Transportation Route Optimization for the State of Ohio's Inland Waterway System: A Case Study for Mid-Ohio River Valley Region

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ABSTRACT

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Transportation Route Optimization for the State of Ohio's Inland Waterway System: A Case Study for Mid-Ohio River Valley Region

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Within the transportation-engineering field, transportation optimization is a paramount concept of the utmost importance for the minimization of costs and maximization of efficiency. This research focuses on the intermodal transportation environment involving truck and barge transportation modes with a particular emphasis on the Mid-Ohio River Valley Region. The study was conducted with the primary objective of optimizing minor port locations within this region by utilizing containers on barge shipping to alleviate highway traffic congestion. In order to determine the optimal minor port locations, a mixed integer mathematical model (MIP) was developed to minimize the transportation and fixed costs associated with opening each potential port. In addition to the developed mixed integer mathematical model, a new heuristic model was specifically developed for this particular problem. The developed heuristic model resulted in similar solutions compared to the mathematical model thereby allowing it to be used as a solution methodology for transportation route optimization.

The model considered warehousing freight transferred from major ports in Cincinnati, OH and Huntington, WV to the Heartland Corridor intermodal terminals of Belpre, OH, South Point, OH, and Wellsville, OH. This study considers various potential port locations with different capacities. The optimization results indicated that proposed

ports should be opened in the following three locations: Proctorville, OH, Ripley, OH, and Ironton, OH. Additionally, according to the sensitivity analysis, the Proctorville, OH minor port facility provided the highest total cost savings since it was located in a critical location for intermodal transportation.

This research was unique in the sense of developing and implementing optimizing approaches to solve real life intermodal transportation problem observed in Ohio River's Inland Waterway System.

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First and foremost, I would like to express my sincere gratitude to my advisor, Dr. McAvoy for her endless help and support during those years! I believe that the completion of this research wouldn’t be possible without her support, guidance and mentorship. I am so grateful to have her as my advisor. Thank you very, very much for everything Dr. McAvoy!

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1. INTRODUCTION

Recent boosts in economic growth have prompted an increase in commercial traffic, thereby contributing considerably to highway congestion. Without roadway capacity improvements, congestion will spread well beyond urban areas and create a substantial disruption in freight movement. According to the United States Department of Transportation (USDOT) & Federal Highway Administration (FHWA) Freight Facts and Figures report in 2013, freight shipments are expected to increase significantly over the years.

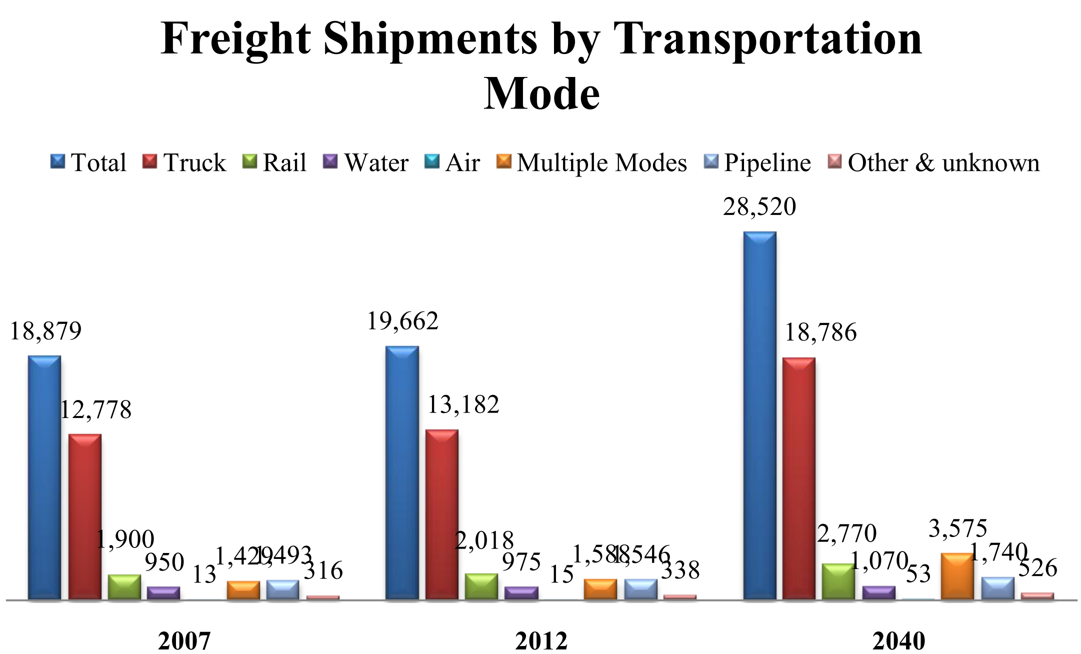


Figure 1: Freight Shipments by Transportation Modes (US DOT, 2013)

Due to the growth in the trucking mode, alternative modes should be considered to alleviate roadway congestion. One approach of reducing congestion is to use alternate modes of moving freight, particularly exploiting the underutilized inland waterway system. In April of 2011, the U.S. Maritime Administration stated that the waterway system was an answer to roadway congestion (Supply Chain Digest, 2011). Inland waterway transport utilizes barge tows to transfer cargo from main ports to smaller port facilities, from which the goods are shipped to intermodal terminals. These intermodal terminals serve as major distribution centers for international shipments. The aforementioned situation often presents a typical supply chain design problem in optimization literature. Indeed, there is a dire need for optimization in transportation field. One primary reasons is transportation optimization solutions help fortify the decision-making in every aspect in the organization, from strategic planning to operation decisions (ORTEC, 2013). It is also discovered that transportation optimization reduces operating costs on average from 5% to 9%. On the other hand, the optimization approach allows logistics providers to save up to 15% on transportation costs (ORTEC, 2013). Different optimization approaches are used in this thesis in intermodal transportation environment. This chapter briefly discusses the solution methods used for optimization as well as the research motivation and objectives.

The next chapters discuss the definition of supply chain management, followed by facility location decisions, challenges in supply chain management, relevant literature for waterway transportation, and developed methodologies. Finally, this paper finishes with results and concluding remarks related to this research.

1.1. Solution Methods for Optimization

Several optimizing techniques are used and developed in the literature, including Mathematical mnodels and heuristic models.

1.1.1. Mathematical Modeling

Various mathematical modeling techniques exist in the literature and those solution methodologies guarantee optimal solutions. Techniques such as: Linear Programming, Integer Programming, Mixed Integer Programming, Dynamic Programming, are the most commonly used for optimizing procedures. However, these mathematical models consist of an objective function and constraints. Accordingly, the major drawback of mathematical models is that they are slow in computation time when the problem size gets larger (Çelikbilek, 2011). In this thesis, Mixed Integer Programming was developed, and the LINGO 15.0 optimization package was used to solve the developed mathematical model.

1.1.2. Heuristics

Heuristics are one of the fastest solution methodologies used in literature for solving optimizational problems. The main drawback of heuristic approaches is that while they are fast procedures, they do not guarantee optimal solutions. Moreover, heuristics are designed for problem-specific and they cannot be used for solving multiple problems and objectives at the same time (Çelikbilek, 2011).

1.1.3. Objective of the Thesis

This research will strive to make inland waterway transport a more feasible alternative by optimizing minor port locations along the river. The Ohio River region will serve as a case study for the optimization model, with a focus on the Mid-Ohio Valley Region. The primary objective of this research was to determine which cities should serve as minor port locations as well as the amount of product that would be shipped from each major port through the minor ports to an intermodal terminal. Figure 2 shows the general distribution diagram. The overarching goal of this research was to minimize the total location, allocation and transportation costs of the system.

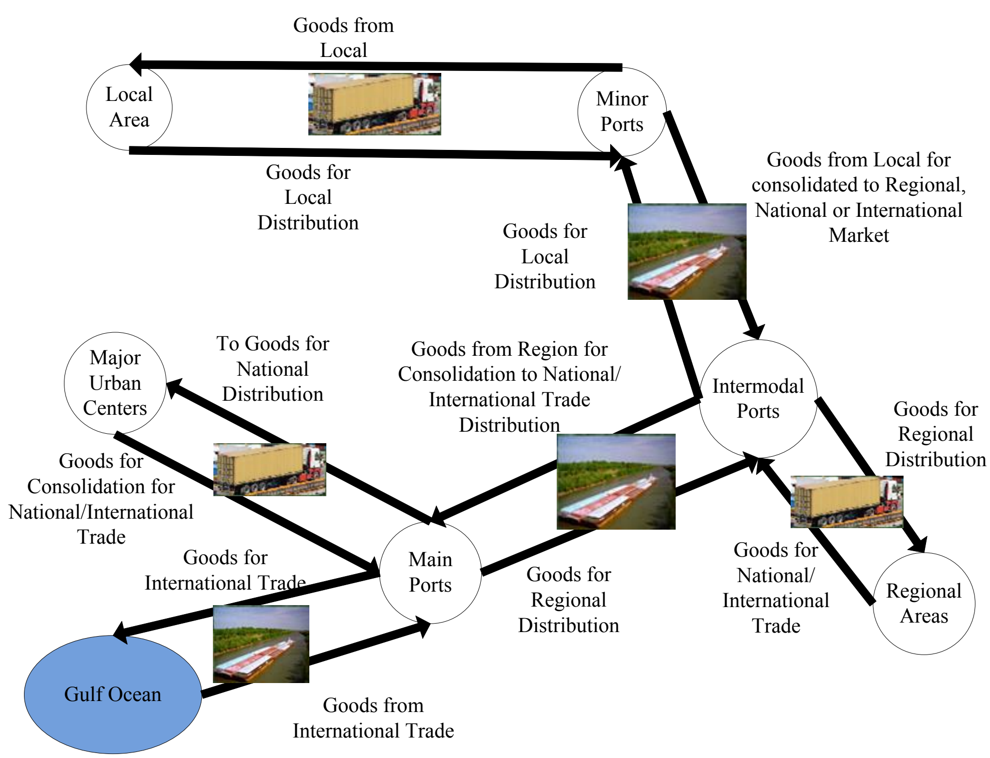


Figure 2: General Distribution Diagram

1.1.4. Why Intermodal Transportation?

The USDOT defines the intermodal transportation as: ―Use of more than one type of transportation; e.g. transportation a commodity by barge to an intermediate point and by truck to destination.” (USDOT Transportation Expressions, 1996)

USDOT places a paramount importance on intermodal transportation. This emphasis is also captured in the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. It is clearly stated in section 2 that:

> It is the policy of the United States to develop a National Intermodal System that is economically efficient and environmentally sound, provides the foundation for the Nation to compete in the global economy, and will move people and goods in an energy efficient manner. The National Intermodal Transportation System shall consist of all forms of transportation in a unified, interconnected manner, including the transportation systems of the future, to reduce energy consumption and air pollution while promoting economic development and supporting the Nation's preeminent position in international commerce. (ISTEA, 1991)

With consideration to the emphasis and importance of intermodal transportation, the overarching goal of this study is transportation route optimization by considering truck freight and inland waterway transportation options. Here are the other significant supporting reasons:

- Waterways have a lot of capacity and infrastructure. This capacity can be used to relieve growing highway transportation congestion. Such congestion lessens local life quality, air quality, public safety and emission quality.
- Driver shortage, increased fuel prices and implementation of new governmental regulations restricting service hours on the road, necessitates the utilization of intermodal shipments.

- Land availability: U.S. has navigable waters and these areas have a large accumulation of economic activities.
- Increase in labor costs, energy prices and particularly petroleum appears to be long term challenge and makes waterway transport appealing.
- Most companies follow a strategy to establish privilege port locations, or gateway access, to access other/international markets. By doing that, companies can improve their market share and guarantee level of service to customers in the current fierce market environment.

Therefore, the ultimate objective is to consider an intermodal transportation network where highway and waterway transportation options will be efficiently utilized in the Ohio River, particularly the Mid-Ohio River Valley region (shown Figure 3) in order to optimize the transportation route network.

Figure 3: Mid-Ohio River Valley Region Study Area (Coles and Associates, 2010)

2. SUPPLY CHAIN MANAGEMENT

Supply Chain Management (SCM) as a broad term, considers the efficient flow and integration of materials, goods and services from suppliers to customers via manufacturers, distribution centers/warehouses and retailers by considering different cost parameters and multiple transportation modes. Overall costs are minimized and service levels are maximized when a SCM is out in place (Simchi- Levi., 2009).

SCM considers the costs and value impact of each and every facility on the supply chain structure in terms of meeting customer needs and expectations. Simchi-Levi (2009) emphasizes that the primary emphasis of SCM is to be cost effective throughout the supply chain structure. The overview of a supply chain system is illustrated in Figure 3. In SCM, three planning levels exist considering the time horizon, which include: strategic, tactical and operational (Melo et al., 2009). Simchi-Levi (2004) indicates that strategic level decisions are long-lasting decisions. These decisions typically last several decades and the number, location, allocation and capacity decisions of facilities, as well as the flow of materials within these facilities are considered as strategic level of decisions. Since facilities serve a fundamental role in supply chain performance and efficiency, a significant connection between facility location models and supply chain management exist.

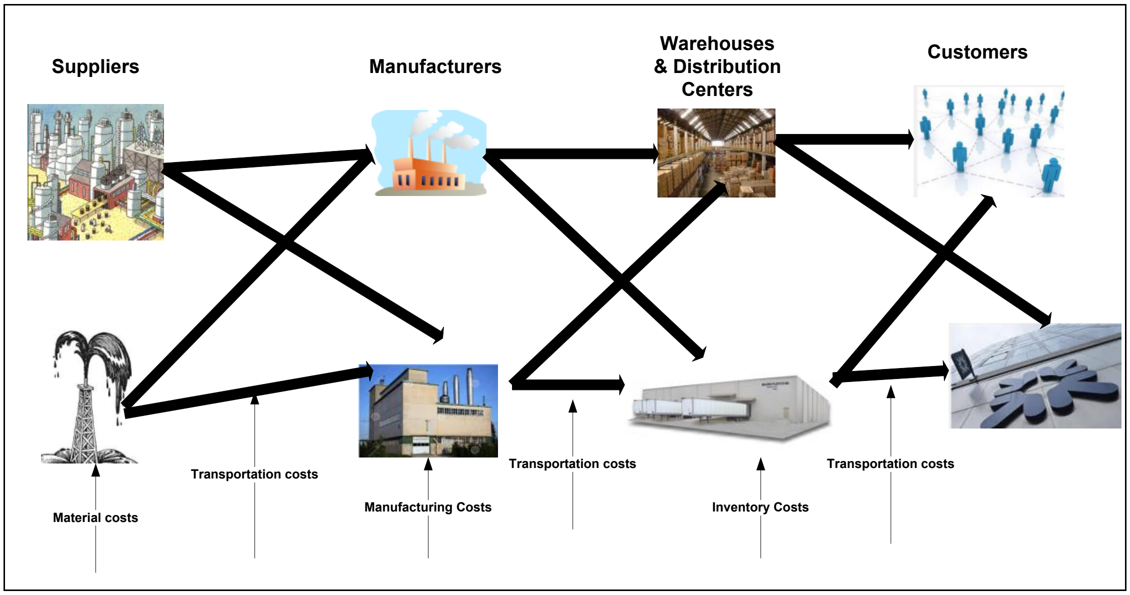


Figure 4: A Supply Chain Network Diagram (Simchi-Levi, 2009)

Similarly, Chopra (2007) emphasized the importance of facility location decisions in the supply chain network design and management. Chopra (2007) emphasized number, location, allocation, transportation and flow decisions of facilities highly impact the supply chain efficiency and overall system productivity. In this dynamic supply chain, facility location decisions have a vital impact on the performance of the supply chain (Simchi-Levi, D et al. 2009). Thus, multiple factors such as distance, transportation cost, land cost, plant capacities and customer demands are considered for the facility location and capacity allocation model in this thesis.

