A Linear Programming Model for Short Sea Shipping in the USA

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August 1st, 2015

Submitted for publication and presentation at the 95th Annual Meeting of the Transportation Research Board, January 10-14, 2016

Word Count: 5,253 text words plus 750 for figures/tables (9*250) = 7,500 total

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Abstract:

Congestion, environmental impact, and fuel costs are factors that influence transportation decisions in both business and personal activies. As economies develop, transportation networks must adjust to accommodate the growing demand for freight transportation. Solutions that exploit underutilized transportation modes may be the best opportunity for minimal-impact growth. For example, redirecting freight that would otherwise be shipped on along the I-95 east-coast highway corridor to the east-coast marine highway corridors, would utilize untapped capacity. Necessarily, Short Sea Shipping, through the use of Ro/Ro vessels must be implemented in a cost-competitive manner. The environmental and congestion reducing benefits are considerable, however for the mode to gain acceptance, this transportation mode must at the same time be both competitive and profitable. A cost benefit analysis can estimate a projected profit margin and attract potential investors and businesses. By developing a mathematical model, the competitiveness of Short Sea Shipping is determined. The study finds that Short Sea Shipping can be both competitive and profitable when vessels carry 1,400 trailers over a distance of approximately 1,000 miles.

Keywords: Mathematical Modeling, Marine Highway System, Short Sea Shipping

INTRODUCTION

The world as we know it today is shaped by transportation modes. Initially, many population centers developed as port cities, at the terminus of sea shipping routes, and then expanded inland. Then expansion inland required land transportation. Thus, transportation has been most exploited mode and the preferred method for transporting people and/or goods (1). Many areas showing critical congestion conditions in the surrounding transportation networks must consider implementing measures in order to ease the strain placed on the land transportation system. The solution to the congestion requires the redistribution of traffic, from the current highway systems to other modes. For the public, this means mass-transit. For freight, this means the identification of underutilized modes of transportation (2).

For the past five decades, trucking has been the primary transportation mode in connecting different areas of the country. Trucking is a popular choice because of the well-developed National Highway System in the U.S. With the ability to provide point-to-point service, freight trucking provided a service that the railroad companies could not (3), and as such, the trucking business has been on the incline for much of the past 4 to 5 decades. Other advantages of trucking mode include routing flexibility, low maintenance, and owner-operator revenue collection. Furthermore, with the increase in global commerce, all freight movements modes have also experienced high levels of growth, which proved to be a good opportunity for the trucking industry to grow. With the growth of the trucking industry came the growth of congestion conditions and together with an increase in costs, the conditions have prompted an urgency to find a solution for more efficient inland transportation.

Trucking faces several challenges. Increases in costs for fuel, maintenance, and most other costs associated with trucking, the profit margins have been eroding (5). Since the year 2000, the price of a barrel of oil has fluctuated from $40 to $150, (The NASDAQ OMX Group, Inc, 2015) (14), the variations, although sometimes beneficial, make for difficult cost planning. Further issues related to fuel contributing in the erosion of profit margins include environmental concerns and the taxation on higher polluting vehicles. Also as long-haul drivers are aging and the trending preference to work close to home takes hold, freight companies are seeing shortage of replacement drivers (7).

The implementation of Short Sea Shipping, also referred to as Marine Highways by the United States Maritime Administration (U.S. MARAD), offers an alternative to freight trucking. There are many
definitions of Short Sea Shipping and the meaning relates to the context and the kind of vessel (Paixa & Marlow, 2013) (15). For the purposes of this article, Short Sea Shipping in meant to generally describe the movement of cargo and/or passengers mainly by sea, along a coast, and without crossing an ocean. Short Sea Shipping has found much acceptance in the European, where as much as 49% of all goods transported intra-European Union have, in some part, been transported by ship (4). This has allowed European Nations to diversify the modality of freight movements and by doing so, expand the freight transportation network.

The objective of this study is to examine the main factors associated with the cost of transporting goods through trucks and Short Sea Shipping. By developing mathematical models that account the varying cost, the total cost can be determined, examined, and evaluated. Once the models are made, Linear Programming optimization tools will be used to determine the cost for moving freight. Furthermore, by using a case study where existing ports can be connected through trucks as well as through Short Sea Shipping, the applicability of this study in the real world can be estimated. Finally, conclusions will be drawn regarding the practicality of the models, as well as determining the optimal conditions to conduct Short Sea Shipping operations.

