EVALUATION OF OPERATION COST IN LINER SHIPPING: A DISCRETE-EVENT SIMULATION APPROACH

Aldo A. McLean[a], William E. Biles[b]

Department of Industrial Engineering
University of Louisville
Louisville, KY 40292

[(a)]aldo.mclean@louisville.edu, [(b)]webile01@louisville.edu

ABSTRACT
An evaluation of the operation costs of a liner shipping network is presented in this study. The approach defines a discrete-even simulation model designed to mimic the dynamic operation and schedule structure of a liner service network of four service routes, 25 container ships, 18 container ports, and 36 port calls a week. Three months planning analysis is considered. The proposed approach includes evaluations of costs related to the operation liners at container ports and at sea. The expected operational results are reported for the overall network and the individual contribution of service routes, ports, and container ships to the network. The results allow for assessing the operation of service routes and defining the set of ports, container ships fleet, and schedules that are performing below and above the expected network level.

Keywords: Liner shipping, simulation, service routes, logistic performance

1. INTRODUCTION

Transportation of goods in containers and the container shipping industry have rather recent histories. Containerization was born to offset the disadvantages of the break-bulk shipping method used by general cargo vessels, providing an effective method to control increasing labor cost and handling time while damage, pilferage, and accidents where minimized. The development of the global trade and, consequently, growing demand for liner services, presented new challenges to the shipping of goods. An increasing number of ports, service reliability concerns, fuel costs, and imbalances in trade markets are some of the obstacles to the profitability of modern liner services.

A liner shipping network is formed by a number of service routes, which are a collection of container ports, container ship, and calling schedules. In a network, a container can move through service routes from an origin to a predefined destination. Schedules allow these containers to reach their destinations in a direct mode if only one service route is used and indirectly if more than one service route is required. Therefore, the configuration and structure of this network is essential to the performance of shipping activities. All these elements impact and contribute to the operational cost and level of operation of the shipping process during a planning period.

The productivity of a liner shipping network is associated with the number of transported entities through the network. Its effectiveness can be related to the ability to satisfy the demand for service and comply with specific performance requirements. The level of cost in liner shipping determines the operational characteristics of the network. Evaluating these service routes, where conditions mimic reality, presents opportunities to determine operation costs, productivity, and performance at various levels of operation in the shipping network and its individual components.

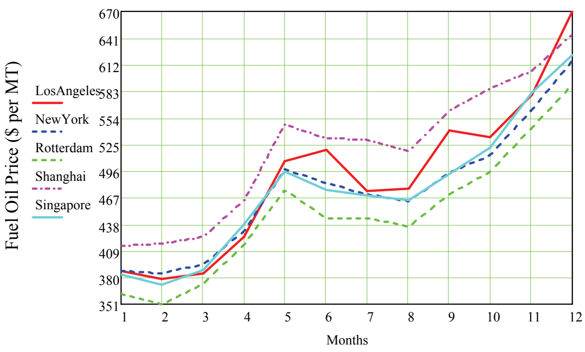

Figure 1. Fuel oil average prices at major ports.

Given the growing demand for liner services and increasing costs of modern operations, liner operators face new challenges. Despite of the improvement in the design and propulsion of container ships, the instability of prices for marine fuel oil, maintenance and other service costs are major concerns in the industry. Current prices for fuel oil oscillate between $500.00 and $650.00 per metric ton (pmt). Recent studies reported the design of service routes under $170.00 and $330.00 pmt price levels. Figure 1 shows the tendency of prices for IFO380 fuel oil in the last 12 months at some of the major container ports. In addition to the price for fuel oil itself, its unstable behavior and its future projections are discouraging as well. Assessing the effect of price factors toward the operational performance of service routes and their relative contribution to a network is critical not only during the design stages but also during regular operation of the system.

This paper presents the evaluation of the operation cost and performance in a liner shipping network where four service routes and an offer of container cargo at ports are modeled. The object of this paper is to use a simulation model to mimic the dynamic behavior service schedules, container fleet, port activities, and container cargo to evaluate the expected operations in a system.