2.1. Challenges in Supply Chain Network Design

Facility location decisions are the crucial element in strategic planning of the supply chain network. For this reason, making a decision regarding a facility location should be carefully considered. Factors such as site costs, taxes, fees, overhead and other miscellaneous costs should be considered in a long-term perspective. However, due to sustainability and maintainability purposes, long lasting impacts and consequences, and changing future circumstances should also be taken into consideration while selecting appropriate facility locations (Owen and Daskin, 1998). Therefore, finding multi-objective facility locations presents a very challenging task for meeting uncertain demands for the future.

Moreover, from a competition standpoint, the right location may even strengthen the company's business operations. The company's close proximity to overall resources and assets may provide an outstanding advantage in terms of long term competition. In summation, strategic location decisions have a paramount advantage for faster, better and more effective delivery to the end users and customer locations. Therefore, while selecting a facility, one should note these aforementioned criteria. (Yang and Lee, 1997). Furthermore, the location decisions are also effective in terms of logistics and transportation policy-making (Ballou and Masters, 1993).

Nutt (1970) suggests that the ideal location of a plant should be determined based on the place where the total cost of production should be minimum and the profits should be maximum.

Facility location decisions have long term objectives including aim to minimize overall cost performances and targets for a responsiveness in a supply chain system (Chopra, 2007). Several factors influence distribution network design with relation to facility location. These factors include: responsiveness, multiple product offerings and their availabilities, customer experiences, ability to adapt market changes, order visibility and return ability (Chopra, 2007).

It is evident that the higher the number of facilities will lead to lower response time (Simchi-Levi, 2009). Also, transportation cost decreases until some extent with a higher number of facilities. The response time increases when multiple facilities are present and facility costs increase when there is an increase of the number of facilities.

2.2. Facility Location Decisions within Supply Chain Design

The main purpose of designing a supply chain network is to minimize costs or maximize the company's profits while satisfying the customer's needs and expectations. The overall framework for a network design decision is shown below.

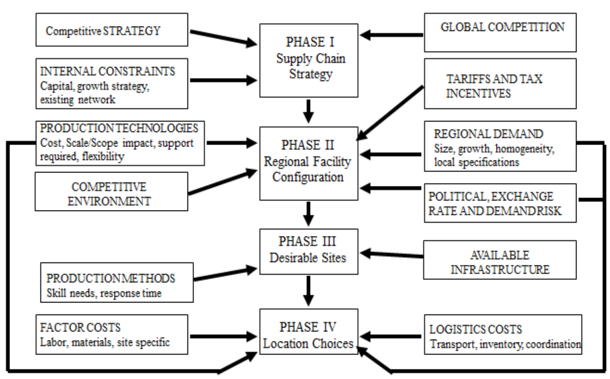


Figure 5: Overall Framework for Network Design Decision (Chopra, S., and Meindl, P. (2007))

Step I: Defining the scope of a supply chain network strategy:

The overall aim of this step is to identify the scope of company's supply chain design. This encompasses identification of the steps within the supply chain. This phase starts with the competitive strategy according to customer expectations.

Step II: Define the regional facility configuration:

The main objective of this step is to narrow down the potential sites where the possible facilities might be located along with their capacity restrictions.

Step III: Select a set of desirable potential sites:

The main purpose of this step is to perform a feasibility assessment within the region for possible site selection.

Step IV: Location choices:

The goal of this final step is to identify the optimal location, number and allocation decisions of each facility (Chopra, 2007).

2.3. Facility Location Metrics within Supply Chain Network

Min and Melachrinoudis (1999) identified six broad categories that potentially affect the facility location decision. These factors include: site characteristics, cost, traffic access, market opportunity, quality of living and local incentives. Within the site characteristics category, they discuss building design, capacity, infrastructure and soil condition. Within the cost category (stated as the primary location decision), it further encompasses land acquisition, appraisals, building construction and maintenance including liability insurance. They also addressed the fact that both land acquisition and building construction require substantial investment (Min and Melachrinoudis, 1999).

In terms of traffic access, Min and Melachrinoudis (1999) highlight the importance of accessibility to transportation modes as well as proximity to highways, railways and even foreign trade zones. In terms of market opportunity, they emphasize the buying power index, in which the measurement of associated market to buy is expressed as a percentage of dollars. Quality of living is another critical factor for a facility location decision because a facility hires employees for each business division, and the employees' lifestyles, productivities and patterns are affected by a facility location decision. Environmental factors, social factors and economical factors are all considered to measure the quality of living, and all of these are highly affected by the facility location decisions (Min and Melachrinoudis, 1999).

Likewise, the location of a specific facility depends on multiple factors and is based on performance metrics that are considered for a firm's business operations and long-term sustainability goals (Yang and Lee, 1997). Multiple factors can be considered for selecting an appropriate site for company's business operations. These range from market and government rules, site specific considerations, proximity to raw materials, supplication requirements, range of services provided, available transportation modes, and lastly, societal expectations (Levine, 1991).

The selection process for the best facility location can also be divided into quantitative and qualitative factors. These factors which are measurable and quantifiable (called quantitative factors) consist mainly of material, labor, manufacturing, equipment, storage, transportation, and logistics cost parameters. On the other hand, qualitative factors can also be taken into consideration while situating an appropriate facility. These parameters include business climate, quality of life, and long term desires. These can also be considered as fundamental in location decisions. Although it is challenging to measure these qualitative factors, it is necessary since factors like shifting businesses, environmental factors, and unexpected natural disasters can also serve as a performance measures in the selection decision in supply chain network design.

Ultimately, based on the individual facility's needs and expectations, the appropriate location will differ (Gopal et al. 2012). While making the facility-related design and location decisions, the following metrics should be considered that influence supply chain performance.

- Proximity to suppliers and markets
- Proximity to potential facilities
- Forecasted market demand
- Site specific labor cost, fixed cost, labor cost
- Cost of logistics and transportation operation between sites
- Site-specific inventory costs
- Market value of the product in different market regions
- Taxes and tariffs
- Customer response time, lead time and other service parameters (Chopra and Meindl, 2007).

There is no one-size-fits-all solution in terms of selecting performance measures; therefore, there might be a conflict between objectives (De Toni and Tonchia, 2001). According to Kearney (2009), three components of logistics costs (transport costs, warehousing costs and inventory costs) are considered as the performance-driven costs for supply chain performance. Ravet (2012) summarizes the several key performance indicators (KPI) from the literature for facility distribution location metrics. Bhatnagar and Sohal (2005) address the main issues for supply chain performance and indicates main plant location metrics. Cost, infrastructure, business services, labor, government, customer/market, supplier/resources and competitors are the main variables used for facility location metrics.

Farahani et al., (2010) pointed out some objectives that are used for the location of new facility sites. Many objectives can be considered such as:

- Total setup cost minimization
- Distance minimization from the situated facility,
- Total establishment cost minimization,
- Total operations costs minimization,
- Total or average time/ distance traveled minimization,
- The number of situation facilities minimization,
- Minimizing the maximum time/distance traveled,
- Service level or customer responsiveness maximization, (Farahani et al. 2010).

The best location is found by considering the aforementioned objectives. In order to achieve those objectives, quantitative methods are preferred. Those methods are explained in the next section.

2.4. Quantitative Methods for Facility Location Decisions

Many techniques can be used by decision-makers and these are:

- Weighted Factor Rating Model.
- Economic Analysis (The Break-Even Model).
- Analytical Hierarchy Process (AHP)

- Facility Location Models & Network Optimization Models (Mathematical Models).

2.4.1. Weighted Factor Rating Model

Weighted Factor Rating Model is commonly used model used to assist making global facility location decisions. The main steps of the process include:

- Specify the critical factors that are fairly important for plant location decision.
- Based on the importance of these factors, assign weights to these factors. The weights should be summed up to 1.
- Develop a relative importance score between 1 to 100 based on the previous step
- Multiply the score by the weight of each factor and sum the weighted scores for all factors.
- Recommend the facility with the highest score point. (Wisner, 2011).

The individual weights and scores are subject to interpretation and bias by the analyst. It is highly recommended that a team approach is used for performing this type of analysis.

2.4.2. Economic Analysis (The Break-Even Model)

The Break-Even Model can also be used when the different types of costs and revenues are known for each potential facility. The steps are as follows:

- Specify the potential/ proposed locations
- Identify the fixed cost of the proposed facility such as; land cost, excavation, building and infrastructure costs, taxes and tariffs, insurance of equipments and facilities.

- Identify the variable cost of each facility. Variable costs change depending on the quantity and volume.
- Calculate the total cost for each proposed facility
- Determine the break-even points for each potential facility.
- Choose the lowest cost facility, consider the break-even point (Wisner, 2011).

2.4.3. Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) is a multi-criteria decision-making technique that relies heavily on the judgment process. The first important part of the process is to identify the objective(s), criteria and alternatives for those criteria. This information should be arranged in a hierarchical order. The second step is to determine the relative importance of the criteria based on judgments and experiences. One of the main drawbacks of this technique is considering qualitative techniques and perceptions. The third step in this process is to construct a pair wise comparison matrix. In this step, the relative importance of one criterion to another is calculated. The fourth step is turning the matrix into ranking criteria by using eigenvectors-matrix algebra. Finally, based on the outcome of the algebraic solution, the priorities of each alternative (with respect to each criteria) is calculated and the highest priority criterion is selected (Saaty, 1990). The major drawback of this methodology is focusing on perceptions and qualitative factors. Min, H., and Melachrinoudis, E. (1999) used the AHP approach for selecting the appropriate location of a manufacturing facility in the U.S. Three alternative plant location points were analyzed according to six major categories of plant locations, and the best location was decided accordingly.

2.4.4. Network Optimization Models (Mathematical Models)

Initially, Hakimi (1964) started using mathematical modeling methodology in the area of node optimality. This is similar to the concept of the hub location problem (HLP). Toh and Higgins (1985) addressed the application of HLP in the airline and aviation industry.

The first mathematical formulation and solution method is proposed by O'Kelly (1986a, 1986b). O' Kelly (1987) tackled the problem of HLP and developed a quadratic integer programming methodology. After this study, many researchers and papers were conducted and published in the hub location literature. Many mathematical formulations have been addressed in the literature as well as in the surveys of HLP literature.

From the literature review already performed, it became apparent that the trend of modeling HLP started in late 1980's followed soon after by optimization and modeling in the 1990's. Later, the advanced models and application of heuristic approaches emerged in the 2000's and still are continuously being developed at a rapid pace.

The surveys conducted up to this date until the present were offered by Campbell (1994a), O'Kelly and Miller (1994). Moreover, in the recent decade Alumur and Kara (2008) elucidated many hub location problems in the literature. More recently Farahani, et al., (2013a) provided an extensive literature review classifying and categorizing various hub location problems accordingly. As it is the latest HLP review in the literature, this research is considered a benchmark for the review and hub-location studies.

First, O'Kelly (1987) presented a single-hub network location problem as an objective function of mini-sum. Non-hub nodes are connected to a single hub and the number of hubs to locate is previously known and is equal to one. In that study, cost of establishing a hub is not considered and there was no capacity restriction for the hub.

Additionally, O'Kelly (1987b) introduced multiple-hub network location problems where multiple incapacitated hubs with no cost of establishment are considered with mini-sum objectives. Campbell (1991) presented the linear mathematical formulation of that problem, calling it p-hub median location problem. Every non-hub node could be allocated to one or more hubs in p-hub median location problems. This model is named multiple allocation p-HLP. This model has similar assumptions except that the flow from non-hub node (i.e. supplier) to non-hub node (i.e. demand) via hub facilities located at different locations. The objective is to minimize the total sum of transportation costs.

Campbell (1994b) developed the first linear integer programming formulation for the capacitated single allocation p-hub median problem. The formulation variables are binary and it has multiple linear constraints (Campbell, 1994b). This study also considers the minimum flow and threshold value of flows. The amount of flow and capacities are considered for hubs. Skorin-Kapov (1994) applied linear extensions to single allocation versions of the Campbell's (1994b) model and obtained better solutions. They solved the problem optimally by using CPLEX.

Ernst and Krishnamoorthy (1996) proposed a new mixed integer linear programming for the incapacitated single allocation p-hub median problem that requires less variables and constraints to solve large problem sizes. They consider the hub movements within each other as a multi-product flow problem. Ernst and

Krishnamoorthy (1999), proposed an integer programming approach for capacitated single allocation p-hub median problem. The proposed integer programming approach could solve up to 50 nodes and solving more than 50 nodes became too slow or impossible.

Ebery et al., (2000) presented a mixed integer linear mathematical model for capacitated multiple-allocation p-hub median (CMAHLP) problem. The model determines the number of hubs that are required for minimizing the total transportation cost of the system. The system consists of i origins, k hubs, l hubs and j demand nodes. It is important to mention that if the nodes are known a priori, then this model becomes a multi-commodity flow problem.

Labbe et al., (2005) tackled the problem of single hub location model where each hub has a fixed capacity by considering the flow of transactions passing through it. The ultimate objective of their study was to minimize the cost of establishing the hub and transfer flow through the hub. They solved the problem by branch-and-cut algorithm.

Costa et al., (2008) proposed two bi-criteria approach for the single allocation capacitated hub location problems. First, the integer mathematical model minimizes the total service time of the hubs then the second integer mathematical model minimizes the maximum service time for the hubs. This study does not consider the capacity restriction on the hubs, which is the main drawback of this study. Also, hypothetical data is used to prove their mathematical formulations.

Martin and Gonzales (2008) proposed a new mixed integer linear programming model for the problem of determining routes and the hubs of the set of products from sources to destinations at a minimum cost in a capacitated network. They proposed two branch-and-cut algorithms. They tested those algorithms with 25 products/commodities and 10 potential hubs.

Costa et al., (2008) developed a multi-objective HLP in which the first objective minimizes the total transportation cost, while the second objective minimizes the maximum service time of the hub nodes. The objective function is both mini-sum and mini-max, and solution domain is the network. Single allocation strategies with known hub locations were considered as well. Costs for hubs and capacity were not considered.

Campbell (1994b) defined the p-hub center problem as a minimax type of problem and proposed three different types of p-hub center problems. The first type of problem was the minimization of the maximum cost origin-destination pair; the second type of problem was the minimization of maximum cost of origin-hub, hub-hub and hub-spoke connection; and the third type of problem was the minimization of the maximum cost of hub-spoke connection. Considering these types of problems were important in the sense of considering time-dependent real-life problems. Campbell et al. (2007) presented the purpose of p-hub center problem is to locate hubs and allocate spokes to hubs such that the maximum travel time (distance) between any origin-destination pair is minimized.

Campbell (1994b) presented the first mixed integer formulations where the establishment cost of hubs is minimized. The hub-set covering problem is equivalent to p-hub median problem with some exceptions. The objective is to minimize the total cost of opening new hub facilities. Each demand pair is trigger to be covered by at least one time by a hub pair.

On the other hand, in p-hub maximal hub-covering problem, the demand is maximized while considering the existing location of hubs. The location of hubs is previously specified. In addition, the fixed cost of establishing hub facilities is not taken into consideration. The objective is to maximize the total transportation demand covered.

The hub-location problem with star-star network is mostly observed in cargo delivery companies. In this type of network, each spoke (non-hub) is connected to a single hub, and then each hub is connected to main hub. The main objective is to minimize the cost of hub establishments as wells as transportation costs within hub locations. Yaman (2008) proposed two mathematical modeling techniques along with a heuristic approach in order to overcome that problem.