LITERATURE REVIEW

Since the introduction of the European Economic Community (EEC) in 1957, and its expansion along the decades, European economist, policymakers and member nations began introducing free market policies in order to promote a common market. Luskin et. al. (2002), translated the problem into a case of allocation and the unfairness of the policies of collection of revenue for highways maintenance. For example, five-axle trucks generate 16.4% of revenues, while generating 29.7% of maintenance costs. The short-fall is paid by the tax payer, and thus the true cost of trucking is actually higher than what some shippers may report. Flott, S. (2004), provided data that argues that the expansion of privately owned and operated Short Sea Shipping would add capacity to the U.S. surface freight transportation at a cost and speed comparable to other land transportation modes. Yonge et. al., (2006), queried users and providers in the Short Sea Shipping businesses and in 2006 published a journal article suggesting that there is a positive view concerning Short Sea Shipping and the interest on the adoption of this mode.

Projections based on reports published by Maritime Transport Coordination Platform (2006), analyzing the implication of using Gross Tonnage as a measure to charge different types of Short Sea Shipping vessels (Ro/Ro, Lo/Lo, Barges, etc.) and by Perry et. al. (2008) comparing aspects of trucking and Short Sea Shipping have significant implications. The reports indicate that with an investment of $50 million, the ports in the Atlantic region can increase their capacity by as much as 21,000 trailers daily. Considering that trucks account for just 10% of the vehicle miles traveled, but that 75% of the funds directed by the Federal Highway Administration’s pavement maintenance costs are necessitated by those miles, an increase of 21,000 trucks could be costly to the taxpayer. Once could conclude that alternatives to that increase are necessary. In a technical report by Transportation Economics and Management Systems in 2008, the state of the American transportation, including means of reducing the volume of trucks, is analyzed. The report found that in 2008, with oil prices at an all-time high of $150 per barrel (NASDAQ OMX Group, Inc.) (14), the cost difference between inland trucking transportation and Short Sea Shipping in the United States was being marginal.

In a second 2008 study by Gross et. al., factors affecting the operational costs of conducting Short Sea Shipping were analyzed and fond that fuel pricing was considered most important. Indeed, fuel pricing was considered the principal cause for annual price variations related to charges for hiring a ship or depreciation costs when Short Sea Shipping operators own the vessels. Even though these two costs are not exactly the same and therefore, are influenced by different elements, it is assumed they are both high fixed costs from these operators’ point of view. The Short Sea Shipping market is highly competitive,
with different operators on a wide variety of routes, and thus sensitive of and responsive to price fluctuation.

In a 2009 study by Darcy, J., these issues are further examined in further detail. The costs associated with Short Sea Shipping are discussed in detail, including in addition to fuel costs, cost of crewing, maintenance, and insurance. Darcy also presents several origin/destination matrixes regarding the movement of freight carrying trucks along the U.S. east coast I-95 corridor. Kruse and Hutson, in 2010 many topics regarding Short Sea Shipping in the United States are discussed. Significantly, the report finds that using Ro/Ro is the best alternative to compete with trucking and to achieve the main objective; directing the bulk of freight away from heavily congested highways to the sea. Additionally, the report recommends that ships with a 150-trailer capacity are the best suited for the to compete with the east coast I-95 corridor. In a 2010 study by Decas examined and reported on the use and methodologies of Short Sea Shipping in Europe.

In a 2013 study published in the International Journal of Industrial Engineering, Daduna [16] finds an additional component necessary to successful competition with truck freight transportation: River-Sea Shipping. Daduna acknowledges the necessary condition for long-term acceptance of an alternative shipping mode is steady, reliable, economical service. For this to become the norm, both Short Sea Shipping and River-Sea Shipping must be involved in the multi-modal transport structures. Daduna sates that studies show, Short Sea Shipping and River-Sea Shipping together act as an important element in creating efficient processes in multi-modal transport. However, he also find that as recently as 2013, the potential of such services that exist in container and Ro/Ro transport had yet to be exploited to a great extent. Furthermore, Daduna sates that only once Short Sea Shipping and River-Sea Shipping potential is exploited in an economically and ecologically sustainable processes, will truly compete against trucking for the customers in the freight shipping market.
However, there may be factor that Daduna overlooks in his prediction. A phenomenon known as a “tipping point,” popularized by Malcolm Gladwell in his 2000 book by the same title, describes the point at which a series of small changes or incidents becomes significant enough to cause a larger, more important change. One of those action is that of the governments, discussed by Hilmola (2012)[17] that he observed that expeditious methods of shipping has been the catalyst for recent increases former Eastern-European countries. However, and unfortunately according to Hilmola, the majority of that has been freight trucks because of “weak competition” offered by Short Sea Shipping alternatives. The solution, as Hilmola sees it, change will come about with government intervention in the form of planned new environmental and infrastructure payments-tolls, which will swing the competitive balance from freight trucking in favor of Short Sea Shipping.