2. LITERATURE REVIEW

Measuring the operation cost in shipping is paramount to a profitable and efficient shipping process. Research in this area is diverse in the application of cost models. Lane, Heaver, and Uyeno (1987) proposed a set of cost functions to determine the cost-efficient fleet on defined trade routes. An operational cost estimation model was presented in Perakis and Jaramillo (1991) for ship deployment purposes. Baird (2002) defined a cost model for transshipment process evaluations.

Other studies had integrated service route analysis and its relationship to the cargo transported. Song, Zhang, Carter, and Field (2005) measure the cost-efficiency of trade routes based upon the assignment of container cargo. Bendall and Stent (1999) evaluated trade routes for container ships to avoid reducing load factors.

Some authors suggest that fuel cost is a minor input for liner shippers because operations rely on delivery speed. Specific algorithms to evaluate fuel consumption in a container ship are presented in Cullinane and Khanna (1998). Shintani, Imai, Nishimura, and Papadimitriou (2007) present an approach using the specific fuel consumption rate for an individual container ship to evaluate the operation cost in route. At the current price levels, the effect of fuel oil on the operation cost in shipping is a major concern to firms. The approach in Eljard (2006) includes a set of equations that account for the individual specification of a container ship to forecast the actual fuel consumption in the vessel at a given sailing speed.

Simulation modeling is defined in Law and Kelton (2000) as an analysis method where computers are used to evaluate a model numerically and gather data in order to estimate the desired true characteristics of the model. Liner shipping operations have been previously studied through simulation. In the study presented in Van Rensburg, He, and Kleywegth (2005) a discrete-event simulation approach was applied to evaluate voyage costs, fuel cost, and capital cost in liner shipping. Research exclusively dedicated to the analysis of service route costs and liner performance is increasing. Lai, Lam, and Chan (1995) develop a simulation model of liner shipping operations in the Europe-Middle East-Far East routes to evaluate policies for container allocations. Ryan (1998) uses simulation to demonstrate advantages in fast ship operations to the service frequency and output.

3. EVALUATION METHOD

A simulation model is used to evaluate the operation cost and logistics performance of a liner shipping network. The model replicates the operation of liners in an end-to-end weekly service schedule structure through a predefined planning period. The model allows for the evaluation of individual operation cost components during shipping activities. Possible delays in sailing segments and port operations are considered.

The arrival time, size, and status of intermodal containers are represented in realistic levels at ports. Two types of intermodal containers are modeled: 20- and 40-foot. Each container is assigned a destination port that can be reached with the current design of the network. Therefore, significant container traffic is generated in service routes as each container ship moves its assigned cargo from port to port within the network.

The liner shipping network under evaluation is composed of four service routes, 24 containers ships, 18 ports, 28 port calls, and four canal transits a week. Table 1 shows the sequence of port calls for each service route evaluated including canal transits. A weekly schedule structure is assumed for all routes and port calls. Service routes are modeled for the Transpacific, Atlantic, and Asia to Europe trade lanes. The Transatlantic route (R1) serves 8,541 nautical miles (nm) in four weeks using four container ships of 4,895 TEU. The Pacific service route (R2) totals 13,155 nm round trip using five 9,6000 TEU container ships. The Asia-Europe Service (R3) requires eight 8,200 TEU to service 21,646 nm round trip including transit through the Suez Canal. The Asia to East Cost North America service (R4) requires eight 4,738 Panamax to serve 23,229 nm in 56 days, round trip.

Table 1. Service Routes and Port Calls Sequence

R1	R2	R3	R4
Rotterdam	Yantian	Bremerhaven	Ningbo
Bremerhaven	Hong Kong	Suez W	Shanghai
Le Havre	Los Angeles	Ningbo	Yantian
Felixstowe	Oakland	Xiamen	Hong Kong
New York	Pusan	Hong Kong	Panama S
Norlfolk	Ningbo	Yantian	New York
Charleston	Xiamen	Tanjung P.	Norlfolk
-	-	Suez E	Savannah
-	-	Algeciras	Panama N
-	-	Rotterdam	-

The services schedule and routes presented in Table 1 were obtained from service proformas and published schedules submitted by supporting shipping operators. The model logic assigns predefined routing sequences to each individual container based upon its destination port. One or more service routes may be required to transport a container from its origin to destination port. Therefore, the model allows for transshipment of cargo through ports and considers transit storage and handling activities. The level of containers at each port and in container ships is measured for logistics analysis. Storage and handling of containers generate operation costs to the system.