As it is observed from literature, the supply chain literature is greatly saturated for facility location and allocation problems that utilize most truck freight transportation. Theoretical formulations and hypothetical scenarios were developed to analyze different aspects of supply chain problems. However, current real-life situations and circumstances make the problems harder to solve; therefore, most of the parameters are either assumed, constant, or negligible in developing supply chain problems. Another aspect to tackling real-life supply chain problems is the need to relax the assumptions in the model and also propose additional solution methodologies. Consequently, considering a real-life situation is important in our analysis. We will be solving real optimization problem which is rarely done in network optimization literature.

With the recent environmental, social, economic implications, the supply chain optimization lean towards the alternative transportation modes. Therefore, more research started to consider the intermodal, multimodal transportation aspects of supply chain optimization literature, especially considering waterway transportation. The recent findings from the literature indicated that, there is a gap for using alternative transportation modes in network optimization literature. Therefore, considering alternative transportation modes in supply chain network optimization will be integral part in our research and analysis.

The next section discusses the recent literature and research conducted in the U.S. regarding inland waterway transportation optimization field.

3. LITERATURE ON WATERWAY TRANSPORTATION OPTIMIZATION

The inland waterway provides an integral part in increasing supply chain performance. Several quantitative studies have been conducted in the U.S. in order to analyze the waterway transportation in supply chain optimization. Recently Caris et al., (2014) addressed the issues in integration of inland waterway transportation in supply chain environment. The researchers pointed out the crucial role of inland waterways in integrated intermodal transportation in supply chain.

Robinson (2002) emphasizes the importance of waterway port selections within the supply chain so that cargo flows with a minimum total cost. Moreover, Groothedde et al. (2005) indicates that inland waterway transport creates advantages in economies of scale and flexibility when combined with the other transportation modes such as roads and rails.

Bush et al., (2003) approached the problem of barge traffic on an inland waterway by proposing an iterative linear programming and simulation models. The results and the parameters of the linear programming were used in a simulation model to minimize the costs associated with the barge movement. These costs included travel costs related to the type of boat used to tow a barge and the total distance traveled.

Walter and Poist (2004) conducted a study for the Midwest to better facilitate commerce by utilizing ports and services. The researchers conducted a qualitative study and asked Iowa shippers about their perceptions and preferences about international and domestic-only shipment for a proposed inland port location. The study aimed to guide policy makers and investors to contemplate an implementation strategy for an inland port location.

Taylor et al., (2005) present a simulation-based system to schedule barge dispatching and boat assignment problems for inland waterways. The efficiency of the system was simulated by using the data provided by American Commercial Barge Line, LLC (ACBL) for the Ohio River. Although the simulation is not an optimization technique, this approach is helpful for observing the large-scale dispatching and load assignment problems in Ohio River.

Konings (2006) discusses the hub-and-spoke networks for container-on-barge (COB) transport and its advantages for improving the performance of COB transport as well as gaining market share for the companies' waterway industry. Konings (2006) also discusses the importance of port locations, the allocation decisions and efficient use of vessel capacity.

Maraš (2008) offers a mixed integer linear programming model for container ship or tow allocation problem. The proposed model determines whether an inland waterway container ship or tow should be charted or not. Chang et al., (2010) considered an environmental perspective of intermodal optimization of container cargoes while incorporating the external costs of the modes. The overall objective is to minimize the total logistic costs, which include total shipping and land costs as well as external costs such as air pollutants and greenhouse gases.

Rahimi et al., (2008) identify and analyze inland port sites in the five counties in California around Los Angeles area. Their study similarly considers inland ports' for potential integration for intermodal transportation. They divide the regions into zones by the Geographical Information System (GIS). A single facility location model was used to identify proximal locations of ports to minimize the total vehicles miles travelled (VMT). The overall objective was to develop a simple mathematical model to determine the internal port locations in a hub-and-spoke network, in order to minimize the total VMT for intermodal transportation.

Winebreak et al., (2008) presented a network optimization model named as GIFT to analyze the cost, time-of-delivery, energy and environmental impacts of the intermodal freight transportation. The researchers conducted three case studies or in other words three different pre-determined origin-destination routes. They considered truck, rail and container transportation options as well as combinations of these for each origin-destination route. Although they pointed out that the outcome of cost, time, energy and environmental emissions depend on the origin-destination points, they proposed that their model can be used to study infrastructure investments. They suggest that this could reduce intermodal transfer penalties while observing the potential impact of highway congestion and contraction.

Fan et al., (2010) propose a general optimization model to determine optimal container flows from origins to destinations in the United States. The proposed model evaluates the inter-port competitiveness and showed the overall impact of congestion on container flows as well as new port locations and routes. The sensitivity results indicate that optimal port, route and interior shipping corridor that are significantly important for shipment efficiencies.

Moreover, Pant et al., (2011) present an interesting novel approach in the multi-modal transportation system. They model the adverse impacts across the inland waterway ports, relating them to disruptive port operations in the related industries across multiple regions. Three disruption scenarios were considered for inland port operations. The quantitative impacts were calculated for multiple regions and industries. Mainly, terminal closure, crane outage and departure stoppage were considered for the Arkansas River. Their proposed multi-regional inoperability input-output model (MRIIM) demonstrates that, the disruption in inland ports resulted in hundreds of millions of dollars in economic loss for almost 10 states. This study clearly presents the importance of inland waterway transportation within intermodal transportation systems. Here, the port locations were situated and known in advance. Therefore, the optimal port locations should be determined in an optimal fashion as well.

Gelareh and Pisinger (2011) developed a mixed integer mathematical model for concurrent optimization of network design and fleet allocation problem for deep-sea liner service provider. They consider an elastic demand environment. Along with the mixed integer mathematical model, an exact decomposition algorithm (benders algorithm) was implemented. Additionally, empirical experimentation environment was considered.

Maraš et al., (2013) propose a mixed-integer programming (MIP) formulation for barge container routing decisions. The research considered that the ports were already established and only concentrated on routing decisions. Along with the MIP formulation, the researchers proposed variable neighborhood decomposition, branching and local branching heuristics. A hypothetical problem environment was generated and the overall objective was to minimize the total routing costs of barge container ships.

Recently, DiPietro et al.,(2015) propose alternative methods to assess the Ohio River system efficiency by proposing stochastic shipping time model. The motivation for this study is to assess the inland waterway infrastructure. Although this study does not consider any optimization approaches, this study is helpful for assessing the characteristics of the Ohio River such as locks, capacities, lock operations, closures and time information.

Moreover, DiPietro et al., (2015) also focused on another study in the Ohio River Basin and developed a new method for tracking the shipment of coal in the study area. This paper demonstrates the difference between vessel trips and commodity shipments. This study only considers a methodology for estimating commodity trips and shipping costs, the number, location and allocation optimization decisions are not performed.

As observed from the U.S. waterway transportation optimization literature, the main focus was to consider a barge dispatching problem. In almost all of the studies, the ports were previously located and shipment decisions were solely considered. In other words, in most cases operational decisions were performed rather than strategical decisions. Another observation with that most of the studies emphasized the importance of inland waterway transportation in network optimization literature. Consequently, there is a gap in Ohio River's transportation optimization literature where location, allocation and dispatching decisions are performed simultaneously. Therefore, it is important to consider these simultaneous decisions in the research and analysis.

Moreover, most of the studies considered the environmental implications such as air pollutants and greenhouses gases. Very few studies considered the Ohio River as their scope of study, but those studies were particularly helpful for assessing the current infrastructure, capacities and current conditions of ports. Along with the recent finding, our study is also considering the port capacities and current conditions of ports.

According to the literature that has been reviewed so far, this thesis will be unique in the sense that it considers new optimization approaches for intermodal inland waterway transportation in the Mid-Ohio River Valley region, where port location, product allocation and dispatching decisions are performed simultaneously.

The proposed mixed-integer-mathematical model and associated heuristic considers an intermodal transportation environment (waterway and truck freight) and determines the number, location and allocation decisions of ports in order to minimize the total transportation and system-wide costs in supply chain environment.

4. AN OVERVIEW OF U.S TRANSPORTATION SYSTEM

This chapter presents an overall framework of different ground transportation modes that are heavily used in the United States. According to the US DOT Framework Policy (2014), the moving freight costs are expected to increase from $882/ton to $1,377/ton between years 2007-2040. Moreover, in terms of tonnage of imports and exports, an increase from 11% to 19% is expected. Along with that, the freight value is expected to increase from 19% to 31% between the years 2007 and 2040 in the US (US DOT, 2014). In the US, freights are often transported via truck, rail, water or some combinations of these. Figure 6 shows an overview of railroads, highways and waterways throughout the US.

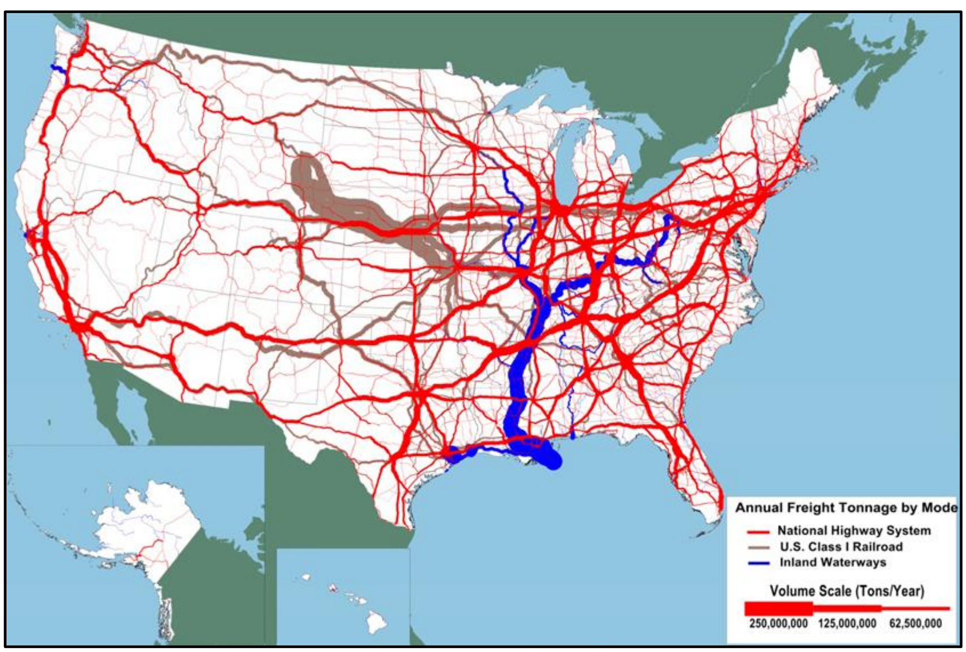


Figure 6: Freight Flow Map of Highway, Railroad and Waterway Transportation-2010 (USACE, 2013; Surface Transportation Board, 2013; U.S DOT, 2013)

In the US, trucks are mainly used as a transportation mode, and carry the highest amount of tonnage and value of freight. In contrast, waterways and railways are mainly used for long distance carrying with a high volume of products. Railways a carry large a volume of commodities between Wyoming and the Midwest, whereas inland waterways mainly carry a large volume of commodities in Lower Mississippi River. As seen from Figure 2, the Mississippi River is the primary inland waterway system, stretching along the state of Minneapolis to the Gulf of Mexico. The Mississippi supports the Ohio River, the Gulf Intracoastal Waterway and the Columbia-Snake River System. The Mississippi River's carrying capacity for each year is equivalent to 58 million truck trips (MARAD, 2014).

According to the U.S DOT Office of Freight Management and Operations, highway segments carry at least 8,500 trucks per day, and move 50 million tons per year with an average of 16 tons per truck. In comparison, rail lines and waterways carry an average of 50 million tons of bulk cargo per year (U.S DOT, 2008). Subsequent sections will discuss different transportation modes in detail.

4.1. Rail Transportation in the United States

Since 1980, the United States has spent $575 billion to create a freight rail network (AAR, 2015). According to the U.S DOT Federal Railroad Administration, the U.S freight rail industry is valued at $60 billion and consists of 140,000 rail miles. According to IBIS World; one of the most powerful market research providers, annual growth is expected to be 5% for the period between 2010 and 2015. Moreover, annual growth is expected to be 3% for the period between 2015 and 2020 (Rivera, 2015). The overall illustration of U.S Railroad Network Map is presented in Figure 7.

Figure 7: U.S Railroad Network Map (Maps of World, 2014)

Almost anything can be carried by railway, and rail is convenient for shipping commodities over long distances. The main rail hubs are primarily situated in big cities such as Chicago, New York, Boston, Philadelphia, Washington DC, Miami, Atlanta, Houston, Dallas, Los Angeles, San Francisco and Seattle. According to the IBISWorld Report; Rivera’s (2015) study and Figure 8 below, bulk freight (54.1%) is heavily transported throughout the U.S.

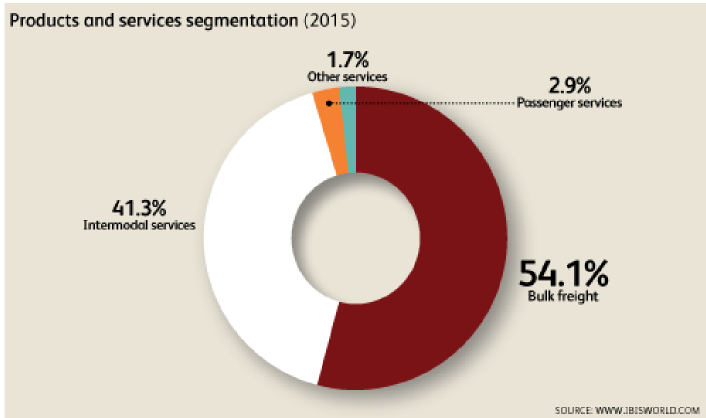


Figure 8: Products and services transported in US Railroad Transportation (Rivera, 2015)

Railway transportation plays a significant role for the country's development in terms of trade, industry and commerce. It enables the transportation of long-distance heavy, bulk goods, which cannot be transported via trucks and trailers. Moreover, railroad transportation is a great source of employment, currently supporting 583 businesses and providing $21.3 billion in wages (Rivera, 2015). The strengths, weaknesses, opportunities and threats (SWOT) analysis is performed for the holistic assessment of various factors for railroad transportation and the results presented in Table 1.

It is important to assess several factors of each ground transportation mode. Overall, the SWOT assessments are synthesized based on the IBISWorld industry reports for rail, long-distance truck freight and inland waterway transportation in the US (Rivera, 2015 and Soshkin, 2015).

Table 1: SWOT Analysis for Railroad Transportation (Rivera, 2015)

Strengths	**Weaknesses**
• Carries heavy bulky roads • Relatively cheaper than trucks • Higher profit margins compared to other transportation modes	• Relatively slow compared to trucks • Not suitable for perishable items • Not flexible mode of transportation
Opportunities	**Threats**
• Newly railroad establishments • Sector grows between 3% -5% over decades • Saturated Industry assistance	• Shifting trends to waterway which is safer and more reliable • Investment costs • High industry competition shifts employment to other modes

4.2. Truck Freight Transportation in the United States

Truck freight transportation grows significantly as the economy, industrial production and general trade volume increases across the country. According to the IBISWorld-leading industry market study by Rivera (2015), the provider- truck freight industry revenue is expected to grow at an average rate of 3.6% and will reach $209.7 billion revenue in upcoming decades. In 2012, the American Trucking Association declared that 9.4 billion tons of commodities were moved by trucks and expected this increase by 2.3% of the annual total by 2024 (Rivera, 2015). Although economic, social and environmental sustainability issues are present, truck transportation will still be the most widely use mode of freight transportation. Statistics of vehicle miles of travel and lanes miles information are shown in Figure 9. Since lane miles were only collected at the beginning of 1970's, prior data is unavailable.

