REDUCING FREIGHT GREENHOUSE GAS EMISSIONS IN THE CALIFORNIA CORRIDOR

The potential of short sea shipping

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Abstract

Greenhouse gases (GHG), the gases that cause climate change, are a major global concern. In the transportation sector, GHG reduction initiatives focus on passenger travel over goods movement, despite increasing freight demand and related emissions. California, with its recent GHG reduction legislation and large freight centers and corridors, provides a unique case study to evaluate the introduction of an alternative freight mode. Short sea shipping (SSS) offers a low GHG emission alternative to overland modes such as heavy-duty trucks. Analysis shows that this service is justifiable from a demand and operational perspective. Estimation of GHG emissions change from mode shift shows that SSS could significantly assist the California freight corridor in meeting a GHG reduction goal. The operational speeds of short sea ships are a more crucial factor than ship size in influencing overall GHG emissions; in addition, the target market does not require excessively high speed. Under lower speed, increasing ship size is not expected to bring significant emission benefits, but adds the operators' economic risks under demand uncertainties. In addition to market segmentation, reliability is another key to the SSS's market penetration. The economic potential of SSS is dependent on both carrier-based efforts and governmental intervention, the latter of which may further favor the development of SSS in the future policy environment.

INTRODUCTION

Greenhouse gas (GHG) emissions and the resulting acceleration of climate change from the transportation sector is a major global challenge. In the United States, the transportation sector is the second largest end-use sector contributing to GHG emissions next to industry. Within transportation, the entire goods movement system, which incorporates heavy-duty trucks, ships, and rail, produces a significant amount of GHGs (*1*). Heavy-duty trucks are the primary means of US freight transportation in terms of ton-miles traveled. In accordance with this mode share, emissions of CO_2, the dominant GHG, from heavy-duty trucks have witnessed an increase from 15.4% to 20.2% of transportation sector emissions in the US, the largest growth rate of any major transportation source and more than twice the growth rate of light-duty vehicles (passenger cars and light-duty trucks) (*2, 3*).

To halt the trend of GHG emission growth, the state of California has set a GHG emission reduction target through the landmark legislation Assembly Bill (AB) 32. AB32 sets the statewide GHG emissions limit for the year 2020 equal to 1990 GHG levels (*4*). For perspective on California's challenge, transportation sector GHG emissions in 2004 were 21% higher than the 1990 level. Transportation is currently the single largest end-use sector contributing to GHG emissions in California, accounting for 40% of total GHG emissions, and the trend in GHG emission growth in this sector is projected to continue at least until 2010 (*5*).

The AB32 initiative is groundbreaking in its reach and goals. However, resulting transportation GHG reduction policies are mode-specific rather than system-wide. The majority of on-going efforts in reducing emissions from transportation are focusing on passenger travel (cars and light-duty trucks), with less attention paid to the large GHG contribution from goods movement. Inclusion of freight in GHG reduction initiatives is particularly critical in California, as the north-south freight corridor is one of the major heavy-duty truck traffic corridors in the nation. There are numerous possible reasons for this skewed focus. One is that California policymakers could be protecting the state economy and business interests wanting to encourage, and not discourage, an increase in freight operations (*6*).

This study seeks to introduce a goods movement innovation that would provide a means for users of the California goods movement system to save fuel and GHG emissions without punitive actions. Considering that CO_2 holds 96 percent of the total GHG emissions from transportation and the data availability, CO_2 is the main concern of this paper. Several studies have identified goods movement modal shift from heavy-duty trucks to a more energy efficient mode as the most promising method of reducing energy consumption and CO_2 emissions in the freight sector (*7*). Although it is still possible to divert some of the truck traffic to the more energy efficient railroads, the capacity limit has strained the rail network with shortages of tracks, locomotives, power, railcars, and crews. The Interstate 5 (I-5) rail corridor is constrained at many locations in California. Nevertheless, the majority of the limited investment on capacity expansion has focused on the higher revenue West-East rail lines and terminals (*8*). From the railroad perspective, capacity limitations are both a blessing and a curse: keeping tight demand-supply balance allows railroads to maintain pricing power, yet even desired improvements are out of reach due to high capital costs. Individual railroad companies therefore have low economic incentives to increase service and capacity.