3.1. Cost Model

Frankel (2002) estimates that the operational cost in a mega mainline container ship of 2000-3000 TEU was \$2,000/hour at sea and \$1,200/hour in port. This estimation includes ship fuel and maintenance cost. It allows for the evaluation of the operation cost in a round trip and service route once the number of container ships is defined. Therefore, the structure of the cost model can greatly influence operation practices and operation decision.

The simulation model is designed to evaluate the cost associated to the individual operations of container ships, port, and service routes. Consequently, cost components are computed in terms of the overall network and individual service routes. Fees and operation charges are fed into the system for each container ship, port activity, and routing point. The model used proposes three main groups for the evaluation of operation cost:

1. Container Ship Related Cost (SC)
2. Port Related Cost (PC)
3. Canal Transit Cost (CC)

Container Ship Related Costs include all aspects associated with operating and maintaining a container ship whether at sea or at port. Fuel oil, diesel, and lubricant costs are grouped under this group. The fuel oil cost is evaluated from the container ship's fuel consumption rate, distance served, and contracted fuel price. The consumption rate is provided by the shipbuilder. Stopford (1996) proposes that the operation of the vessel at lower speeds results in fuel savings because of the reduced water resistance modeled by the *cube rule*. This relationship shows that the level of fuel consumed is very sensitive to speed:

$$F = F^* \left(\frac{S}{S^*} \right)^a \qquad (1)$$

In the cube rule, F and F* are the actual and designed fuel consumption in tons/day respectively. The exponent *a* has a value of about three for diesel engines. The S and S* represent the actual and designed sailing speed of the container ship in knots, respectively.

Lubricant cost is computed as a 5% of the fuel oil consumption rate per hour of operation multiplied by lubricant price. Lubricant and fuel oil costs are added and reported as fuel oil for simplicity of the reports. Diesel cost is evaluated for auxiliary generator while the ships undergo service at container ports.

Other SC costs are related to capital investment, hull insurance, crew manning, operation auxiliary expenses, and ship maintenance and repair and are regarded as Fixed Cost. These costs depend mostly upon physical characteristics of individual container ships. The capital cost was estimated for all ships at a 2007 chartering rate of \$12.00 per 14-ton slot per day. Meanwhile, the hull insurance and maintenance and repair cost were estimated upon 10% and 5% per day of the capital cost respectively. Crew and auxiliary costs are allowances for manning and living support onboard. For simplicity it was decided to charge a fixed rate of \$500 and \$50 per crew member per day of operation crew and auxiliary cost respectively.

Port Related Costs are costs incurred while servicing a container ship at port, including ship dockage charges, stevedoring charges, and intermodal container storage charges. Charges and fees are specified per individual port. An approach using a standard berthing fee per hour for the first 150m LOA and an extended berthing fee per hour for additional meter of LOA is used. A penalty is charged for a ship overstaying outside the scheduled service time at ports. Overstaying was charged at a rate per meter LOA for every 15 minutes or fraction. Stevedoring and storage charges are related to the size of containers and handling port. Stevedoring rates change upon container port, status of the container (e.g. full or empty), and size. Rates are given for full 40- and 20-foot containers and determined for empty containers at 40% of its rate full (e.g. \$80 for full and \$55 for empty 40 foot containers). Storage charges are given in TEU per hour units. Storage charges were defined by container port and classified in two categories that include storage during first departure (CPT) and storage during transshipment (CTT1).

Canal Transit Costs include fees related to transiting the Panama and Suez Canals. For the Panama Canal, an approximation of \$54 per ship's registered TEU capacity was used, while for the Suez Canal an approximation of \$80, \$56, and \$50 per registered TEU capacity and ship type considering feeders, panamax, and post-panamax, respectively (ACP 2005). These fees are assigned to each Canal per service route.

3.2. Logistic Model

Surveys among shippers show that quality of service aspects, such as transit time and frequency of service (Gwulliam, 1993) are very important criteria for carrier selection due to effects on inventory carrying costs of shippers and receivers. Shippers and customers have different criteria for which logistics metrics should be used to assess shipping performance. Evaluating the performance of the shipping process and its relationship to the operation cost suggests opportunities for improved services for shippers and savings for carriers.

