The Economics of a Bi-State Ferry

Final Report

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1. Executive Summary

This study investigated the economic feasibility of a roll-on, roll-off trailer ferry linking Milwaukee, Wisconsin and Muskegon, Michigan using a set of western origination cities and eastern destination points. An operational model and corresponding economic model was developed and analyzed using computer simulation. This simulation modeling approach allowed the capture of the inherent variability and intangible elements of the process and the reporting of a realistic, long term expected estimate of the financial expectation of the truck ferry operation. The primary objective of the study was to determine if a trailer ferry operation could be financially feasible in removing trailers from the heavily congested Chicago interstate highway corridor.

An experimental design procedure was used in the simulation model with parameters representing the ferry capacity, the cost of a barrel of oil, and the Harbor Maintenance Tax. Additionally, fourteen elements representing fundamental system operational costs were included in the roll-on, roll-off ferry model. Performance metrics, expressed in per trailer moved units included total cost, total transit time, transit time variability, and fuel consumption.

This research project concluded that trucking is a very efficient industry and that a trailer ferry across Lake Michigan could be financially feasible only under a set of given conditions. In eighty-eight percent of the scenarios tested, the truck mode was more cost efficient with an average per trailer difference of $445. In twelve percent of the scenarios tested, the ferry mode was more efficient with an average per trailer difference of $158. Depending on the capacity of the ferry, expected payback period was determined to be in the range of seven months to 75 years.

The Harbor Maintenance Tax was analyzed as a design parameter and it was shown that if the tax did not exist, the ferry mode would be more cost effective in thirty-two percent of the scenarios.

The cost of fuel did not significantly impact the results since the distance of the trips between the cities with and without the ferry were of similar length. Trips with a ratio of less than .70 were more cost effective by ferry, suggesting that the amount of distance the ferry operates is an important design factor.

The project investigated the cost differential between the modes across all experimental design parameters and concluded that if a subsidy were to be provided to incentivize the development of a ferry, the necessary range would need to be $356 to $535 per trailer moved.

The conclusions reached by this project were consistent with findings from similar studies and anecdotal evidence provided by a number of industry personnel. The project made important contributions in the development of a methodology to further investigate the intangible impact of congestions, weather, and incidents on congested traffic corridors.

2. Introduction

Infrastructure is the basic building block of economic activity, development, and growth. An enabling infrastructure is a critical ingredient to creative sustained economic growth. Ray LaHood, United States Department of Transportation Secretary recently remarked “One of President Obama’s top priorities making sure that we strengthen and revitalize our transportation sector – including our waterways. The President and I are looking for new and creative ideas that will enable us to move goods more efficiently, conserve energy, protect the environment, and ensure we can compete globally in the 21st century.” In this research project, a natural infrastructure, the Great Lakes, is investigated as a supplement to a congested artificial infrastructure, the Interstate Highway system, through the use of a short-sea shipping concept.

The supply chain of the American economy consists of the movement of raw materials, components, and finished products across a vast infrastructure that includes ports, railroads, and interstate highways. With the growth of the global economy over the last few decades came an increased amount of intermodal traffic that used a combination of trucks and trains to move standardized containers of goods offloaded from large ocean vessels. This led to an increase in the amount of trucks on the highways. Trucks, while a necessary and critical component of the economy, create congestion and impose large social and environmental costs to society.

The objective of this project is to investigate the impact that a roll-on, roll-off trailer ferry across Lake Michigan would have on routes that necessitate travel through the I90/I94 Chicago corridor. The ferry operation would be a classic case of short-sea shipping, which is popular in the European Union. Ferry operations can have beneficial impact on the transportation system by providing congestion, environmental, and safety relief. Chicago, known as the Crossroads of America, is experiencing severe traffic congestion. The Chicago corridor is ranked as the third worst congested area in the United States and the worst area for long haul freight movement [13]. This congestion causes increased wear and tear on the highway, increased costs to truckers in terms of time and fuel, increased time to commuters, increased frequency of incidents and the ripple effects of these incidents, and an increase in CO_2 to the atmosphere. Despite the obvious economics of moving freight by rail, trucking remains the dominant mode. A large portion of the truck traffic in the Chicago vicinity is simply passing through, as evidenced by Figure 2.1. Estimates of the annual number of trucks passing through the region that could potentially use this ferry from the Wisconsin and Michigan Departments of Transportation ranged from 800,000 to 1,300,000. Thus, any bypass method, including the use of a ferry operation that could alleviate congestion would be of interest to planners, investors and policy makers. Throughout the duration of the project, anecdotal evidence from a number of stakeholders continually reinforced the feasibility and need for a ferry operation, but for the concept to become a reality, the economics need be feasible as well.

This project analyzes the economic and operational feasibility of the operation of a roll-on roll-off trailer ferry between Milwaukee, Wisconsin and Muskegon, Michigan in terms of the impact of avoiding the congested Chicago corridor.

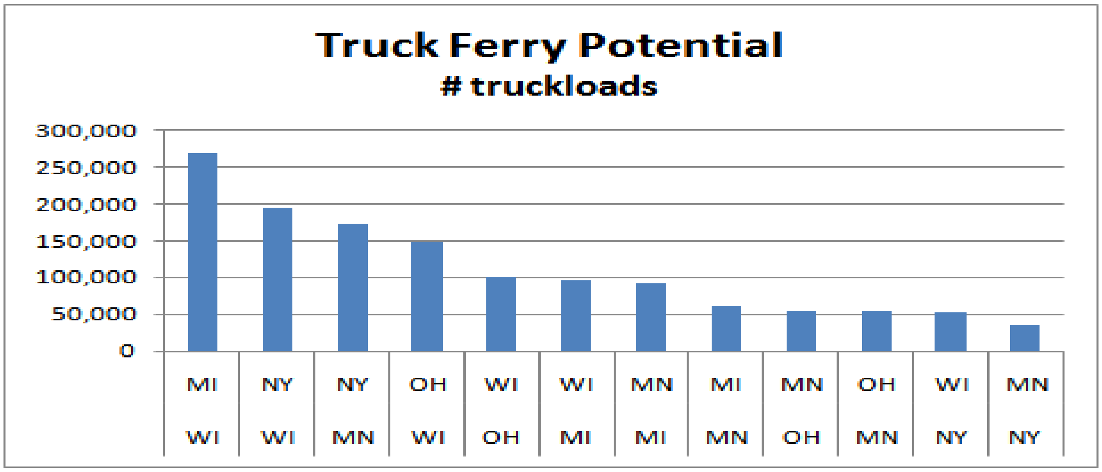


Figure 2.1 Truck Ferry Potential

Traffic flow carried out over any infrastructure is subject to a large amount of variability. This variability is compounded by the interdependencies of the infrastructure, weather, other traffic, and numerous other factors. Predictive models of traffic flow must be able to accurately depict variability effects and factor them into the analysis being carried out. For this project, a computer simulation model of the truck and ferry operation was developed. Computer simulation is the ideal tool for the analysis of dynamic systems. It can provide accurate, long term estimates of performance metrics of interest. For this project, the simulation model is used to generate realistic performance estimates of time, reliability, cost, and fuel usage of transit between a set of origin/destination points for truck and combined truck/ferry modes.

The scope of this project was limited to a geographic area that a semi-truck could traverse within a twelve hour period that required passage through the Chicago corridor. The cities of Minneapolis, MN, Madison, WI, Milwaukee, WI, Lansing, MI, Toledo, OH, and Detroit, MI were chosen for the study and an analysis of the movement between the combinations of the west and east cities using the ferry operation was performed. Figures 2.2 and 2.3 illustrate the routes between Minneapolis, MN and Detroit, MI using the conventional interstate highway route and the proposed ferry route.

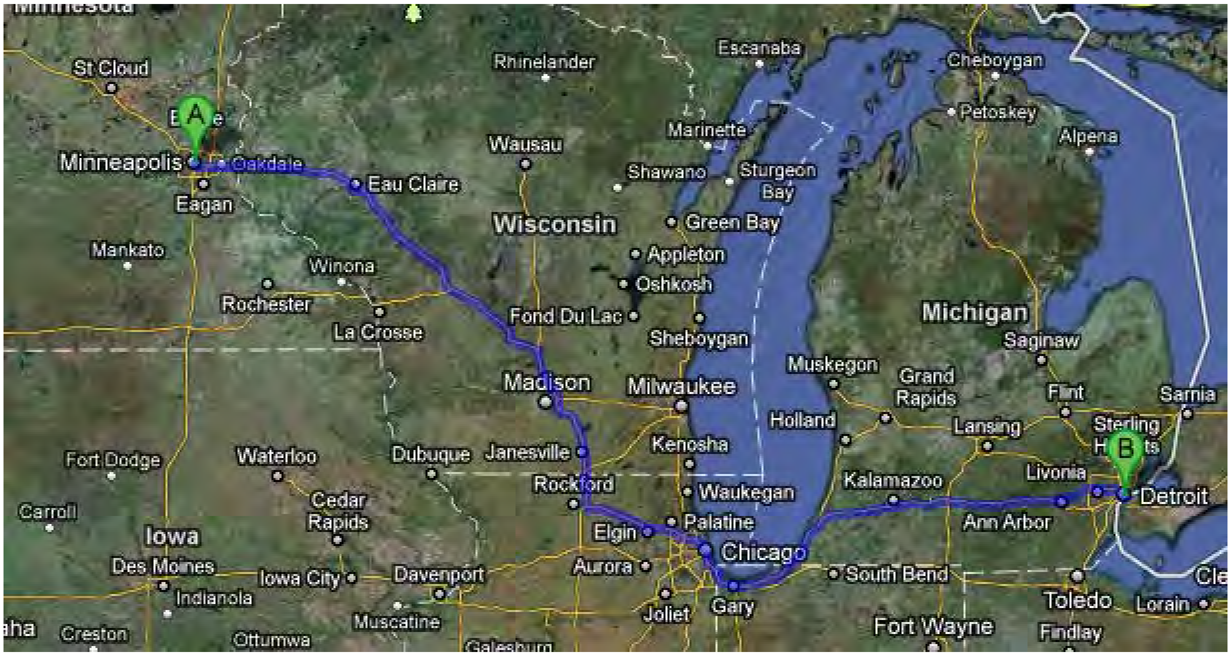


Figure 2.2 Minneapolis to Detroit Truck Route

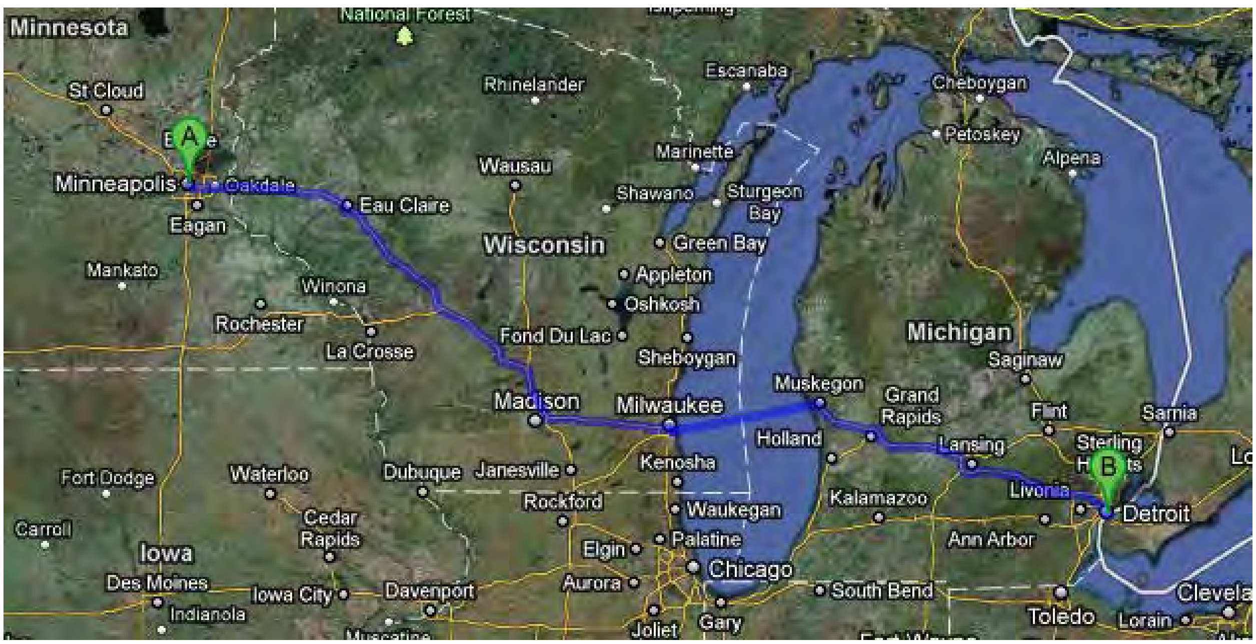


Figure 2.3 Minneapolis to Detroit Ferry Route

The process of the proposed ferry operation in this study is that of a roll-on roll-off operation in which, for example, an eastbound semi delivers a trailer to an area at the port where it awaits the ferry. The driver and the tractor is not a part of the ferry operation, and in a steady state operation, ideally would pick up a westbound trailer that has been delivered by the ferry. Once the ferry arrives, the trailers would be loaded onto the vessel by a stevedoring or port crew. This process would then be repeated on the other side of the lake.