METHODOLOGY

From the Literature Review, it was observed that many studies focused on steps taken by government agencies in pursuing the implementation of Short Sea Shipping through direct government action. By reducing the constraints and burdens on domestic maritime freight, the water transportation is proven to be competitive. But, it was also observed that not much work had been dedicated into the actual cost benefit from the private sector’s point of view. This sector, which is skeptical to changes unless results are shown to be very satisfactory, is the main protagonist in the transportation of Freight. Studies must focus on convincing private sector stakeholders.

The methodology is a basic representation of the work completed, along with the methods and theories used to develop the solution to the existing problem. Figure 1, illustrates the Methodology flowchart implemented in this study. The first step of the Methodology Procedure emphasizes the gathering of required information in order to understand the relationships between the different factors affecting the operational costs. Information about fuel cost and consumption, salaries, maintenance and management costs, leasing and purchasing costs, and insurance was compiled and written in such a format, where a linear relationship was established. Then, using Linear Programming, selected modes of transportation were modeled. Constraints of the models were manipulated in order to model multiple condition. Once the Models were established, the minimum cost of moving freight via Trucking Model and Short Sea Shipping Model was determined.
Major assumptions used throughout this study, differentiating between those used in the Trucking Model and the Short Sea Shipping Model, as well as other general assumptions used, are presented below:

**General Assumptions**

For this study, the amount of information obtainable was very limited, but in order to formulate the desired equations properly, the following general assumptions were considered.

- All Freight transported through Short Sea Shipping will be conducted using trucks in Ro/Ro vessels.
- The amount of Freight (measured in number of trucks transported) is the same when connecting point (a) with point (b) or when connecting point (b) with point (a).
- At sea, the cost is measured in time and the rate of expenditure is the same for all routes.
- Vessels of the same type consume the same amount of fuel, regardless of the amount of cargo transported.
- Out of 365 days in a year, vessels are operational for 343 days, the remaining time is spent in maintenance inspections and renovations.
- The model only accounts for point-to-point services, where trucks through land, and vessels by sea, connect only two points.
The Short Sea Shipping model only considers the cost for moving freight, in this case trucks, from port to port. The costs of berthing is calculated and applied in the same manner at all ports.

These two modes of transportation, which differ in many aspects, have multiple similarities that allow them to be compared using similar models. Both modes rely on origin and destinations, route selection, cargo to be transported, and the costs associated on performing such a task.

**Mathematical Modeling for Trucking Analysis**

The mathematical formulation enables the estimation of the cost associated with transporting a truck on a round trip between any two given points:

\[ 2T \sum_{i=1}^{n} dX_n \]

where:
- \( T = \text{Number of Trucks} \)
- \( d = \text{Distance covered on a one-way trip} \)
- \( X_n = \text{The constraints used for the study, measured in cost per mile} \)

The \( X_n \) will account for any constraint used to evaluate the cost of operating a truck. Additionally, the model also uses a constant \( 2 \) as a multiplier, since the objective of this study is to determine the costs as a round-trip basis, considering that the truck will need to return to its original starting point from which it normally operates.

**Mathematical Modeling for Short Sea Shipping Analysis**

Most of the issues that have an influence in the cost for trucking operations also have an impact in the operations of Short Sea Shipping. As such, fuel cost, crewing salaries, maintenance and management, purchase/lease, and cargo handling, are important issues that need to be taken into account. Since the impact that these individual factors have on a vessel are different than that of the impact on a ship, a different formulation is required. So, by determining the cost associated for a round trip operation between two ports using Short Sea Shipping, results can be obtained in cost per round trip that can be comparable to results obtained from the trucking mathematical model.