Short sea shipping (SSS), or ships moving freight along coastal regions, provides a less understood lower emission alternative mode to heavy-duty trucks. It has the potential to abate GHG emissions while also yielding several other benefits such as reducing local pollutants emissions, mitigating highway congestion, and improving road safety. However, many unknowns exist due to the nascent body of literature on SSS and climate change. To this end, this paper will investigate the potential of SSS to reduce CO_2 emissions from goods movement with a focus on the north-south California corridor. In view of the current research and practices, this paper seeks to answer the following questions, 1. What is the size of the potential market for the proposed SSS in the north-south California corridor? 2. To what extent could the SSS help reduce CO_2 emissions in this corridor? 3. To make the new freight service successful, what are the issues to take into account and how should they be addressed? These are questions explored in this study.

EXISTING RESEARCH AND EXPERIENCES

While there is no uniform definition of short sea shipping, the term generally refers to non-ocean-going waterborne transportation moving commercial freight along coasts, sometimes including inland waterways (*9, 10*). The emergence and development of SSS is motivated by environmental awareness, increasing freight transportation demand, and limited overland infrastructure supply (*10*). Environmental awareness encourages SSS because ships emit less CO_2 per ton-kilometer than heavy-duty trucks and diesel trains (Table 1). Emission factors of other local pollutants reflect a similar trend (*11*). Other sources of emission factor estimates indicate that the CO_2 emission factor of SSS is comparable to that reported in Table 1, with one estimate at about one seventh that of heavy-duty trucks (*12*).

TABLE 1 Energy Use and CO_2 Emissions

Mode	Type	Energy Use (MJ/ton-km)	CO_2 Emissions (g/ton-km)
Truck	35 tons GVW (Gross Vehicle Weight)	1.34	100
	20 tons GVW	2.77	200
Train	Diesel	0.95	69
	Electric	0.83	38
SSS	Diesel	0.19	13
	Fuel Oil	0.17	12

Source: (*11*)

Research on the relationship between a freight mode shift to SSS and a change in GHG emissions is limited. Corbett et al. (*13*) develop an intermodal freight network model to evaluate freight route assignment among ships, rail, and trucks. This model performs route optimization under different objectives, such as the minimization of emissions, time, or cost. As each mode exhibits different characteristics (trucks have a faster travel speed than ships, yet a higher emission factor), a key component of the modeling capability is the ability to construct tradeoff curves between time and CO_2 emissions. Although the model incorporates some simplifications, such as all-or-nothing freight assignment, the results suggest that costal ships are a preferred mode when goods movement costs and emissions are concerned.

In addition to a lower CO_2 emission factor, SSS has other advantages over alternative modes. Paixao and Marlow (*9*) find that infrastructure construction and maintenance costs for SSS are lower than those for highway and rail. Another key benefit is the virtually unlimited capacity of the sea: increasing freight transport does not incur costs in the building of sea-lanes. Paixao and Marlow (*9*) also note that in Europe 60-70% of industrial and production centers are located within 150-200 km of the coast, providing SSS with a geographical advantage and facilitating the door-to-door transport of certain cargoes. Lombardo et al. (*10*) finds that SSS can both be cost-competitive and alleviate travel delay on highways in the US. The Government Accountability Office (GAO) (*14*) concludes that besides air quality improvement, the development of SSS operations may increase the capacity of congested freight corridors.

These numerous advantages of SSS have attracted the interest of various institutions seeking to innovate their freight transportation system. The European Union set SSS as an objective in the common transport policy (*15, 16*). The EU experience tells stories of clear success: by shifting some cargo volume from surface modes, short sea transport grew by 29.6% between 1990 and 1999. Forty percent of intra-EU trade now travels by sea (*17*). In the US, the benefits and potential of SSS encouraged the US Department of Transportation Maritime Administration (MARAD) to identify the acceleration of SSS as one of the six high-priority initiatives through the National Freight Action Agenda. To support this notation, the Maritime Administration has organized a series of programs aimed at examining and promoting waterborne freight movements (*18*).