The ferry vessel chosen for the analysis of this project is of a tug and barge type. While this type of vessel is slower and smaller than a dedicated ship, it is significantly cheaper from a capital investment perspective.

A computer simulation model was constructed and used to capture and fully represent the minute by minute operational detail of trailer movement between the origin and destination cities by traditional truck transport and the combined truck/ferry method. By its nature, simulation modeling technology can capture minute details of any complex system. To accurately compare the performance characteristics of the two systems in terms of cost, reliability, time, and fuel usage, numerous cost elements for the transport modes were considered and built into the model. These elements are described in Table 2.1.

Table 2.1 Cost Elements

Transportation Mode	**Cost Elements**
Truck Travel	MPG Driver Style Cost of Fuel Driver Cost Truck Operating/Maintenance Cost Tolls DOT regulations
Ferry Travel	Ferry Crew Ferry Costs Fuel Harbor Maintenance Tax Stevedoring Storage Insurance

The animation screen of the simulation model is shown in Figure 2.4.

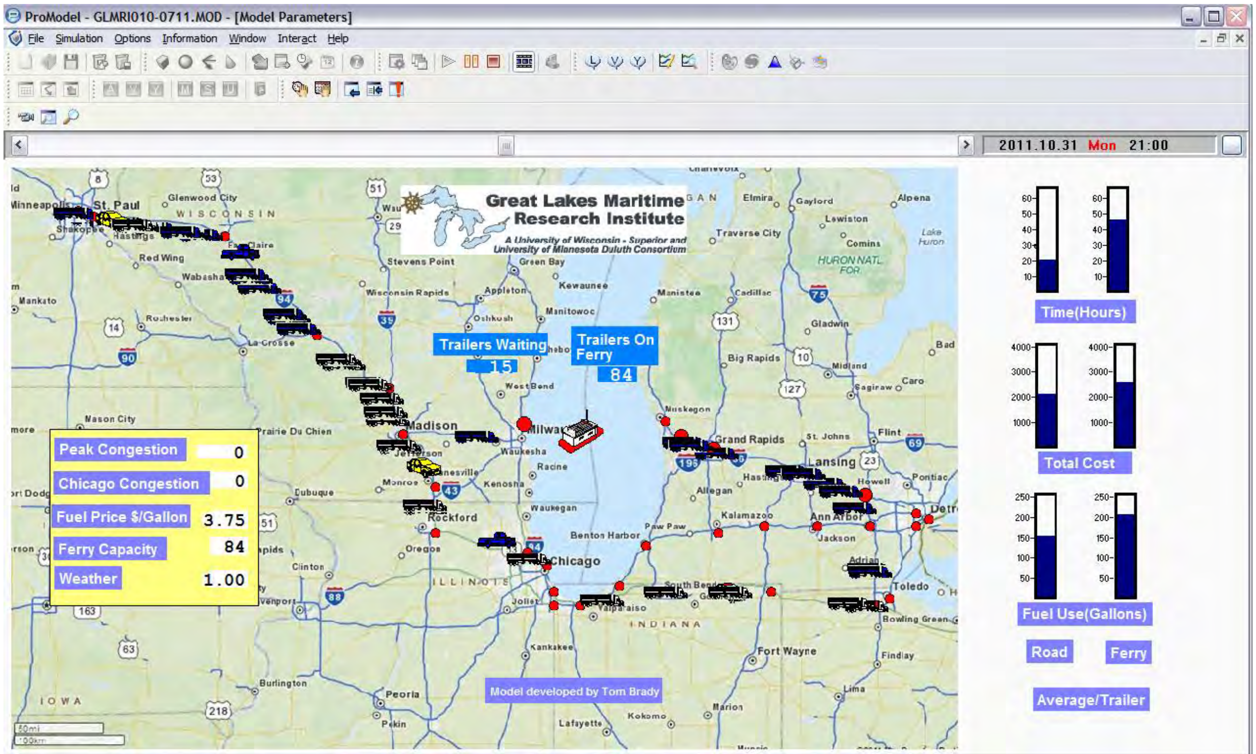


Figure 2.4 Computer Simulation Animation Screen

During the conceptualization and development of the project, three issues arose concerning the collection and application of critical cost and operational aspects of the proposed system. These issues included the Harbor Maintenance Tax, the Chicago corridor speeds and the price of oil. The resolution of how to represent these elements into the analysis reinforced the methodology and validity of this study and thus the results obtained. In any system where variability and volume exist, the calculation of long term performance estimates are dependent on the fidelity of the input data.

The Harbor Maintenance Tax [HMT] has been a controversial issue since it was enacted in 1986 as part of the Water Resources Development Act. The tax was originally created to offset the cost of channel maintenance dredging by the US Army Corps of Engineers. Opponents contend that it will render waterway movements economically unviable while proponents contend that it will fund necessary upkeep and improvements, thus increasing economic potential. Current estimates indicate that the Trust Fund has a balance of over 3 billion dollars, indicating that revenue is more than offsetting spending. Proposals for ferry-type services and other water-borne methods have long cited that Harbor Maintenance Tax is a major discouragement for the use of water transport of domestic cargoes. The Harbor Maintenance Tax & Congestion Relief **B**ill authored in 2005 suggested that a waiver of the HMT for certain cargoes be enacted to stimulate the use of vessels in short-sea shipping locales. This bill, ultimately defeated, suggested that short-sea shipping would not be viewed as competition to trucking, but would increase the capacity of the nationwide transportation system. The bill even went so far as to identify that barges would be the ideal vessels for short-sea shipping. Additionally, the bill noted that the start-up of short-sea shipping is difficult to commence, particularly in untested markets, and the waiver of the HMT would be a cost-effective method of subsidization.

The current HMT rate is set at .125% of the value of the cargo. To accurately include this on a trailer by trailer basis, the model required that each trailer be assigned a cargo value. Using data from the American Trucking Association, it was estimated that the average value of the cargo in a trailer in 2010 was $550,000. Applying the HMT based on these figures would incur a cost of approximately $700 per trailer, putting the ferry cost at a significant disadvantage. However, data from the Army Corp of Engineers estimated that an average HMT of $137 per trailer was realized in 2010. Due to the uncertainty and difficulty in capturing accurate data, the HMT was set as an experimental design parameter for the project.

The Chicago corridor portion of route consists of approximately 85 miles. To approximate normal and congested conditions, the INRIX Travel Tax time method was built into the model using figures from the 2010 INRIX report [13]. Subsequent meetings with personnel from the Chicago Metropolitan Agency for Planning revealed that the INRIX figures significantly underestimated observed congestion effects. The Chicago Metropolitan Agency for Planning provided the study with a very detailed set of hourly speed figures at each milepost of the Chicago corridor highway system. These values were summarized and included into the model. Figure 2.5 shows a summary of the average speed by hour of the day along the Chicago corridor.

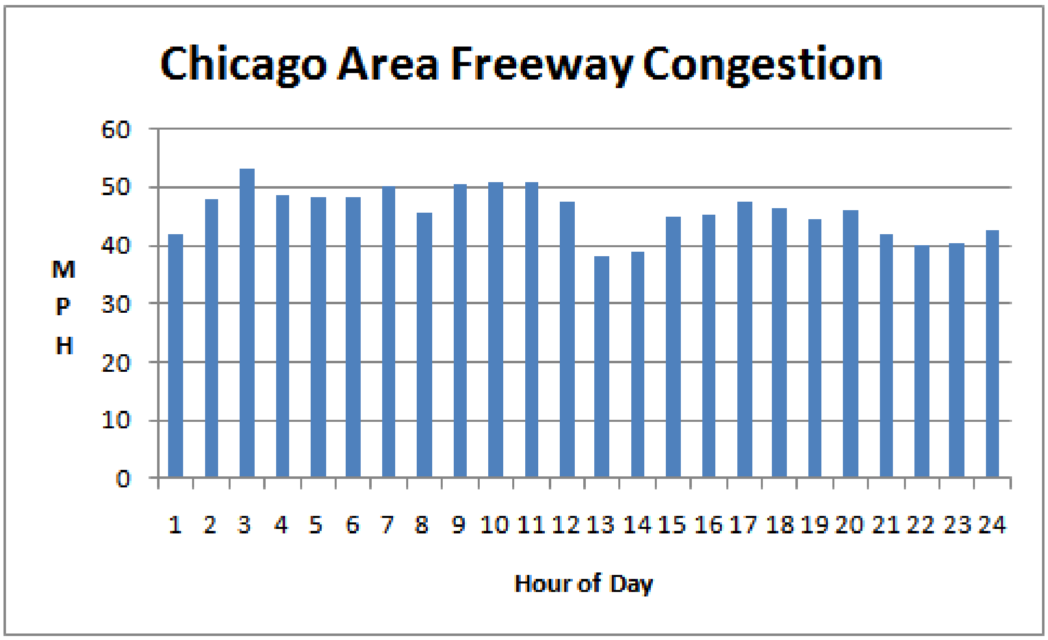


Figure 2.5 Chicago Area Freeway Congestion

The price of oil is one of the basic measures of the world economy. As Figure 2.6 shows, it was relatively stable throughout history until the 1970's, resulting in the development of and reliance upon a transportation infrastructure dominated by trucking. Since then, extreme oil price variation has been common, resulting in numerous policy debates at the governmental level and fear and uncertainty for those industries dependent on oil. Expert opinion about the future price of oil indicates that extreme volatility and a long term increase in the price will be the norm rather than the exception. Figure 2.7 displays the volatility of the price of a barrel of oil during the period of May 2011 through March 2012. For the purposes of this project, select values for the price of a barrel of oil were chosen based on these two graphs.

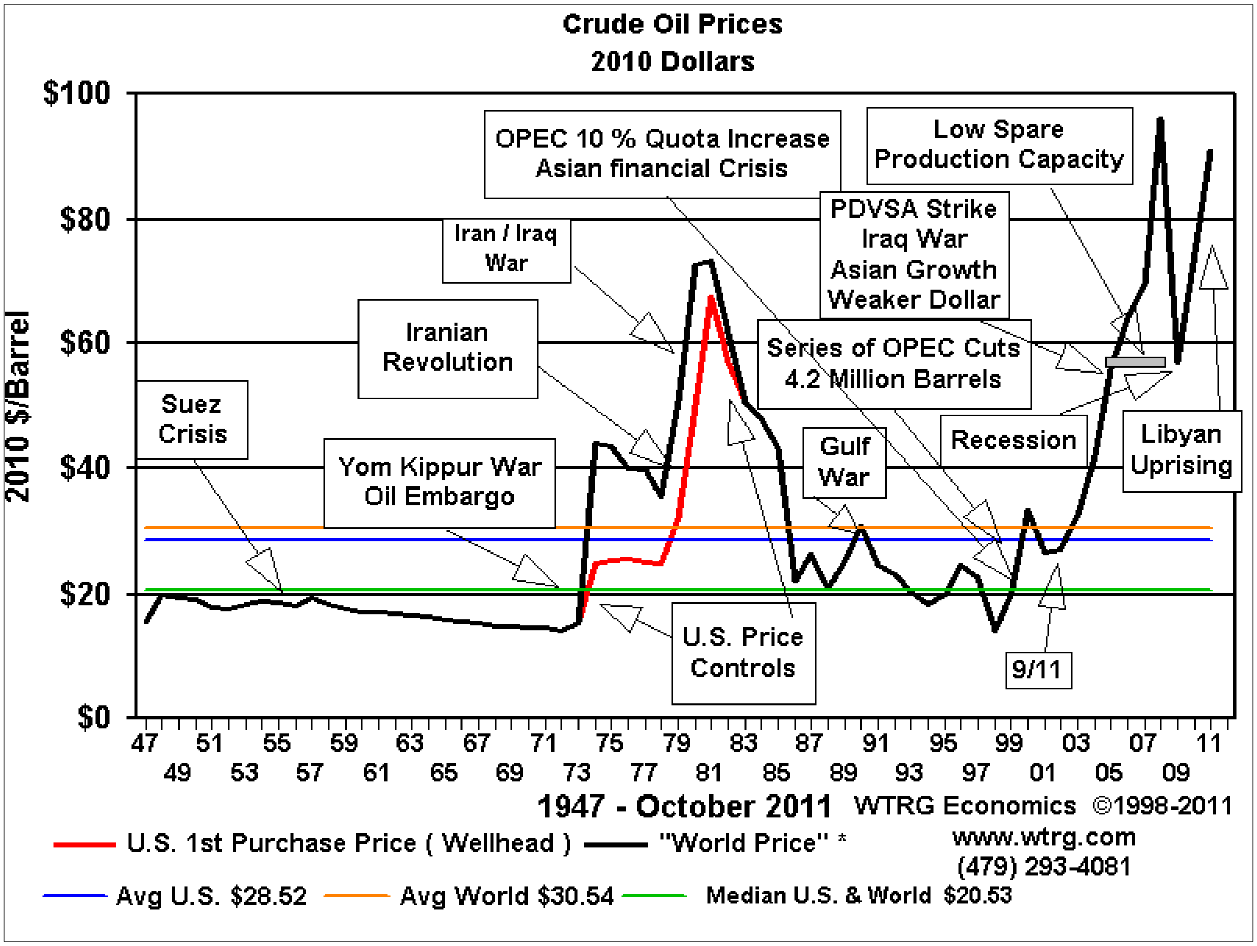


Figure 2.6 Historic Crude Oil Prices

Figure 2.7 Crude Oil Prices: May 2011 – March 2012

The comparison of the truck versus truck/ferry operation is based upon four performance metrics: transit time, cost, fuel usage, and reliability. Each metric is expressed in terms of a single trailer unit. The transit time is the total elapsed time to move a trailer from origin to destination. The cost is the sum of all costs to move a trailer from origin to destination. The fuel usage is the sum of all fuel used to move a trailer from origin to destination. The reliability measure is the standard deviation of the transit time to move a trailer from origin to destination.

