inventory management, which can be leveraged for better operational strategies.

The lack of modal integration is a significant challenge, as there is no integrated approach that connects IWT with other transportation modes, which hinders the development of a cohesive intermodal transportation system. Insufficient depth in rivers is another challenge, as shallow routes may not be navigable, limiting the effectiveness of IWT. Inadequate terminal and port development poses a barrier, as the absence of permanent terminals affects the loading, unloading, and storage operations necessary for efficient IWT. The lack of interlinking rivers leads to weak interconnectivity, which is essential for a seamless water-based transport system. Governance issues and policy bias are critical barriers that affect the overall development and integration of IWT into the transportation system. High-cost requirements for infrastructure development and maintenance also challenge the integration of IWT into intermodal systems.

A focus on inland waterway transport can reduce congestion and pollution. Governance and policy adjustments are needed for inland waterway development. Strategic national waterway initiatives would provide depth maintenance and channel enhancement. An increase of capital investments in inland waterways ensures sustainable growth. Enhancing interlinking of rivers and water bodies ensures seamless transport. Issues of insufficient depth in rivers can be addressed by considering alternative routes or channel deepening.

2.2.6 Benedecti, Silva et al. (2024) Challenges and Opportunities

Current infrastructure may not have the resilience for IWT, particularly in the context of inland waterway ports. Infrastructure systems face a growing number of disruptions due to their age, condition, and interdependence with other infrastructures, leading to vulnerabilities. Natural disasters, such as Hurricane Sandy and the Japanese earthquake, have become more frequent and impactful, complicating resilience efforts. The need for effective resilience building strategies is emphasized, as traditional risk planning focused more on protection than recovery. Budget limitations significantly influence resilience enhancing investments, affecting the restoration of damaged infrastructure.

Resilience building strategies are needed for inland waterway transportation, particularly in the context of disruptions from natural disasters and human made incidents. Utilizing Bayesian networks can provide insights into which factors need to be fortified to achieve specific resilience levels, thus offering strategic opportunities for improvement. The case study of the Port of Catoosa illustrates the potential for enhancing resilience through targeted strategies that address vulnerabilities from both natural disasters and hazardous material threats. The study emphasizes the need for effective communication and information flow, skilled labor, and physical protection as qualitative contributors to resilience, which can be leveraged as strategic opportunities.

Limited capacities of transport infrastructures pose significant operational hurdles for freight transport operators. Traffic congestion on freeways complicates timely deliveries and increases operational costs. Environmental issues, such as traffic emissions, are becoming increasingly critical in the context of sustainable freight transport. The dynamic nature of transport demands, and traffic conditions adds complexity to planning and operational decision-making processes.

Efficient and sustainable hinterland haulage can benefit freight transport operators and enhance competitiveness for deep seaports. This presents an opportunity for improving inland waterway transportation by integrating it into the intermodal freight transport network. The development of an intermodal freight transport network model captures key characteristics such as modality change phenomena and time dependent transport times, which can be leveraged to optimize inland waterway transportation.

2.2.7 Bernacki and Lis (2024) Challenges and Opportunities

It is difficult to understand the cost structure of different IWT types and their sensitivity to changes in operational conditions and costs per TEU. This paper highlighted the impact of operational characteristics such as delays, weather conditions, and subsidies on terminal costs. Additionally, the paper noted the limited scientific attention given to investing in and exploiting IWTs, which complicates the analysis of terminal efficiency and investment decisions. The need for a classification system that accurately reflects the diverse characteristics of IWTs was also emphasized.

There was a noted potential for subsidies to reduce costs for inland waterway terminals, particularly benefiting smaller terminals that face higher relative investment costs. This presents an opportunity for terminal operators to seek government support to enhance their financial viability. There was an emphasis on the importance of optimizing terminal operations to improve cost efficiency, suggesting that investing in better management practices and technologies could lead to significant savings. The analysis indicated that larger terminals tend to be more cost efficient, which suggests a strategic opportunity for smaller terminals to expand and increase their throughput to achieve economies of scale. The research pointed out that improving gate operations and reducing inefficiencies in terminal processes can enhance overall service quality and reduce costs, indicating a strategic focus area for terminal operators. The study suggests that understanding and analyzing the cost structure of inland waterway terminals can help operators develop better pricing strategies, which can be an opportunity for improving profitability.

It can be challenging to integrate environmental factors into traditional transportation management systems, which often rely on simplistic models that do not account for CO_2 emissions effectively. This paper highlighted the complexity of transportation planning, particularly as shipment sizes increase, necessitating advanced solution methodologies like metaheuristic algorithms. The authors noted the limitations of current systems in handling real time and stochastic data, which can lead to inefficiencies during disruptions. Additionally, the paper identified the need for robust transportation plans that can adapt to unexpected events, thereby reducing costs and emissions.

The paper identified a need for improved emission calculation models specific to IWT to enhance decision making and optimize environmental performance. It suggested developing a detailed emission calculation approach for IWT that considers vessel parameters and waterway characteristics, which could lead to more accurate assessments of environmental impacts. The integration of green logistics principles into transportation planning was emphasized, which could help stakeholders address environmental concerns and improve the ecological performance of IWT. The paper indicated that incorporating advanced multi objective optimization algorithms could provide transportation planners with better tools to balance economic and environmental objectives in IWT. There is an opportunity to enhance systems by integrating algorithms that account for CO_2 emissions, which could lead to cost savings and improved operational efficiency.

2.2.8 Shobayo, Bedoya-Maya et al. (2024) Challenges and Opportunities

One challenge focused on the evolving relationship between transport geography and logistics activities, emphasizing the need for improved coordination. Another challenge was to encourage efficient operations in IWT, which includes synchronizing operations and integrating planning systems. Additionally, the paper highlighted the importance of developing models that integrate intermodal transport decisions with supply chain decisions and the need for external cost calculations.

Integration of IWT in the intermodal supply chain could enhance supply chain service performance. The paper emphasized a need for the development of a system-wide model for IWT to encourage efficient operations. Research efforts should focus on integrating operational planning systems and analyzing bundling networks to improve IWT efficiency. Further development of models that integrate intermodal transport decisions with supply chain decisions is essential for shippers and consignees. The creation of green supply chains was highlighted as a significant opportunity, promoting environmentally friendly practices in IWT. The integration of value-added services at intermodal hubs can motivate the use of inland waterway transportation, enhancing overall supply chain performance. Future research should explore strategic collaborations for inland waterway terminals to adapt to changing distribution structures and increasing container volumes. There was a call for quantifying and formulating multiple objectives—including cost, time, service level, and sustainability—to identify synergies in IWT. The promotion of IWT was recognized as a long-term priority for achieving a sustainable transport system in Europe, indicating a strategic opportunity for policy makers.

The repositioning and use of empty containers are critical issues for intermodal transportation, which can hinder the efficiency of IWT systems. There is a need for advanced modeling research to optimize the supply chain at the operational level, incorporating the option of container repositioning to minimize total costs. Coordination among multiple logistics entities at different spatial locations presents challenges, complicating the integration of IWT into intermodal systems. The seasonality and variability of agricultural production create transactional needs for equipment, leading to inefficiencies in equipment availability during low export months.

Improving infrastructure for inland waterway transportation is a promising strategy to accommodate the growing demand for container shipments, particularly for soybean exports. This can help reduce transportation costs over long-haul distances. The optimal use of existing infrastructure, alongside the expansion of current facilities or construction of new ones, is essential for enhancing the efficiency of inland waterway transportation. Strategic planning is necessary to balance supply and demand effectively, ensuring optimal traffic flow across multiple transport modes and stakeholders. The expansion of the Panama Canal is projected to lower ocean shipping costs, which could create opportunities for increased containerized soybean exports via inland waterways. Coordination among logistics entities and advanced modeling research can optimize the supply chain at the operational level, particularly for container repositioning and minimizing total costs.