A few SSS services currently exist in the US, mainly along the Gulf and East Coast. Research on SSS on the New York-Boston and New York-Miami routes showed savings in external infrastructure cost, local air pollutions, noise emissions, and congestion delays due to the introduction of SSS (*19*). Along the Pacific coast, Matson operated fixed-day weekly feeder services connecting LA and Seattle/Vancouver between 1994 and 2000 in the absence of external financial assistance, opposite to the case in the East Coast (*15*). It proved to be able to offer highly on-time performance and attract cargoes composed of three major categories: container loads for connecting carriers, empty repositioning containers, and domestic US freight. Demand seemed to be sufficient to maintain the service frequency - for example, the service once had connecting carrier agreements with 46 carriers and 60 shipper accounts, and generated positive cash flow. However, due to the capital-intensive nature of SSS operations, the system failed to cover the capital cost regardless of its efforts to keep start up costs at a minimum.

To evaluate a proposed SSS system and the potential savings in GHG emissions, an analysis of the market size (potential freight demand) in the north-south California corridor market is performed.

NORTH-SOUTH CALIFORNIA CORRIDOR FREIGHT DEMAND

California's major economic activities are close to the coast (within 150-200km) and geographically concentrated in four metropolitan areas (Sacramento, San Francisco Bay Area, Bay Area, Los Angeles, and San Diego). The major gateway ports are located in Oakland (SF Bay Area) and the San Pedro Bay (SPB) ports in Los Angeles, also known the Ports of Los Angeles/Long Beach. In the proposed SSS system, a line-haul SSS route would connect these four areas distributed in northern and southern California. Cargoes suitable to the SSS mode fall into two categories: domestic goods and international containers. To enable time for system development and to support the AB32 GHG reduction timeframe, the year 2020 is set as the evaluation year.

Domestic Goods

Domestic cargoes are goods that are both produced and consumed within US borders. MARAD (*20*) notes that the US target market for SSS is the domestic cargoes currently moved by overland modes. Trucks are the primary mode for domestic goods transport between north-south California, accounting for over 98% of the total commodity volume transport (*8*). Freight tons in 2020 are expected to be 70% greater than 2003 levels along all of the OD pairs in the northern to southern California freight corridor (*14*) (Table 2).

TABLE 2 Domestic Demand Forecast Results (million tons, 2020)

	Destination			
Origin	SF Bay Area	Sacramento	Los Angeles	San Diego
SF Bay Area	Not applicable to SSS		202.63	20.93
Sacramento			37.72	3.49
Los Angeles	199.23	35.59	Not applicable to SSS	
San Diego	20.56	3.62		

Source: (*8*)

Due to agglomeration of demand along the SF Bay Area-Los Angeles pair, these two regions are selected as the origin/destination of the proposed SSS route. As these two regions have major gateway ports, the large volume of domestic freight on this corridor can be supplemented with international containers.

International Containers

Short Sea Shipping could be a continuation of deep-sea ocean transport and assist in the development of a hub-and-spoke maritime shipping system. On the west coast, international container shipping usually exhibits the multi-leg feature of calling major gateway ports (SPB, Oakland, and Seattle/Tacoma), with SPB holding the majority of the first port calls (*8*). Over half (52%) of the transpacific vessel strings make their first North America call at the San Pedro Bay (SPB) ports; this percentage approaches 100% for vessels from other continents (*21*). The Port of Oakland absorbs one fourth of the total containers with destinations other than SPB (*8*). Liners currently calling both SPB and Oakland could reduce the ports of call through SSS, helping increase liner service frequency.