For the ferry portion of the route, the total cost of the ferry trip is allocated on an equal basis to the number of trailers that are on board for the particular trip. The model input assumes that the ferry will attain a capacity utilization rate of approximately ninety percent.

The distance across Lake Michigan from the respective ports is approximately eighty miles. For the set of origin and destination cities, the ferry distance represents between twelve and twenty-three percent of the entire trip. Thus, whichever mode is used, a significant portion of the trip will be made by truck movement. Thus, the project will essentially determine the breakeven point between the cost of a ferry operation and the cost of travelling through the congested Chicago corridor.

This report is organized into eleven sections. Section one presents an executive summary of the project. Section two presents an introduction to the project scope and operational environment. Section three presents a literature review relative to critical elements in the project definition. Section four presents the research plan and methodology. Section five presents a description of the physical system that is analyzed and the translation of that system into a computer simulation model. Section six presents the results and discussion of key findings. Section seven presents an economic analysis of the ferry operation. Section eight presents the conclusions reached by the project. Section nine presents a set of recommendations for expansion of the project. Section ten presents the potential economic impact of the project. Section eleven details the dissemination of project results to date.

3. Literature Review

Ferries have historically been an integral component of the United States transportation infrastructure and continue to provide cost efficient, reliable service to many ports carrying many types of commodities. Figure 3.1 presents a map of ferries that historically operated on Lake Michigan. While most are long out of business ferry operations still exist. For example, The Wall Street Journal recently published a story of a rail car ferry in New York operated by the Port Authority[16], and Canadian National railway operates the Cogema ferry on the St. Lawrence Seaway from Matane to Baie Corneau, ferrying 25 railcars per crossing.

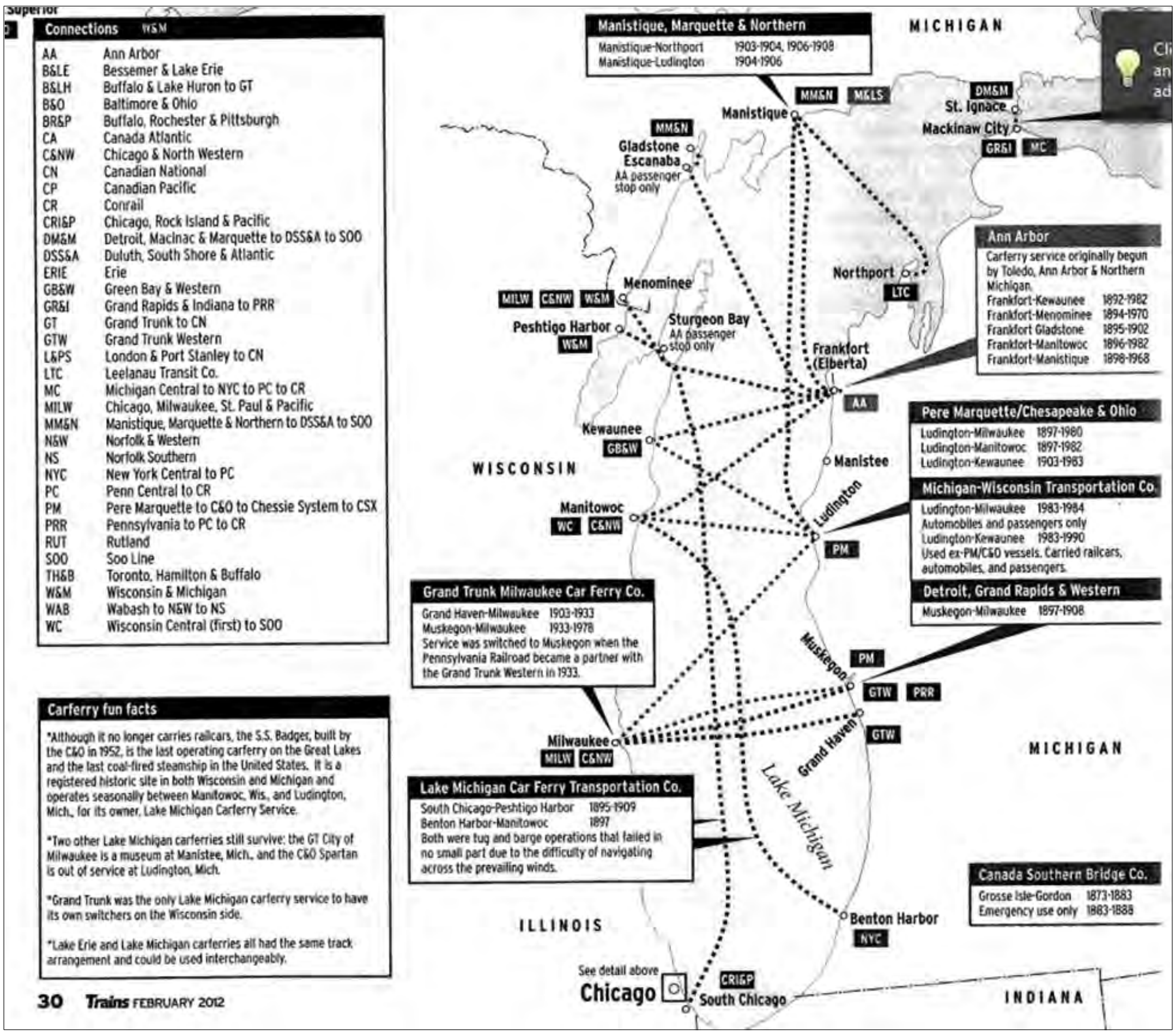


Figure 3.1 Historic Great Lakes Ferries

With the advent of the interstate highway system, inexpensive fuel, and an explosion in the number of tractor trailers, ferry service became less used and now handles less than five percent of typical over the road cargo. However, road congestion, fuel prices, and environmental concerns have opened the door to reconsider ferry operations. Six main sources form the basis for this research project. Summaries of these sources and a conclusion are presented below.

3.1 Four Corridor Case Studies of Short-Sea Shipping Services

In 2006, Global Insight [9] performed a business case analysis of short-sea shipping for the US Department of Transportation. The intent of the study was in response to the inability of the rail and trucking industry to keep up with increased freight demands and to revisit the concept of short-sea shipping to alleviate traffic on the interstate highway system. Along with providing baseline definitions for short-sea shipping, the study developed four in-depth corridor case studies as proof of concept and market feasibility. The Great Lakes corridor was chosen as one of the case studies, and a route from Madison, WI to Detroit, MI was studied, paralleling one of the routes addressed in this study. Although the figures in the study are from the 2003-2006 timeframe, the corridor volumes do support the short-sea shipping concept, though the study points out that the downside for short-sea shipping is that achieving these economies will require the substantial absorption of a large segment of the road freight on specific corridors. This will require some time before the breakeven point is passed." In the case study, a RoRo ferry with a capacity of 200 trailers was used. The economic model made a number of simplifying assumptions about the system and concluded that ferry service could be superior to that of a truck operation in terms of time and cost. The cost advantage was estimated to be in the range of twelve to eighteen percent, assuming that twenty percent of the market could be captured. There was little detail provided in the study concerning the capital cost of the vessel used in the analysis. The study also discussed the potential impact of the Harbor Maintenance Tax and used an assumption that shippers would add a 'mark-up' fee to account for the tax. The study concluded that when certain conditions exist, short-sea shipping can be a viable business proposition. These conditions, including economies of scale with the vessel, 'best-in-class' marine management, and operational routes that avoid congested areas, fit in with the objectives of this study and provide a set of data and assumptions for which to compare results.

3.2 Northwest Indiana Regional Planning Commission Freight Study

The Northwest Indiana Regional Planning Commission (NIRPC) issued a Freight Study in 2010 as part of its Comprehensive Regional Plan titled 2040 CRP[3]. The study, performed in conjunction with Cambridge Systematics, Inc. was aimed to improve freight movement throughout the region which encompasses the largest freight hub outside the coasts. The study noted that "As the volume of passengers and goods moving across aging infrastructure increases, so does the complexity of transportation planning, policy-setting, and decision-making." The study mentioned that the density of the freight infrastructure in the region would be affected by major developments on the horizon including the Panama Canal widening, Eastern US rail capacity improvements, fuel cost uncertainty, and climate change. Freight projections mentioned in the study noted that the percentage of truck share would increase to sixty-six percent in 2035 while waterways would account for four percent of the freight movement. The study concludes that the region should seek methods to reduce freight congestion, including the use of water, noting that "…stakeholders expressed interest in developing short-sea shipping opportunities on the Great Lakes. Key harbors such as Milwaukee, WI and Muskegon, MI could potentially be served by regular lake barge service." They further suggest that due to the efficiency of trucking, it will take some form of subsidy or incentive to fully shift a significant amount of freight to water, noting that "However, to initiate such service, it would likely need to be subsidized, at least initially, to develop the market. Additionally it would be difficult to offer freight rates competitive with trucking. As increased attention is paid to climate change and policy development, incentives could be built in for shipping freight by less polluting modes such as water. Some type of incentive that makes water more financially competitive will be critical to effecting any significant mode shift to water."

3.3 Parameters for a Roll-On Roll-Off Marine Intermodal Service on Lake Superior

This study provided a general overview of the issues present in operating a ferry service on the Great Lakes [19]. The study made general recommendations on what types of ports, terminal facilities, vessels, and chassis systems would be needed for the ferry and provided a detailed investigation of the costs involved in starting up and operating a ferry service. An important conclusion reached by the study was that no physical constraints exist that would prevent the operation of a ferry in the northern portion of the Great Lakes.

3.4 Enabling a Modal Shift to Great Lakes/St. Lawrence Seaway – Ferries Across the Great Lakes – What Does the Future Hold?

In a paper delivered to the Society of Naval Architects & Marine Engineers[21], the author writes about the historical development of ferries and the conditions necessary for success in today's economy. The paper speculates that the "Incan Superior", which hauled forest products as most likely the last operational ferry on the Great Lakes was shut down due to the impact of the Harbor Maintenance Tax. The author concludes that the Harbor Maintenance Tax has a significant cost impact on ferry operations, and estimates that standard 'higher value' truck loads could be subject to taxes of $128 in 1997 dollars. In terms of vessel design, the author notes that design, construction, and operational criteria for ferries in the twenty knot category are well understood. There are regulatory constraints concerning vessels on the Great Lakes, and the author suggests that ferries would operate under the Subchapter K category. Icing conditions on southern Lake Michigan could prove difficult for aluminum hull ferries, thus suggesting that year round operation is not feasible. The author examines current operating ferries on the Great Lakes and provides a review of the "Milwaukee Clipper" Milwaukee to Muskegon service that existed in the 1960's. He speculates that the growing congestion on interstate routes through Chicago has provided the impetus for much study of ferries that could bypass the Chicago area and notes that a solid numerical basis for pricing and passenger has been developed, yet gives no further details. The paper contains a useful section detailing the economic impact of a Niagara to Toronto ferry and notes that the creation of ancillary services at and around the ports could be considerable. In this section, the author alludes to environmental savings that will accrue to society from a ferry operation including pavement wear, accidents, noise, and emissions. He estimates that these benefits would be approximately 6.5 million dollars per year per one million truck trips. There is also an estimate on the amount of CO2, CO, No, and particulate reductions that could be achieved on this route. The author concludes the paper by noting that the most significant opportunities for ferries exist on routes in the lower sections of Lakes Ontario, Erie, and Michigan, yet none of this opportunity will be acted upon "…until the import portion of the Harbor Maintenance Fee is replaced with a non-value based alternative."

3.5 Port of Milwaukee Board of Harbor Commissioners Lake Michigan Trailer Ferry Study

The Port of Milwaukee commissioned a study from the Roethle Group [17] concerning the justification of a trailer ferry linking Wisconsin and Michigan. Findings from the study indicated that the concept of short sea shipping is ripe for exploration given the federal government interest in reducing heavily congested highway and freight corridors such as Chicago. The study provided a preliminary estimate of the potential numbers of trailers available for a ferry operation and noted that the major concern of a ferry operation is schedule reliability. It also noted that "elimination of the Harbor Maintenance Tax would be an incentive." The study concluded that the increases in rail and highway congestion in the Wisconsin, Illinois, Indiana, and Michigan corridor will continue to grow at a rapid pace leading to increased "pain" for all users of the Interstate system. This congestion could be reduced by a ferry system, yet the economics for such a system remain uncertain. The study also referenced a DOT study that concluded a potential cost saving of eighteen percent using a ferry for a corridor from Detroit, MI to Madison, WI.