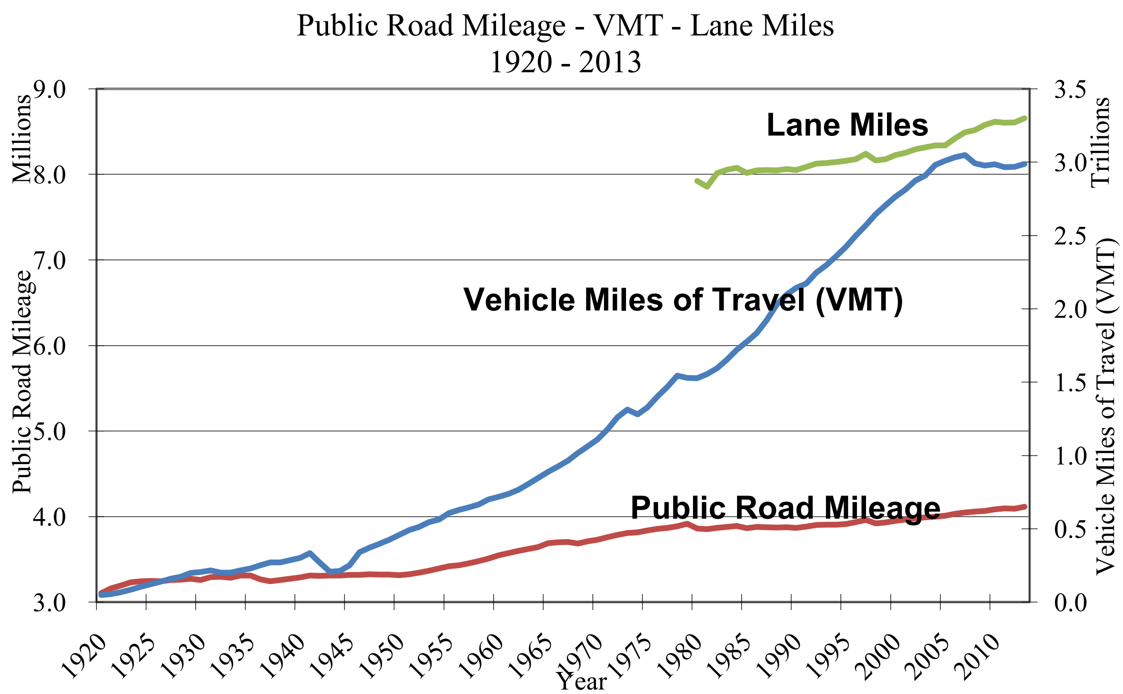


Figure 9: US VMT and Road Mileage

(Retrieved from: USDOT, Office of Highway Policy Statistics- Highway Statistics 2013)

The statistics recently showed that 3 trillion vehicle miles of travel and approximately 9 million lane miles have been observed in the road transportation industry. USDOT (2013) indicates that there is an increasing VMT trend in the industry. An illustration for National Highway System Route is shown Figure 10.

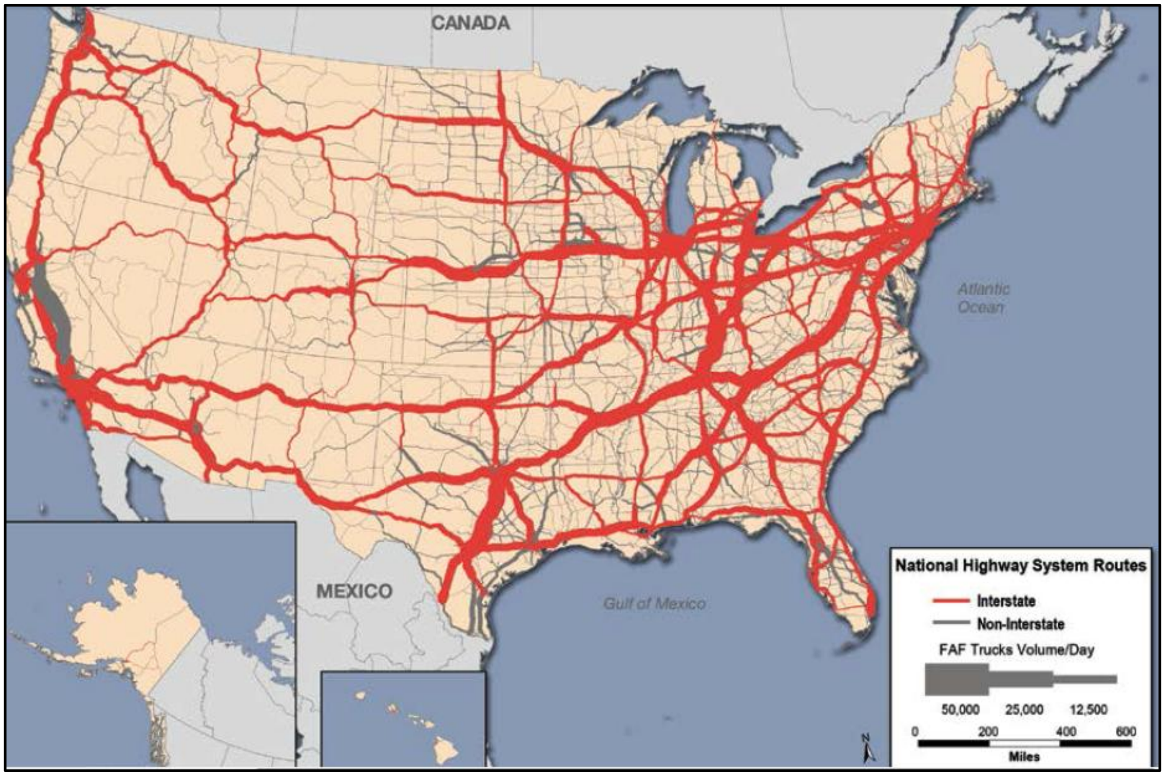


Figure 10: National Highway System Routes (US DOT, 2013)

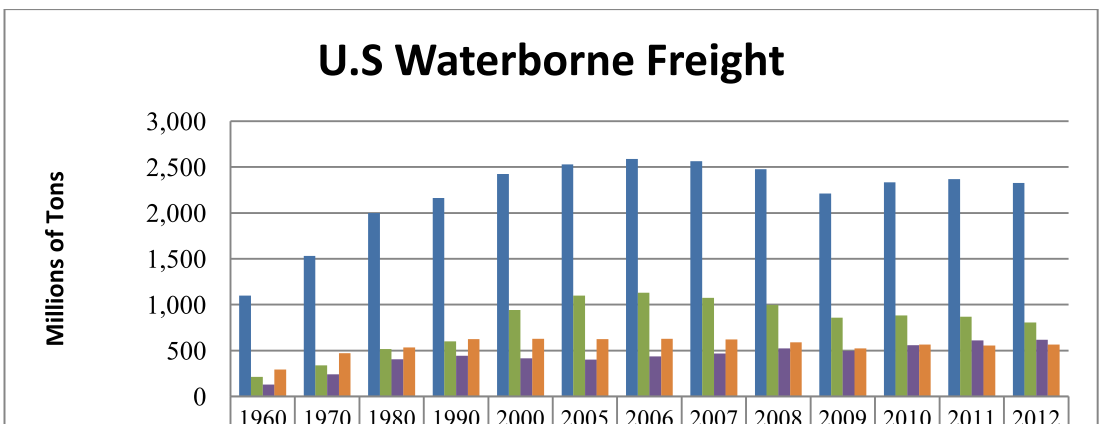
In terms of the products and services, truckload carriers are taking the lead by 62.1% and 25.7% less than truckload carriers. Other small-scale services constitute 12.2% of overall products and services. In order to assess the truck transportation in a managerial perspective, a SWOT analysis was synthesized based on Rivera's (2015) study and presented in Table 2.

Table 2: SWOT Analysis for Truck Freight Transportation (Rivera, 2015)

Strengths	**Weaknesses**
• Faster, flexible mode • Ideal for perishable items • Can be cheaper for short hauls	• Higher fuel costs • Frequent maintenance costs • Size and weight restrictions • Too expensive for bulk items • Driving regulations • Bad weather can cause delays • Traffic delays
Opportunities	**Threats**
• Sector grows 3.6% • Leasing, third-party logistic providers • Saturated Industry	• Shifting trends to waterway which is safer and more reliable • Investment costs • Different state policies/no standardization on truck size and weight • Highway capacity restrictions • High industry competition shifts employment to other modes

4.3. Inland Waterway Transportation in the United States

Due to fierce competition among other transportation modes, increasing economic conjecture, growth of markets, and economic, social and environmental sustainability factors, the volume of freight transported via inland and coastal waterways will predictably rise. Currently, the industry revenue is around \$7.7 billion, but demand for industry services will increase at an annualized 2.6% to \$8.7 billion, including 2.4% increase in 2015 (Soshkin, 2015). According to the recent data on different mode of freight shipments, waterway transportation carried 434 billion ton miles in 2011 (Freight Shipments within the U.S. by Mode, 2014). Figure 11 also shows the U.S Waterborne Freight information in millions of tons of freight and the portion of inland waterways.



	1960	1970	1980	1990	2000	2005	2006	2007	2008	2009	2010	2011	2012
TOTAL freight	1,099	1,531	1,998	2,163	2,424	2,527	2,588	2,564	2,477	2,210	2,334	2,367	2,327
Imports	211.3	339.3	517.5	600.0	939.7	1,096	1,130	1,075	998.7	858.9	883.1	869.1	804.5
Exports	128.0	241.6	403.9	441.6	415.0	401.8	434.0	466.8	522.1	494.8	557.8	610.4	617.4
Inland	291.1	472.1	535.0	622.6	628.4	624.0	627.6	621.9	588.5	522.5	565.6	553.6	565.0

Figure 11: U.S Waterway Freight Transportation- U.S Waterway Freight Transportation. (2014).

As seen from Figure 11, Inland waterway freight transportation carried tonnage has grown recently and shown fluctuations over the last decades.

The U.S waterway system is comprised of 12,000 miles of navigable waterway containing the Mississippi, Ohio, Gulf and the Pacific Coast systems (NETS, 2009; U.S Army Corps of Engineers, 2005).

Figure 12: Ports and Navigable Waterways in U.S (U.S Army Corps of Engineers, 2014)

Overall, the Ohio River Basin encompasses 2,800 miles of navigable water and incorporates other rivers such as the Tennessee, Cumberland, Monongahela, Allegheny, Green, Kanawha, and Big Sandy Rivers. Moreover, it supports the states of Alabama, Illinois, Indiana, Kentucky, Mississippi, Ohio, Pennsylvania, Tennessee and West

Virginia (NETS, 2009; U.S Army Corps of Engineers, 2005). The products and service segmentation within inland waterway transportation is illustrated in Figure 13.

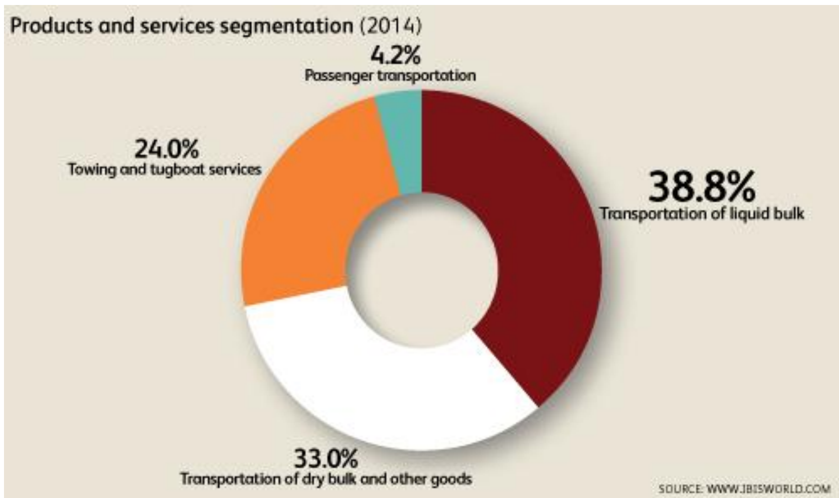


Figure 13: Types of products and services transported within Inland Waterway (Soshkin, 2015)

Inland waterway transport presents four principal advantages over conventional truck transport: capacity, energy efficiency, minimal CO_2 emission impacts, and safety. The capacity of barge tows greatly exceeds that of semi-trucks, thereby alleviating some of the burden on aging transportation infrastructure systems. According to the U.S. Army Corps of Engineers, a single fifteen-barge tow possesses a capacity comparable to that of 1,050 semi-trucks (American Commercial Lines, 2012; Neff, 2010; Coles and Associates, 2010). A visual representation of this comparison is provided in Figure 14. Apart from this increased capacity, river transport is also a more energy efficient alternative than truck transport. As exemplified in Figure 15, a tow of barges can travel 576 ton-miles per gallon of fuel, while trucks can only travel approximately 155 ton-miles per gallon of fuel (American Commercial Lines, 2012; Neff, 2010; Coles and Associates, 2010; Ingram Marine Group, 2014). Furthermore, river transport presents an eco-friendly alternative to truck transport. As illustrated in Figure 16, barges emit nearly one quarter of the carbon dioxide released by semi-trucks (US Army Corps 2014). An additional environmental benefit is the reduction of hazardous material spills, which is about 50% less for barges than for trucks, as shown in Figure 17 (Ingram Marine Group, 2014; American Commercial Lines, 2012). Finally, as exhibited in Figure 18, river transport is considered a safer means of transporting cargo, with only one barge related fatality for every 155 truck related fatalities (Neff, 2010; Ingram Marine Group, 2014).

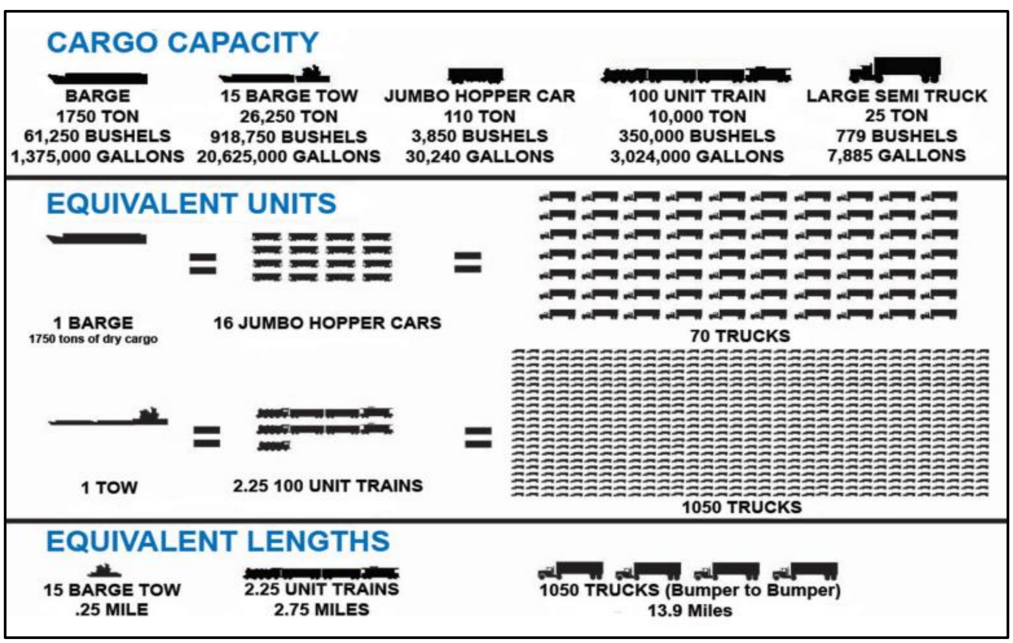


Figure 14: Cargo Capacity Comparison of Multiple Transportation Modes

United States Army Corps of Engineers (2014).