It was determined that representative indicators of the level of operation in the network were the operation cost, vehicle-miles traveled, and TEU Delivered. However, the Operation Cost per TEU Transported and the Network Cost per Hour of Operation are indicators of the level of productivity of the system. Other important indicators evaluated by the model include the storage time of container, utilization of the stowage capacity in container ship and storage at port, and throughput per service routes.

3.3. Simulation Model

The main component of the simulation model is the Port Module Structure. The main purpose of a Port Module is to evaluate cost and performance during shipping operations. Therefore, a port module is divided in four activity areas: arrival, berthing, service, and departure. A total of eighteen port modules were designed for the model and configured to mimic basics characteristics in current container ports. These configurable parameters include physical aspects including access channel length, number of berths, container storage capacity, lift off-lift on procedures, number and performance of quay cranes, and departure procedures. The costs related to activities at port are part of the network setup parameter that includes storage cost per TEU per hour, stevedoring charges, and container ship docking charges. These activities are evaluated and their statistics collected at these modules for individual container ships, ports, and service routes. Several tables created in Microsoft Access database were used to store, update, and feed these initial parameters into the simulation model. Evaluation of time performance for shipping events and logistic results are also tasks of these port structures.

The Canal Modules are also important structures in the simulation model. Canal Modules manage the transit schedules for container ships to enter the Panama and Suez Canals, measuring the distance traveled, transit cost, and time performance while waiting and transiting the channels. There are two canal modules in the model and the transit are measured at a service speed of 5 knots for container ships. Ports and routing points are interconnected in the network and distances between origin-destination pairs are defined in a Distance Matrix.

In the simulation, the sailing time between ports is determined by the service speed of container ships and distance in a voyage within consecutive port calls. These parameters are feed to the simulation through in Segment Speed and Distance Tables. However, a provision for delays in voyages due to weather and sea conditions is included in the model. This event is modeled through a uniform distributed variate on the interval between 0 and 1% of the sailing or voyage distance. The voyage time summary of service proformas and the model animation were used to verify and validate the representation of the model to a real shipping system.

4. NETWORK RESULTS

The results for three months' analysis of the operation of the liner shipping network evaluated show operation costs, transit time, and container ship utilization levels consistent with quarterly reports in liner shipping industry. The initial setting parameters were constant for all port and container ships through the simulation experiment. The main parameters are presented as follow:

Berthing fee = $150.00 per hour
Additional fee = $4.00 per hour
Overstaying penalty = $4.00 per 15 minute units
Fuel oil price = $350.00 pmt
Diesel price = $560.00 pmt
Lubricant price = $1,000 pmt
Consumption rate for 4,700; 4,895; 8,200 TEUs (including 9,600 TEU) = 133; 156; and 248 mt per day at maximum cruising speed.

The analysis of the operation yields an average Network Operation Cost of $419.581 million in three months of operations. The largest contribution to the operation cost is given by Fixed Cost, $258.243 million, representing 62%. The second largest cost is the Network Fuel Oil Cost at $78.661 million, or 19% of Cost. The summary for the network also reveals 10% for Stevedore Cost. Canal transits reached 5% of the operation cost at $20.073 million. Storage cost was 4% or $15.442 million, driven by the cost of retaining containers before their first departure (e.g. CPT) at $15.111 million and storage during transshipment procedures or CTT1 at $0.330 million. These results are shown Table 2:

Table 2. Operation Cost results from Model Run.

Cost Item	Average	Half width	H-Observed	Share
Fuel Oil	$ 78,661,436.31	10,774.71	$ 78,686,379.46	19%
Diesel Oil	$ 2,405,583.47	1,118.82	$ 2,408,449.37	1%
Dockage	$ 4,877,440.89	2,012.87	$ 4,880,861.36	1%
Canal	$ 20,073,960.00	0.00	$ 20,073,960.00	5%
Stevedor	$ 40,207,830.80	41,999.26	$ 40,317,186.00	10%
Storage	$ 15,442,176.36	388,290.14	$ 16,173,004.50	4%
CPT	$ 15,111,737.88	389,081.57	$ 15,840,205.94	-
CTT1	$ 330,438.49	4,860.45	$ 341,545.53	-
CTT2	$ -	0.00	$ -	-
Fixed	$ 258,243,757.70	2,111.69	$ 258,247,733.00	62%
Total Operations	$ 419,581,747.05	374,798.44	$ 420,302,456.37	-