- **Fuel Consumption (FC)**

Equation (a) is used to determine the fuel consumed per ship taking into account the amount of fuel used per vessel type, and multiplying it by the number of vessels used per operation.

\[ \sum_{V}^{n} \sum_{i=1}^{I} \sum_{j=1}^{J} F_{ij}^{V} N_{ij}^{V} \quad \forall, \quad V = 1, 2, \ldots, n \quad (a) \]

\[ i = 1, 2, \ldots, I \]

Where:
- \( F_{ij}^{V} = \text{Vessel type } V\text{'s Fuel Consumption connecting ports } i \text{ and } j \)
- \( = [(\text{SHP} \times 2 \times \text{Route Length})/(23.4s)] \times \text{cost per gallon of bunker } f \text{ Fuel} \)
- \( N_{ij}^{V} = \text{Number of Vessels of type } V \text{ connecting ports } i \text{ and } j \)
Crewing Cost (CS)

The Crewing cost is determined in equation (b), by the number of crew per vessel, as well as their annual salaries. Once this value is multiplied by the number of vessel per operations, the annual expense in salaries can be determined, and by dividing it with the number of annual trips, the cost in salaries per round trip is extracted.

\[
\sum_{V}^{n} \sum_{i=1}^{I} \sum_{j=1}^{J} \frac{C_{ij}^{V} N_{ij}^{V}}{T A_{ij}^{V}}
\]

\(\forall, \ V = 1, 2, \ldots, n \quad (b)\)

\(i = 1, 2, \ldots, I\)

Where:

\[C_{ij}^{V} = \text{Annual cost for Salaries per vessel connecting ports } i \text{ and } j\]

\[= 1.20 \left[ (NM \times MS) + (NCE \times CES) + (NFM \times FMS) + (NSE \times SES) + (NAS \times ASS) + (NW \times WS) + (NC \times CS) \right]\]

\[T A_{ij}^{V} = \text{Number of annual trips by vessel of type } V \text{ between ports } i \text{ and } j\]

\[= \frac{(343 \times 24)}{T_T}\]

\[T_T = TS + TB = \text{Total Duration of Round Trip}\]

\[T_S = \text{Time spent at sea} = \frac{(2 \times \text{Route Length})}{\text{Speed}}\]

\[T_B = \text{Time Spent Berthing per Round Trip} = T_i^V + T_j^V\]

\[T_i^V = \text{Time Spent Berthing at Port } i\]

\[T_j^V = \text{Time Spent Berthing at Port } j\]

Ship Cost (SC)

In equation (c), the Ship’s cost is determined by the amount paid annually paid on the credit per vessel, and type, multiplied by the number of vessels in the operation. Once this value is divided by the number of round trips conducted annually, the value obtained shows the expense dedicated to paying for the vessel per round trip.

\[
\sum_{V}^{n} \sum_{i=1}^{I} \sum_{j=1}^{J} \frac{L_{ij}^{V} N_{ij}^{V}}{T A_{ij}^{V}}
\]

\(\forall, \ V = 1, 2, \ldots, n \quad (c)\)

\(i = 1, 2, \ldots, I\)

Where:

\[L_{ij}^{V} = \text{Annual Credit or Payment on the Ship}\]

Management Cost (MC)

Assuming that the managerial cost can be estimated as a percentage of the vessel’s value, then by multiplying this factor with the value of the ship, times the number of vessels in operation, then the annual cost for management can be formulated. And by dividing the annual cost on management by the number of round trips generated annually, the management cost per round trip is determined. This is shown in equation (d).
\[ \sum_{V}^{n} \sum_{i=1}^{I} \sum_{j=1}^{J} P_{Wi_j}^V \left( W_{i_j}^V N_{i_j}^V \right) TA_{i_j}^V \]

Where:
- \( P_{Wi_j}^V \) = Percentage of the Value of the Ship directed for Management
- \( W_{i_j}^V \) = Given Value of the Ship for the Year

\[ \sum_{V}^{n} \sum_{i=1}^{I} \sum_{j=1}^{J} TO(H_{i_j}^V + H_{j_i}^V)N_{i_ij}^V \]

Where:
- \( TO \) = Number of Truck Loading/Unloading operations per Truck
- \( H_{i_j}^V \) = Truck Handling Cost per Loading/Unloading Operation at port \( i \)
- \( H_{j_i}^V \) = Truck Handling Cost per Loading/Unloading Operation at port \( j \)
- \( N_{i_ij}^V \) = Number of Trucks Boarding the Vessel Travelling from port \( i \) to \( j \)

\[ \sum_{V}^{n} \sum_{i=1}^{I} \sum_{j=1}^{J} \left[ T_i^V (D_i^V L^V) + T_j^V (D_j^V L^V) \right] N_{i_j}^V \]

Where:
- \( T_i^V \) = Time Spent berthing at port \( i \)
- \( D_i^V \) = Docking Charge at port \( i \)
- \( T_j^V \) = Time Spent berthing at port \( j \)
- \( D_j^V \) = Docking Charge at port \( j \)
- \( L^V \) = Length of Vessel type \( V \)