As only the Ports of SPB and Oakland are concerned here, international containers that are candidates for SSS fall into two categories. The first category includes cargoes imported from locations abroad with destinations beyond the first US port of call. The second category includes goods produced in a region beyond the origin gateway port through which they will be exported abroad. It should be noted that, due to the Cabotage rules, only US based domestic shippers could perform such a service with international containers.

Potential northbound international container flows for SSS are calculated by summing the containers that make their first call at SPB. First, ports located abroad, excluding Asia, are considered. For these ports, it is assumed that all vessels make their first domestic call at SPB; and these freight volumes including the portion of the containers bound for Oakland. For containers bound for the US from Asia, 52% make their first call at SPB; and of these containers, 25% are bound from Oakland (*8*). The sum of these figures is the northbound freight volume suitable for the SSS, which is 1.165 million Twenty-foot Equivalent Units (TEU) in 2005.

The volume of southbound flow potential of international containers is relatively small because very few liners call SPB after Oakland. Therefore, it is reasonable to assume that the coastwise southbound service will mainly serve US domestic goods traveling from northern California to be exported out of SPB; this value is approximated by summing outbound containers currently from Port of Oakland, which results in 0.86 million TEUs (*8*). The volume gap between the two directions could be filled by empty repositioning containers, and it is therefore assumed that the container flows will be equal.

An extrapolation based on historical container traffic data gives a prediction of the overall international cargo volumes and the resulting volumes suitable for the proposed SSS in the year 2020, assuming the current liner service patterns persist (*21*). The predicted international cargo volumes are shown in Table 3, together with the domestic demand, which is converted to the number of trailers based upon the average allowable trailer payload (45,000lb) (*8*).

It is clear that domestic freight holds the majority of the potential market. As the TEU imbalance on directional flows will be filled with empty containers, no significant volume discrepancy should be present. This is desirable as the vessel size is *a priori* determined by the loading capacity measured by the number of TEUs/trailers. In view that a typical trailer's size is about twice that of a TEU, it comes up with a total "trailer equivalent" volume (Table 3) (*8, 22*). Such estimates will provide the basis for choosing vessel size.

Given the potential market size suitable for SSS, the following section will develop an estimate to evaluate the SSS's potential for CO_2 emission reductions, based on designed operating procedures and "common" vessel configurations.

TABLE 3 Maximum Potential Market Breakdown (2020)

Freight Demand		Domestic (# Trailers)	International (# TEUs)	Equivalent Total (# Trailers)
Annual	Northbound	11910000	2080000	12950000
	Southbound	11690000	1533000	12460000
Daily Average	Northbound	32600	5700	35500
	Southbound	32000	4200	34000

Source: Calculated from (*8; 14; 21; 22*) by the authors; daily average assumes SSS operates 365 days per year.

EMISSIONS REDUCTION POTENTIAL EVALUATION

Service Pattern

As noted previously, the proposed SSS operates between Oakland and the SPB ports due to freight demand concentration for domestic commodities. Domestic freight produced or consumed in Sacramento/San Diego areas need to be transported between the point of production/consumption and the ports on heavy-duty vehicles. This is termed as a "connection stage". Within the metropolitan area where commodities are produced or consumed, some distance of local travel for either initial drayage or final delivery should be taken into account.

The normal payload of a short sea ship can range from 50 to several hundred trailers (*8, 23*). According to the demand estimate, even a small mode share of the SSS (e.g. 1%) would meet the minimum requirement for daily dispatch. Regarding the transit time, it takes 9.8 to 12.7 hours to complete the line-haul transport, assuming sailing speeds from 27 to 35 knots. The total transit time using the SSS would satisfy the one- or two-day delivery business model, which is prevalent among trucking companies in this market (*24*). Given an equal delivery time, stationary inventory cost at a warehouse can be reduced if goods are shifted from trucks to ships, as the goods would spend more time en-route. Correspondingly, the pipeline inventory cost will increase, but these costs are lower than the stationary costs (*25*). The overall effect is that transition increases the cost advantage of SSS.