2.2.9 Nayak, Sarmah et al. (2024) Challenges and Opportunities

Trade imbalance between Europe and China exacerbates the problem of empty container repositioning. This paper highlighted the uncertainty in forecasting demand for empty containers, influenced by unpredictable return dates and travel times. The lack of coordination among various transport companies complicates the return of empty containers, particularly in rail transport. Additionally, the paper noted the high costs associated with empty container storage and transportation, which do not generate revenue, leading to inefficiencies in the supply chain.

Technical innovations like foldable containers and container sharing, alongside mathematical programming models for optimizing repositioning can address issues with trade imbalance.

Cargo containerization technology also poses a challenge. One significant challenge is the high fixed costs related to containerization facilities, which can lead to elevated costs per container due to the currently limited market scale of containerization. Additionally, the empty container usage cost poses a challenge, as logistics companies incur expenses for supplying empty containers, which includes costs for purchases, rentals, or repositioning. Furthermore, governments face difficulties in accurately evaluating the environmental contributions of containerization and promoting its implementation effectively.

The potential for increased utilization of cargo containerization technology in inland waterway transportation can lead to reduced transportation costs and improved efficiency for logistics companies. Governments can play a crucial role by investing in cargo containerization facilities at depots, which would help reduce costs for logistics companies and encourage the adoption of containerization. The implementation of big data analytics technology can facilitate better market information sharing among logistics companies, enhancing the efficiency of containerization and empty container repositioning. Developing tailored policies and subsidy schemes for containerization can incentivize logistics companies to adopt environmentally friendly practices, thereby promoting sustainability in inland waterway transportation. The establishment of new supply chain contracts that include logistics time and incentives for reducing cargo loss can encourage logistics companies to implement containerization technologies. Exploring the installation of scrubbers on vessels can improve the green performance of shipping, potentially increasing the demand for cargo containerization.

2.2.10 Trivedi, Jakhar et al. (2021) Challenges and Opportunities

The necessity for a strong justification for the financial investment required for dry port establishment is emphasized in this paper, as it represents a major financial commitment. There is a need for appropriate organizational, technological, and infrastructural changes to enhance cargo transport in Croatia. The outdated railway network requires expansion and reconstruction to gain a competitive advantage in multimodal transport. The integration of Zagreb into a single EU transport system based on intermodality and sustainable development poses additional challenges.

The establishment of a dry port in Croatia presents an opportunity to enhance multimodal transport, integrating various transport modes including inland waterways. Investments in improving the navigability of the Danube, Sava, and Drava rivers are planned, which could significantly benefit inland waterway transportation. The development of a multimodal logistics center in Zagreb could facilitate better connections between inland waterways and other transport modes, improving overall efficiency. The modernization of inland waterway ports is also part of the strategic plans, which could enhance the capacity and effectiveness of inland waterway transportation. The integration of existing projects, such as the Sava River navigability project, into a cohesive multimodal transport strategy could optimize the use of inland waterways in Croatia.

There was an established need to mitigate environmental impacts of the inland fleet. The paper highlighted the importance of strengthening multimodal connectivity and developing logistics and special industry zones along waterways. The paper emphasized the necessity of applying emerging technologies to enhance IWT operations. Additionally, it pointed out the need for improved safety management, particularly in monitoring and supervising small family-owned vessels. Lastly, the integration of regional ports and its impacts on IWT development require further examination.

The development of a more feasible and sustainable institutional framework is a priority to enhance IWT in China, focusing on environmental responsibilities and waste management systems. Promoting green and sustainable IWT is essential, as China aims to align with the Sustainable Development Goals and reduce the environmental impact of its large inland fleet. Developing multimodal transport connections is crucial for integrating IWT into the national transportation system, ensuring seamless connections with rail and road networks. The implementation of digital innovations can significantly improve the efficiency of IWT, particularly in managing vessel traffic and reducing waiting times at locks. Enhancing human resources and addressing labor issues in the IWT sector is necessary to attract more young professionals to the industry. Diversifying financing sources for IWT infrastructure projects can facilitate investment and development, leveraging public private partnerships and local government initiatives.

2.2.11 Hosseini and Barker (2016) Challenges and Opportunities

Development of a hybrid metaheuristic model, combining the Bee Colony Optimization algorithm and the MARCOS decision-making method, may address the complex nature of integrating various modes of transportation. A sensitivity analysis was conducted in this study to assess the feasibility of the DP concept under different evaluation criteria settings. There was an emphasis on the importance of mathematical formulation and modelling to consider various objective functions simultaneously, ensuring a comprehensive approach to problem-solving.

The development of dry port terminals within the framework of inland waterway container terminals (IWCTs) presents a sustainable opportunity for enhancing intermodal transportation systems. Establishing regular shuttle connections between dry port terminals can cover a broader set of container flows, thereby improving the efficiency of inland waterway transport. The integration of rail transport with inland waterways can significantly enhance the connectivity and utilization of these transport modes, addressing the current inadequacies in the system. The application of the hybrid model for optimizing the location and capacity of dry port terminals can lead to more effective logistics networks and regional sustainability.

2.3 Insights from Literature Review

The literature highlights a range of challenges and opportunities, emphasizing infrastructure limitations, regulatory complexities, and stakeholder coordination issues. Infrastructure gaps in IWT are a significant challenge globally, affecting the efficiency and sustainability of this transport mode. Various regions face unique issues, such as insufficient lock capacity leading to congestion, as seen at the Three Gorges Dam in China, and outdated infrastructure in North America, where many dams and locks were constructed in the 20th century and have not been adequately maintained (Calderón-Rivera, Bartusevičienė et al. 2024). In India, the lack of coordination among multiple agencies and insufficient interlinking of rivers are major barriers, hindering the development of a seamless water-based transport system (Hosseini and Barker 2016). Additionally, the absence of permanent terminals and inadequate port development further exacerbate these infrastructure gaps, limiting the potential for IWT to provide comprehensive door-to-door services (Hosseini and Barker 2016). The situation is compounded by a lack of political interest and financial support, with many countries prioritizing road and rail investments over IWT, as seen in France and Vietnam (Calderón-Rivera, Bartusevičienė et al. 2024). Moreover, the resilience of infrastructure systems is crucial, as they are increasingly vulnerable to disruptions from natural disasters and common cause failures, which can lead to significant economic impacts, such as port closures causing cargo congestion and production stoppages (Liu, Bai et al. 2017). Addressing these gaps requires a multifaceted approach, including the modernization of fleets, implementation of new technologies, and the establishment of public-private partnerships to leverage investments in infrastructure (Calderón-Rivera, Bartusevičienė et al. 2024). In India, the development of adequate governance and policy frameworks, along with increased financial participation from private players, is essential to overcome high-cost requirements and ensure the availability of necessary navigational infrastructure (Hosseini and Barker 2016). Overall, bridging these infrastructure gaps is critical for enhancing the reliability and competitiveness of IWT, thereby supporting sustainable development and reducing the burden on other transport modes.

The studies discuss various policy constraints related to transportation systems, particularly focusing on maritime and intermodal transport. One significant policy constraint is the limitation on the number of operations, such as bulk containerization or load shedding, that can be performed when a ship sails to a port. This constraint ensures that these operations do not exceed the ship's cargo capacity and maintain the flow balance of cargo at ports and inland destinations (Kovač, Tadić et al. 2023). Additionally, there are constraints related to the physical dimensions of vessels, such as ensuring that the height of the vessel does not exceed bridge height limits, and that the ship's draught is compatible with inland waterway depths. These constraints are crucial for maintaining safe and efficient navigation (Kovač, Tadić et al. 2023).