Where:
- \( i = 1, 2, \ldots, I \)
- \( j = 1, 2, \ldots, J \)
- \( V = 1, 2, \ldots, n \)
Harbor Maintenance Cost (HMT)

In equation (g), the Harbor Maintenance Tax is calculated by taking a particular percentage of the value transported per vessel. By multiplying the value of cargo per truck times the number of trucks transported the value transported per trip is determined, and by multiplying this value by 2, then the Harbor Maintenance Tax cost per round trip is determined.

\[
\sum_{V=1}^{n} \sum_{i=1}^{I} \sum_{j=1}^{J} HMTC[2(N_{T_{ij}}^V V_{T_{ij}}^V)] \quad \forall, \ V = 1, 2, \ldots, n \quad (g)
\]

\[
i = 1, 2, \ldots, I
\]

Where:

\[
HMTC = \text{Harbor Maintenance Charge Coefficient}
\]

\[
V_{T_{ij}}^V = \text{Value of Cargo on Truck being transported between ports } i \text{ and } j
\]

Rates at for berthing vessels can be measured differently by different port. For example, it can take into account how much space or time the vessel occupies or, how much equipment it needs to conduct its operations. In the Short Sea Shipping model idealized, all ports are considered to use the same method to determine a docking charge for the vessel using its installations. This rate depends on the length of the vessel as well as the period that it stays in port unloading/loading, resupplying and/or conducting other businesses.

Thus, the following Objective Function is:

\[
\text{MIN} \{ FC + CS + SC + MC + HC + DC + HMT \}
\]

\[
\begin{aligned}
\text{MIN} \left\{ & \sum_{V=1}^{n} \sum_{i=1}^{I} \sum_{j=1}^{J} F_{T_{ij}}^V N_{T_{ij}}^V + \sum_{V=1}^{n} \sum_{i=1}^{I} \sum_{j=1}^{J} C_{T_{ij}}^V N_{T_{ij}}^V T_{A_{ij}}^V + \sum_{V=1}^{n} \sum_{i=1}^{I} \sum_{j=1}^{J} L_{T_{ij}}^V N_{T_{ij}}^V T_{A_{ij}}^V + \sum_{V=1}^{n} \sum_{i=1}^{I} \sum_{j=1}^{J} P_{W_{ij}}^V W_{T_{ij}}^V N_{T_{ij}}^V T_{A_{ij}}^V ) \right. \\
& \left. + \sum_{V=1}^{n} \sum_{i=1}^{I} \sum_{j=1}^{J} T O(H_{T_{ij}}^V + H_{T_{ij}}^V N_{T_{ij}}^V + \sum_{V=1}^{n} \sum_{i=1}^{I} \sum_{j=1}^{J} T_{T_{ij}}^V (D_{T_{ij}}^V L_{T_{ij}}^V + \tau_{T_{ij}}^V (D_{T_{ij}}^V L_{T_{ij}}^V) ) \\
& \right. \\
& \left. \sum_{V=1}^{n} \sum_{i=1}^{I} \sum_{j=1}^{J} HMTC[2(N_{T_{ij}}^V V_{T_{ij}}^V)] \right\} 
\end{aligned}
\]

Subject to:

Constraint (1) states that there will be no negative values regarding the number of Vessels of different type sailing from port i to port j:

\[
N_{T_{ij}}^V \geq 0, \quad \forall \ i, j, V \quad (1)
\]

Constraint (2) states that the number of trucks transported by Vessel of type V, from port i to port j (N_{T_{ij}}^V) cannot be a negative value.
Constraint (3) states that the number of Vessels of type $V$ sailing from port $i$ to port $j$ is equal to the number of Vessels being operational at a given time, meaning that the cost of only the vessel operating between the two specific ports is considered.

$$
N^V_{rij} \geq 0, \quad \forall \ i, j, V
$$

Constraint (4) states that the consideration takes into account that the number of trucks transported by vessels of different type from port $i$ to port $j$ is equal to the total trucks moved from $i$ to $j$.

$$
\sum_{i=1}^{I} \sum_{j=1}^{J} N^V_{ij} = Q_i, \quad \forall \ V
$$

Where:

$$
Q_i = Volume \ of \ Truck \ per \ Round \ Trip
$$

Constraint (5) states that the number of trucks that the vessels of different type can transport needs to be greater or equal to the number of trucks transported from port $i$ to port $j$ by vessels of different type.

$$
\sum_{V} N^V_{ij} S^V \geq N^V_{rij}, \quad \forall \ i, j
$$

where:

$$
S^V = Capacity \ of \ Vessel
$$

As for constraint (5), the number of trucks that the vessels of different type can transport needs to be greater or equal to the number of trucks transported from port $i$ to port $j$ by vessels of different type.