3.6 Bi-State Domestic Freight Ferries Study

The Rudin Center for Transportation Policy & Management[6] performed a study that explored the feasibility of a freight ferry that would cross the Hudson River and link New York to New Jersey. The study examined factors that would lead to successful ferry operations, rather than specifying certain routes. Two important conclusions were reached by the study. The first conclusion reached was that serving niche markets was the best method to ensure long term success for a ferry operation. In this particular geographic region, they suggested that hazardous materials, over-weight vehicles, construction materials, and air cargo were suitable niche markets for a ferry. A second, and potentially more significant conclusion from the study was "…a freight ferry would not provide the time and/or cost savings necessary to attract general freight movement given current, tolerable levels of congestion and shippers' preference for highway service. Thus, without public policy intervention and leadership it is unlikely that a ferry market for trucks will readily develop on its own."

3.7 Summary

Four consistent themes are present in literature related to freight movement, transportation infrastructure, and ferry operations. First, there is consensus that demand for freight movement, particularly by trucks, will continue to grow at rates that will increasingly tax the already congested highway system. Second, the Harbor Maintenance Tax, in its current form, is seen as an inhibitor for the development of alternative and capital intensive freight movement methods using the inland waterways. Third, over the road trucking is an incredibly efficient enterprise and any competing forms of transportation will most likely need some type of governmental policy and/or subsidy to compete and survive in the marketplace. Fourth, the most likely scenario for a ferry operation to prosper is by developing and serving a niche market.

This research project directly addresses three of these issues. The Harbor Maintenance Tax is defined as one of the main experimental factors. The reduction in semi-trucks on the congested Chicago corridor will be estimated. Finally, the economics of a ferry operation will be explored and the magnitude of any possible subsidy needed will be analyzed.

4. Research Plan

4.1 Research Objectives

The objective of this project is to compare door to door truck service with a roll-on, roll-off trailer ferry operation which would link the Ports of Milwaukee and Muskegon, Michigan. This proposed ferry operation would aim to reduce truck traffic through the heavily congested Chicago I-94, I-90 truck corridor. Three performance attributes of each operation will be identified and compared: transit times, frequency and reliability of the ferry operation, and cost per Trailer.

The specific tasks of the research project include:

- Literature Review of Truck/Trailer Ferry operations
- Assess trucking costs between points East and West of Lake Michigan
- Comparison of truck versus truck ferry costs and services
- Development of a computer simulation model of the proposed transportation network
- Analysis of the projected tipping point of the truck versus truck ferry operation

4.2 Research Methodology

To accomplish the research objectives, a multi-step approach was used. The steps included:

4.2.1 Perform a literature review of ferry operations

A literature review of ferry operations was performed to define the scope and parameters of the problem environment and to fully develop and refine the research questions addressed in this study.

4.2.2 Define and develop a computer simulation model of the system

A computer simulation model of the truck and ferry system was developed for the purpose of generating as accurate as possible operational and financial estimates of the proposed system. Computer simulation is an analytical tool that allows minute by minute detail modeling of physical systems. The simulation environment serves as an experimental testbed where parameters of importance to the overall system can be manipulated and the impact assessed in a consistent fashion.

4.2.3 Develop an experimental design

Based upon the literature review and the development of the proposed ferry system, experimental factors and levels will be identified and set and the simulation model will be used with these factors to generate experimental data for the economic analysis.

4.2.4 Perform an economic analysis

An economic model will be developed to explore the financial feasibility of the proposed ferry operation. This model will be based upon estimates of performance generated by the simulation model. To perform the analysis, a comparison will be made of the variable costs involved in the operation. For those cases in which the ferry operation is the dominant choice, the fixed, capital cost of the vessel will be used to generate a payback period.

4.3 Experimental Design Factors

The experimental design factors for the analysis include the cost of a barrel of oil, the ferry capacity and the Harbor Maintenance Tax. These factors and their associated levels for experimentation are shown in Table 4.1.

Table 4.1 Experimental Design Factors and Levels

Factor	Low Value	Average Value	High Value
Cost of Barrel of Oil	$100.00	$150.00	$200.00
Ferry Capacity (Trailers)	84	126	168
Harbor Maintenance Tax	$0.0	$137.00	$687.50

The experimental levels used for the **Cost of a Barrel of Oil** factor were determined using the figures of historical prices presented in Section 2. The conversion of the cost of a barrel of oil to the cost of a gallon of diesel fuel was based on a regression analysis. The regression equation is:

$$\text{Cost of Gallon of Diesel Fuel} = 1.238 + .0254 * \text{Cost of Barrel of Oil} \qquad (1)$$

The correlation coefficient for this regression was .927, indicating a very strong fit. Table 4.2 shows the estimated price of a gallon of diesel fuel according to this calculation.

Table 4.2 Barrel to Gallon Conversion

Cost of Barrel of Oil	Cost of Diesel Fuel per Gallon
$100.00	$3.78
$150.00	$5.05
$200.00	$6.32

The experimental levels used for the **FerryCapacity** factor were determined through conversations with industry experts. Further details on the proposed vessel can be found in Section 5.

The experimental levels used for the **Harbor Maintenance Tax** factor were determined using on-line resources and industry experts. The average value was obtained through an Army Corp of Engineers estimate. The maximum value was determined by using an average value of truckload shipments from FleetOwner of $566,000 [12].

4.4 Performance Metrics

The performance metrics used in this analysis include:

- ***Transit Time* –** The Transit Time is defined as the total elapsed time from commencement at origination point to arrival at destination point. It includes all wait times and delays. The unit of measure is hours.
- ***Transit Time Standard Deviation* –** The Transit Time Standard Deviation is the standard deviation of all Transit Times incurred during the scenario. This value is calculated as the population standard deviation and is used as a measure of the reliability of the particular transport method.
- ***Fuel Usage* –** The Fuel Usage is defined as the total amount of fuel consumed by the trailer during the move from origination point to destination point.
- ***Total Cost* –** The Total Cost is defined as the sum of all costs incurred by the trailer during the move from origination point to destination point. The complete definition of all costs considered in the analysis is described in Section 5.

Each performance metric, with the exception of the Transit Time Standard Deviation are reported as a long run ***expected value per trailer moved***.

4.5 Experimental Design

The experimental design chosen for this project is a Taguchi L9[18]. Taguchi designs are commonly used when 3 – Level factors exist. This design was chosen after preliminary tests of the simulation model indicated that elapsed times for each scenario took approximately one hour. At this rate, a full enumeration of the experimental space would take approximately 10.1 days to complete. The Taguchi design is shown in Table 4.3.

Table 4.3 Taguchi Design

Experiment	**Ferry Capacity**	**HMT**	**Cost of Barrel of Oil**
1	68	0.00	100
2	68	137.00	150
3	68	687.50	200
4	126	0.00	150
5	126	137.00	200
6	126	687.50	100
7	168	0.00	200
8	168	137.00	100
9	168	687.50	150

For each set of origination/destination points, the Taguchi L9 experimental design scenarios were simulated. Thus, 81 total simulation experiments were performed.

5. Ferry System Description

A computer simulation model of the transportation network between the origination and destination points was developed. This section describes the physical system of the truck and ferry operation and the translation of that system into the simulation model.

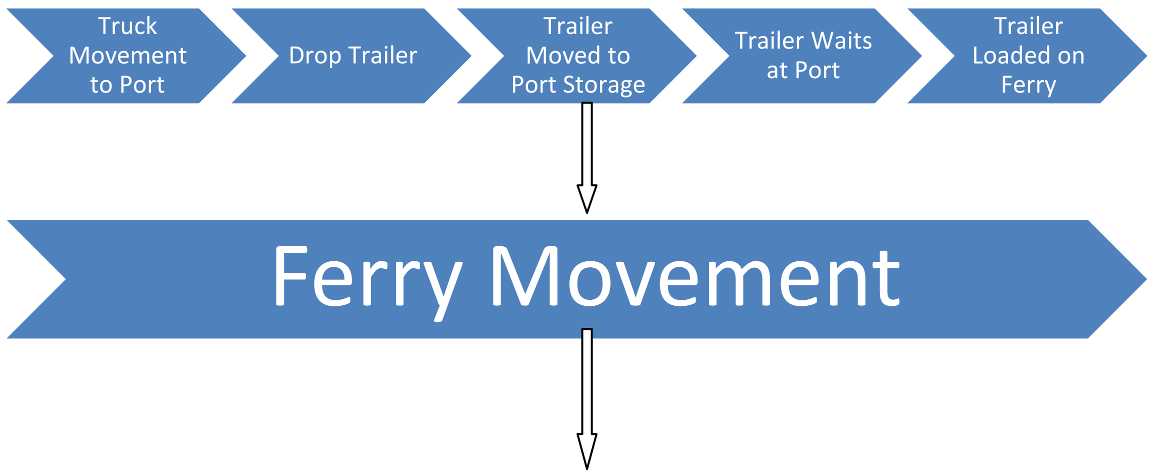
5.1 Transportation Process

The translation of the physical transportation network consisting of the highway and ferry to a simulation model was accomplished using the concept of a link. A link is defined as a segment of a transportation system, consisting of two end points connected by an arc. A combination of links forms a route. Each link contains a number of attributes that define how activity is carried out as each link is traversed. These activities are carried out at both the end points and along the arc connecting the end points. As an example, consider the ferry movement across the lake. The end points consisted of Milwaukee and Muskegon, while the arc was the distance across the lake. To increase the fidelity of the model, the distance across the lake could have been split into many links. For the road network, links were defined to coincide with mile markers at significant points such as toll plazas, large cities, and corridor entry and exit points. As traffic is simulated across a series of links, statistics concerning performance measurements are captured and long term estimates of system performance can be estimated. It is through this methodology that the performance aspects of the ferry can be compared to that of trucking.

The following sections detail the activities included in the model for each mode of transportation.

5.2 Ferry Movement Process

The process for moving trailers on the proposed ferry is shown in Figure 5.1. The process consists of pre-ferry activities, the ferry transport across the lake, and post-ferry activities. Details of this process and the cost elements captured are shown in Table 5.1. A significant component of the Ferry Movement Process consists of standard truck movement. The process of how the standard truck movement is captured in the model is detailed in the following section. Movement across the lake is defined as one link.



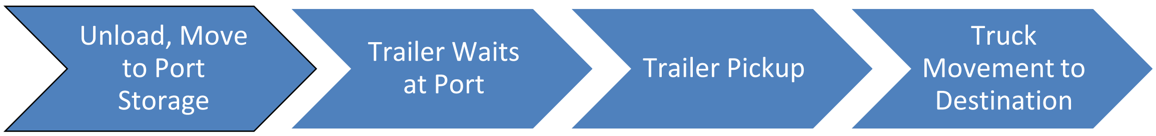


Figure 5.1 Ferry Process

Table 5:1 Ferry Process Step Cost Elements

Process Step	**Cost Elements**
Truck Travel to/from Origin to Port	MPG Driver Style Cost of Fuel Driver Cost Truck Operating/Maintenance Cost Tolls DOT regulations
Drop Trailer	
Trailer Moved to Port Storage	Stevedoring Rates
Trailer Waits at Port	Storage Insurance
Trailer Loaded on Ferry	Stevedoring Rates
Ferry Movement	Ferry Crew Ferry Costs Fuel Harbor Maintenance Tax
Unload Trailer, Move to Port Storage	Stevedoring Rates
Trailer Waits at Port	Storage Insurance
Trailer Pickup	
Truck Travel From Port to Destination	MPG Driver Style Cost of Fuel Driver Cost Truck Operating/Maintenance Cost Tolls DOT regulations

5.3 Truck Movement Process

The process for truck movement is straightforward. The truck movement begins at an origination point and travels over the pre-defined transportation network to the desired destination point. Details of the truck movement process and the associated cost elements are shown in Table 5.2. Cost elements are occurred at each link in the model.

Table 5.2 Truck Process Step Cost Elements

Process Steps	Cost Elements
Truck Travels from Origination Point to Destination	MPG Driver Style Cost of Fuel Driver Cost Truck Operating/Maintenance Cost Tolls DOT regulations

5.4 Travel Routes

The mileage between origin and destination points for both modes of transportation is shown in Tables 5.3 and 5.4. Truck routes and mileage between the origin and destination points were determined using Google Maps. These routes are also shown graphically in Figures 2.2 and 2.3. Links were constructed for these routes based upon highway marker points that either defined noteworthy cities or variances in traffic flow. There are 34 defined links in the simulation model that represent the highway routes between the origin and destination points.