Another policy constraint involves the cost structure associated with containerization, which includes fixed costs for facilities and equipment, as well as costs related to empty container usage. These costs can be significant barriers to the widespread adoption of containerization, as they are often high due to the limited market scale (Kovač, Tadić et al. 2023). Furthermore, the development of DP terminals and their connections to IWCTs is constrained by the need to ensure that container flows do not exceed terminal capacities, although the existing capacities are often underutilized. This suggests a policy focus on attracting more intermodal flows without being limited by current capacity constraints (Trivedi, Jakhar et al. 2021). These constraints highlight the complex interplay between operational, physical, and economic factors in transportation policy, emphasizing the need for strategic planning to optimize the use of existing infrastructure while considering cost and environmental impacts.

The integration of IWT into intermodal transportation systems faces several environmental challenges that are critical to address for enhancing its role in sustainable logistics. One significant challenge is the impact of climate change, which affects water levels and, consequently, the navigability of waterways. This can lead to reduced vessel loading capacities and increased transport costs, as seen in the Rhine River, where low water levels have historically disrupted container throughput and increased reliance on less sustainable transport modes like road transport (Bedoya-Maya, Beckers et al. 2023). Additionally, the environmental benefits of IWT, such as lower emissions compared to road transport, are under pressure due to technological advancements in other modes that are rapidly reducing their environmental footprints. The occurrence of extreme weather events, such as prolonged droughts or floods, further complicates the reliability of IWT, necessitating resilient infrastructure and adaptive management strategies to maintain its competitiveness and environmental advantages (Bedoya-

Maya, Beckers et al. 2023). Moreover, the integration of IWT into intermodal systems requires addressing the external costs associated with transshipments and terminal operations, which can offset the environmental benefits if not managed effectively. The development of innovative solutions, such as smart navigation systems and modular mobile terminals, is essential to enhance the efficiency and sustainability of IWT, but these innovations must be carefully evaluated for their environmental impacts (Caris, Limbourg et al. 2014). Furthermore, the spatial and temporal variability of water levels, particularly in critical regions like the Rhine-Alpine Corridor, poses a challenge to maintain consistent service levels and requires improved forecasting and coordination among stakeholders to mitigate disruptions (Bedoya-Maya, Beckers et al. 2023).

One significant challenge is the lack of coordination among various stakeholders, including government agencies, port authorities, and private sector participants, which can hinder the development and operational efficiency of IWT systems. This lack of coordination is often exacerbated by differing priorities and regulatory frameworks across regions, as seen in the case of India, where the integration of river basins and the alignment of policies across different governmental levels are necessary for effective IWT development (Shobayo, Bedoya-Maya et al. 2024). Additionally, the need for harmonized legislation and digitalized processes for border controls and cargo handling is crucial for improving stakeholder coordination and ensuring the reliability of IWT systems (Calderón-Rivera, Bartusevičienė et al. 2024). The complexity of managing multiple stakeholders is further highlighted by the necessity for public-private partnerships, which can ease financial burdens but require careful management to balance economic, environmental, and social impacts (Calderón-Rivera, Bartusevičienė et al. 2024). In Europe, the integration of IWT into intermodal supply chains is challenged by the need for synchronized operations and the development of business models that incentivize cooperation among stakeholders, such as shippers and terminal operators, to achieve economies of scale and enhance competitiveness (Caris, Limbourg et al. 2014). Moreover, the development of multimodal transport hubs that facilitate seamless transitions between IWT, rail, and road transport is essential, yet it requires significant stakeholder engagement to align interests and investments. The Chinese experience with IWT highlights the importance of a coordinated approach involving central and local governments to manage port integration and infrastructure development, which can serve as a model for other regions seeking to enhance their IWT systems (Lu, Aritua et al. 2023). However, the unique governance and socioeconomic systems in China suggest that while some strategies may be transferable, they must be adapted to local contexts. Overall, the successful integration of IWT into intermodal transportation systems depends on overcoming these stakeholder engagement challenges through improved coordination, policy alignment, and the development of collaborative frameworks that address the diverse needs and priorities of all involved parties.

IWT faces several operational and logistic challenges that impact its efficiency and reliability. One significant challenge is the low speed of IWT compared to other transport modes, which makes it suitable primarily for large quantities of cargo and oversized loads, but less competitive for time-sensitive shipments. This is compounded by long waiting times at seaports due to the lack of priority for inland vessels, as well as the dependency on meteorological conditions that affect navigability and water levels, leading to increased operational costs and reduced reliability (Calderón-Rivera, Bartusevičienė et al. 2024). Additionally, the integration of IWT into the broader logistics network is hindered by a lack of coordination among stakeholders, which affects the synchronization of operations such as lock planning and quay handling. This lack of integration can lead to inefficiencies and congestion, particularly in port areas (Shobayo, Bedoya-Maya et al. 2024). Furthermore, the infrastructure supporting IWT, including terminals and navigational aids, is often underdeveloped, which limits the potential for seamless intermodal connections and increases the complexity of logistics planning with the need to analyze barriers to inland waterways. Climate change exacerbates these challenges by causing extreme weather events that lead to fluctuating water levels, further impacting the reliability and cost-effectiveness of IWT operations (Bedoya-Maya, Beckers et al. 2023, Calderón-Rivera, Bartusevičienė et al. 2024). To address these issues, innovative solutions such as the development of new vessel designs capable of operating under low water conditions, and the implementation of smart navigation systems, are being explored to enhance the resilience and efficiency of IWT. Additionally, the integration of digital solutions and improved coordination among logistics partners can help optimize route planning and reduce delays, thereby improving the overall performance of IWT in the supply chain (Bedoya-Maya, Beckers et al. 2023). Despite these challenges, IWT remains a crucial component of sustainable transport networks, offering significant environmental benefits over road and rail transport, which underscores the importance of addressing these operational and logistic barriers to fully realize its potential (Bedoya-Maya, Beckers et al. 2023, Calderón-Rivera, Bartusevičienė et al. 2024).

The integration of IWT into intermodal transportation systems offers significant sustainability and environmental benefits, primarily through the reduction of external costs and emissions. IWT is recognized for its lower external costs compared to road transport, contributing to a more sustainable freight transport market structure by minimizing accidents, noise, congestion, and emissions (Bedoya-Maya, Beckers et al. 2023). The development of DP terminals within the framework of IWCT can further enhance sustainability by facilitating the efficient integration of IWT into intermodal systems. This integration can lead to reduced operational and external logistics costs, thereby promoting a more sustainable logistics network (Kovač, Tadić et al. 2023). Additionally, IWT's potential to mitigate transport externalities is supported by its ability to transport large volumes of cargo with lower emissions per ton-kilometer compared to road and rail, making it a viable option for long-distance transport within intermodal systems (Caris, Limbourg et al. 2014, Shobayo, Bedoya-Maya et al. 2024). The use of IWT in urban areas also presents environmental advantages by reducing truck trips and associated emissions, as demonstrated in the case of Brussels, where significant truck trips are avoided annually due to IWT (Caris, Limbourg et al. 2014). Furthermore, the integration of IWT into intermodal supply chains can support the creation of green supply chains, aligning with corporate social responsibility goals and promoting the internalization of external costs (Caris, Limbourg et al. 2014). Despite these benefits, the full potential of IWT in intermodal systems is often underutilized due to infrastructural and operational inefficiencies, which can be addressed through strategic planning and the development of multimodal transport hubs (Shobayo, Bedoya-Maya et al. 2024). Overall, the integration of IWT into intermodal transportation systems not only enhances sustainability by reducing environmental impacts but also supports economic efficiency and regional connectivity, making it a critical component of future transport strategies (Bedoya-Maya, Beckers et al. 2023).