CASE STUDY ANALYSIS

The U.S. Maritime Administration (U.S. MARAD) has identified multiple scenarios where Short Sea Shipping, labeled by the agency as Marine Highways, can be successfully implemented. In Figure 2, the East Coast of the United States can be observed as well as the location of the mentioned ports. The location of these ports allows great coverage to the entire I-95 corridor, which extends from Maine to South Florida, and covering all states in between. The dashed lines represent the areas corresponding to each port’s influence, where trucks being transported from long distance could choose the optimal port location, depending on the closest port from their destination. Thus, for this study, the following ports were selected (see Figure 2):

- Port of Boston, Massachusetts
- Port of Wilmington, Delaware
- Port of Norfolk, Virginia
- Port of Savannah, South Carolina
- Port Canaveral, Florida
- Port of Miami, Florida
The distances between these locations by road and the sea determined by Table 1 and Table 2. In Table 1, a matrix where the distances needed to be covered are shown, if the freight transported by trucks were to be travelling by road.

### Table 1: Distance in Miles between Selected Ports by Road

<table>
<thead>
<tr>
<th>From</th>
<th>Boston</th>
<th>Wilmington</th>
<th>Norfolk</th>
<th>Savannah</th>
<th>P. Canaveral</th>
<th>Miami</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boston</td>
<td>344 m</td>
<td>582 m</td>
<td>1,029 m</td>
<td>1,318 m</td>
<td>1,507 m</td>
<td></td>
</tr>
<tr>
<td>Wilmington</td>
<td>344 m</td>
<td>245 m</td>
<td>689 m</td>
<td>978 m</td>
<td>1,168 m</td>
<td></td>
</tr>
<tr>
<td>Norfolk</td>
<td>582 m</td>
<td>245 m</td>
<td>482 m</td>
<td>772 m</td>
<td>958 m</td>
<td></td>
</tr>
<tr>
<td>Savannah</td>
<td>1,029 m</td>
<td>689 m</td>
<td>482 m</td>
<td>298 m</td>
<td>484 m</td>
<td></td>
</tr>
<tr>
<td>P. Canaveral</td>
<td>1,318 m</td>
<td>978 m</td>
<td>772 m</td>
<td>298 m</td>
<td>199 m</td>
<td></td>
</tr>
<tr>
<td>Miami</td>
<td>1,507 m</td>
<td>1,168 m</td>
<td>958 m</td>
<td>484 m</td>
<td>199 m</td>
<td></td>
</tr>
</tbody>
</table>

The distance to be covered is one of the main features needed to be determined. In addition, some variables, such as the calculation of the fuel consumption per round trip needs to be determined according to the route length, verifying the importance of establishing the distances to be covered by the modes in any given network. Table 2, determine the distances covered by the vessels connecting different ports from the short sea shipping network, where a nautical mile is equal to 1.15 miles.
**Table 2: Distance in Nautical Miles between Selected Ports by Sea**

<table>
<thead>
<tr>
<th>From</th>
<th>Boston</th>
<th>Wilmington</th>
<th>Norfolk</th>
<th>Savannah</th>
<th>P. Canaveral</th>
<th>Miami</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boston</td>
<td></td>
<td>509 nm</td>
<td>559 nm</td>
<td>946 nm</td>
<td>1,089 nm</td>
<td>1,199 nm</td>
</tr>
<tr>
<td>Wilmington</td>
<td>509 nm</td>
<td></td>
<td>235 nm</td>
<td>658 nm</td>
<td>799 nm</td>
<td>916 nm</td>
</tr>
<tr>
<td>Norfolk</td>
<td>559 nm</td>
<td>235 nm</td>
<td></td>
<td>505 nm</td>
<td>646 nm</td>
<td>762 nm</td>
</tr>
<tr>
<td>Savannah</td>
<td>946 nm</td>
<td>658 nm</td>
<td>505 nm</td>
<td></td>
<td>247 nm</td>
<td>404 nm</td>
</tr>
<tr>
<td>P. Canaveral</td>
<td>1,089 nm</td>
<td>799 nm</td>
<td>646 nm</td>
<td>247 nm</td>
<td></td>
<td>176 nm</td>
</tr>
<tr>
<td>Miami</td>
<td>1,199 nm</td>
<td>916 nm</td>
<td>762 nm</td>
<td>404 nm</td>
<td>176 nm</td>
<td></td>
</tr>
</tbody>
</table>