Emission Factors

Distance, speed, engine power, and fuel type all affect vehicle CO_2 emissions. The operating behavior and related GHG emissions of heavy-duty vehicles which is well established is assumed to remain steady in the future. As an approximation, the standard emission factor for trucks quoted in Table 1 is used in comparison with SSS. On the maritime side, the "grams CO_2/ton fuel consumed" metric is adopted. Compared to other emission factor metrics (e.g. gCO_2/KWh and gCO_2/ton-mile), this metric permits a better depiction of the speed effect on fuel consumption and emissions as it is easier to relate fuel consumption to speed.

A number of studies regarding SSS propose roll-on-roll-off (Ro-Ro) as the more appropriate form of vessels as opposed to lift-on-lift-off (Lo-Lo) (*8, 23, 26*). The Ro-Ro configuration allows trailers to be drayed directly via trucks, rather than using specific handling equipment, e.g. cranes, resulting in substantial time savings. To meet the Ro-Ro deployment, international containers should be put on chassis. At the initial deployment of a SSS system, smaller vessel capacities are recommended (*23*) (50-120 trailers), which better guarantee the load factors and provide more time flexibility.

The most commonly used vessel fuel is Heavy Fuel Oil (HFO). Marine Diesel Oil (MDO) is regarded as one of the potential substitutes. MDO has greater fuel efficiency and a lower CO_2 emission factor than the other fuels. Its combination use with the gas turbine-mechanical system is more capable of meeting the speed requirements and considered the most promising for this application (*8*). It is for these reasons that in our study this configuration is chosen as the power system option for SSS vessels.

Mulligan et al. (*12*) estimate the fuel consumption for different combinations of speed and vessel size. The CO_2 emissions and fuel consumption have a strong linear relationship based on performance data of a typical gas turbine plant LM 2500 (*8*). Equation (1) shows the relationship between CO_2 Emissions (lbs) and the fuel consumption (FC) of a ship operating on MDO (lbs).

$$CO_2 = 3.1683 * FC$$

Following the above methods, a series of emission factors in terms of gCO_2/ton-mile are obtained as a function of vessel size and speed, which respectively range from 50 to 120 trailers, and 27 to 35 knots. The figure for SSS presented in Table 1 sits within the range of these emission factors, suggesting the consistency of the two estimates.

Emission Reduction Evaluation

Goods shifted from heavy-duty vehicles to waterborne vehicles still maintain surface components to complete a trip. In this case, overland transport is demanded by local travel within the metropolitan areas for all OD pairs and connection stages for ODs other than the SF Bay Area-LA. At both origins and destinations for a journey, the distance to the destination is calculated. A 20-mile voyage is assumed to represent the local truck travel; for freight bound beyond the local region, the distances between metropolitan area centers are used for calculating these connection stages as well as the overland line-haul movements in the absence of SSS. Waterborne trip length is assumed to be 395 miles, longer than the landside SF Bay Area-LA line-haul movements distance (*8*).

This study regards the CO_2 emissions from international goods as the same regardless of traveling on a short sea vessel or a transoceanic vessel. One may argue that there are emission advantages of such containers traveling on transoceanic vessels due to economies of ship size.

Such effects is expected to be offset considering traditional larger ships utilizing polluting diesel machines and HFO instead of smaller yet more fuel-efficient ones relying on gas turbine plants and MDO. Furthermore, the difference in CO_2 emissions between transoceanic liners and short sea vessels is much less evident than that between trucks and the coastwise ships, which represents a more drastic mode change.

In the absence of detailed surveys among shippers/carriers and comprehensive data about shipping characteristics, conventional methods of forecasting the mode share cannot be pursued. Instead, calculated frontiers of percent mode shift quantify the effect of SSS on CO_2 emission reduction. Because rail accounts for only a little more than one percent of the total freight demand and there seems no signal from the rail companies of increasing their capacity, it is assumed that the effect of SSS on the rail demand is negligible and vice versa. Following this, the emissions reduction effects under different mode shift scenarios from trucks to SSS are calculated. Figure 1 shows the total CO_2 emissions, including landside and waterborne components, before and after introducing the SSS service.