Technological advancements play a crucial role in integrating IWT into intermodal transportation systems, enhancing their efficiency and sustainability. The development of innovative vessel designs, and smart navigation systems is pivotal for optimizing IWT operations, particularly under challenging conditions such as low water levels, which are becoming more frequent due to climate change (Shobayo, Bedoya-Maya et al. 2024). The implementation of River Information Systems exemplifies how technology can improve communication and coordination among stakeholders, thereby enhancing the operational efficiency of IWT by providing real-time data on vessel traffic and waterway conditions (Caris, Limbourg et al. 2014, Calderón-Rivera, Bartusevičienė et al. 2024). Furthermore, the integration of digital solutions, such as automated barge terminals and floating container terminals, can address congestion issues and improve the handling of cargo at ports, making IWT a more competitive option compared to road transport (Kovač, Tadić et al. 2023). The use of advanced planning systems, which synchronize operations like lock planning and quay handling, can significantly reduce waiting times and improve the flow of goods through the IWT network, thus enhancing its role in the intermodal supply chain (Caris, Limbourg et al. 2014). Additionally, the development of DP systems within the framework of IWT terminals can expand the catchment areas of inland waterways, facilitating a more seamless integration with road and rail transport and promoting a modal shift towards more sustainable transport options (Kovač, Tadić et al. 2023). These technological advancements not only improve the operational efficiency of IWT but also contribute to reducing external costs associated with transport, such as emissions and congestion, thereby supporting broader environmental and economic goals (Bedoya-Maya, Beckers et al. 2023, Shobayo, Bedoya-Maya et al. 2024). As such, the strategic implementation of these technologies is essential for enhancing the competitiveness and sustainability of intermodal transportation systems that incorporate IWT.

The full potential of IWT into multimodal logistics is often underutilized due to operational inefficiencies and a lack of integration with other transport modes (Calderón-Rivera, Bartusevičienė et al. 2024). To address these challenges, the development of multimodal transport hubs is crucial, as they facilitate seamless transitions between IWT, rail, and road transport, thereby improving the overall efficiency of container logistics systems (Calderón-Rivera, Bartusevičienė et al. 2024). Such integration can significantly reduce delays and enhance the reliability of cargo movements, making IWT a more viable option for various types, including time-sensitive goods. Furthermore, the implementation of innovative solutions, such as smart navigation systems and modular mobile terminals, can optimize IWT operations and improve its integration with other modes. The use of River Information Systems and digital infrastructure can also enhance the coordination and synchronization of IWT with other transport modes, reducing transshipment costs and improving operational efficiency (Caris, Limbourg et al. 2014). Additionally, the integration of IWT into urban freight transport networks can alleviate congestion and reduce environmental impacts, as demonstrated by the substantial benefits observed in cities like Brussels, where IWT helps avoid numerous truck trips annually. Despite these opportunities, challenges such as insufficient infrastructure, lack of policy support, and inadequate terminal facilities remain significant barriers to the effective integration of IWT into multimodal systems, particularly in regions like India (Feng, Song et al. 2023). Addressing these barriers through strategic investments and policy reforms can unlock the potential of IWT as a key player in sustainable multimodal transport networks.

The integration of IWT into intermodal transportation systems is significantly influenced by policy and government support, as evidenced by various studies. These policies advocate for the integration of IWT into hinterland cargo transportation, demonstrating a commitment to fostering a more sustainable transport network. Similarly, China's experience with IWT underscores the importance of coordinated planning and government intervention. The Chinese government has implemented long-term comprehensive plans, focusing on infrastructure development, fleet modernization, and financing diversification, which have been pivotal in integrating IWT with other transport modes (Lu, Aritua et al. 2023). This approach includes the development of multimodal transport corridors and the promotion of logistics zones, which enhance the connectivity between river ports and other transport networks. Furthermore, the establishment of provincial port groups in China aims to optimize port functions and improve intermodal services, thereby strengthening the role of IWT in the national transport system (Lu, Aritua et al. 2023). In India, despite the challenges, there is recognition of the need for policy parity and governance reforms to support IWT integration. The lack of interlinking rivers and insufficient infrastructure are identified as critical barriers, suggesting that government support in these areas could significantly enhance IWT's role in intermodal transport (Caris, Limbourg et al. 2014). Additionally, the European context emphasizes the need for improved data collection and the integration of planning systems to enhance operational efficiency in IWT, which can be supported by government policies that encourage technological advancements and infrastructure investments. Overall, these examples illustrate that effective policy frameworks and government support are crucial for the successful integration of IWT into intermodal transportation systems, facilitating a shift towards more sustainable and efficient logistics networks.

IWT can significantly enhance cost efficiency in multimodal transport chains by leveraging its inherent advantages and integrating effectively with other transport modes. The use of IWT in multimodal chains can lead to substantial cost savings, particularly when it is combined with rail and road transport, as it allows for economies of scale and reduced external costs compared to road transport alone. The development of intermodal IWT terminals, which serve as consolidation centers, facilitates the modal shift from road to water, thereby optimizing the transport chain's cost structure . Larger IWT terminals, in particular, benefit from lower handling costs per container due to higher throughput, which can be passed on as cost savings in the multimodal chain. Additionally, the integration of IWT into intermodal supply chains can reduce transport costs by maximizing load factors and optimizing routes, which not only lowers per-unit transport costs but also enhances the sustainability of the transport chain by reducing emissions (Caris, Limbourg et al. 2014). Furthermore, the implementation of innovative solutions, such as digital infrastructure and smart navigation systems, can further improve the cost efficiency of IWF by minimizing delays and enhancing the reliability of cargo movements. The strategic use of subsidies and incentives for IWT can also lower operational costs, making it a more competitive option within multimodal chains. However, the full potential of IWF in improving cost efficiency is contingent upon overcoming existing inefficiencies, such as poor container handling and high waiting times at terminals, which currently limit its competitiveness against road and rail transport (Caris, Limbourg et al. 2014). By addressing these challenges and fostering better integration with other transport modes, IWF can play a crucial role in enhancing the overall cost efficiency of multimodal transport chains, aligning with broader environmental and economic goals.

2.4 Future Directions and Research Gaps

Enhancing the integration of IWT into intermodal systems requires addressing critical infrastructure and connectivity challenges. Future research should focus on modernizing ports, improving waterway navigability, and strengthening multimodal linkages with road, rail, and maritime networks. This includes exploring cost-effective strategies for developing transshipment hubs and optimizing terminal layouts to facilitate seamless cargo transfers between transport modes. Additionally, the adoption of smart technologies, such as AI-driven systems, could enhance real-time tracking, scheduling, and route optimization, ultimately improving operational efficiency and network coordination.

A cohesive policy and governance framework is essential for the successful integration of IWT into intermodal systems. Fragmented regulations and inconsistencies across jurisdictions often create barriers to effective multimodal transport. Future research should examine ways to harmonize policies across regions, foster international cooperation, and assess the impact of incentive schemes—such as subsidies for multimodal infrastructure projects and green logistics initiatives—to encourage greater utilization of IWT. Additionally, studies should evaluate governance models that promote collaborative decision-making among key stakeholders, including policymakers, carriers, and shippers, to reduce operational inefficiencies and align policy objectives.

Beyond infrastructure and policy considerations, operational, economic, and social factors must be explored to strengthen IWT's role in intermodal transport. Research should focus on building resilient supply chains that can adapt to fluctuating water levels and climate-related disruptions while maintaining efficiency. Economic analyses should assess the cost-effectiveness of IWT within multimodal networks, emphasizing freight flow optimization and reductions in total transportation costs. Furthermore, socio-economic studies should evaluate the broader impact of intermodal IWT projects on local communities, ensuring equitable distribution of benefits and identifying best practices for stakeholder engagement. Addressing these research gaps will provide strategic insights to inform policy decisions and investment priorities, aligning IWT development with sustainability, efficiency, and economic growth objectives.

Chapter 3 Theoretical Framework

This study leverages Stakeholder Theory (ST) and Grounded Theory (GT) to analyze the state of the IWT system in the U.S. through stakeholder interviews. ST provides a framework for identifying and prioritizing the interests of various actors in the IWT system, while GT offers a systematic approach for generating theory from qualitative data. By integrating these approaches, this study develops a holistic understanding of the barriers and opportunities in optimizing the U.S. IWT system.