Table 5.3 Conventional Interstate Highway Mileage

From/To	Lansing	Detroit	Toledo
Minneapolis	625	690	625
Madison	364	428	391
Milwaukee	309	374	336

Table 5.4 Truck Ferry Mileage

From/To	Lansing	Detroit	Toledo
Minneapolis	525	613	640
Madison	269	357	384
Milwaukee	189	277	304

Table 5.5 presents the ratio of the ferry mileage to the road mileage for each of the routes. As the table shows, the route from Minneapolis to Toledo using the ferry is actually longer than the conventional highway route while the route from Milwaukee to Lansing is considerably shorter using the proposed ferry.

Table 5.5 Ratio of Mode Distances

From/To	Lansing	Detroit	Toledo
Minneapolis	.84	.89	1.02
Madison	.74	.83	.98
Milwaukee	.61	.74	.90

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5.5 Ferry Characteristics

The vessel chosen to carry out the ferry operation for this study consisted of a tug and barge arrangement. The base vessel characteristics consisted of a tug and two barges, with each barge having a capacity of forty-two trailers. Operational costs for this arrangement are detailed in Appendix A. The capital cost for a vessel of this type is estimated to be thirteen million dollars. These figures were provided by Sand Products Corporation.

The capacity of the ferry is an experimental design parameter for this study. Due to the environmental characteristics of Lake Michigan, expert opinion suggested that the maximum number of barges that could be strung together would be four, providing a maximum load of 168 trailers. It was estimated that each additional barge beyond the base configuration of two would require a capital cost of 3.5 million dollars.

5.6 Computer Simulation Model Description

A computer simulation model was developed using ProModel that incorporated the concepts and system logic for each mode of transportation described in this Section. Major parameters and the values used for the scenario analysis are shown in Table 5.6. Definitions of these parameters are given below. The power in using simulation to build complex models of systems lies in its ability to represent variability. Simulation models use random variable distributions to represent concepts like MPG, speed, fuel use, etc. The Triangular distribution is one of the most popular distributions used in cases where data does not fit classical distributions such as the normal. The notation to describe a Triangular distribution is T[x,y,z] where x denotes the minimum value, y denotes the most likely value, and z denotes the maximum value. This distribution is used to represent all of the random variables in the model.

Table 5.6 Computer Simulation Model Parameters

Parameter	Value
Weather Incident	4%
Weather Incident Time Multiplier	T[1.0,1.1,1.35]
Maximum Consecutive Driving Hours	11
Driver Rest Period(Hours)	8
Stevedore Rate/Trailer Move	$115.00
Good Driver Percent	75%
Illinois Toll Cost	$64.00
Driver Cost/Hour	$84.00
Inefficient Driver Time Multiplier	T[1.00,1.07,1.30]
Road Segment Time Variability Multiplier	T[.90,1.0,1.1]
Indiana/Ohio Toll Road Toll Amount	$86.56
Chicago Area AM Rush Hour Time Multiplier	T[.98,1.51, 1.99]
Chicago Area PM Rush Hour Time Multiplier	T[.98,1.80,2.25]
Peak Rush Hour Incident Percent	5%
Peak Rush Hour Incident Time Multiplier	30%
Barge Load/Unload Time(Minutes)	T[55.0,60.0,95.0]
Ferry Fuel Consumption(Gallons) – 1 way trip	T[1300,1343,1400]
Semi-truck Speed(MPH)	T[55.0,65.0,70.0]
Semi-Truck MPG	T[4.8,5.2,6.1]
Inefficient Driver MPG Multiplier	T[.70,.85,.97]
Ferry Capacity Target	90%

The **Weather Incident** parameter is a factor relative only to the highway system in the model. At specified points in each day, the model randomly generates a weather event based upon the value specified by this parameter. The value used in the scenarios was determined by looking at fog, wind, and precipitation data for the last ten years for the Chicago metropolitan area.

The **Weather Incident Time Multiplier** is a multiplier factor applied to the time value for traversing a link in the model if the Weather Incident parameter has been invoked.

The **Maximum Consecutive Driving Hours** is the amount of consecutive hours that a driver may be driving. This value was obtained from the DOT website.

The **Driver Rest Period** is the amount of hours a driver must rest after reaching the maximum consecutive driving hour threshold. This value was obtained from the DOT website.

The **Stevedore Rate/Trailer move** is an estimate of the amount of money charged by a typical port stevedoring firm to move a trailer. This value was obtained from information provided by the Ports of Indiana, the North American Stevedoring Company, and the DOT website.

The **Good Driver Percent** is the percent of semi drivers classified as good, thus enabling them to achieve the standard MPG values during their driving periods. This attribute is assigned to every tractor in the model, and the value is supplied by the Cummins Engine Company[4].

The **Illinois Toll Cost** is the amount of toll incurred by a truck using the I-PASS rate. This value is determined from the illinoistollway.com site and is dependent on the route taken.

The **Driver Cost/Hour** is the estimate of the average hourly cost of an over the road driver. This value was estimated from DOT and industry-specific web sites.

The **Inefficient Driver Time Multiplier** is a multiplier factor applied to the time required to traverse a link in the model by a given truck. This value accounts for the added variability due to inefficient driving by the specified percent of drivers defined as such.

The **Road Segment Time Variability Multiplier** is a random factor applied to the time calculation for traversing a given link in the model. This factor is added to account for the inherent variability in the transportation process.

The **Indiana/Ohio Toll Road Amount** is the toll charge for a commercial Class 4 truck travelling the Indiana/Ohio toll road from the West Plaza entrance in Indiana to the WestGate entrance in Ohio to Exit 64 Perrysburg/Toledo exit.

The **Chicago Area AM Rush Hour Time Multiplier** is a multiplier factor applied to the time value for traversing a Chicago area link in the model to account for additional time and cost during the defined morning rush hour.

The **Chicago Area PM Rush Hour Time Multiplier** is a multiplier factor applied to the time value for traversing a Chicago area link in the model to account for additional time and cost during the defined afternoon rush hour.

The **Peak Rush Hour Incident Percent** is a factor that determines if there is an incident on the highway that causes additional delay and cost. At random points each day, the model randomly generates an incident based upon the specified input probability. The value used in the scenario analysis was determined from an analysis of wrecks on the Chicago interstate portion of the highway during rush hour periods.

The **Peak Rush Hour Incident Time Multiplier** is a multiplier factor applied to the time value for traversing a link in the model if a Peak Rush Hour Incident is active.

The **Barge Load/Unload Time** is the time for a stevedoring crew to load or unload a barge. This value was estimated from conversations with the North American Stevedoring Company, Hormoz Marine, and the Ports of Indiana.

The **Ferry Fuel Consumption** is the estimated amount of fuel consumed by the tug for a one way crossing of Lake Michigan. The randomness applied to the amount is to account for the variability in the water and weather conditions.

The **Semi-Truck Speed** value is the expected average speed of a truck traveling through the I-94/I80 corridor. This value was estimated with data provided by the Chicago Metropolitan Agency for Planning.

The **Semi-Truck MPG** is the average miles per gallon obtained from a standard semi-truck diesel engine. This data was supplied by the Cummins Engine Company [4].

The **Inefficient Driver MPG Multiplier** is a multiplier factor applied to the MPG for a given truck in the model. This factor accounts for the degradation in MPG obtained by inefficient driving methods. This data was supplied by the Cummins Engine Company [4].

The **Ferry Capacity Target** is a parameter used to route trailers for the ferry. Due to the randomness in the simulation model, this value is a target and the actual number of trailers available for each specific ferry trip will depend on model dynamics.

5. Results and Discussion

The computer simulation model was used to generate expected long term cost estimates of the bi-state truck ferry operation and the traditional truck operation. The complete table of results for each of the eighty-one scenarios is presented in Appendix B. This section presents a complete analysis of the results obtained by the project.

6.1 General Results

In eighty-eight percent of the scenarios, the standard truck mode was the most cost efficient method. The average cost to move a trailer using the standard truck mode over all the experimental conditions was $1609.66 compared to $2055.01 for the proposed ferry operation. Figure 6.1 presents a boxplot of the cost per trailer values and the difference between the modes for all of the scenarios tested.

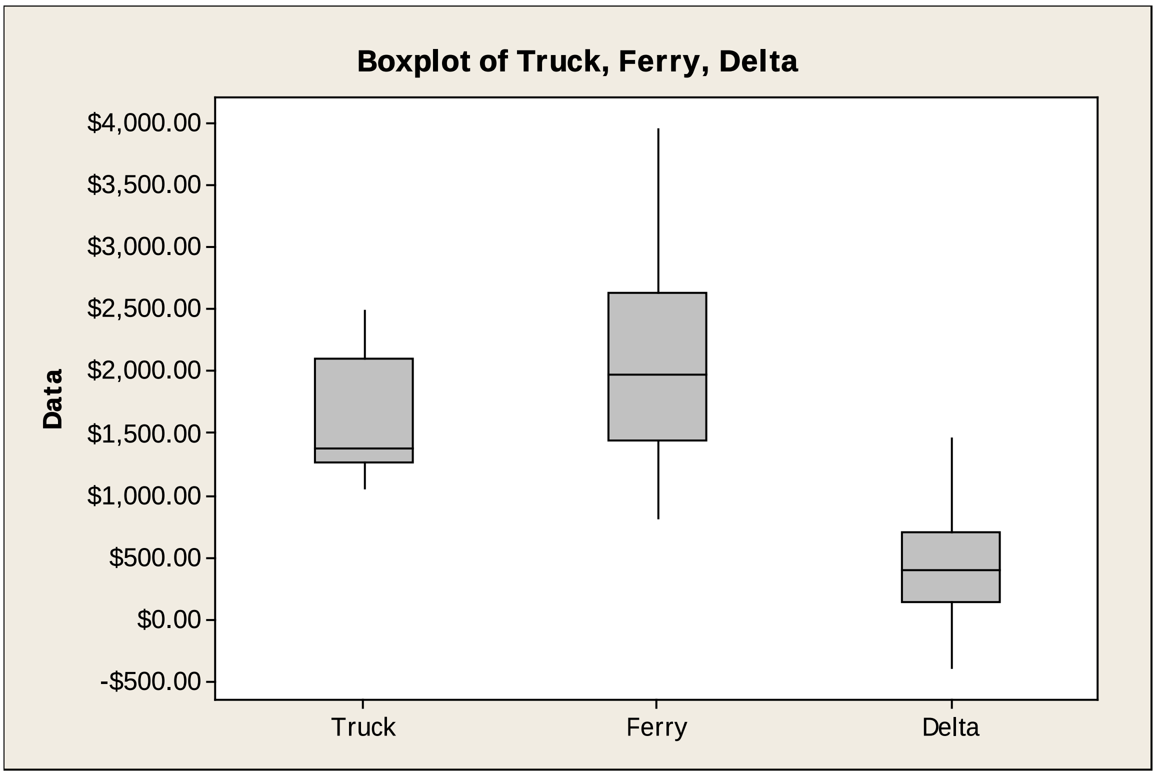

Figure 6.1 Cost per Trailer Summary

Table 6.1 shows the percentage of scenarios for each origin – destination pair in which the truck only mode was the most cost efficient method. As the table shows, the only scenarios in which the ferry was cost efficient was with Milwaukee as the origination point. Furthermore, as the total distance of the route was increased, the ferry became less desirable. Linking this observation with Table 5.5 indicates that there exists a ratio which might suggest a threshold in which a ferry operation would be feasible. In this case, the ratio appears to be in the .7 range or smaller.

Table 6.1 Percent of Cost Effective Ferry Routes

From/To	Lansing	Toledo	Detroit
Minneapolis	100	100	100
Madison	100	100	100
Milwaukee	33	89	67

Table 6.2 shows the estimated annual number of trailers that would be removed from the Chicago corridor based on the operational details of the simulation and the different ferry capacities. The utilization of the ferry capacity was taken directly from the simulation results. The estimate was calculated using this value and an operational schedule of 300 days per year.

Table 6.2 Annual Trailer Reduction Potential

Ferry Capacity	Simulation Capacity(%)	Trailers Removed Annually
84	84	42,600
126	90	67,800
168	97	94,200

Using the figures supplied by the constituent DOT's of the region, the proposed ferry could remove anywhere from 5.3 to 11.8 percent of the truck traffic in the corridor.

As part of the original research plan, trucking costs were investigated. Table 6.3 presents a summary of estimated trucking costs for a sample of routes within the project scope that were obtained in the summer of 2011. These figures are approximately 25 to 50 percent lower than those produced by the simulation model. Possible explanations for the difference in these values include the price of fuel and the inclusion of travel time delays and costs.

Table 6.3 Estimated Trucking Costs

			Dry Van OTR		
Origin City	Dest City	Miles	RPM	Linehaul	Total Fuel
Minneapolis	Muskegon	598	$2.16	$1,293.78	305
Minneapolis	Lansing	629	$2.09	$1,312.90	321
Minneapolis	Toledo	654	$2.06	$1,347.61	334
Madison	Muskegon	341	$2.67	$910.72	174
Madison	Lansing	373	$2.50	$931.48	190
Madison	Toledo	397	$2.43	$964.54	202
Milwaukee	Muskegon	286	$2.88	$823.34	146
Milwaukee	Lansing	317	$2.66	$842.46	162
Milwaukee	Toledo	333	$2.59	$862.40	170

The literature review revealed several sources where previous studies estimated the cost advantage of a ferry to be in the range of twelve to eighteen percent. In the scenarios in this study where the ferry was the cheaper alternative, the cost advantage averaged 13.4 percent. This result provides a simple validation point for the methodology of this study.