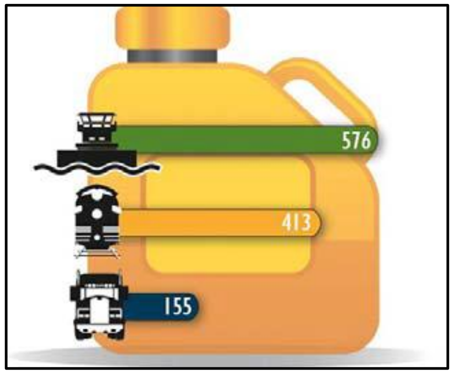


Figure 15: Comparison of Multi-Modal Ton-Miles Traveled per Gallon of Fuel

(Neff, 2010; Coles and Associates, 2010; Ingram Marine Group, 2014)

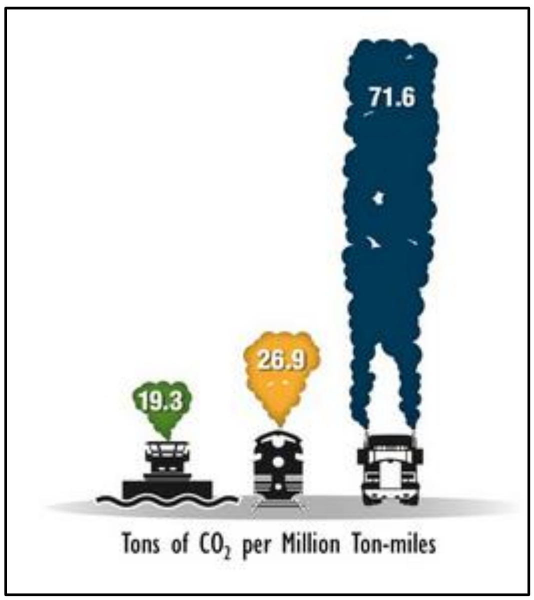


Figure 16: Comparison of Carbon Dioxide Emissions by Transportation Mode.

American Commercial Lines (2012).

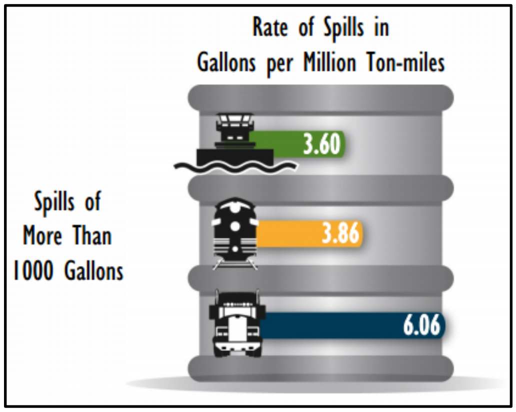


Figure 17: Comparison of Hazardous Material Spill Rates by Transportation Mode

(Ingram Marine Group, 2014; American Commercial Lines, 2012)

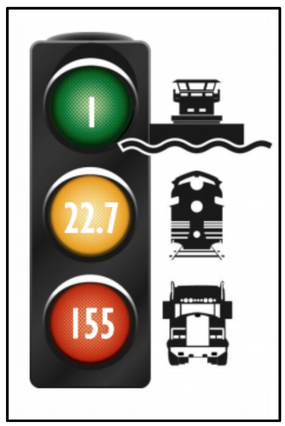


Figure 18: Ratio of Fatalities by Transportation Mode

(Ingram Marine Group, 2014)

Despite all the advantages of inland waterway transport, this method of conveying cargo remains underutilized primarily as a result of inadequate inland waterway infrastructure including locks and dams. As such, in order to realize the full potential of river transport and encourage manufacturers and customers alike to embrace intermodal means of shipping, the location of port facilities must be carefully selected to minimize infrastructure cost while maintaining an efficient system. This statement holds true particularly for the state of Ohio, which has access to the Atlantic Ocean and the Gulf of Mexico through Lake Erie and the Ohio River, respectively.

Waterway transportation carries goods and services with fewer societal, economical and environmental impacts than other modes of ground transportation. A hypothetical study conducted in Texas Transportation Institute (TTI) Center for Ports and Waterways discussed the possible consequences of shutting down the Mississippi and Illinois Rivers. The results indicated that this would result in a, 200% increase in truck traffic, as well as a 500% increase in traffic delays, a 36% to 45% increase in injuries and fatalities on Interstates. Finally, an 80% to 93% increase in maintenance costs would be observed. All in all, this study clearly delineates the merit of using river transportation for society (Texas Transportation Institute, 2008). Therefore, diverting highway cargo from the nation’s interstates would dramatically alleviate traffic congestion thereby improving highway capacity.

Similarly, a SWOT analysis was conducted and presented in Table 3 for Inland Waterway Transportation in U.S.

Table 3: SWOT Analysis for Inland Waterway Transportation (IBISWorld, 2015)

Strengths	**Weaknesses**
• Low Cost • Larger capacity • Flexible service compared to railways • The Safest mode • Lower CO_2 emission	• Slow • Not good for perishable goods • Limited area • Seasonality
Opportunities	**Threats**
• Sector annually grows 2.7% • New Trend • Alleviates traffic congestion • Reduces highway capacity	• Obsolete waterway infrastructure • Having diverse range of clients • Ability to accommodate emission requirements • Optimum capacity utilization

With these aspects in mind, it is essential to integrate highway and waterway transportation as stated by the USDOT's National Freight Policy Framework (USDOT, 2006). This integration is further discussed in the next section.

4.3.1. Ohio's Waterway Transportation

Ohio is a maritime state surrounded by 716 miles of navigable waterways and is 8th in the Nation for total tonnage moved. Ohio's maritime ports and river terminals handle over 103 million tons of commodities which values $11 billion worth of cargo per year generated by the Lake Erie and Ohio River System. The Lake Erie system has 265 miles of coast line that transports 40.6 million tons of commodities with a value of $3.6 billion worth of cargo. The Ohio River has 451 miles of coastline and carries 63 million tons of commodities with a value of $7.4 billion worth of cargo. This study only considers the Ohio River, and specifically, the Mid-Ohio River valley region (ODOT, 2004).

Ohio River terminals provide a pathway to the Gulf and Pacific Ocean by using the Panama Canal, thereby invigorating business transactions in Ohio (ODOT, 2010). The Panama Canal promotes shipping via the Ohio River and provides a cost effective access to global and domestic markets. Additionally, due to a change in global supply chain causing national freight congestion to become a prominent issue, there is an opportunity for the Ohio River to expand waterborne transportation. Moreover, the Ohio River eases congestion, and the statistics indicate that the Ohio River carries an equivalent of 58 million highway truck trips per year. Also, the statistics indicate that if the Ohio River's cargo is redirected from highway and rail routes into Ohio River's waterways, truck traffic on interstates would diminish by 50% and rail tonnage would decrease by 25%. Therefore, an optimal balance is needed for efficient transportation integrated system (ODOT, 2012).

Ohio River water ports provide a convenient access to other transportation modes such as highways and rails terminals; and therefore, serve as important intermodal connectors. Figure 19 shows the total ports of Ohio River considered in our study (lower portion of the map).

Figure 19: Ohio River Water Ports (ODOT, 2004)

In terms of inter and intra state regional analysis, the Ohio River serves these states: Kentucky, Indiana, Ohio, West Virginia and Pennsylvania as shown in Figure 16.

4.3.2. Ohio River Study Area Terminals

The local highway and interstate connectivity is also an important parameter to consider for intermodal transportation systems. Figure 20 illustrates the interstates and highways in the study area depicted in red.

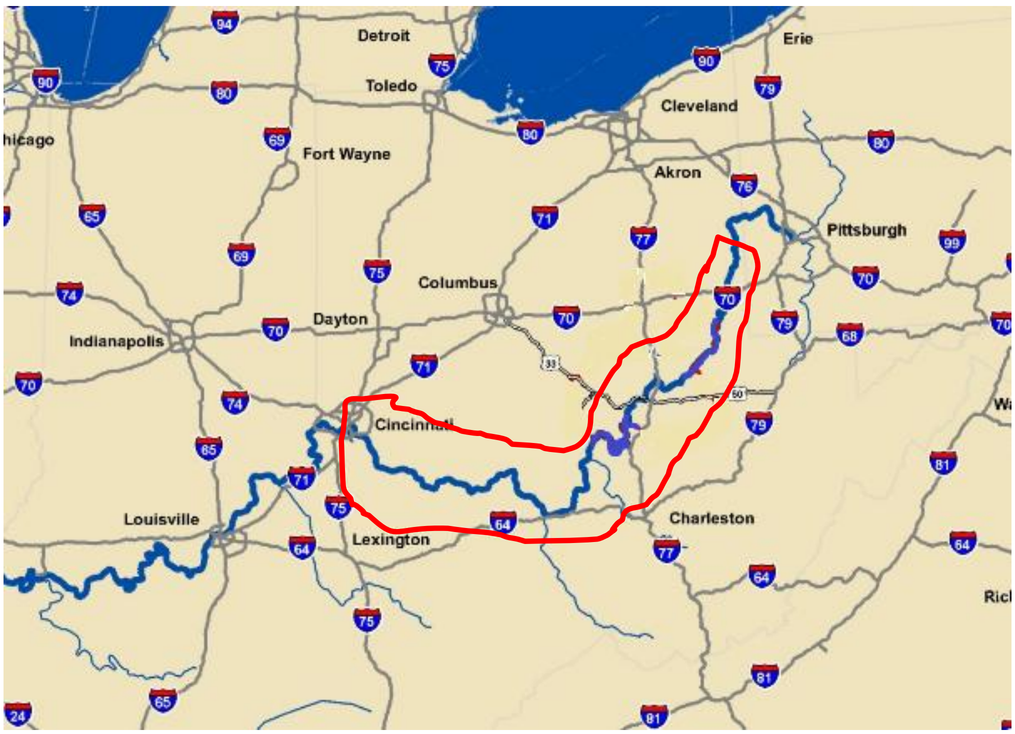


Figure 20: Highway and Interstate Connectivity of Study Area

The terminals along the Ohio River are clustered into three regions: the Cincinnati region, Portsmouth-Marietta and West Virginia- Panhandle (Ohio River Terminals Analysis, Ohio State Wide Freight Study, 2013). The characteristic of these regions are described briefly below.

4.3.2.1. Port of Cincinnati

The Cincinnati terminal is the main terminal that has barge, truck, rail loading and unloading opportunities. I-71, I-74, and I-75 converge in the region, and I-275 fortifies the flexibility for routing opportunities (River Trading Company, 2015). The terminal stretches along a mile of the Ohio River. The Port of Cincinnati has a mix of cargo specialties including dry bulk and packaged commodities. General cargo and fuel are the primary products transported from this port. The terminal has three barge unloading docks and one barge loading dock. The total ground storage capacity is 200,000 tons (River Trading Company, 2015). The terminal's annual capacity is 1.5 million tons of coal, and 2 million tons of bulk material per year. Ten acres of outside storage and 57,000 sq. ft. of inside storage is available and can handle multiple commodities at the same time (River Trading Company, 2015). Figure 21 shows the Port of Cincinnati.

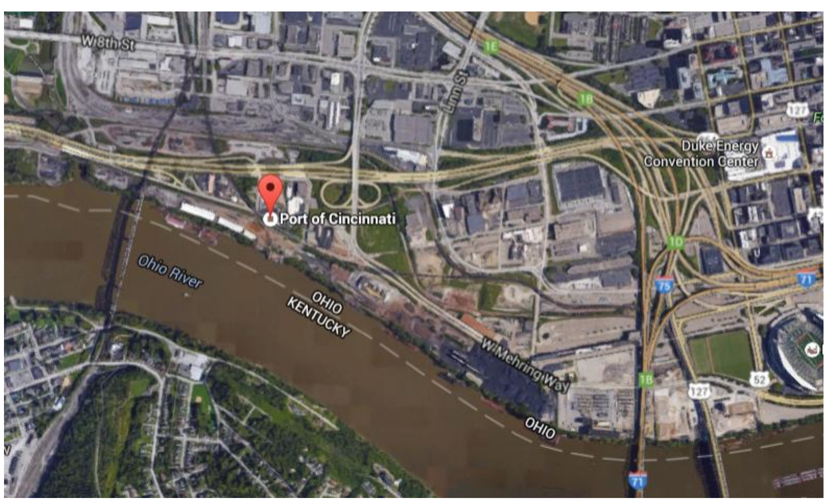


Figure 21: Port of Cincinnati

4.3.2.2. Port of Huntington- Tristate

The Port of Huntington in West Virginia (WV) is one of the biggest inland ports in the United States. Approximately 80 million tons of cargo ($5.3 billion of cargo) is moved through the Port of Huntington, WV. Among the cargo, 60% is coal and 30% is petroleum/chemical products. The port is situated along 100 miles of the Ohio River, 90 miles along the Kanawha River and 9 miles of the Big Sandy River. Based on the 2010 data, 461 commercial vessels per month use the Port of Huntington (National Waterways Council, 2014; US Army Corps of Engineers, 2012). Figure 22 illustrates the Port of Huntington.

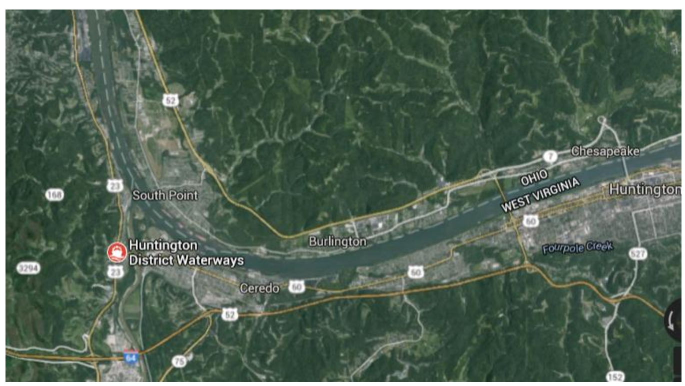


Figure 22: Port of Huntington, WV

The Port of Huntington has close access to I-64 and sits in the intersection of US 23 and US 52. Interstate-64 provides an efficient access to multiple corridors. In addition, I-64 provides a convenient access point to the I-77 North-South corridor (The Point Industrial Park, 2011). The Port of Huntington accommodates 15 jumbo-sized barges. For comparison purposes, this equals two and a quarter trains and 900 trucks (Rosenberger, 2010).

4.3.2.3. South Point Intermodal Terminal

The South Point, Ohio terminal is situated on a 500 acres Ohio land. The terminal is capable of handling multiple transportation modes (rail, truck, and barge). Three vessels can be handled for loading and unloading purposes. The facility has a dock load capacity of over 300 tons each lift (Alten, 2009).

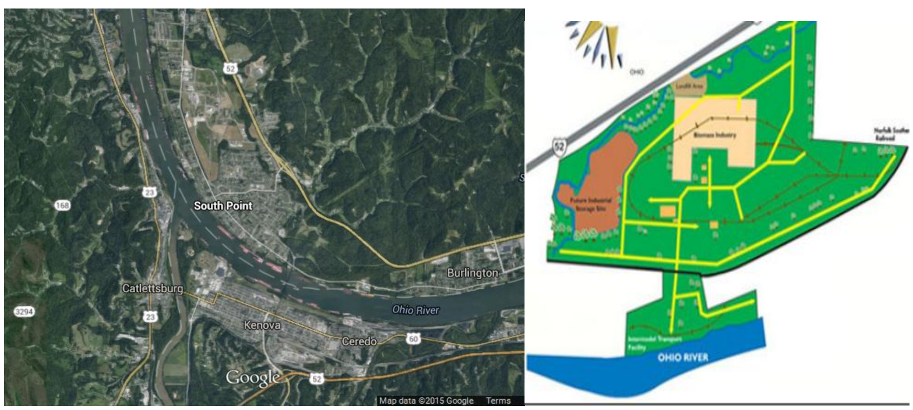


Figure 23: South Point Intermodal Terminal
(The Point Industrial Park, 2011)

The commodities are transported via US 52. The terminal has a capacity of six barges and two cranes to load and unload barge items (Alten, 2009). In conclusion, the South Point is a truly multimodal facility for the facilitation of cargo movement between river, interstate and rail.