In terms of operations, R1 produced 22% of cargo throughput consuming only 11% of the cost in the system. Route 2 was the most productive service route with 33% of throughput and 25% of the total operation cost. The high productivity of route R3 was offset by its cost of 39% of operations in the network. A required transit through the Suez Canal imposes schedule limitations and high transit charges on this route. The lowest operation level was found in R4. An average of 429,196 TEU were delivered during the analysis.

In terms of productivity, the Operation Cost per TEU was reported for R1, R2, R3 and R4 at $517, $712, $1,275 and $1,598 respectively. Throughput on these routes reached levels of 92, 143, 125, and 67 thousand TEU delivered. Meanwhile, the Operation Cost per Hour per Ship was reported for R1, R4, R3 and R2 in $5,397, $8,832, $9,029, and $9,325 respectively. These values are average with half-width lower than 1%. Improving the current network operation cost was possible based upon changes to the service speed in service routes, improving service route R3 yield to $414.00 million in operation costs for the network, 2% lower than previously measured in the initial network.

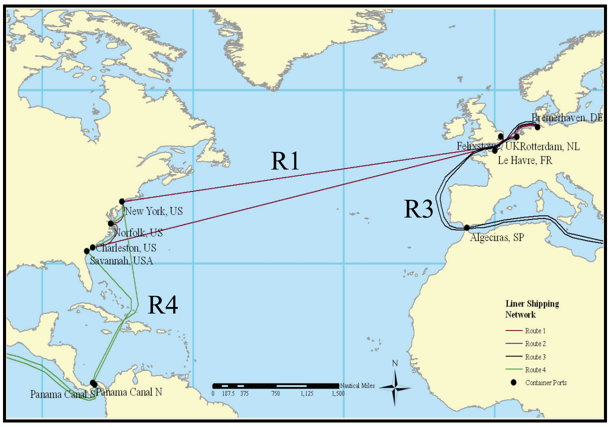

Figure 2. Service Routes, North Atlantic Operations

5. CONCLUSIONS

The results obtained from the simulation study to this particular liner shipping network support the idea that highest share in the operation cost for both the network and service routes is the Fixed Cost of operation. These results support the decision of to purchase over chartering large container ships to reduce fixed cost without considering initial capital investment and shipyard delivery time.

A comparison between the operation cost per TEU obtained and the average market freight rates per TEU for trade routes reported in UNCTAD and Containerization International annual reports would show opportunities and drawbacks to operators from using this network during the planning period. The model estimated an average cost of $1,275.96 per TEU transported between Europe and Asia, whereas freight rate reports, for the first quarter of 2007, $755 per TEU from Europe to Asia and $1,549 in the opposite direction. If these rates were maintained for the last quarter of 2007 a net profit of $273.00 per TEU could be expected from shipments from Asia to Europe and losses of $520.00 per TEU for shipments in the other direction.

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AUTHORS BIOGRAPHY

ALDO McLEAN is an Instructor in the Department of Industrial Engineering at the University of Louisville. He spent eight years working in the consumer electronics and telecommunication industries with responsibilities in engineering and management for global firms including LG Electronics, Siemens, NEC, and Panasonic. He developed expertise in logistics, quality improvement, and engineering management. His current research interest includes transportation logistics and operation management. He earned is Ph.D. in Industrial Engineering in 2008.

WILLIAM E. BILES is the Clark Chair of Computer Aided Engineering in the Department of Industrial Engineering of the University of Louisville. He spent two years in the US Army and seven years in industrial R&D before undertaking an academic career. He has held academic appointments at the University of Notre Dame, Penn State, Louisiana State University, and the University of Louisville. Dr. Biles received the Distinguished Engineering Alumnus award from the University of Alabama in Huntsville in 2004. His most recent publication is “Environmentally Benign Manufacturing” Chapter 1 in the 2007 John Wiley handbook Environmentally Conscious Manufacturing.