3.1 Stakeholder Theory

Stakeholder Theory (Freeman 1984) argues that organizations and systems should be analyzed in terms of the stakeholders who influence and are influenced by them. Stakeholders are individuals or groups with vested interests in an organization or system's operations and outcomes. Unlike traditional economic theories that prioritize shareholders, ST emphasizes the role of multiple actors, including regulators, customers, suppliers, and communities, in shaping system performance and decision-making.

In the context of IWT, key stakeholders include government agencies and regulators, such as the U.S. Army Corps of Engineers and the Department of Transportation, as well as barge operators, shipping companies, port authorities, cargo owners, freight forwarders, environmental organizations, and local communities, including labor unions. Each stakeholder group has distinct priorities and expectations regarding IWT operations. Regulatory agencies focus on safety, infrastructure maintenance, and policy enforcement, while shipping companies prioritize cost efficiency, reliability, and intermodal connectivity. Environmental organizations advocate for sustainable practices, and local communities are concerned about the economic and environmental impacts of IWT activities.

ST provides a structured lens to analyze the competing interests within the IWT system. Understanding these perspectives is essential for optimizing the system while balancing economic, operational, and environmental considerations. By mapping stakeholder concerns and priorities, this study identifies barriers to IWT efficiency and explores strategies for enhanced collaboration among stakeholders.

A stakeholder-focused approach in IWT optimization ensures that solutions are inclusive and practical, addressing diverse concerns such as infrastructure investment, regulatory reform, sustainability considerations, and intermodal integration. For instance, stakeholders advocate for increased funding to modernize locks and dams, while policy adjustments are needed to streamline licensing and operational constraints. Environmental groups push for reduced emissions and ecological protection, whereas logistics stakeholders call for improved connections between IWT, rail, and road networks. By applying ST, this research provides a balanced understanding of how these interests intersect and influence decision-making in the IWT system.

3.2 Grounded Theory

Grounded Theory (Glaser and Strauss 1967) is a qualitative research methodology that enables the development of theory based on systematically gathered and analyzed data. Rather than testing predefined hypotheses, GT builds theory inductively from real-world observations and experiences. This approach allows researchers to derive insights directly from the data, ensuring that findings are grounded in actual stakeholder experiences rather than preconceived assumptions.

In this study, GT is used to analyze stakeholder interviews, allowing for an emergent understanding of IWT challenges and opportunities. GT provides a structured approach to qualitative data collection, coding, and theory development, ensuring that findings are data-driven and reflective of stakeholder insights. By following this methodology, the study captures the complexities of IWT operations, uncovering key issues that may not be evident through traditional hypothesis-driven research.

This study follows the key principles of GT in analyzing stakeholder perspectives on IWT optimization. With data collection through semi-structured interviews, iterative coding and categorization, and theory development from patterns in data.

Interviews were conducted with IWT stakeholders, including regulators, barge operators, cargo owners, and environmental groups. Open-ended questions encouraged stakeholders to describe current system inefficiencies, operational barriers, and policy constraints. This flexible approach allowed participants to share their perspectives freely, leading to a richer understanding of the factors influencing IWT operations.

The collected data was coded using open and selective coding methods. Open coding identified key themes emerging from the interviews, while selective coding refined the analysis to highlight core categories shaping IWT challenges and solutions. Relationships between themes were analyzed to identify underlying mechanisms affecting IWT efficiency. By mapping stakeholder interactions and their influence on decision-making, the study developed a context-specific understanding of the forces shaping IWT operations. This approach allowed for the identification of systemic challenges and opportunities, providing actionable recommendations for improving IWT efficiency and stakeholder collaboration.

By applying GT, this research ensures that insights are deeply rooted in stakeholder experiences, contributing to a more comprehensive and applicable framework for understanding and optimizing IWT.

This chapter outlined the theoretical foundation for analyzing the U.S. IWT system by integrating ST and GT. ST provides a framework for identifying key actors, their interests, and the interplay between various groups that influence IWT operations, ensuring that solutions address diverse economic, regulatory, and environmental considerations. Meanwhile, GT offers a systematic approach to qualitative data collection and analysis, allowing for the emergence of themes and patterns directly from stakeholder perspectives. By combining these two approaches, this study develops a comprehensive understanding of the barriers and opportunities within IWT, ensuring that recommendations are both data-driven and stakeholder-inclusive. This theoretical framework sets the stage for subsequent analysis, facilitating the development of actionable insights to enhance the efficiency, sustainability, and resilience of the IWT system.

Chapter 4 Research Methodology

A qualitative research approach was employed to examine stakeholder perspectives on the optimization of the U.S. IWT system. Given the complexity of IWT operations and the diverse interests of stakeholders, a qualitative approach allows for an in-depth exploration of issues that may not be fully captured through quantitative methods.

We follow an exploratory research design, incorporating semi-structured interviews with key stakeholders involved in IWT operations. The qualitative data collected through these interviews is analyzed using an iterative coding process, allowing us to identify emerging themes and develop theoretical insights that reflect stakeholder priorities, concerns, and recommendations.

To capture diverse perspectives on IWT operations, we rely on semi-structured interviews with a range of stakeholders. This approach provides rich qualitative data while allowing participants the flexibility to elaborate on their experiences, concerns, and suggestions. By engaging directly with stakeholders, we ensure that our analysis is grounded in real-world insights, offering a more comprehensive understanding of the challenges and opportunities within the IWT system.

4.1 Data Collection

To capture diverse perspectives on IWT operations, our study relied on semi-structured interviews with a range of stakeholders. These interviews provided rich qualitative data while allowing flexibility for participants to elaborate on their experiences, concerns, and suggestions.

We identified stakeholder groups based on their involvement in and influence over IWT operations, ensuring a comprehensive representation of perspectives. Key stakeholder categories included government agencies and regulators, such as the U.S. Army Corps of Engineers. Barge operators and shipping companies, responsible for waterborne cargo transport, provided insights into operational challenges and logistics. Port authorities, managing inland ports and intermodal connections, contributed perspectives on infrastructure and connectivity. Cargo owners and freight forwarders, whose businesses depend on IWT for freight movement, shared concerns about efficiency and cost-effectiveness. To promote diverse participation, we employed a snowball sampling method, where initial interviewees recommended additional relevant stakeholders, enabling us to capture a wide range of experiences and perspectives. Table 4.1 presents an anonymized list of participants.

Table 4.1 Summary of Interview Participants and Stakeholder Representation

Interviewee ID	Stakeholder Group	Organization Type	Role	Years of Experience
INT-01	Carriers	Logistics Service Provider	General Manager	20
INT-02	Community	Economic Development Advocacy	Executive Director	27
INT-03	Infrastructure	Inland Waterways Trade Association	Executive Director	11
INT-04	Carriers	Logistics Service Provider	Operations Manager	6
INT-05	Automotive Industry	Shipper	Supply Chain Manager	8
INT-06	Infrastructure	Inland Port	Operations Manager	4
INT-07	Shippers	Agrifood Industry	Operations Manager	12
INT-08	Infrastructure	Army Corps of Engineers	Omitted to preserve anonymity	8
INT-09	Shippers	Mining Industry	Logistics Manager	31
INT-10	Carriers	Trucking Company	Sales Manager	4

Interviewee ID	Stakeholder Group	Organization Type	Role	Years of Experience
INT-11	Shippers	Retail Industry	Distribution Manager	12
INT-12	Shippers	Agriculture & Transportation Advocacy	Executive Director	16
INT-13	3PL	Logistics Service Provider	Sales Manager	3
INT-14	Community	City Government	Omitted to preserve anonymity	17
INT-15	Shippers	Automotive Manufacturing	Yard Manager	9
INT-16	Carrier	Railroad	Operations Manager	7
INT-17	Shippers	Agrifood Industry	Supply Chain Executive	11
INT-18	Carrier	Trucking Company	Owner Operator	14
INT-19	Receivers	Agrifood Industry	Operations Management	5
INT-20	Shippers	Agrifood Industry	Operations Management	12
INT-21	Receivers	Retail	Supply Chain Executive	10

This study adheres to ethical research guidelines, ensuring that all participants provided informed consent before the interview. Participants were assured of confidentiality, and data was anonymized to protect their identities. The research protocol was reviewed and approved by an Institutional Review Board to ensure compliance with ethical standards.