4.3.2.4. Belpre Intermodal Terminal

The Belpre Intermodal Terminal is situated on 160 acres of land along the Ohio River. The terminal connects to OH SR 7 and US 50. The location provides convenient access to rail, truck and waterways. The terminal has a capacity of 6,000 tons of silo, three acres of concrete stockpile area and 10 acres of coal storage area. This terminal offers various commodity handling opportunities as well. Figure 24 shows the location of Belpre Intermodal facility (The Price Inland Terminal, 2013).

Figure 24: Belpre Intermodal Terminal (The Price Inland Terminal, 2013)

The facility has 9000 feet of river frontage with barge mooring facilities, 3 docks (each with a 100-ton crane), 3 front end loaders, a barge loading and unloading facility, 1000 feet portable conveyors, and 1000 feet stationery conveyors and a belt sampler system. Unlike others, Belpre Intermodal Terminal is operated by the private sector, and ownership is held by private parties (The Price Inland Terminal, 2013). This terminal also has an important role in moving a variety of goods and services along the Mid- Ohio Valley region.

4.3.2.5. Wellsville Intermodal Terminal

The Wellsville Intermodal Terminal is situated on the northern point of the Ohio River and near the Ohio State Route 7. It provides intermodal truck access to locations north and west of the Ohio River. The commodities are diverted from barge to truck or rail for outbound transportation. The main locations are, Pittsburg, PA at 46 miles, Cleveland, OH at 95 miles, Buffalo, NY at 209 miles and Detroit, MI at 250 miles. Figure 25 illustrates the Wellsville facility (Wellsville Terminals Co., 2014).

Figure 25: Wellsville Intermodal Terminal
(Wellsville Terminal Co., 2014; O'Brien, 2013)

The Wellsville Intermodal Terminal has a capacity of handling of 12-14 barges per month and is expected to grow significantly up to 28 barges a month. The terminal has a 60-ton overhead crane and delivers 200 to 400 trucks a day at the site (O'Brien, 2013). Most importantly, the Wellsville intermodal facility is currently one of the fastest developing facilities within Ohio due to its technological infrastructure and close proximity to large customer locations.

4.3.2.6. The Proposed Minor Port Locations

Integrating minor ports into the intermodal commodity movement is the emphasis of this research effort. The main ports (Cincinnati, OH and Huntington, WV) serve as the gateway to the Gulf of Mexico, Oceans and major urban areas across the Midwest region via rail and interstates. The intermodal distribution terminals provide service to the Ohio Valley Region via rail, state routes and some interstates. The primary focus of the minor ports is to serve local areas via trucks traveling along state and local roadways. The primary effort is to propose the best location, number and allocation decisions for inland ports to facilitate domestic trade activity within the Ohio River Valley. In the system, the assumption was that the containers will be transported to the minor ports by truck from the local distributors and then delivered via barges to intermodal terminals for distribution to the region or to main ports for distribution to major urban areas or international trade. Using intermodal terminals, the commodities will be going to their final destinations. Significant reductions in vehicles miles traveled (VMT), congestion, air pollution and other aspects (see next section for details) in the Mid-Ohio River Valley region are expected as a result of this integration.

The proposed minor ports include: Wheeling, WV, Moundsville, WV, Proctor, WV, New Martinsville, WV, Paden City, WV, Matamoras, OH, Newport, OH, Williamstown, WV, Marietta, OH, Parkersburg, WV, Hockingport, OH, Sherman, WV, Ravenswood, WV, Racine, OH, Pomeroy, OH and Middleport, OH. Point Pleasant, WV, Gallipolis, OH, Glenwood, WV, Rome, OH, Proctorville, OH, Ironton, OH, Sciotoville, OH, Portsmouth, OH, Vanceburg, KY, Manchester, OH, Marysville, OH, and Ripley, OH. If implemented as ports, these locations can offer many benefits. The locations were determined based on economic development and wealth, population, available workers, costs, increased revenues and potential social benefits.

Moreover, these ports were selected based on the physical infrastructure, proximity to the river, time required to move through the commodity, labor availability, and tax considerations. Minor ports could not be considered in these locations due to serious maintenance and infrastructure renovations (facility upgrade, technology upgrade) in order for them to be utilized effectively. Therefore, truck distribution is only considered at the minor ports to/from local areas. Ohio River distribution diagram is shown in Figure 26.

Figure 26: Ohio River Distribution Diagram

5. PROPOSED SOLUTION METHODOLOGIES

The main emphasis of this study is the determination of the optimal locations for docks and transportation routes for different commodities. This is optimally done by mathematical modeling approach. The State of Ohio’s Inland Waterway system is the central focus. Mathematical model and associated heuristic approach are proposed to find optimal solutions. One of reasons to propose both approaches was to present the trade-off between two approaches in terms of solution quality and time. Another reason was to support that a heuristic approach can be also used an alternative optimization methodology. The following two sections discuss each model including parameters, limitations and assumptions.

5.1. Mathematical Model

LINGO 15.0 optimization studio is used for solving the Mathematical Model. The objective function is to minimize total transportation and the total fixed cost of the system; it is given in Equation (1). Each main port has a certain capacity that cannot be exceeded as shown in Equation (2). Equation (3) guarantees that minor port capacity is not exceeded. Equation (4) guarantees each demand constraint is satisfied. Equation (5) ensures that each intermodal terminal/customer zone must be served by a single minor port. Equation (6) ensures to open the port if it serves to the intermodal terminal, and Equation (7) is the binary constraint, i.e. it is either ―1―selected” or ―0―not selected”.

Notation:

Indices:

i *product index*

j *main port index*

k *minor port index*

l *intermodal terminal index*

Parameters:

I *number of products*

J *number of main ports*

K *number of minor ports*

L *number of intermodal terminals*

d_{il} *Demand of product i in intermodal terminal zone l*

c_{ijk} *Unit cost of transportation for product i from any main port j to any minor port k*

c_{ikl} *Unit cost of transportation for product i from any minor port to any intermodal terminal l*

f_k *Fixed cost of minor port k*

S_{ij} *Main port capacity for product i at main port j,*

Q_k *Minor port Capacity*

Decision variables:

X_{ijk} *demand flow of product i from any main port j to any minor port k*

y_{kl} *1 if any minor port k is linked to any intermodal terminal zone l, 0 otherwise.*

z_k *1 if any minor port k is open, 0 otherwise.*

Minimize

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} c_{ijk} * x_{ijk} + \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{l=1}^{L} c_{ikl} * d_{il} * y_{kl} + \sum_{k=1}^{K} f_k * z_k \qquad (1)$$

Subject to

$$\sum_{k=1}^{K} x_{ijk} <= S_{ij}, \qquad \forall i, \forall j \qquad (2)$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} x_{ijk} <= Q_k * z_k, \qquad \forall k, \qquad (3)$$

$$\sum_{j=1}^{J} x_{ijk} = \sum_{l=1}^{L} d_{il} * y_{kl}, \qquad \forall i, \forall k, \qquad (4)$$

$$\sum_{k=1}^{K} y_{kl} = 1, \qquad \forall l, \qquad (5)$$

$$y_{kl} \leq z_k \qquad \forall l, \forall k, \qquad (6)$$

$$y_{kl} \in \{0,1\} \qquad \forall k, \forall l, \qquad (7)$$

In terms of the cost perspective of the system, the overarching goal of this research is to minimize the total cost of the system for the public sector. A heuristic approach is also implemented along with the aforementioned Mathematical Model. Both will be explained in the next section.

5.2. Mathematical Model Limitations & Assumptions

In developing the Mathematical Model, assumptions were made regarding the locations of terminals and potential ports, the capacities of the various river transport entities, the types and amounts of cargo, and the transport distances. Also, due to the nature of each problem setting, some limitations are also discussed below:

- Only one product category, warehousing product, was considered.
- Potential port locations were selected based on the proximity to river, highways and land availability.
- Each main port had a certain supply capacity.
    - Cincinnati, OH: 100,000 TEUs/yr.
    - Huntington, OH: 100,000 TEUs/yr.
- Each minor port had a certain capacity constraint.
    - Low Capacity: 48,970 TEUs/yr.
    - Medium Capacity: 78,351 TEUs/yr.
    - High Capacity: 107,731 TEUs/yr.
- Transfer time of cargo between barge, truck and rail were not considered.
- Each intermodal port had a certain demand based on the demand volume transactions.
    - Wellsville, OH: 51,700 TEUs/yr.
    - Belpre, OH: 50,600 TEUs/yr.
    - South Point, OH: 7,700 TEUs/yr.

- River carrying capacity and seasonality factors were not considered.
- Lock carrying capacities were not considered.
- Environmental effects such as impacts on water quality, animal habitat and etc. were not considered.
- Each intermodal terminal was supported by only one minor port.
- Modeling was performed based on the port capacity, travel distances & costs, establishment/fixed cost of ports, demand of intermodal terminals.
- Travel time was not considered due to high correlation with travel distance. However, for every lock a vessel an additional minutes was included for lock maneuvering and water transition once the vessel was secured within the lock.

Modeling assumptions are listed in the subsequent sections.

5.2.1. Terminal and Port Assumptions

As previously mentioned, this research considers the Ohio River region, with a specific focus on the Mid-Ohio Valley Region. This area was selected in accordance with recent research conducted on behalf of the Ohio Department of Transportation for which inbound and outbound freight data was available (Coles and Associates, 2010). As such, the following ports and intermodal terminals were considered the ―manufacturing plant" and ―customer" locations. These cities, which serve as major hubs along the Heartland Corridor, are as follows:

- Cincinnati, OH – river port
- Huntington, WV – river port
- South Point, OH– intermodal terminal

- Belpre, OH – intermodal terminal
- Wellsville, OH – intermodal terminal

As for the minor port locations, the following cities were selected as potential candidates for new port facilities:

- Wheeling, WV
- Moundsville, WV
- Proctor, WV
- New Martinsville, WV
- Paden City, WV
- Matamoras, OH
- Newport, OH
- Williamstown, WV
- Marietta, OH
- Parkersburg, WV
- Hockingport, OH
- Sherman, WV
- Ravenswood, WV
- Racine, OH
- Pomeroy, OH
- Middleport, OH
- Point Pleasant, WV
- Gallipolis, OH

- Glenwood, WV
- Rome, OH
- Proctorville, OH
- Ironton, OH
- Sciotoville, OH
- Portsmouth, OH
- Vanceburg, KY
- Manchester, OH
- Marysville, KY
- Ripley, OH

5.2.2. Inland Waterway Infrastructure Capacities

In determining constraints for the Mathematical Model, the tow capacity, port capacity, and river capacity was considered. In defining tow capacity, the capacities were specified in twenty-foot equivalent units (TEUs) rather than tons since warehousing freight is considered a container on barge shipping. A single TEU refers to a twenty-foot container; thus, a container that is forty feet in length would be considered two TEUs. Each TEU typically holds approximately 26 tons of cargo.

As for Ohio River transport, each tow consists of 15 barges, with each barge capable of carrying 1750 tons of dry bulk freight; therefore, each tow possesses a maximum capacity of 26,250 tons (Coles and Associates, 2010). However, with regards to a container on barge shipping, space was the limiting factor controlling tow capacity, with each fifteen-barge tow capable of transporting 750 TEUs (Southeastern Ohio Port Authority, 2008).

Port capacity depends primarily on three factors: mechanical handling capabilities, storage facilities, and transport capabilities (Eastgate Regional Council of Government, 2013). Existing ports along the Ohio River provided the basis for the derivation of realistic port capacities for optimization. In order to assess the sensitivity and observe port location parameters, three capacity levels were considered. These ports classified as low, medium, or high capacity according to the specifications listed in Table 4. The purpose of considering different level of port capacity scenarios was based upon considering the uncertainty associated with the future. These scenarios were also constructed by considering the changing demand patterns, geographical distribution, population and growth. Also, these levels of port capacity scenarios were considered in order to observe different port selection decisions based on the changing capacity classifications.

Table 4: Mid-Ohio River Port Capacities

Capacity Classification	***Mechanical Handling***	***Storage Facilities***	***Transport Capabilities***
Low	*48,970 TEUs/yr*	*1029 TEUs*	*1 TEU/Truck*
Medium	*78,351 TEUs/yr*	*1646 TEUs*	*1 TEU/Truck*
High	*107,731 TEUs/yr*	*2264TEUs*	*1 TEU/Truck*

Although Table 4 defines capacities in terms of all three factors, only the mechanical handling capabilities dictated the capacity of proposed minor ports for the purposes of this case study.

The river capacity was dictated by the capacity of the locks along the river. Each lock and dam averages one hour per tow through the system. Also, according to The Barge Association, the maximum speed of each barge is approximately 7.5 mph and an average cruising speed approximately 3.7 mph (The Barge Association, 2013). Thus, the time required traveling through the 10 locks between Cincinnati and Wheeling would be considered approximately 72 hours, considering the allowances as well. The locks are capable of accommodating up to 20 fifteen-barge tows per day. These locks are pictured in Figure 27.

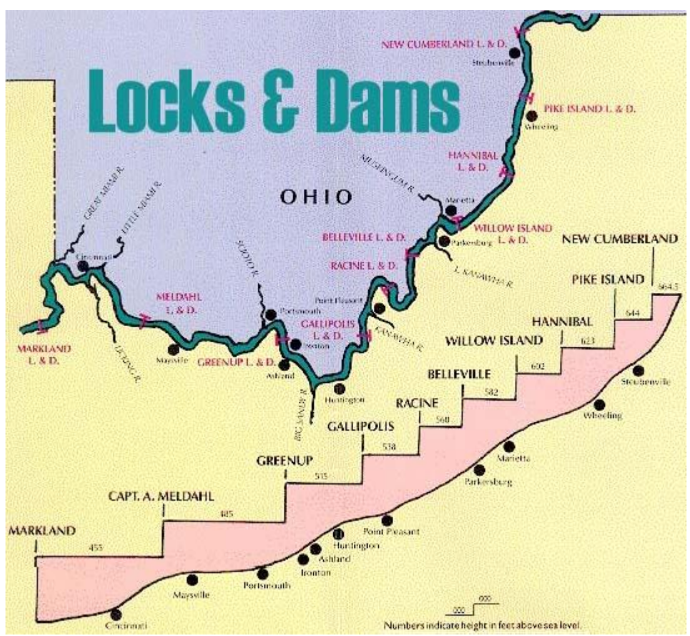


Figure 27: Locks and Dams along the Ohio Valley Region (Neff, 2010)

5.2.3. Cargo Assumptions

Assumptions were also made with regard to the type of cargo that will be considered in this case study. After reviewing the various inbound and outbound commodities for the region, warehousing freight was selected as the cargo of choice for this study. This decision was made on the basis of three factors. First, the overall value of the cargo was considered, which $5,222,916,547 and $20,812,124,247 was for outbound and inbound shipments, respectively. Second, the percentage of this cargo currently transported by truck was considered such that river transport would be able to effectively reduce truck traffic. As for warehousing freight, 100% of the 3,204,409 tons of inbound and 804,164 tons of outbound cargo is transported via trucks (Coles and Associates, 2010). Thus, if this freight could be transferred via container on barge shipping instead, a considerable reduction in truck traffic would be experienced. Finally, due to the fact that warehousing freight was constituted of non-perishable containerized consumer goods, these products can be manufactured early and will not require expedited shipping. In consideration of these three factors, this type of cargo was a prime candidate for containers on barge shipping.