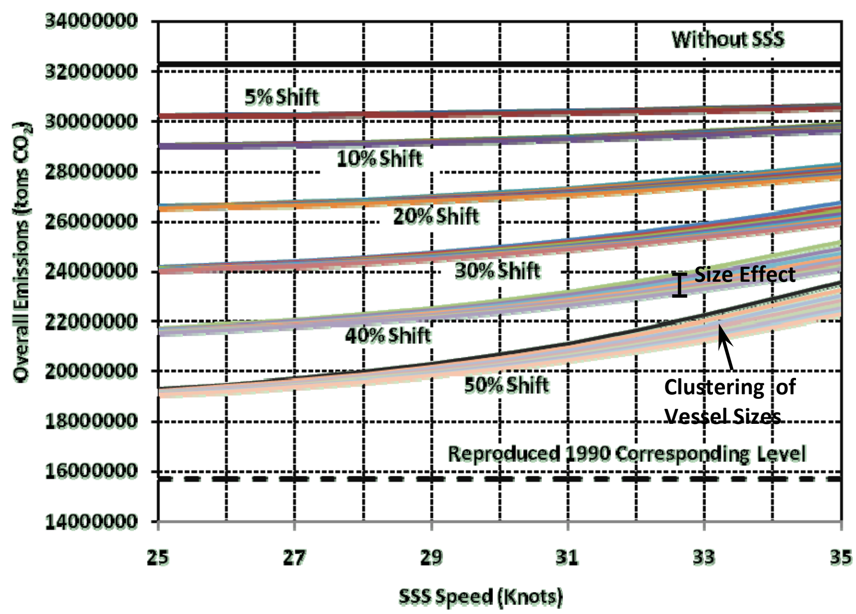

FIGURE 1 Emissions reduction potential under different scenarios (2020).

Each of the clusters in Figure 1 represents the GHG reduction potential estimates using different shipment sizes given a certain percentage of mode shifts. The largest shipment sizes represent the lower bound of the clusters for overall emissions; the smallest shipments are the upper bound. Observing Figure 1, it seems that the size of a short sea ship affects CO_2 emissions marginally when traveling at low speeds. This impact increases gradually with the rise of the SSS market share: a 40 percent mode share can result in more than one million tons CO_2 emission savings from choosing the largest over the smallest ship sizes, holding speed at the highest level.

Compared to vessel size, vessel speed exhibits more effect on total CO_2 emissions. In the case of a 40% mode shift and a 120-trailer vessel configuration, the CO_2 emission difference reaches 2.7 million tons (Figure 1). This difference grows with shrinking vessel size. Speed is also a key operational determinant: faster service is desirable to attract more commodities, but burns expensive fuel at a higher rate. As previously noted, moderate-to-low speed (e.g. 27 knots) would be sufficient to enable carriers to complete overnight line-haul transport and meet the one- or two-day transit time requirement; coastal carriers are therefore more likely to travel at a lower speed out of their own economic incentive.

It is illuminating to evaluate to what extent the SSS helps achieve the California CO_2 emission target calling for 1990 CO_2 emission levels by 2020 in this corridor. The corresponding 1990 level emission is reproduced (Figure 1), based on the emissions data in the transportation sector in California (*27*). The introduction of the SSS service alone is not able to accomplish the reduction target, even when its market share is set to be very high (50%); no precedent for such market share exists around the world. However, lower and more realistic projected mode share of the SSS already makes significant contributions. For example, a 20 and 30 percent could assist achieving one third and half of the total emission reduction quantity, respectively. Such results are very promising, keeping in mind that it is not expected for all of the reductions to come from one single change, but rather from a collection of reduction strategies, as discussed by Ganson (*5*) related to passenger travel.

DISCUSSIONS

The benefit of introducing SSS to assist the freight transportation sector in mitigating CO_2 emissions is apparent. A moderate mode shift compared to the European experience (such as 20%) is able to take over a substantial part of the total planned reduction amount. This strategy deserves consideration especially when other benefits such as the amelioration of local environmental issues and road congestion are considered. There are challenges to implementation a SSS system, including attracting enough market share and achieving cost savings.