4.2 Data Analysis

Our data analysis followed the principles of GT, ensuring that themes and patterns emerged inductively from the data rather than being imposed by predefined assumptions. The analysis process unfolded in three key stages. First, open coding involved an initial review of interview transcripts to identify key concepts and emerging themes. Next, selective coding integrated the most significant themes to develop a theoretical framework that explains stakeholder perspectives on IWT optimization. To enhance the trustworthiness and reliability of our findings, we incorporated several validation measures. Triangulation was used to compare insights across different stakeholder groups, ensuring consistency and credibility in our interpretations. Member checking involved providing participants with summaries of findings to confirm that their perspectives were accurately represented. Additionally, we engaged in peer review, consulting experts in IWT and qualitative research to review our coding and interpretations, further strengthening the validity of our analysis.

This chapter outlined the qualitative research design, explaining how ST and GT guide data collection and analysis. Semi-structured interviews were conducted with key IWT stakeholders, and data was analyzed using an iterative coding approach to identify themes and stakeholder perspectives on IWT optimization. The following chapter will present the findings and discussion, detailing the key insights gained from stakeholder interviews and their implications for improving the IWT system.

Chapter 5 Findings and Discussion

This chapter presents the key findings of our study, structured into three main areas: an overview of the current inland waterway system, the major challenges limiting its broader use, and the emerging opportunities that could enhance its role in freight transportation.

5.1 Current State of Inland Waterway Transport

Most interviewees noted that IWT is both a crucial component of freight movement and an underutilized resource. While the barge sector carries significant volumes of agricultural and chemical commodities, it has considerable unused capacity. As one expert stated, inland waterways "*are actually operating at 60% capacity...there's a lot of slack in the line to take on more cargo.*" This suggests that there is ample opportunity to increase the use of IWT for both traditional and non-traditional freight.

The majority of inland waterway shipments consist of bulk commodities, particularly agricultural products. One interviewee highlighted this dominance, explaining, "*Our main commodity is grain or soybeans, and we see about 52% or so of our export flows by barge in normal years.*" Given the volume of these staple goods, IWT remains a vital link in the agricultural supply chain, particularly for exports. However, this commodity focus means that other sectors have not yet taken full advantage of barge transport.

Cost efficiency is a defining characteristic of IWT, making it a preferred option for heavy and bulk freight. "*Waterways remain one of the most economical ways of moving heavy product long distances...but it's not time-sensitive*," summarized one interviewee. While the low-cost nature of IWT is attractive, its slower transit times make it less competitive for industries requiring speed and just-in-time delivery. This trade-off limits IWT's expansion into markets that prioritize rapid freight movement.

Despite some existing roll-on/roll-off and container-on-barge services, their adoption remains limited to specific corridors such as Memphis to New Orleans and St. Louis to New Orleans. These niche operations indicate potential for diversification, but widespread expansion has been hindered by several challenges. Participants frequently cited fluctuating water levels, unreliable lock schedules, and a lack of coordinated investment as major barriers. Without solutions to these issues, the broader use of IWT for containerized freight remains constrained.

Overall, IWT presents a paradox: it is an efficient and cost-effective freight mode with excess capacity, yet it remains largely confined to bulk commodity transport. The combination of infrastructure challenges, transit time concerns, and funding uncertainties prevents wider industry adoption. Addressing these limitations through strategic investment, improved coordination, and better integration with other modes of transport could unlock IWT's full potential and make it a more viable alternative in the logistics network.

5.2 Key Challenges

Inland waterway transport faces several structural and operational challenges that limit its full potential despite its cost advantages. Key issues include aging infrastructure, unpredictable service times, climate-related disruptions, low industry awareness, modal competition, and evolving regulatory pressures.

- Infrastructure Deficits and Funding Gaps: A common concern among interviewees is the deteriorating state of locks, dams, and channels, which undermines the efficiency of inland waterway transport. One barge sector representative noted, "*We have a backlog of critical maintenance...Army Corps has not produced a database so Congress can see precisely how much is needed.*" Another interviewee emphasized that waterway reliability depends on "*consistent dredging, well-maintained locks, and predictable water* *levels*," but lamented that "*there's never enough funding for improvements until a crisis occurs.*" The fragmented nature of infrastructure management further complicates the issue, as the Army Corps of Engineers' multi-district approach leads to inconsistent upgrades and poor coordination. One participant described the consequences: "*...the Army Corps districts are not communicating with each other...one might release flows or schedule maintenance, and the next district doesn't coordinate. That's when you have a break in the supply chain.*" The lack of lock modernization, particularly on the Upper Mississippi where many date back to the 1930s, further discourages shippers from relying on barge transport for large or recurring shipments.

- Unpredictable Service Times and Reliability: Beyond infrastructure constraints, the inherent slow pace of barge navigation and unpredictable lock scheduling make transit times highly variable. One interviewee from the automotive sector highlighted the stark difference in speed: "*It was about five to seven days from St. Louis to New Orleans. Meanwhile, a truck could do that same trip in a day.*" Another participant pointed out that barge transport is especially vulnerable to delays caused by external factors: "*If a barge gets delayed by fog or at a lock, we lose the entire schedule.*" These uncertainties make inland waterway transport less viable for industries that rely on just-in-time supply chains, fresh produce shipments, or other time-sensitive deliveries. Until reliability improves, many shippers will continue to favor truck and rail for critical freight movements.
- Seasonal and Climate-Driven Disruptions: Weather-related disruptions also play a significant role in the reliability of inland waterways. High water levels can halt barge movements, damage port infrastructure, and create unpredictability in shipping schedules.

One participant recalled, "*We had a 2019 flood on the Arkansas River that inundated rail lines, port property, (and) forced closures.*" Conversely, drought conditions can significantly reduce barge capacity by limiting draft depths, leading to increased costs and lower efficiency. As one shipper explained, "*After two consecutive years of low water, barge rates spiked, and cost advantage eroded.*" Ice accumulation further complicates matters for northern river operations, where freezing conditions can close waterways for months at a time. "*Once you're north of St. Louis, the river might freeze, so you lose consistent year-round movements.*" These seasonal and climate-related factors introduce further uncertainty into IWT planning and investment decisions.

- Education and Awareness Deficits: Several interviewees highlighted a lack of awareness and education about inland waterway transport among potential shippers. Many companies are unfamiliar with barge operations, available services, or the steps required to integrate IWT into their supply chains. One expert noted, "*We're not an easily understood industry...it's not obvious who to call for quotes or how many times you handle the load.*" This knowledge gap means that in many logistics networks, barge transport is overlooked, particularly for containerized or break-bulk cargo. Another participant suggested that better marketing could help attract new shippers: "*We suspect if more mid-sized manufacturers realized the cost savings, they'd be open to switching, but no one is marketing effectively to them.*" Without proactive outreach and clearer industry communication, many businesses remain unaware of IWT as a viable and cost-effective shipping alternative.
- Fragmented Communication and Modal Competition: Rather than working together to create integrated solutions, different transportation modes—rail, truck, and barge—often

operate in direct competition with each other. One automotive logistics manager observed, "*We need synergy, but I've seen in 30 years mostly truck, rail, (and) barge trying to steal each other's business.*" This lack of collaboration hinders the development of multimodal strategies that could make freight transportation more efficient. The same participant pointed out that no one has approached major automotive manufacturers with a coordinated proposal: "*Nobody's gone to big automakers with a joint pitch of 'rail + barge + truck' to handle non-time-sensitive shipments*." By failing to present barge transport as part of a broader multimodal solution, industry stakeholders miss opportunities to optimize logistics and reduce overall costs.