6.2 Transit Time and Reliability Results

Figure 6.2 displays a graph of the average transit time per trailer for the origin/destination pairs. Clearly the truck mode is much quicker on an absolute time basis. The comparatively larger value for the ferry transit time is primarily due to the queue time that exists at both sides of the ferry process. At the origination point, the trailers wait for the ferry to arrive, while at the destination point they wait for tractors to pick them up.

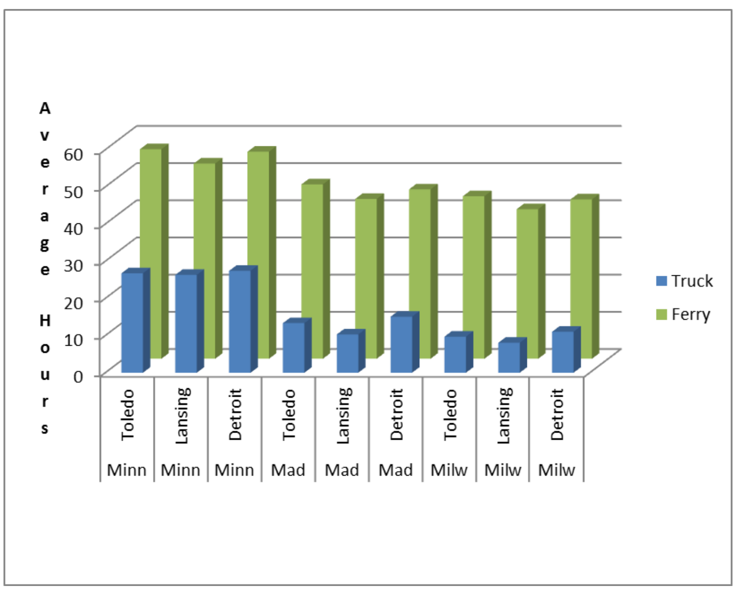

Figure 6.2 Transit Time Summary

Variability of the transit time is used as a measure of the reliability of the ferry operation. Figure 6.3 displays the transit time variability per trailer for each mode of travel. The results show that the reliability measure for the ferry operation is much more consistent than that of the truck mode. However, a measure like this in isolation provides little insight into the operation from a comparison perspective.

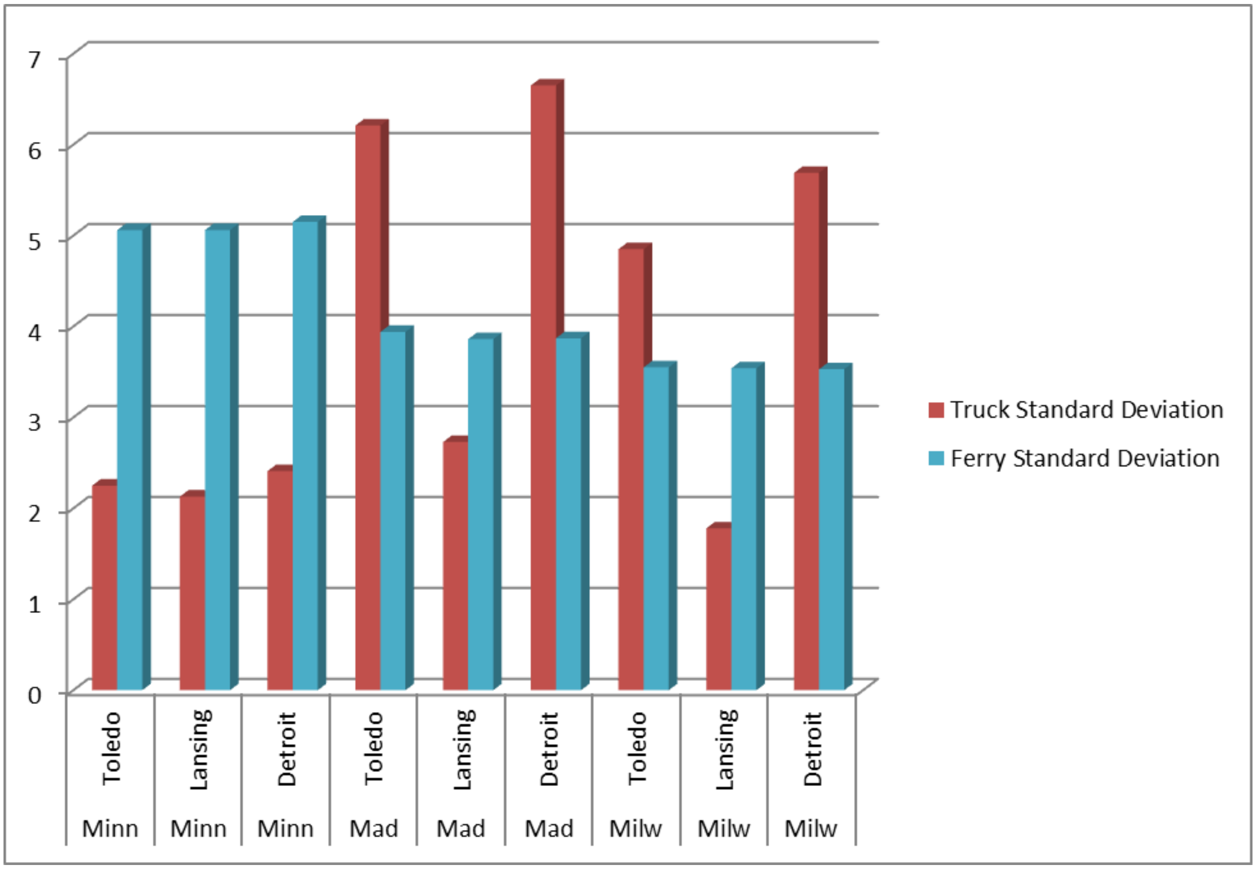

Figure 6.3 Transit Time Standard Deviation Summary

Figure 6.4 presents a different representation of the reliability of the operation by using the coefficient of variation. The coefficient of variation is the ratio between the standard deviation and average values of a measure. This figure shows that the reliability of the truck mode is much more variable than that of the ferry mode, particularly at the mid to short distance routes. A major factor in the excess variability in the truck mode is due to DOT regulations concerning maximum driving time per day. When traffic conditions or incidents create congestion, the truck mode uses the daily allotment of hours in a non-productive fashion. If reliability rather than time is the decision criteria, the ferry operation compares quite favorably to the truck mode.

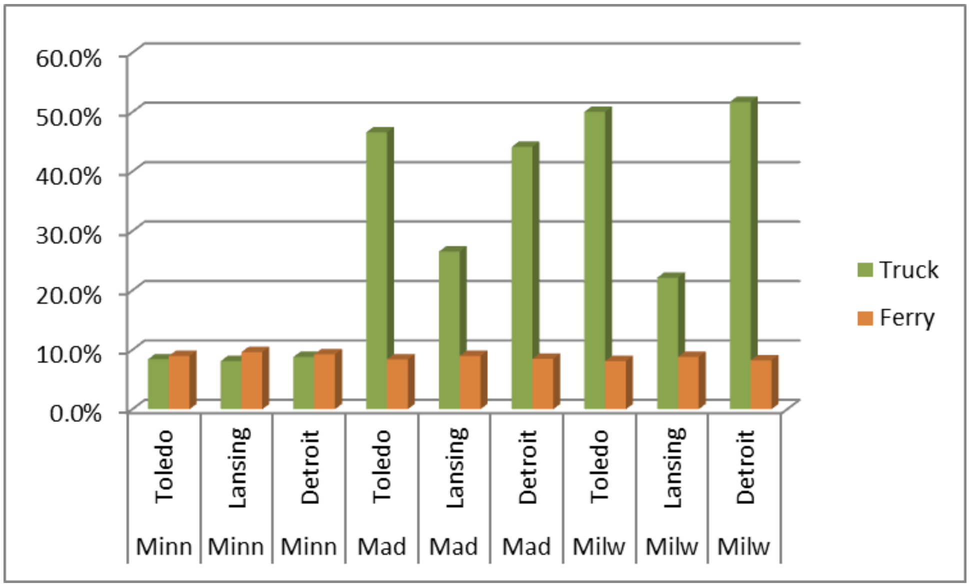

Figure 6.4 Transit Time Coefficient of Variation

6.3 Total Cost Results

The total cost per trailer move results were briefly presented in section 6.1. The cost figures were influenced by a number of factors, with the main ones being the experimental design factors. By far the most difficult cost factor to represent and estimate in the study was the Harbor Maintenance Tax. A short discussion of the history of this tax and the data used in this study is presented in Sections 2, 3 and 4.

Figure 6.5 displays the impact of the Harbor Maintenance Tax from an overall perspective. The radar chart depicts the average cost per trailer difference between the truck and ferry modes for each of the L9 Taguchi design scenarios. For example, scenario 1 considered a ferry capacity of 84, a Harbor Maintenance Tax of $0 and a fuel cost of $100 per barrel. The average cost differential between the truck and ferry mode over all of the origination/destination pairs was approximately $445.00. In scenarios 3, 6, and 9, the Harbor Maintenance Tax factor was set at the high level and Figure 14 clearly shows that the cost differential was greatest. While this is an intuitive result, it demonstrates that the tax clearly puts the ferry mode at a direct disadvantage.

From a different perspective, if the Harbor Maintenance Tax did not exist, 26 of the 81 scenarios would have favored the ferry operation. This represents a 160 percent gain over the case in which the tax was present.

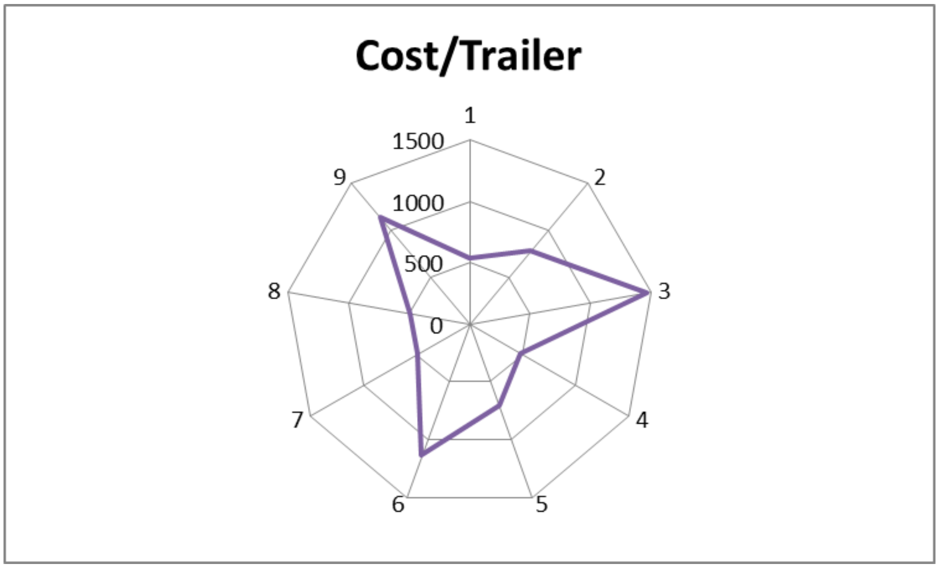

Figure 6.5 Cost per Trailer Radar Chart

6.4 Fuel Usage Results

Figure 6.6 displays the fuel usage results on a per trailer moved basis. The vessel design for this project does not provide an advantage in fuel usage, but is comparatively the same as the truck mode for shorter distances. As mentioned in Section 5, as the amount of miles in the route that involves the truck operation increases, the cost is dominated by the truck, and in most instances cannot be overcome by the economy of scale efficiency of the ferry.