This research will only consider the outbound freight that needs to be transferred through the region to the intermodal terminals since information regarding the exact destination of inbound freight was ambiguous. As such, the demand shall be set at 804,164 tons/yr (110,000 TEUs/yr) and the supply shall be equal to the demand. All of the supply will originate from the Cincinnati and Huntington ports, which will provide equal amounts of supply (50% each), respectively. Due to the fact that warehouse freight was currently only shipped via trucks, these percentages were derived from the proportion of each port's capacity to the total capacity of both ports combined. The demand at each intermodal terminal was assumed to be 47%, 46%, and 7% for

Wellsville, Belpre, and South Point, respectively (Coles and Associates, 2010). These percentages were based upon the final destinations of cargo to Canada and regions in the United States, assuming that cargo through the aforementioned intermodal terminals will end up in the following locations:

- Wellsville, OH → Central Midwest, Northeast, Midwest, West Pacific, and Canada
- Belpre, OH→ West Mountain and West South Central regions
- South Point, OH → South Atlantic and East South Central

5.2.4. Transportation Distances and Costs

In order to optimize the minor port locations, transport distances and the corresponding costs were determined. Due to the fact that the cargo would be transported through multi-modal means, river mileage was obtained for the tows and roadway mileage was obtained for the trucks. As such, the distances from the main ports to each proposed minor port were derived upon the basis of the Ohio River mileage. Similarly, the distance from each proposed minor port to the intermodal terminals assumes transport will take place along the major routes. All distances considered in this study, which are given in miles, have been compiled in Table 5.

Table 5: Transport Distances between Minor Ports, Main Ports, and Intermodal Terminals (distances in miles)

Potential Minor Port Locations	Main Ports (road)		Intermodal Terminals (river)		
	Huntington	Cincinnati	South Point, OH	Belpre, OH	Wellsville, OH
Wheeling WV	205	231	228.9	92.9	17.8
Moundsville WV	176	242	218.1	82.1	28.6
Proctor WV	156	260	200.3	64.3	46.4
New Martinsville, WV	152	265	191.8	55.8	54.9
Paden City, WV	144	238	186.3	50.3	60.4
Matamoras, OH	135	255	177.6	41.6	69.1
New Port, OH	123	218	163.8	27.8	82.9
Williamstown, WV	112	208	158.3	22.3	88.4
Marietta, OH	106	202	148.5	12.5	98.2
Parkersburg WV	95.1	192	134.5	1.5	112.2
Hockingport, OH	84.5	181	120.3	15.7	126.4
Sherman, WV	73.6	183	102.5	33.5	144.2
Ravenswood, WV	70.2	179	98.9	37.1	147.8
Racine, OH	72	169	77.8	58.2	168.9
Pomeroy, OH	59.2	156	69.3	66.7	177.4
Middleport, OH	57.1	156	67.3	68.7	179.4
Point Pleasant, WV	42.2	151	54.5	81.5	192.2
Gallapolis, OH	39.3	148	50.3	85.7	196.4
Glenwood, WV	22.4	168	33.5	102.5	213.2
Rome, OH	73.8	84	16.6	119.4	230.1
Proctorville, OH	4.7	154	14.5	121.5	232.2
Ironton, OH	19.8	132	7.2	143.2	253.9
Sciotoville, OH	40.4	118	29.2	165.2	275.9
Portsmouth, OH	46.2	104	35.6	171.6	282.3
Vanceburg, KY	60.8	89.6	57.5	193.5	304.2
Manchester, OH	87.2	73.8	69.5	205.5	316.2
Maysville, KY	88.5	62.9	86.7	222.7	333.4
Ripley, OH	99.6	52.5	96.4	232.4	343.1

With the transportation distances determined, costs were assigned to each link from main port to minor port and minor port to intermodal terminal. The cost calculations assume a variable cost of \$0.97/ton-mile and \$5.35/ton-mile associated with transporting freight via barge tows and trucks, respectively (Eastgate Regional Council of Government, 2013). These costs were then multiplied by the distances provided in Table 2 and converted from tons to TEUs to obtain the cost/TEU for each possible link in the network, which is summarized in Table 6. An additional cost that was also considered in this study was the fixed cost for each potential minor port. Without access to specific fixed cost data for ports, the fixed cost was based upon costs associated with similar existing port facilities along the Ohio River. In terms of determining the fixed cost, or the total investment cost of a port, tax incentives were considered. It is assumed that the less populated areas have lower taxes and densely populated locations have higher taxes. The cost of establishing a fully functional port in the highest populated city was set at $500,000, and it changes based on the population parameter (Eastgate Regional Council of Government, 2013).

Table 6: Variable Cost of Transport along Network Links (in $/TEU)

Potential Minor Port Locations	Main Ports		Intermodal Terminals		
	Huntington	Cincinnati	South Point, OH	Belpre, OH	Wellsville, OH
Wheeling WV	42.18	47.53	8.54	3.47	0.66
Moundsville WV	36.22	49.80	8.14	3.06	1.07
Proctor WV	32.10	53.50	7.47	2.40	1.73
New Martinsville, WV	31.28	54.53	7.16	2.08	2.05
Paden City, WV	29.63	48.97	6.95	1.88	2.25
Matamoras, OH	27.78	52.47	6.63	1.55	2.58
New Port, OH	25.31	44.86	6.11	1.04	3.09
Williamstown, WV	23.05	42.80	5.91	0.83	3.30
Marietta, OH	21.81	41.57	5.54	0.47	3.66
Parkersburg WV	19.57	39.51	5.02	0.06	4.19
Hockingport, OH	17.39	37.24	4.49	0.59	4.72
Sherman, WV	15.14	37.66	3.82	1.25	5.38
Ravenswood, WV	14.45	36.83	3.69	1.38	5.51
Racine, OH	14.82	34.78	2.90	2.17	6.30
Pomeroy, OH	12.18	32.10	2.59	2.49	6.62
Middleport, OH	11.75	32.10	2.51	2.56	6.69
Point Pleasant, WV	8.68	31.07	2.03	3.04	7.17
Gallapolis, OH	8.09	30.45	1.88	3.20	7.33
Glenwood, WV	4.61	34.57	1.25	3.82	7.95
Rome, OH	15.19	17.28	0.62	4.45	8.58
Proctorville, OH	0.97	31.69	0.54	4.53	8.66
Ironton, OH	4.07	27.16	0.27	5.34	9.47
Sciotoville, OH	8.31	24.28	1.09	6.16	10.29
Portsmouth, OH	9.51	21.40	1.33	6.40	10.53
Vanceburg, KY	12.51	18.44	2.15	7.22	11.35
Manchester, OH	17.94	15.19	2.59	7.67	11.80
Maysville, KY	18.21	12.94	3.23	8.31	12.44
Ripley, OH	20.49	10.80	3.60	8.67	12.80

Based on the aforementioned input parameters, both models will be solved and the results will be discussed in the following section.

5.3. The Proposed Heuristic for the Inland Waterway Transportation

Heuristic approaches are specifically designed for the problem settings. In this research, a heuristic is proposed for finding the optimal number, location and allocation decisions of the ports, and the total transportation cost of the system. The following are the steps for the proposed heuristic:

Step 1: Calculate shipping costs of all product demands from minor ports to intermodal terminals.

Step 2: Construct a two-dimensional matrix by calculating the total cost of each minor port-intermodal terminal link for products

Step 3: Now we have the total costs of minor port-intermodal combinations that includes sum of all products. It is now decide which intermodal terminals should be opened. This is called the First Round in the heuristic.

Step 4: A threshold value is calculated for each customer whether it is worth to assign that minor port to that intermodal terminal. Threshold value is calculated by max-min average shipping costs that are calculated in step 3.

Step 5: Once step 5 is performed, check whether the cheapest total cost of minor port-intermodal terminal combination is worthwhile to be linked, in the meantime the capacity of the minor ports are checked.

Step 6: If the capacity is available and it is worthwhile to assign intermodal to port, then assign it and opened that port. If not, hold that intermodal terminal in the reserve list.

Step 7: Continue with the second intermodal terminal and check again whether the cheapest total cost of port-intermodal combination is worthwhile to be linked while checking the capacity. If the capacity is full, check the next cheapest total cost of port-intermodal combination.

Step 8: Assign if it is worthwhile to assign compared to threshold. If it is not worthwhile, hold that intermodal terminal in the reserve list.

Step 9: Perform steps 6-7-8 until all intermodal terminals are either assigned or hold in the reserve list. It is now time to perform The Second Round of the heuristic, which is called the assignment of unassigned intermodal terminals from the reserved list.

Step 10: Select the highest total shipping cost of intermodal terminal from the reserved list and start assigning that intermodal to the available port.

Step 11:Based on the selected customer in step 11, calculate total system cost by adding the total shipping cost with the total minimum cost of major port-minor port combination for each product to find the total cheapest cost of that minor port-intermodal combination.

Step 12: If the calculated total cheapest value combination for that minor port is previously opened, then assign it if the capacity is available. If capacity is not available, check the next total cheapest value combination and assign it if that minor port is previously opened and capacity is available. If aforementioned rules are not met, open a new minor port and assign that customer.

Step 13: Perform steps 11-12 for the rest of the unassigned reserved list intermodal terminals.

Step 14: Since each and every customer is satisfied by the corresponding minor port, it is time to determine major port-minor port combination.

Step 15: Calculate the cost combination for each major and minor (with its corresponding products) and connect the cheapest major-minor combination.

Step 16: Now calculate the total system-wide cost (total shipping costs from major ports to minor ports and total shipping costs from minor ports to intermodal terminals)

Step 18: Terminate

6. OPTIMIZATION RESULTS

The analysis was conducted with the Mathematical Model and the heuristic model to determine the optimal locations of minor ports such that demand would be satisfied, supply would not be exceeded, and total costs would be minimized. Both models also yielded the amount of TEUs that would need to be transported through each selected route. Three different scenarios based on low, medium, and high minor port capacities were considered to observe different port location decisions within the region. The Mathematical Model coded in LINGO 15.0 is presented in Appendix A.

6.1. Low-Capacity Scenario

First, low port capacity was considered, for which each proposed port location could only transfer 50,000 TEUs/yr. Based upon this assumption, new port facilities were opened at Proctorville-OH, Ironton-OH, and Ripley-OH. These results appear to be fairly intuitive, as the proximity of these three locations to major highway networks such as U.S. Route 52 and I-64 minimize the truck transport costs. The flow of TEUs through each proposed minor port is summarized in Tables 7 and 8. This set of results yielded a total cost of $3,044,137.

Table 7: TEU Transfer from Major Ports to Minor Ports with Low Capacity

Main Port	Proposed Port Location	Flow - TEU's
Cincinnati, OH	28-Ripley, OH	50,600
Huntington, WV	21-Proctorville, OH	51,700
	22-Ironton, OH	7,700
	Total	**110,000**

Table 8: TEU Transfer from Minor Ports with Low Capacity to Intermodal Terminals

From Proposed Port	To Intermodal Terminal Location	Flow - TEU's
21-Proctorville, OH	3- Wellsville, OH	51,700
22-Ironton, OH	1-South Point	7,700
28-Ripley, OH	2-Belpre, OH	50,600
	Sum of Demand	**110,000**

The commodity flow diagram from each main port to intermodal terminal via minor ports is illustrated in Figure 28, Figure 29 and Figure 30, respectively. The black line denotes the truck transportation and blue color denotes the barge transportation for the region.

Figure 28: Flow of Commodities from Cincinnati to Belpre via Ripley Minor Port

In Figure 28, the warehousing freight is shipped by truck from the origin destination, Cincinnati, OH main port to Ripley, OH and travels along the Ohio River via a tow of barges to its final destination – Belpre, OH intermodal facility.

Similarly, Figure 29 illustrates the flow of warehousing freight that is shipped from Huntington, WV main port to Proctorville, OH minor port facility by truck and from there, the commodities are transported via barges to their final destination Wellsville, OH intermodal facility.

Figure 29: Flow of Goods from Huntington, WV to Wellsville, OH via Proctorville, OH

Also, Figure 30 shows that the commodities are shipped from Huntington, WV facility to South Point, OH terminal via Ironton, OH facility.

Figure 30: Flow of Goods from Huntington, WV to South Point, OH via Ironton, OH

6.2. Medium-Capacity Scenario

Similar optimization was conducted considering a medium port capacity of 80,000 TEUs/yr. This modification in the minor port capacity reduced the number of port locations to two (Proctorville and Ripley), which also reduced the total cost to $2,522,374. The flow of TEUs from the major ports through the minor ports to the intermodal terminals is compiled in Tables 9 and 10.

Table 9: TEU Transfer from Major Ports to Minor Ports with Medium Capacity

Main Port	Proposed Port Location	Flow - TEU's
Cincinnati, OH	28-Ripley, OH	50,600
Huntington, WV	21-Proctorville, OH	59,400
	Total	**110,000**

Table 10: TEU Transfer from Minor Ports with Medium Capacity to Intermodal Terminals

From Proposed Port	To Intermodal Terminal Location	Flow - TEU's
21-Proctorville, OH	1- South Point, OH	7,700
21-Proctorville, OH	3- Wellsville, OH	51,700
28-Ripley, OH	2- Belpre, OH	50,600
	Sum of Demand	**110,000**

Figure 31 clearly illustrates that the flow of warehousing freight shipments are shipped from Cincinnati, OH facility to Ripley, OH facility by trucks and then transferred and transported via barges to its final destination to Belpre, OH intermodal facility terminal. Figure 32 shows the flow of goods from Huntington, WV main port terminal to Proctorville, OH by using trucks and then transferred and shipped to South Point, OH intermodal terminal by using barges. Figure 33 also shows the flow of goods from main port to minor port by trucks and then shipped via barges to reach its final destination.

Figure 31: Flow of Goods from Cincinnati, OH to Wellsville, OH via Proctorville, OH

Figure 32: Flow of Goods from Huntington, WV to South Point, OH via Proctorville, OH

Figure 33: Flow of Goods from Huntington, WV to Wellsville, OH via Proctorville, OH

6.3. High-Capacity Scenario

The final optimization analysis performed with the model considered minor ports with a high capacity of 110,000 TEUs/yr. Coincidentally, this scenario assumes that the minor ports have a capacity equivalent to the total amount of TEUs that need to be transferred in order to satisfy customer demands. Thus, this optimization analysis only opened a port in Proctorville-OH through which all cargo would be transferred. The cost associated with this scenario was $2,416,415.

Table 11: TEU Transfer from Major Ports to Minor Ports with High Capacity

Main Port	Proposed Port Location	Flow - TEU's
Cincinnati, OH	21-Proctorville, OH	36,052
Huntington, WV	21-Proctorville, OH	73,948
	Total	**110,000**

Table 12: TEU Transfer from Minor Ports with High Capacity to Intermodal Terminals

From Proposed Port	To Intermodal Terminal Location	Flow - TEU's
21-Proctorville, OH	1- South Point, OH	7,700
21-Proctorville, OH	2- Belpre, OH	50,600
21-Proctorville, OH	3- Wellsville, OH	51,700
	Sum of Demand	**110,000**

The computation time for all of these scenarios takes several seconds in LINGO 15.0 optimization software. Figure 34 illustrates that goods are transported from Huntington, WV to Proctorville, OH minor facility by truck, and then transferred to barges to reach Belpre, OH intermodal facility.