- Regulatory and Sustainability Pressures: Regulatory requirements related to sustainability and emissions targets introduce both challenges and opportunities for inland waterway transport. Barge shipping has a significantly smaller carbon footprint per ton-mile than trucking, making it an attractive option for companies looking to meet environmental goals. However, new regulatory mandates for electrification, emissions reductions, or environmental compliance can increase costs for barge operators and port facilities, creating an uneven playing field. One interviewee explained, "*When the administration demands net-zero, that can be cost-prohibitive if the equipment for barge or terminal is not well-developed.*" While sustainability initiatives may ultimately favor increased IWT use, the associated costs and regulatory uncertainties remain significant barriers to widespread adoption.

5.3 Opportunities for Growth and Innovation

Notwithstanding these challenges, the interviews paint a picture of multiple opportunities for inland waterway transport to expand its market share and attract new commodity segments.

- Ample Capacity and Lower Costs for Bulk Freight: Barge transport remains cost-competitive for large, heavy, non-time-sensitive cargo traveling hundreds of miles. One participant observed, "*We're the only mode that can fit 80 truckloads worth of product on a single barge. If time is flexible, we're the cheapest by far*." The system has capacity to handle much more. According to a port representative, "*We're at 60% capacity, so we have slack in the line to accept new shipping volumes*."
- Container-on-Barge Potential: Multiple participants referenced container-on-barge as a promising niche for expansion. As one interviewee noted: "*We tested container moves from St. Louis to New Orleans. If you have seasonal or less urgent product, that can really yield cost savings*." While reliability and speed remain concerns, containerizing shipments allows intermodal synergy, easy loading/unloading, and potential backhaul gains. Another stakeholder reported barge experiments for automotive parts or small-lot shipments.
- Carbon Footprint Reduction: Growing sustainability imperatives push shippers to reconsider more energy-efficient modes. One major automotive sector participant said: "*We know barge is more carbon neutral than truck... If we can solve time constraints, barge is very attractive in meeting emission targets*." Similarly, an agricultural shipper pointed to lower greenhouse gas emissions per ton-mile. This aligns with corporate environmental, social, and governance goals, leading to a reevaluation of IWT.
- Multi-Modal Synergies: Several interviewees advocated robust cooperation among trucking companies, railroads, and barge operators. A barge advocate argued, "*If we collectively approach the shipper with a guaranteed corridor, we could give a single rate, handle the line haul by water, finalize the last 50 miles by truck*." Another said, "*I*

see a real advantage in storing product or staging it at an inland port, then trucking it locally." Combining short-distance trucks with line-haul barge moves provides the reliability of local dray plus the cost advantage on the water.

5.4 Strategies to Overcome Challenges

Based on the interviews, several strategic approaches could help address the challenges facing IWT and unlock its full potential. These strategies focus on improving infrastructure funding, enhancing reliability, increasing industry awareness, fostering modal collaboration, leveraging sustainability incentives, and strengthening resiliency planning. By implementing these measures, IWT can become a more competitive and viable freight transport option for a broader range of industries.

- Predictable Funding and Maintenance Coordination: A consistent theme across interviews was the urgent need for predictable funding and a more coordinated approach to maintenance. Many interviewees supported the creation of a "critical maintenance backlog" database, which would provide Congress with a clear picture of funding priorities for lock and dam rehabilitations. This would help ensure that infrastructure upgrades are planned systematically rather than in response to crises. Additionally, interviewees emphasized the importance of streamlining multi-district and multi-agency communication within the Army Corps of Engineers. Currently, inconsistent coordination between districts leads to unplanned closures or water releases that disrupt barge traffic. A centralized scheduling and maintenance coordination system could mitigate these inefficiencies and reduce costly delays for shippers.
- Improved Reliability and Scheduling: Unpredictability in barge transit times remains a major deterrent for shippers. To improve reliability, one proposal is the development of

barge corridor “transit time agreements” or contractual performance metrics that guarantee shipment windows, similar to existing commitments in rail and trucking. These agreements would give shippers confidence in delivery times, making IWT a more viable alternative for certain supply chains. Additionally, investing in advanced traffic management technology—such as real-time tracking for lock operations, dredging schedules, and channel marking—could further enhance efficiency. By adopting digital monitoring systems, delays caused by congestion, low water levels, or mechanical failures at locks could be better managed, reducing the variability in barge transit times.

- Shipper Education and Outreach: A lack of awareness about barge transport options prevents many businesses from considering IWT as part of their supply chain strategy. One solution proposed by interviewees is the creation of a dedicated program within the Maritime Administration to actively market the waterway system, develop educational materials, and participate in shipper conferences. Such an initiative would ensure that manufacturers, retailers, and logistics managers are informed about the benefits and processes involved in using barge transport. Additionally, some participants suggested expanding the Foreign Trade Zone (FTZ) concept to encourage “just-in-case” inventory staging near inland ports. This would allow companies to maintain buffer stock at inland hubs, making barge transport more appealing by reducing reliance on strict just-in-time supply chain models.
- Modal Collaboration: Historically, rail, truck, and barge operators have competed rather than collaborated, limiting opportunities for integrated logistics solutions. Interviewees recommended that transportation providers form rail-barge-truck consortiums to present shippers with cohesive, multi-modal solutions rather than working against one another.

As one logistics expert noted, "*We must collectively sell these services, not undercut each other.*" In addition to strategic partnerships, investment in multi-modal hubs—such as in Memphis, St. Louis, and Cincinnati—would provide dedicated barge transloading capacities, rail spurs, and truck connectors. These hubs would create seamless transitions between modes, making IWT a more attractive and flexible option for shippers.

- Sustainability and Incentives: With growing emphasis on carbon reduction, sustainability incentives could drive increased adoption of barge transport. Some interviewees proposed offering carbon credits or "nautical nudge tax credits" to companies that opt for barge transport over trucking. Such incentives would help offset road congestion, accidents, and emissions, making IWT a more attractive option for businesses looking to meet sustainability targets. Additionally, expanding green finance options for ports to modernize infrastructure—such as electrifying cargo handling equipment or adopting low-emission barge engines—would further support the transition to more environmentally friendly transport practices.
- Resiliency Planning: Climate-related disruptions, such as flooding, drought, and extreme weather, pose an ongoing threat to barge transport reliability. To mitigate these risks, interviewees advocated for the development of "best practice" guides to help inland port operators prepare for and respond to extreme weather events. This would include protocols for flood mitigation, ice management, and alternative routing during disruptions. Another key recommendation was expanding reservoir capacity or improving water release coordination to prevent extreme low-water conditions that hinder navigation, particularly on high-volume corridors like the Lower Mississippi. Proactive

planning for climate resilience would ensure that IWT remains a viable and stable mode of transportation, even in the face of increasing environmental uncertainties.

Inland waterway transport possesses inherent advantages—particularly large volume capacity, cost efficiency, and lower carbon emissions—that strongly position it within modern supply chains. Yet the interviews reveal a complex matrix of challenges, from infrastructural deficits and reliability issues to insufficient outreach and policy fragmentation. Through carefully designed interventions—predictable lock-dam investment, synergy among modes, advanced forecasting, shipper education, and targeted sustainability incentives—barge transport can broaden its role beyond the traditional bulk commodity domain. As one stakeholder succinctly put it: "*We can handle far more freight, keep roads safer, reduce emissions, and save costs... But we've got to fix maintenance funding and truly market ourselves if we want to move beyond these niche applications*."

Unlocking the full potential of IWT will require a shift from reactive to proactive policy and investment approaches. Rather than waiting for infrastructure failures to prompt funding allocations, a systematic maintenance and upgrade program is necessary to ensure long-term reliability. Similarly, embracing multi-modal collaboration—where barge, rail, and truck providers work together rather than compete—can create a more integrated and efficient freight system. This requires both industry leadership and policy support to incentivize coordination and streamline regulatory bottlenecks.