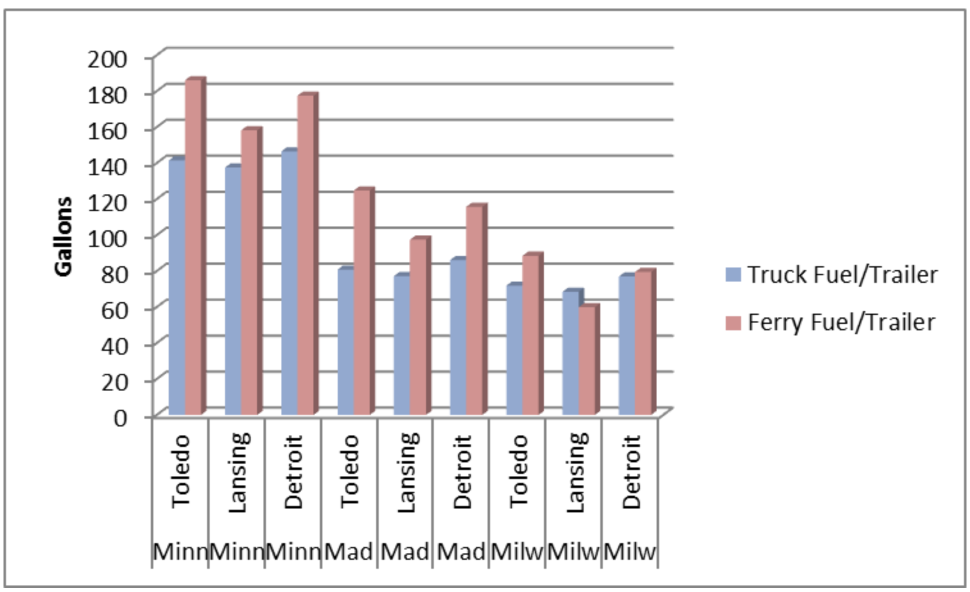

Figure 6.6 Fuel Usage Summary

6. Economic Analysis of Ferry Operation

The establishment and operation of the proposed truck ferry requires substantial capital investment. To justify expenditures at these levels, significant financial return must be possible. The methodology of this project focused on generating realistic estimates of variable operational expenses of the ferry through the use of computer simulation. This figure is then used to determine the economic feasibility of the proposed ferry operation using Return On Investment(ROI) methodologies.

7.1 Economic Model

The economic model used is:

*Expected Annual Ferry Potential = Yearly Operating Days * Ferry Capacity * Cost Advantage*

The Cost Advantage is the per trailer difference in operational costs between moving a trailer from the set of origination/destination points using the proposed ferry. As mentioned is Section 6, the ferry was more cost effective in ten of the scenarios tested. Only these scenarios present a case in which the ferry is a viable alternative. Additional assumptions used in the analysis include:

- The ferry will operate 300 days in a year
- The ferry will make two crossings per operating day
- The ferry will operate at a 90% capacity utilization

Table 7.1 presents a summary of the results of the economic model.

Table 7.1 Economic Model Summary

Scenario	Ferry Cost Advantage/Trailer	Ferry Capacity	90%	Trailers Moved Annually	Expected Annual $ Potential
G7	$28.20	168	151	90,600	$2,554,920
H1	$180.76	84	76	45,600	$8,242,656
H2	$3.80	84	76	45,600	$173,280
H4	$290.99	126	113	67,800	$19,729,122
H5	$155.91	126	113	67,800	$10,570,698
H7	$382.88	168	151	90,600	$34,688,928
H8	$228.76	168	151	90,600	$20,725,656
I4	$95.60	126	113	67,800	$6,481,680
I7	$174.26	168	151	90,600	$15,787,956
I8	$41.84	168	151	90,600	$3,790,704

7.2 Return On Investment Analysis

The capital cost for the vessel used in this project is estimated to be thirteen million dollars for the base configuration of one tug and two barges for a total capacity of 84 trailers. Each additional barge is estimated to cost 3.5 million dollars and hold 42 trailers. Using these figures, Table 7.2 presents the simple payback period for the scenarios in which the ferry produced a cost advantage.

Table 7.2 Payback Period Summary

Scenario	Ferry Cost Advantage/Trailer	Ferry Capacity	Capital Cost	Expected Annual Profit	Payback Period(Years)
G7	$28.20	168	$20,000,000	$2,554,920	7.83
H1	$180.76	84	$13,000,000	$8,242,656	1.58
H2	$3.80	84	$13,000,000	$173,280	75.00
H4	$290.99	126	$16,500,000	$19,729,122	.84
H5	$155.91	126	$16,500,000	$10,570,698	1.56
H7	$382.88	168	$20,000,000	$34,688,928	.58
H8	$228.76	168	$20,000,000	$20,725,656	.96
I4	$95.60	126	$16,500,000	$6,481,680	2.55
I7	$174.26	168	$20,000,000	$15,787,956	1.27
I8	$41.84	168	$20,000,000	$3,790,704	5.28

As the table shows, there is considerable variability in the payback for the ferry operation. Table 7.3 presents the range in payback years based on the capacity of the ferry. In terms of payback periods for capital intensive equipment, the variability in the small capacity ferry is clearly risky at best. However, the mid-range capacity ferry payback period shows promise for investors[15].

Table 7.3 Payback Period Range

Ferry Capacity	Range of Payback (Years)
84	1.58 – 75.00
126	.84 – 2.55
168	.58 – 7.83

7.3 Subsidy Analysis

The literature review revealed that some type of initial subsidy may be a necessary condition to guarantee long term viability for a ferry operation. The Transportation Research Board, a major division of the National Research Council, issued a report titled "Equity of Evolving Transportation Finance Mechanisms"[20] that addressed the issue of financing systems in which society benefits. In this project context, society in general, and in particular those who use the Chicago corridor for work and pleasure are clearly paying a price for the congestion.

To speculate on what an initial subsidy might look like based upon the results of this project, the magnitude and direction of the difference between the modes of transportation is an appropriate starting point. Figure 7.1 displays the statistical summary of the average cost difference per trailer between the modes over all the scenarios. While this is clearly a macro approach that blends the factors from the experimental design, it is useful as a starting point to determine the bounds under which a subsidy might be successful.

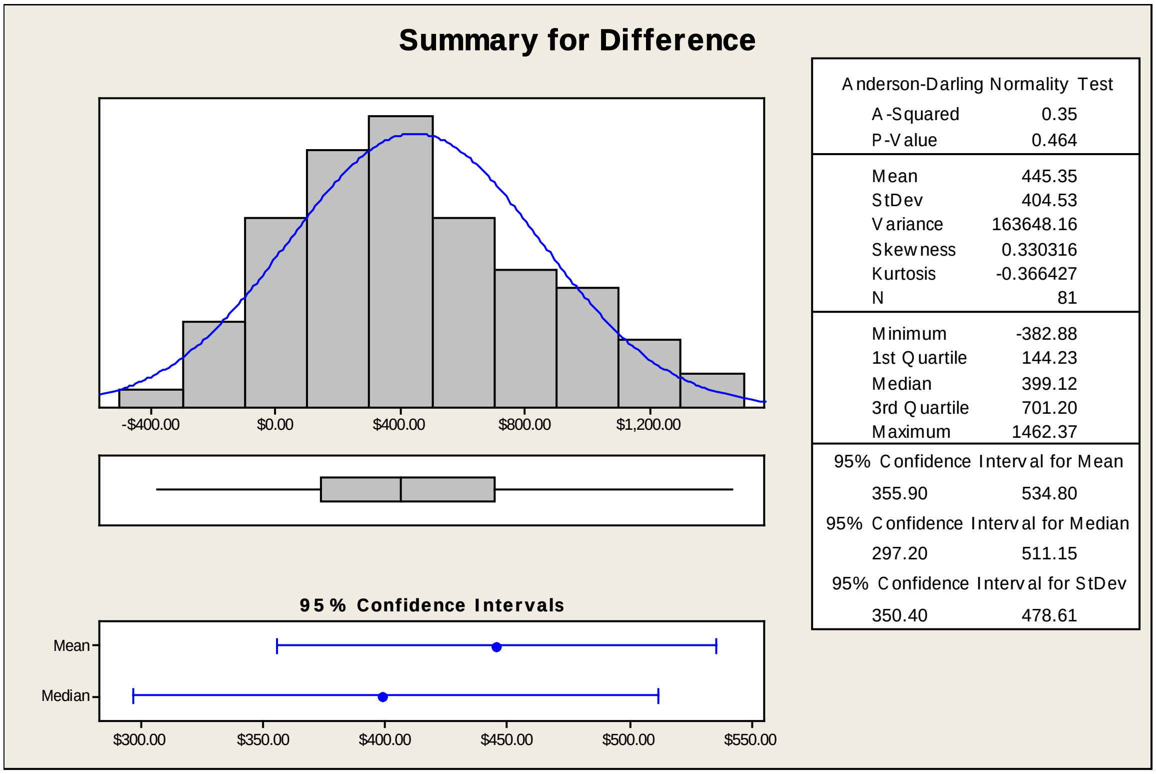

Figure 7.1 Cost per Trailer Mode Difference Summary

The average difference over all the scenarios was $445.35 in favor of the standard trucking mode. Thus, a simple starting point for a subsidy would be this particular value. However, there was a large amount of variability seen in the results and using a confidence interval approach to set a range of possible values for a subsidy would provide a more robust answer. Using a 95% confidence value, the lower and upper bounds for any potential subsidy would be $355.90 and $534.80 per trailer respectively.

7. Conclusions

This research project investigated the economics of a roll-on, roll-off trailer ferry operating between Milwaukee, Wisconsin and Muskegon, Michigan. Computer simulation was used to model the process on a minute by minute basis to capture as accurately as possible operating and financial measures of the operation. The variable costs of both modes of operation were captured on a per trailer basis. The intent of the capture of variable costs was to identify conditions in which the ferry would be a financially viable operation. In the scenarios where the ferry was cost effective on a variable cost basis, capital costs for a ferry operation were factored in and return on investment calculations made.

The results obtained were consistent with anecdotal evidence and conclusions reached in previous studies. Under certain conditions, a ferry operation across Lake Michigan for trailers only may be economically viable. Detailed conclusions of the study include:

- A ferry operation can be more cost effective than trucking given certain conditions. In 12.3 percent of the scenarios investigated (10 of 81), the ferry resulted in an average cost per trailer gain of $158.30, with a range of $3.80 to $382.88. Depending on the capacity of the tug and barge ferry, a payback period between 7 months and 75 years could be realized. The favorable conditions included:
    - A **<u>ferry total distance to truck total distance ratio of .70 or less</u>**. As the total distance of the trip with respect to the ferry distance increased, the efficiency of trucking proved too great of a cost advantage to overcome.
    - A **<u>small or non-existent Harbor Maintenance Tax</u>**. If the Harbor Maintenance Tax did not exist, the ferry would have a cost advantage over trucking thirty-two percent of the time.
    - **<u>Time criticality is less important than time variability</u>**. The ferry operation coefficient of variability was lower than that of trucking across all scenarios.

- Trucking is a very efficient industry in which medium to long range distances are involved. In this study, trucking was the more cost effective method in eighty-eight percent of the scenarios investigated (71 of 81). The average cost advantage per trailer for the truck only mode was $445.35.

- The Harbor Maintenance Tax is an inhibiting factor in the feasibility of a ferry operation, but a ferry operation can still be effective with the tax in place. In forty percent (4 of 10) of the scenarios in which the ferry was more cost effective, a Harbor Maintenance Tax was in place.

- A successful ferry operation can remove semi-trailers from congested corridors. Using the ferry capacity values in this study, a range of 42,600 to 94,200 trailers could be removed annually from the Chicago corridor. While this may not seem like a significant number relative to the current traffic volumes, the reduction of the multiplier effect of congestion incidents caused by semi-trailers cannot be ignored.

- If ferry operations were to receive a cash subsidy, a range of $350 to $530 per trailer would be an appropriate range of values as a basis.

- The effects of intangible conditions such as congestion, weather, and road incidents have an effect on the economics of freight movement, yet data to accurately assess the impact is non-existent or very difficult to obtain and represent in any type of model. Thus, the true impact and cost of these important factors to society and the industry are unknown, yet borne by all. This study developed a framework to include these factors into the cost modeling and used the best estimates available. However, this methodology and the data estimates did not have a major impact on the results, thus providing little support for anecdotal evidence of the large impacts these factors are said to cause. In particular, the impact of 'incidents' was difficult to estimate. This suggests that a more rigorous examination of these factors be taken up.

- Under the current structure and mechanics of the Harbor Maintenance Tax, a ferry operation on Lake Michigan would favor low value goods and commodities due to the short distance across the lake at the points investigated.

9. Recommendations

This research project used computer simulation technology to investigate the concept of short sea shipping on Lake Michigan. A general model of the concept at a macro level was developed and used to generate expected values of system performance using three experimental design factors. With this model, the research was able to validate recommendations reached by previous studies under today's conditions concerning the feasibility of short sea shipping on the Great Lakes. As the results were disseminated, the level of interest in the project indicated that further expansion of the methodology and investigation of additional factors is warranted and encouraged. It is recommended that specific case studies be developed and analyzed to take advantage of the simulation model that was developed for this project.

An important extension to this work would be the investigation of vessels other than a tug and barge configuration for the ferry operation. Dedicated vessels such as flat deck types, military style vehicle transports, and commodity-type ships could all be integrated into the simulation model with ease. Capital and operating costs of these vessels could then be factored into the economic analysis.

Another important extension of this work would be the investigation of specific commodity types. In this extension, the short sea concept could be examined as part of the overall supply chain for a given commodity and/or company operating in a particular industry rather than just as a general purpose transportation alternative serving the general public.

It is also recommend that the methodology be expanded to model at a significantly expanded level of detail. The addition of more details to the simulation model would allow more specific analysis of such issues as trailer dwell time at the ports and the coordination required to the drop off and pick up operations that play a vital role in the ultimate feasibility of the short sea concept.