**RESULTS**

Many factors had to be considered and evaluated in order to make the experiment both realistic and interesting. The routing plan is an optimal plan for a situation at a particular period. The results presented were performed on an Intel® Core TM i5 CPU 3.20 GHz, 4.00 GM of RAM. The experiments varied according to vessel capacity and numbers of ports considered, and in the presentation of the experiments, time measurements as well as cargo parameters are expressed in terms of cost per truck transported per round trip. Once all of the appropriate information and assumptions were taken into account, the equations formulated the Mathematical Models needed to be written in a Linear Programming program. For this study LINDO 6 Linear Programming optimization software was used in order determine the minimum costs of the Trucking Mathematical model, as well as the Short Sea Shipping Mathematical model.

In the models, all assumptions and values were entered either, directly, or by entering the Objective Coefficients from an Excel Spreadsheet developed, where values were extracted after the respective equations were calculated. In the LINDO 6 models, the objective was to determine the minimum cost associated with moving freight. The Trucking Model program provided the cost to move a single truck, which was then multiplied by the number of trucks intended to be transported from the origin to the destination, giving the total cost to conduct such operation. In the case of the Short Sea Shipping Model, the program was asked to determine the cost of assigning a vessel to a particular route, and by combining this value with the number of trucks intended to transport, provided the actual number and type of vessels to be assigned in order to obtain the minimum operational cost.

The results suggested that when transporting 145 or fewer trucks, Vessel type I was the most economical, while when transporting between 145 and 360 trucks, assigning a Vessel type III was the most economical. This information, together with additional data obtained from the Optimization program was plotted using Microsoft Excel, where the relationship between the total costs of transporting freight using the different modes was determined for all routes.
Figure 3 shows the cost per truck when connecting Boston, MA with the other ports being analyzed in this study. An important trend seen in this graph is that the further away the destination the more competitive is Short Sea Shipping, even when transporting low volumes of freight.

Figure 3: Cost per truck by distance between ports at different freight volumes

Figure 4 shows the cost per truck when transporting different volumes of freight on truck between the ports of Boston, MA and Wilmington, DE. The graph shows that between these locations, distanced 344 miles apart, trucking business is currently more economical when transporting around as few as 200 truckloads of cargo, and even though at higher volumes, Short Sea Shipping is more competitive, the benefit for a round trip is near $100 per truck. It is important to point out the spiking that occurs in the Short Sea Shipping line, is a result of requiring an additional vessel to be assigned to the route in order to accommodate the increasing number of trucks needed to be transported.

Figure 4: Cost per Truck, Boston, MA to Wilmington, DE
Figure 5 shows the results of a comparison of the two transportation modes in the Boston, MA to Miami FL route, which suggests a profitable outcome to Short Sea Shipping at all volumes analyzed. This cost difference increases from $1,500 when transporting 50 truck of Freight to as much as $3,500 when transporting as much as 800 trucks per group of trucks. As such, it is clear that Trucking can be as much as three times more expensive when transporting Freight cargo by road, when connecting Boston with Miami.

![Cost per Truck, Boston, MA to Miami, FL](image)

Figure 5: Cost per Truck, Boston, MA to Miami, FL

The results of the graph data were tabulated (see Table 2) to determine whether the scenario and the selected ports were adequate to conduct Short Sea Shipping operations competitively with conventional trucking.

Table 3: Results from the Short Sea Shipping network Departure from Boston

<table>
<thead>
<tr>
<th>Port of Boston to</th>
<th>Trucking Typical Cost</th>
<th>Short Sea Shipping Max Cost</th>
<th>Short Sea Shipping Min Cost</th>
<th>Profit Margin Min / Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wilmington DE</td>
<td>1,178</td>
<td>1,997</td>
<td>1,076</td>
<td>-41.1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9.5%</td>
</tr>
<tr>
<td>Norfolk VA</td>
<td>1,992</td>
<td>2,110</td>
<td>1,103</td>
<td>-5.6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>80.6%</td>
</tr>
<tr>
<td>Savannah GA</td>
<td>3,522</td>
<td>2,985</td>
<td>1,316</td>
<td>12%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>167.7%</td>
</tr>
<tr>
<td>Cape Canaveral FL</td>
<td>4,511</td>
<td>3,301</td>
<td>1,393</td>
<td>36.7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>223.8%</td>
</tr>
<tr>
<td>Miami FL</td>
<td>5,157</td>
<td>3,556</td>
<td>1,455</td>
<td>45.1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>254.5%</td>
</tr>
</tbody>
</table>
Table 3 shows the cost associated with transporting freight between two ports. The trucking cost does not vary regardless of the volume of freight transported. However, trucks transported via Short Sea Shipping have a higher cost when +/-50 trucks are transported per round trip. Conversely, when, say 1,400 trucks are transported, that total cost spread over more units, and thus, the cost per truck is much lower.