Additionally, education and outreach efforts must bridge the knowledge gap that currently limits shipper adoption of barge transport. Many mid-sized manufacturers and retailers remain unaware of how inland waterways can fit into their supply chains. By expanding marketing efforts, improving visibility tools, and demonstrating cost savings, the industry can attract a broader base of users beyond traditional bulk commodity sectors. Coupled with sustainability incentives—such as carbon credits for barge users—these efforts can help shift more freight onto waterways, alleviating congestion and reducing emissions in the broader transportation network.

Ultimately, inland waterway transport represents an underutilized national asset with the potential to enhance supply chain efficiency, economic competitiveness, and environmental sustainability. However, achieving this potential will require a concerted effort across public agencies, private industry, and logistics providers. With strategic investment, enhanced reliability, and greater industry awareness, IWT can evolve from a niche freight mode to a central pillar of the U.S. transportation system.

Chapter 6 Conclusions

This study employed a comprehensive research methodology to examine the challenges and opportunities within the IWT sector in the U.S. Our approach combined an extensive literature review with semi-structured interviews conducted with key stakeholders, including government regulators, barge operators, port authorities, cargo owners, environmental organizations, and advocacy groups. By integrating Stakeholder Theory and Grounded Theory, we systematically analyzed stakeholder perspectives, allowing for an in-depth understanding of the critical barriers affecting IWT operations and potential strategies for improvement.

Our research identified several key challenges and opportunities facing the IWT sector. One of the most pressing issues is aging infrastructure and rising costs. Many carriers reported operational inefficiencies due to outdated locks, dams, and navigational aids, which cause delays and increased expenses. Stricter environmental regulations have further escalated costs, as carriers must retrofit vessels or invest in new technologies to comply with emission and sustainability standards. These factors underscore the urgent need for infrastructure modernization and targeted investment to ensure the long-term viability of IWT as a reliable and cost-effective mode of transportation.

Another significant challenge is economic vulnerability and demand volatility. Industries that heavily depend on IWT—such as agriculture, energy, and manufacturing—experience cyclical fluctuations in production and shipping needs, making long-term planning difficult. This unpredictability complicates profitability and operational efficiency for barge operators. To navigate these uncertainties, carriers must adopt flexible and resilient operational strategies that allow them to adjust to market shifts while maintaining service reliability.

Despite these challenges, IWT plays a crucial role in supply chain resilience and alternative routing. Inland waterways offer a vital backup transport mode when disruptions occur in rail or trucking networks, helping maintain goods movement during infrastructure failures, natural disasters, or labor strikes. However, many shippers lack awareness of IWT's capabilities, and accessibility remains limited. Expanding integrated logistics systems that facilitate seamless modal shifts between water, rail, and road transport can significantly enhance supply chain flexibility and resilience.

IWT also faces intense competition from other modes of transport, particularly rail and trucking. These alternatives offer faster transit times and more direct routes, making them more attractive for many shippers. Additionally, limited intermodal integration further restricts IWT's ability to compete. Addressing these issues requires innovative solutions, such as improved digital logistics platforms, enhanced intermodal hubs, and policy incentives that encourage shippers to incorporate waterways into their distribution networks.

Further complicating the sector's growth are workforce shortages and connectivity gaps. A lack of skilled labor, including pilots, engineers, and maintenance staff, has resulted in delays and inefficiencies. Moreover, shippers often struggle to connect with IWT service providers, limiting its adoption. Expanding workforce development programs and establishing integrated digital platforms that streamline shipper-carrier interactions can help address these issues and improve accessibility within the sector.

Another key limitation of IWT is its geographic and scheduling constraints. Inland waterways are limited by their physical geography, making them inaccessible to many regions without navigable rivers or inland port infrastructure. Additionally, longer transit times and inflexible scheduling reduce IWT's suitability for time-sensitive shipments, such as perishable goods. To address these concerns, adaptive scheduling practices, better integration with rail and trucking services, and optimized routing strategies are needed to enhance service efficiency and expand IWT's usability.

A major barrier to modernizing IWT is the complexity of intermodal transfers and the lack of containerized options. Many shippers find it difficult to navigate the multi-step, multi-stakeholder process required to use IWT, as there is no centralized system for managing contracts and coordinating logistics. Additionally, containerized transport remains limited on inland waterways, making it less appealing for modern supply chains. Investing in standardized intermodal practices and expanding container-on-barge solutions could significantly improve accessibility and encourage wider adoption.

Finally, environmental and seasonal risks pose ongoing challenges for IWT operations. Fluctuating water levels, droughts, ice, and extreme weather events frequently disrupt inland waterway services. Without improved contingency planning and infrastructure upgrades, the sector remains vulnerable to climate-related disruptions. Strengthening resilience strategies and developing adaptive policies will be critical for ensuring the long-term sustainability and operational reliability of IWT. By addressing these challenges, IWT can position itself as a more competitive and resilient mode of transportation in the evolving logistics landscape.

To fully leverage the potential of inland waterway transport and address its key challenges, a series of strategic recommendations emerged from the interviews. One of the most pressing concerns is predictable funding and maintenance coordination. Stakeholders emphasized the need for a "critical maintenance backlog" database to provide Congress with clear visibility on the urgent rehabilitation needs of locks and dams. Additionally, better inter-agency communication within the Army Corps of Engineers is essential to prevent uncoordinated water releases and unexpected maintenance closures that disrupt supply chains.

Enhancing reliability and scheduling is another critical priority. To build confidence among shippers, industry leaders suggested developing barge corridor transit agreements that offer guaranteed delivery windows. This could help mitigate the unpredictability often associated with IWT. Additionally, advanced traffic management technology for locks, dredging, and channel operations should be implemented to reduce delays and improve operational efficiency.

A significant barrier to wider adoption of IWT is the lack of shipper awareness and outreach. Many businesses remain unaware of how barge transport can fit into their logistics strategies. To address this, a Maritime Administration program should be established to promote IWT at industry conferences and through dedicated informational materials. Furthermore, expanding the FTZ policies could encourage businesses to use inland ports for inventory staging, making barge transport a more attractive option.

Greater modal collaboration is essential to unlocking IWT's full potential. Historically, rail, truck, and barge operators have competed rather than cooperated. Interviewees stressed the need for rail-barge-truck consortiums to present integrated transportation solutions rather than undercut each other. Developing multi-modal logistics hubs in key locations such as Memphis, St. Louis, and Cincinnati—with dedicated transload facilities—could facilitate smoother freight movement across modes.

Sustainability incentives and resiliency planning are also crucial for the long-term success of IWT. Introducing carbon credits or "nautical nudge" tax incentives could make barge transport a more attractive option for shippers looking to reduce their environmental footprint. Meanwhile, green finance initiatives should support inland port modernization efforts, such as the adoption of electrified cargo-handling equipment and low-emission barge engines. Finally, to mitigate climate-related disruptions, industry stakeholders recommend developing best-practice guidelines for inland ports facing floods, droughts, and hurricanes, as well as expanding reservoir capacity and coordinating water releases to maintain navigability during low-water conditions.

While this study provides valuable insights, several areas warrant further research. Future studies could explore quantitative modeling approaches to assess the economic impact of infrastructure investments and policy changes on IWT efficiency and competitiveness. Additionally, comparative analyses between inland waterways in different regions or countries could provide insights into best practices and potential strategies for improving operational performance. Another critical area for research involves technology adoption in IWT, such as the role of automation, digital tracking systems, and AI-driven logistics optimization in enhancing efficiency and reducing costs. Furthermore, longitudinal studies tracking the effects of regulatory changes, workforce development initiatives, and climate adaptation strategies could provide a deeper understanding of the evolving landscape of inland waterway transport. Addressing these research gaps would further contribute to data-driven policies and industry strategies that strengthen the resilience and sustainability of the IWT system.

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