Market Share

A challenge to SSS is how to attract a sufficiently large portion of the total freight demand to justify such as service. The previous estimate demonstrates that the expected total transit time, which includes time spent on the line-haul, and drayage to/from the port, could allow the SSS to meet the one- or two-day delivery requirement. Shippers therefore may not take transit time as the major concern in choosing between SSS and truck modes. Rather, the market success of the SSS may be determined by other factors discussed below.

Reliability

Reliability in freight transportation rests on the on-time performance in order for shippers to minimize safety stock. In the SSS context, congestion on routes entering and leaving the ports and at terminals could lead to unreliability of delivery. Using ports other than the major gateways provides a possible solution; dedicated terminal facilities, albeit debatable, keep the SSS vessels away from sharing lands and equipment with other ships, therefore significantly reducing terminal-related delay. On the other hand, efficacious integration of different modes is also critical. This requires strong coordination with trucking companies, if self-owned tractor fleet is a less possible choice. For landside trucking alone, a multi-home owner-operator network is recommended, to coordinate hand offs at load and discharge ports.

Market Segmentation

Compared to landside modes, SSS is more attractive to non-time-sensitive and low-value commodities scheduled for non-Just-In-Time warehouse replenishment or materials for manufacturing with long transit times built into the supply chain (*24*). Scrutiny of the cargo flow reveals that current commodities falling into this category account for more than 40% the total demand, for all the OD pairs in this market (*8*). As daily service is possible even for a small market share, overnight shipping is a better pattern, as described in an earlier section. Incremental demand can be accommodated by either augmenting vessel size or dispatching more ships.

From Figure 1 it is observed that the effect of increasing ship size on total emissions decreases with speed, for a given market share. The non-time-sensitive market suggests moderate-to-low speed (e.g. 27 knots) is sufficient and economically more appropriate. Under this condition, proposals of larger vessels with the capacity of 500-700 trailers do not bring significant emission changes, based on the same calculation approach (*24*). Compared to the 120-trailer configuration, only around 0.15 million tons of CO_2 savings is gained from using the aforementioned larger vessels, providing a 20% mode shift. Such discrepancy becomes even less visible in the system as the market share of SSS is lower. However, the selection of vessel size does impose significant financial risk differences for carriers especially when demand is uncertain at the outset of the development of the SSS. From both the emission and operation perspective, smaller vessels with adjustable fleet size to demand are a more judicious choice than blindly using larger ships.

Cost Analysis

The discussion of vessel size raises a new question about the economic viability of SSS. In addition to maximizing demand, minimizing costs is also the goal of a new system. Low costs enable the SSS to offer competitive rates compared with heavy-duty vehicles, which in turn help promote its market share. Current practices of the Gulf Coast show the shipping price of SSS is attractive to shippers compared to that of trucking (*14*). Furthermore, an assessment the economic feasibility of SSS on this California market found that the ratio of SSS/trucking in terms of total costs per trailer load can reach 0.7 to 0.8, assuming a useful vessel life of 20 years (*8*). Experience has shown that the ability to profit over the long-term meets is challenged by high capital cost and added fees to operating costs.

Start-up Cost

Despite research showing that the total costs per trailer load using SSS is less than that of trucks, there are still barriers to the economic feasibility of SSS. Lumpy initial capital costs, including vessel procurement costs and port infrastructure-related costs, are much higher in SSS than in trucking, which deters operators to invest on such business. Experiences from Matson and existing services on the East Coast suggest governmental funding is almost a prerequisite. Adequate use of subsidies helps ease the expropriation of lands for implementing dedicated terminals, improves the operational efficiency by employing more market-suitable equipment, and facilitates the coordination between the SSS business and other parts in the logistics chain. In addition, policy intervention from the government also plays the role of indirectly reducing start-up costs. The Jones Act of 1916 obliges SSS operators to purchase ships built domestically. These ships carry a greater capital cost than ships built abroad, which substantially raises the operators' capital costs and affects their ability to keep shipping prices competitive with trucking.