Additionally, the impact of cost indirectly associated with the transportation of freight through Short Sea Shipping was evaluated. These factors, which included the Truck Handling cost, and the Harbor Maintenance Tax (HMT), affect the total cost that is charged to shippers, and as such, can account for a large section of the operation’s total cost. Table 4 shows the cost per truck when the most selected vessels are commuting at full capacity, as well as the cost per truck committed to Truck Handling and Harbor Maintenance Tax (HMT).

Table 4: Shipping Cost Per Vessel

<table>
<thead>
<tr>
<th>Port of Boston to:</th>
<th>Min Cost Vessel I</th>
<th>Min Cost Vessel III</th>
<th>Other Cost: Handling</th>
<th>Other cost: HMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wilmington DE</td>
<td>1,200</td>
<td>1,068</td>
<td>280</td>
<td>500</td>
</tr>
<tr>
<td>Norfolk VA</td>
<td>1,239</td>
<td>1,095</td>
<td>280</td>
<td>500</td>
</tr>
<tr>
<td>Savannah GA</td>
<td>1,540</td>
<td>1,301</td>
<td>280</td>
<td>500</td>
</tr>
<tr>
<td>Cape Canaveral FL</td>
<td>1,650</td>
<td>1,376</td>
<td>280</td>
<td>500</td>
</tr>
<tr>
<td>Miami FL</td>
<td>1,738</td>
<td>1,436</td>
<td>280</td>
<td>500</td>
</tr>
</tbody>
</table>

The results demonstrate that vessels operating near to or at full capacity the other costs are less of a factor; an example of Economy of Scale.

CONCLUSION

This study emphasized in providing a mathematical modeling tool where the traditional and popular trucking business can be compared with the rising Short Sea Shipping. It was theorized, that by doing so, results would be obtained where the profitability of using ships to transport trucks would be in manifest, and depending on the range of this margin, provide a tool for stakeholders to base their future moves and decisions. Furthermore, the impact of factors was also evaluated in order to determine their respective impact on the total cost for transporting trucks by using Short Sea Shipping.

The analysis of the East Coast of the United States showed that for the most part, Short Sea Shipping can compete with Trucking for delivering freight along the I-95 corridor. It showed a difficulty to compete at short ranges, such as in the connection between Boston and Wilmington, where the margin of profit at best was minimal, and required a volume of freight. It was also determined that the main reason for Short Sea Shipping’s inability to compete at short ranges is because of fixed costs, such as trucking handling fees, as well as the Harbor Maintenance Tax.
Considering the limitations of this study and the formulations developed, as well as the constraints and general assumptions taken, the study successfully compared the trucking operational cost with the Short Sea Shipping operational costs. Short Sea Shipping profit margins are dependent on greater distances and large freight volumes.

The conclusion illustrates somewhat of an interdependent problem. That is, whereas economies of scale will bring about more competitive pricing, and more competitive pricing will bring about more formidable competition to trucking, that competitive force won’t occur without the volume; a circular issue. Furthermore, the widespread use of Short Sea Shipping may be necessary to initiate a River-Sea Shipping intermodal component, which Daduna suggests is a prerequisite for Short Sea Shipping competitiveness. The circular nature of this condition supports the necessity of finding “tipping point,” and as Hilmola observed, government intervention may be the means to that end. While Hilmola sees that in the future of former Eastern-European countries, which have a history of socialists governments, the probability of such government intervention in the U.S. is another matter altogether.

In summary, the work conducted in this study completed the initial step on developing a complete model that will more accurately account the costs associated with the trucking and Short Sea Shipping, and obtain accurate results for stakeholders to base their decisions when considering a shift from trucking to Short Sea Shipping for transportation services. Furthermore, the mathematical models developed are user friendly, and can be expanded to merge future studies on this particular field.

**REFERENCES**