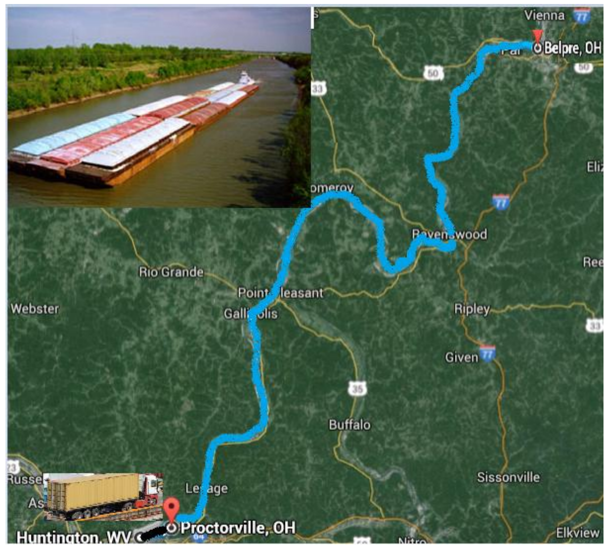


Figure 34: The Flow of Goods Huntington, WV to Belpre, OH via Proctorville, OH

Figure 35 shows that goods are transported from Cincinnati, OH to Proctorville, OH minor facility by truck and then transferred to barges for their final destination to Wellsville, OH.

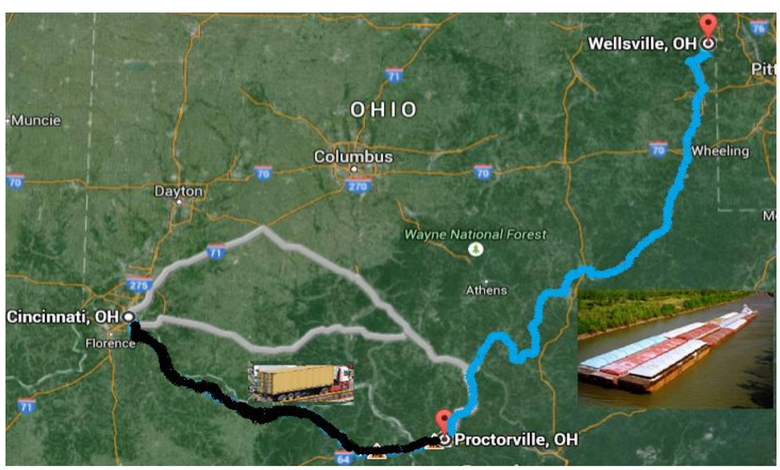


Figure 35: The Flow of Goods from Cincinnati, OH to Wellsville, OH via Proctorville

Figure 36 illustrates that the warehousing freights are shipped by trucks from Huntington, WV to Proctorville, OH minor facility and then transferred to barges to reach its final South Point, OH intermodal destination.

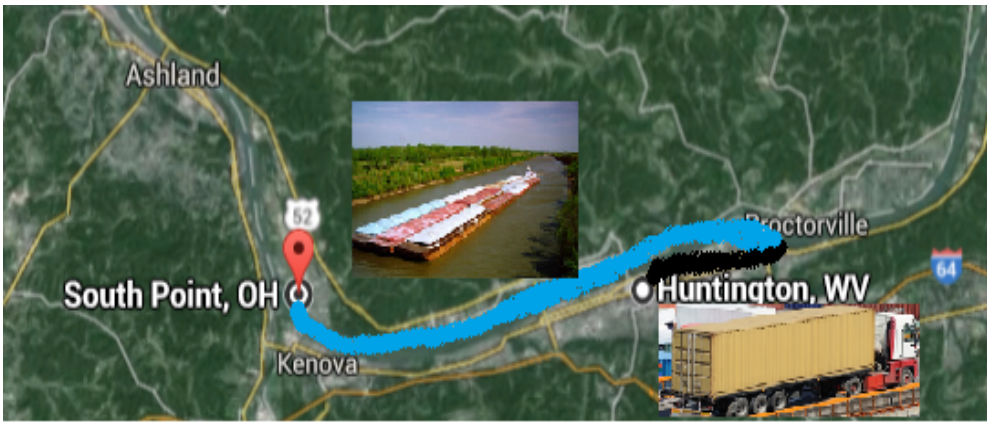


Figure 36: The Flow of Goods from Huntington, WV to South Point, OH Proctorville, OH via Proctorville, OH

6.4. Overall Findings

The overall optimization results--opened minor ports as well as the flow of goods from main ports to intermodal terminals via minor ports--revealed that the trucks were heavily used for short haul distances and the barges are used for long haul transportation. The overarching goal of this research was satisfied by optimal location of minor ports to alleviate the truck traffic congestion within the region. One of the primary objectives was to consider barge transportation for longer haul distances to minimize the truck freight costs as well as relieve the highway congestion and maximize the overall quality of life for the Mid-Ohio Valley region. As shown, the primary goal of this research was satisfied.

6.5. Comparison of the Model Results (Mathematical Model vs. Heuristic)

The results of the Mathematical Model were discussed in the aforementioned sections. Since heuristics are designed specifically for problem settings and the proposed heuristic in section 5.3 was designed for the Mathematical Model and the problem at hand, both results were identical. The scope of our study consisted of two main ports, twenty-eight proposed minor port locations and three intermodal terminals, as well as the number, location and allocation decisions. All the profits associated with each scenario were same; however, the solutions might change on different problem sizes and scopes.

Heuristic approaches are developed for cases where mathematical models cannot solve larger problems in a timely fashion, or rather, cannot find any solutions due to limited capacity. In such cases, although heuristics do not guarantee optimal solutions, they are fast procedures and are used for finding solutions in a timely manner. All in all, since the scope of our study is well-established and defined, the heuristic here found the solutions in even less than one second with exactly the same results as the mathematical model. The overall findings of both models are shown in Table 13.

Table 13: Summary of Model Results

	Capacity Scenario	Mathematical Model	Heuristic
The Proposed Port Locations	Low (50,000 TEU/yr)	21-Proctorville, OH 22-Ironton,OH 28- Ripley, OH	21-Proctorville, OH 22-Ironton,OH 28- Ripley, OH
	Medium (80,000 TEU/yr)	21-Proctorville, OH 28- Ripley, OH	21-Proctorville, OH 28- Ripley, OH
	High (110,000 TEU/yr)	21-Proctorville, OH	21-Proctorville, OH
Total Cost ($)	Low	$3,044,137	$3,044,137
	Medium	$2,522,374	$2,522,374
	High	$2,416,415	$2,416,415
Computation Time (hour)	Low	00:00:03:15	00:00:01:02
	Medium	00:00:02:56	00:00:00:52
	High	00:00:01:34	00:00:00:44
Gap (%)		0%	0%

Although the computation time difference is negligible for our models, the proposed heuristic solves faster than the Mathematical Model.

6.6. Discussion of Model Results and Sensitivity Analysis

The optimization results of different scenarios show that the capacity decisions determine the port locations. When low-capacity restrictions exist in minor port locations, more ports are open and able to cover the demand in the region. Since more ports are open, a higher total cost is observed. On the other hand, when there is a large-capacity in minor port locations, fewer ports are needed to cover the demand in the region. Therefore, the number of opened facilities significantly affects the total cost of the system. Specifically, in high capacity scenario, only Proctorville, OH facility is located within the region. The highest total cost is observed in low capacity scenario where Proctorville, OH, Ironton, OH and Ripley, OH minor port facilities are open to facilitate the flow around the region.

A sensitivity analysis is conducted to observe the effects of different parameters on the model and a solution quality. Although the sensitivity of the model is tested by changing port capacities, it is observed that changing port capacities significantly affecting the number of opened ports and overall cost of the system. Moreover, a sensitivity analysis is also conducted among ports to assess which port has significantly affected the solution quality and the total cost of the system. Assuming that the minor port is shut down or no longer in service (while the others are in service), the total cost savings is compared based on the original solution. Figure 37 shows the sensitivity results for low-capacity scenario. All in all, the sensitivity analysis aims to justify which ports provides the highest cost savings and more importantly than the other selected minor port locations.

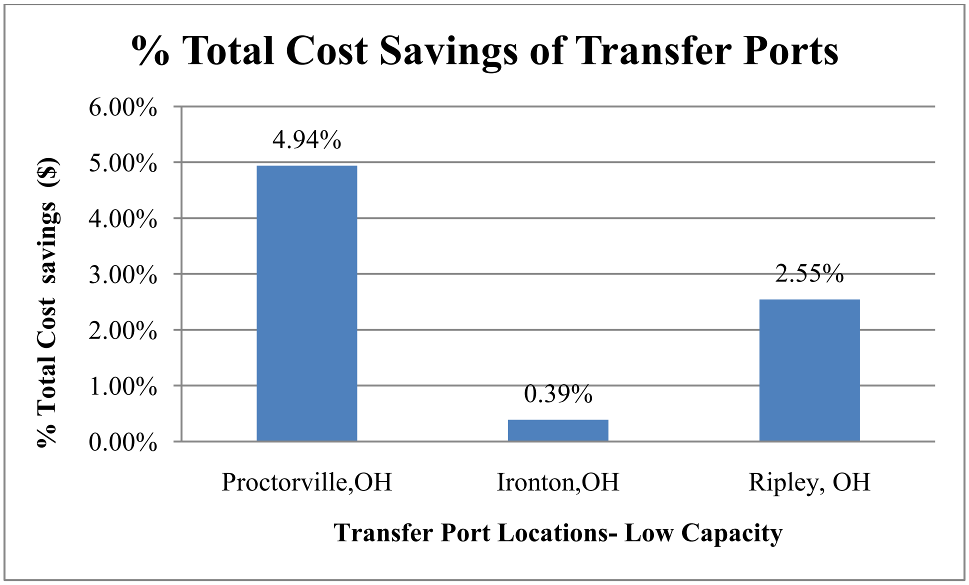


Figure 37: % Total Cost Savings of Minor Ports

The sensitivity results indicated that if the Proctorville, OH port is shut down, the total cost would be $3,194,653- 4.9% increase- from the original total cost value. Secondly, if the Ironton, OH minor facility is shut down, the cost would slightly increase by 0.39% from the original total cost value. Thirdly, if Racine, OH facility is shut down, the total cost would be $3,056,945 with an increase of 2.55% compared to existing solution. In conclusion, based on the current situation in a low capacity scenario, Proctorville, OH minor port facility is located in a more critical place than the others for total cost savings of the public sector investment.

7. CONCLUSIONS & FUTURE DIRECTIONS

This research was performed with the overall objective of optimizing minor port locations such that inland waterway transport could become a more preferable and viable alternative to conventional truck transport. In doing so, a mathematical model was developed whereby port locations were selected such that the total cost of transportation and investment was minimized. The mixed integer mathematical model and the proposed heuristics were then utilized for optimization, considering three levels of minor port capacities. Based upon this optimization, the number of port locations necessary to accommodate the inflow and outflow of warehousing freight ranged from one to three for the various port capacity levels. For low port capacities, Proctorville, OH, Ripley, OH and Ironton, OH were identified as optimal port locations. However, as port capacity increased to medium and high levels, the number of port locations dropped to two and one, respectively. Of the three locations identified for low capacity levels, Proctorville, OH and Ripley, OH were retained for medium capacity levels. At the high capacity level, only Proctorville, OH was selected for a proposed port facility.

Since the heuristic model was specifically designed for the current problem setting and the mathematical model, it provided exact optimal solutions within faster computation time. Moreover, the conducted sensitivity analysis indicated that among the most open minor port facilities, Proctorville, OH transfer port facility provides the highest total cost savings, located on the critical location for inflow and outflow of goods around the region.

The primary objective of this thesis was achieved by using barges for long haul transportation instead of truck freights. Therefore, truck traffic, congestion, truck-related fatalities and CO2 emission around the region will be diminished, whereas the quality of life, safety and utilization of existing water resources will be increased.

While these results represent a step forward in the quest to reduce roadway traffic congestion by utilizing inland waterway transport, several other factors will need to be considered in future works. In terms of future work, the following suggestions can be investigated. The mathematical model developed for this case study can be improved by obtaining more exact data regarding the fixed costs of investment, operation and maintenance for each port location. Furthermore, the model could also be expanded to include smaller shipments from the minor ports to minor distribution centers and customers within the counties that comprise the study region. As more information is gathered, the model can be modified to consider each individual type of product that is currently considered part of warehousing freight as well as the manufacturing schedules and customer due dates. Once the model has been validated again following the inclusion of these factors, the study region can be expanded to consider additional waterways in the inland waterway system. For instance, the smaller navigable waterways within the Ohio River system might be considered as potential routes for distributing goods to specific customers with each region. Furthermore, the model could also be applied on a larger scale to include the entire the Mississippi River system as a whole such that freight may be more readily accessible for barge travel.

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APPENDIX: LINGO MATHEMATICAL MODEL CODE

```
MODEL:
! CAN'S OHIO RIVER PORT LOCATION MODEL;
SETS:
! one products;
  PRODUCT/ A/;
! Two ports;
  PLANT/ P1, P2/;
! Each minor port has an associated fixed cost, F,
  and an "open" indicator, Z.;
  DISTCTR/ DC1..DC16/: F, Z, Q;
! Three intermodal terminals;
  CUSTOMER/ C1, C2,C3/;
! D = Demand for a product by a intermodal terminal.;
  DEMLINK( PRODUCT, CUSTOMER): D;
! S = Capacity for a product in a port;
  SUPLINK( PRODUCT, PLANT): S;
   ! Each intermodal is served by one minor port,
  indicated by Y.;
  YLINK( DISTCTR, CUSTOMER): Y;
! C= Cost/ton of a product from a port to a minor port,
  X= tons shipped.;
  CLINK( PRODUCT, PLANT, DISTCTR): C, X;
! G= Cost/ton of a product from a minor to a intermodal;
  GLINK( PRODUCT, DISTCTR, CUSTOMER): G;
ENDSETS
DATA:
! Port Capacities;
S = @OLE ('data3', 's'); !port capacities
! minor CAP;
Q = @OLE ('data3', 'k');
! Shipping costs, port to transfer;
C =  @OLE ('data3', 'pdc');
! Minor port fixed costs;
 F = @OLE ('data3', 'f');
! unit cost of transportation, minor to intermodal;
 G =@OLE ('data3', 'dcc');
! Intermodal Demands;
 D = @OLE('data3', 'demands');
ENDDATA
!----------------------------------------------------;
! Objective function minimizes total costs.;
 [OBJ] MIN = SHIPDC + SHIPCUST + FXCOST;
 SHIPDC = @SUM( CLINK: C * X);
 SHIPCUST =
  @SUM( GLINK( I, K, L):
   G( I, K, L) * D( I, L) * Y( K, L));
 FXCOST = @SUM( DISTCTR: F * Z);

! Port capacity;
 @FOR( PRODUCT( I):
  @FOR( PLANT( J):
   @SUM( DISTCTR( K): X( I, J, K)) <= S(I, J))
```

```
);
! Minor port CONSTRAINT;
 @FOR( DISTCTR( K):
   @SUM( PRODUCT( I): @SUM( PLANT( J): X( I, J, K)))<= Q
 );
! Minor balance constraints;
 @FOR( PRODUCT( I):
  @FOR( DISTCTR( K):
   @SUM( PLANT( J): X( I, J, K)) =
    @SUM( CUSTOMER( L): D( I, L)* Y( K, L)))
 );

! Intermodal Demand;
  @FOR( CUSTOMER( L):
  @SUM( DISTCTR( K): Y( K, L)) = 1
 );

! Force Minor K open if it serves intermodal L;
 @FOR( CUSTOMER( L):
  @FOR( DISTCTR( K): Y( K, L) <= Z( K))
 );

! Y binary;
 @FOR( DISTCTR( K):
  @FOR( CUSTOMER( L): @BIN( Y( K,L)))
 );

END
```