At the same time, the amendment of Jones Act is still very controversial on the ground that the act helps create job positions and protect the American shipbuilding industry (*10*).

Nonetheless, carriers could make their own efforts to lower the start-up costs. Careful market analysis is important for choosing the best ship configurations and fleet size, and so is the design of an appropriate operational pattern. In the presence of uncertainty in the debut of SSS, conservative actions appear better than aggressive ones, to some extent suggesting again smaller vessel sizes would be a better choice.

Operating Cost

The two operating cost categories are vessel and landside costs. Speed is the major factor affecting fuel consumption and therefore operating costs. Operating speed is largely determined by the types of commodities transported. On the landside, operating costs are reduced through several ways, e.g. employing draymen to realize door-to-door service and negotiating with dockworkers and port authorities to reduce port charges and stevedoring costs (*24*).

Besides traditional ways of financially supporting the daily operations of SSS, government's influence is also present in the daily operations of SSS. An example is the harbor maintenance tax (HMT). On the pacific coast, HMT can account for 6-10% of the total costs per trailer load (*8*). HMT was originally collected from overseas cargoes, but was declared by the Supreme Court to be unconstitutional in 1998. Congress further waived the HMT for cargoes moving in the "non-contiguous" domestic market. If efforts to abandon this tax on domestic cargoes were successful this change would have direct impact on reducing operating costs, permitting further rate competitiveness of SSS.(*28*).

The increasing concern of mitigating CO_2 emissions provides SSS with additional opportunities. Future environmental taxes based on CO_2 emissions could provide the rationale to subsidize SSS, or to reduce shippers' incentive to utilize trucks by levying taxes on trucks. In addition, any sort of emissions trading system would put the coastwise mode in an advantageous position and stimulate its popularity among shippers.

CONCLUSIONS

Short sea shipping is an innovative concept as an alternative to landside modes in the north-south California freight transportation corridor. It provides an efficacious path towards mitigating CO_2 emissions and realizing the California 2020 emissions reduction target. In this study, the potential of SSS to reduce CO_2 emissions from goods movement in the California freight corridor is estimated and discussed. Results show that the potential demand would be sufficient to support the minimum operations of SSS even given a small market share. As the percent of goods shifted to SSS from heavy-duty vehicles increases the CO_2 emissions savings from goods movement increase. Considering non-time-sensitive commodities are most likely to be the target goods for SSS, travel at modest-to-low speed mentioned in the paper is a better choice, whereas ship size seems not to significantly affect emissions. From a cost perspective, slower speed and smaller vessel size also make a big difference for the start-up of the service.

The success of the SSS concept depends upon both the market share and cost competitiveness. The first is achieved by enhancing its service reliability and effective market segmentation. Governmental subsidies and favorable policies would certainly assist operators in overcoming the initial financial obstacles. Operational cost cutbacks could be realized through carriers' own efforts, the relinquishment of unjustifiable taxes, and environment-oriented policy changes in the future.

This study illustrated the promise of a new coastwise freight transportation system in reducing CO_2 emissions. However, some aspects involved in this study deserve further work. First, the emissions models and figures used in the study are empirical; it is very likely that in the future the coastwise ships and the alternative modes would be more fuel-efficient. The availability of such data would enable a more accurate representation of the emission reduction potentials from the SSS. Second, local truck travel assumptions or modeling must be fine-tuned. Although the associated emissions are not a significant portion in the total, improved methodology is necessary to build a more precise picture. Thirdly, demand analysis shows that international cargoes constitute a small portion in the potential demand. International cargoes were included to increase the SSS's frequency, however, this contribution was limited and such cargo further adds to the transloading complexity. Although believed to be comparatively small, emissions differences before and after including international cargoes to the domestic cargoes for SSS are still unclear. The suitability of international cargoes as compared to domestic ones merits further investigation.

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