The expansion of detail in the simulation model would also include more specific logic relative to intangible elements of the transportation system such as weather, congestions, accidents, construction, etc. While elements of this type were included in this project from a macro perspective, evidence indicates that the impacts of such elements are vastly under estimated in the analysis of transportation systems. More thorough definition of these elements and the inclusion of this expanded detail into the current simulation model would add a level of realism to the analysis that does not exist today and could potentially make a much stronger economic case for the adoption of short sea shipping as an integral part of the United States transportation infrastructure.

10. Potential Economic Impact of Research Results

This research is of value to economic development directors, entrepreneurs, and marine professionals who are seeking general feasibility for specific short sea shipping opportunities on the Great Lakes. The findings of this study verified those of similar research conducted in the last ten years and provided guidance for sensitivity concerning the volatile nature of the price of oil. Of major importance to this group of professionals is the section on subsidy analysis.

This research also is of value to policy planners in the government sector of the maritime industry. The Harbor Maintenance Tax was analyzed as a design factor for short sea shipping scenarios and the impact of various levels of this tax were investigated.

Additionally, the simulation model developed in this research could be used to generate operational and financial estimates for more specific studies of short sea opportunities.

11.Dissemination of Study Results

Presentations of this research project were made at the following venues:

1. "Northwest Coal Corridor", Indiana Center for Coal Technology Research, CCTR Advisory Panel Meeting, July 24, 2012, West Lafayette, IN.

2. "The Economics of a Lake Michigan Truck Ferry", Institute of Industrial Engineers, 2012 Annual Conference, May20, 2012, Orlando, FL.

3. "Feasibility of a Lake Michigan Truck Ferry", Urban Transportation Center, University of Illinois, Chicago, October 12, 2011, Chicago, IL.

4. "The Economics of a Bi-State Truck Ferry", Great Lakes Maritime Research Institute, 2011 Annual Meeting, September, 2011, Duluth, MN.

5. "Transportation Infrastructure Modeling and Economic Development", Indiana Center for Coal Technology Research, CCTR Advisory Panel Meeting, April 2011, Indianapolis, IN.

A Transportation Research Board paper was submitted in November, 2012. This paper was not selected for publication at that time.

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Appendix A

Muskegon-Milwaukee Tug/Barge Operation

	Forecast January	Forecast February	Forecast March	Forecast April	Forecast May	Forecast June	Forecast July	Forecast August	Forecast September	Forecast October	Forecast November	Forecast December	Forecast Total	Cost Per Day
Full Crew Days	0	0	25	30	31	30	31	31	30	31	30	31	300	
Layup Crew Days	31	28	6	0	0	0	0	0	0	0	0	0	65	
Crew Travel Days	0	0	0	0	0	9	0	0	0	9	0	0	18	
Operating Expense														
Management Fee	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	120,000	400
Charter Hire-Tug	67,739	67,739	67,739	67,739	67,739	67,739	67,739	67,739	67,739	67,739	67,739	67,739	812,868	2,710
Charter Hire Barge	119,014	119,014	119,014	119,014	119,014	119,014	119,014	119,014	119,014	119,014	119,014	119,014	1,428,170	4,761
Labor, Benefits and Taxes-sailing	0	0	82,839	99,407	102,721	99,407	102,721	102,721	99,407	102,721	99,407	102,721	994,074	3,314
Labor, Benefits and Taxes layup	17,205	15,540	3,330	0	0	0	0	0	0	0	0	0	36,075	120
Galley	0	0	3,850	4,620	4,774	4,620	4,774	4,774	4,620	4,774	4,620	4,774	46,200	154
Labor-Travel	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	18,000	60
Supplies	0	0	6,250	7,500	7,750	7,500	7,750	7,750	7,500	7,750	7,500	7,750	75,000	250
Regulatory, Compliance and other	500	500	500	500	500	500	500	500	500	500	500	500	6,000	20
User / Professional Fees	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	18,000	60
O/S Power and Fleeting	3,100	2,800	600	0	0	0	0	0	0	0	0	0	6,500	22
Fuel & Lubes	0	0	329,711	395,654	408,842	395,654	408,842	408,842	395,654	408,842	395,654	408,842	3,956,537	13,188
Insurance	16,667	16,667	16,667	16,667	16,667	16,667	16,667	16,667	16,667	16,667	16,667	16,667	200,000	667
Total Monthly Operating Expenses	**237,225**	**235,260**	**643,501**	**724,101**	**741,007**	**724,101**	**741,007**	**741,007**	**724,101**	**741,007**	**724,101**	**741,007**	**7,717,424**	25,725
Cumulative total	**237,225**	**472,485**	**1,115,986**	**1,840,087**	**2,581,093**	**3,305,194**	**4,046,201**	**4,787,208**	**5,511,309**	**6,252,316**	**6,976,417**	**7,717,424**		
Maintenance														
Hull Maintenance	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	120,000	400
Machinery Maintenance	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	120,000	400
Drydock / Overhaul Accrual	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	240,000	800
Total Maintenance Expenses	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**480,000**	**1,600**
Cumulative total	**40,000**	**80,000**	**120,000**	**160,000**	**200,000**	**240,000**	**280,000**	**320,000**	**360,000**	**400,000**	**440,000**	**480,000**		
TOTAL MONTHLY	277,225	275,260	683,501	764,101	781,007	764,101	781,007	781,007	764,101	781,007	764,101	781,007	$ 8,197,424	$ 27,325

Appendix B

Scenario	Cost of Barrel of Oil	Ferry Capacity	HMT	Origination	Destination	Average Truck Time(Hrs)	Truck Standard Deviation	Average Ferry Time(Hrs)	Ferry Standard Deviation	Truck Fuel/Trailer	Ferry Fuel/Trailer	Truck Cost/Trailer	Ferry Cost/Trailer	Difference
A1	$100.00	84	$0.00	Minn	Toledo	26.75	2.25	56.36	5.06	141.5	186.0	$2,119.18	$2,654.94	$535.76
2	$150.00	84	$137.00									$2,300.55	$3,074.36	$773.81
3	$200.00	84	$687.50									$2,480.26	$3,942.63	$1,462.37
4	$150.00	126	$0.00									$2,297.08	$2,776.95	$479.87
5	$200.00	126	$137.00									$2,473.53	$3,174.83	$701.30

6	$100.00	126	$687.50									$2,114.51	$3,249.93	$1,135.42
7	$200.00	168	$0.00									$2,476.19	$2,961.71	$485.52
8	$100.00	168	$137.00									$2,119.11	$2,613.22	$494.11
9	$150.00	168	$687.50									$2,298.35	$3,434.62	$1,136.27
B1	$100.00	84	$0.00	Minn	Lansing	26.30	2.13	52.50	5.06	137.5	158.2	$1,977.60	$2,210.10	$232.50
2	$150.00	84	$137.00									$2,152.05	$2,596.71	$444.66
3	$200.00	84	$687.50									$2,326.78	$3,422.72	$1,095.94
4	$150.00	126	$0.00									$2,154.68	$2,283.36	$128.68
5	$200.00	126	$137.00									$2,329.36	$2,645.07	$315.71
6	$100.00	126	$687.50									$1,979.15	$2,781.91	$802.76
7	$200.00	168	$0.00									$2,335.61	$2,418.66	$83.05
8	$100.00	168	$137.00									$1,971.53	$2,159.82	$188.29
9	$150.00	168	$687.50									$2,099.63	$2,797.97	$698.34
C1	$100.00	84	$0.00	Minn	Detroit	27.40	2.41	55.70	5.15	146.5	177.4	$2,057.41	$2,411.66	$354.25
2	$150.00	84	$137.00									$2,242.01	$2,783.32	$541.31
3	$200.00	84	$687.50									$2,424.33	$3,597.55	$1,173.22
4	$150.00	126	$0.00									$2,240.90	$2,505.50	$264.60
5	$200.00	126	$137.00									$2,420.06	$2,879.86	$459.80
6	$100.00	126	$687.50									$2,056.89	$2,976.42	$919.53
7	$200.00	168	$0.00									$2,416.19	$2,649.37	$233.18
8	$100.00	168	$137.00									$2,061.22	$2,355.62	$294.40
9	$150.00	168	$687.50									$2,243.21	$3,126.95	$883.74
D1	$100.00	84	$0.00	Madison	Toledo	13.33	6.21	46.90	3.94	80.8	124.7	$1,315.43	$1,776.55	$461.12
2	$150.00	84	$137.00									$1,416.69	$2,104.54	$687.85
3	$200.00	84	$687.50									$1,518.09	$2,867.22	$1,349.13
4	$150.00	126	$0.00									$1,416.40	$1,815.52	$399.12
5	$200.00	126	$137.00									$1,522.08	$2,122.89	$600.81
6	$100.00	126	$687.50									$1,319.14	$2,345.33	$1,026.19
7	$200.00	168	$0.00									$1,521.40	$1,902.38	$380.98
8	$100.00	168	$137.00									$1,315.83	$1,723.38	$407.55

9	$150.00	168	$687.50									$1,417.34	$2,436.55	$1,019.21
E1	$100.00	84	$0.00	Madison	Lansing	10.29	2.73	42.99	3.86	77.2	97.4	$1,179.15	$1,338.92	$159.77
2	$150.00	84	$137.00									$1,275.70	$1,648.92	$373.22
3	$200.00	84	$687.50									$1,372.89	$2,374.56	$1,001.67
4	$150.00	126	$0.00									$1,273.70	$1,355.31	$81.61
5	$200.00	126	$137.00									$1,373.79	$1,627.90	$254.11
6	$100.00	126	$687.50									$1,179.46	$1,915.51	$736.05
7	$200.00	168	$0.00									$1,371.54	$1,399.71	$28.17
8	$100.00	168	$137.00									$1,179.22	$1,298.32	$119.10
9	$150.00	168	$687.50									$1,276.25	$1,977.36	$701.11
F1	$100.00	84	$0.00	Madison	Detroit	15.06	6.65	45.56	3.87	86.1	115.7	$1,303.20	$1,648.11	$344.91
2	$150.00	84	$137.00									$1,414.11	$1,972.18	$558.07
3	$200.00	84	$687.50									$1,522.06	$2,718.54	$1,196.48
4	$150.00	126	$0.00									$1,414.10	$1,687.19	$273.09
5	$200.00	126	$137.00									$1,525.15	$1,974.36	$449.21
6	$100.00	126	$687.50									$1,309.03	$2,217.62	$908.59
7	$200.00	168	$0.00									$1,520.24	$1,752.59	$232.35
8	$100.00	168	$137.00									$1,305.67	$1,600.97	$295.30
9	$150.00	168	$687.50									$1,413.45	$2,302.18	$888.73
G1	$100.00	84	$0.00	Milwaukee	Toledo	9.69	4.85	43.72	3.55	71.88	88.5	$1,190.26	$1,309.59	$119.33
2	$150.00	84	$137.00									$1,282.72	$1,586.95	$304.23
3	$200.00	84	$687.50									$1,373.17	$2,302.47	$929.30
4	$150.00	126	$0.00									$1,283.06	$1,313.23	$30.17
5	$200.00	126	$137.00									$1,370.91	$1,567.07	$196.16
6	$100.00	126	$687.50									$1,189.95	$1,874.40	$684.45
7	$200.00	168	$0.00									$1,368.23	$1,340.03	-$28.20
8	$100.00	168	$137.00									$1,192.12	$1,252.90	$60.78
9	$150.00	168	$687.50									$1,282.64	$1,921.27	$638.63
H1	$100.00	84	$0.00	Milwaukee	Lansing	8.04	1.78	40.24	3.54	68.5	59.9	$1,054.37	$873.61	-$180.76
2	$150.00	84	$137.00									$1,139.00	$1,135.20	-$3.80

3	$200.00	84	$687.50									$1,225.34	$1,811.27	$585.93
4	$150.00	126	$0.00									$1,138.36	$847.37	-$290.99
5	$200.00	126	$137.00									$1,225.94	$1,070.03	-$155.91
6	$100.00	126	$687.50									$1,053.33	$1,443.35	$390.02
7	$200.00	168	$0.00									$1,227.21	$844.33	-$382.88
8	$100.00	168	$137.00									$1,051.10	$822.34	-$228.76
9	$150.00	168	$687.50									$1,137.40	$1,455.62	$318.22
I1	$100.00	84	$0.00	Milwaukee	Detroit	11.00	5.69	42.87	3.53	76.97	79.4	$1,178.51	$1,182.28	$3.77
2	$150.00	84	$137.00									$1,274.37	$1,465.45	$191.08
3	$200.00	84	$687.50									$1,370.90	$2,172.30	$801.40
4	$150.00	126	$0.00									$1,274.02	$1,178.42	-$95.60
5	$200.00	126	$137.00									$1,368.96	$1,426.39	$57.43
6	$100.00	126	$687.50									$1,175.83	$1,753.81	$577.98
7	$200.00	168	$0.00									$1,368.06	$1,193.80	-$174.26
8	$100.00	168	$137.00									$1,175.84	$1,134.00	-$41.84
9	$150.00	168	$687.50									$1,272.55	$1,788.31	$515.76
												$1,609.66	$2,055.01	$445.35