The demand and supply of trans-oceanic sea routes: the case of east Asia-US east coast container trade

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Abstract: The Panama Canal expansion will create a new lane of traffic for larger ships, up to 13000 -14000 TEUs. While trade between Asia and the US continues to increase, a number of supply factors may impact the Canal’s position. First, several US and Canadian west coast ports plan to increase service levels. Second, railroads serving the US west coast are examining the possibility of lowering freight rates. Third, the Nicaragua Grand Canal has been proposed and started construction. Fourth, the Suez Canal is expanding operations and may capture some of the traffic currently transiting the Panama Canal. Fifth, multiple Central American countries are considering constructing ‘dry canal’ rail links between the Pacific and Caribbean coasts. These together may result in an excess supply of trans-oceanic sea services. This paper examines the possible changes in supply and demand with emphasis on East Asia-US container trade.

Keywords: Panama Canal; demand; supply; Asia; US; Nicaragua Canal.
1 Introduction

The Panama Canal is a vital node and logistics hub in the global maritime network, and for over a hundred years served as the only all-water link connecting the Atlantic Ocean to the Pacific Ocean via the Caribbean Sea. In 2014, a total of 13,482 vessels transited the Canal, on average 40 ships per day (ACP, 2015a). The Canal has been servicing many important trade routes, with the most prominent one between East Asia and the US east coast, which accounted for nearly 40 percent of total tonnage passing through the Canal in 2014 (ACP, 2015b).

In order to accommodate projected future growth of global commerce and consequently maritime shipping traffic using the Panama Canal, the Panama Canal Authority (ACP) has begun its largest expansion project in history. The completion of the canal expansion by 2016 will create a new lane of traffic, allowing more and larger ships to transit, including post-(relative to the existing locks) and neo-Panamax vessels (relative to the new Panama locks) with up to 13,000-14,000 TEUs. The expansion will double the canal’s traffic handling capacity and have a direct impact on scale economies in international maritime trade (ACP, 2015c).

In addition to the Panama Canal expansion, the supply of interoceanic liner capacity for Asia—US East Coast maritime trade is likely to be further increased due to several other major maritime infrastructure initiatives. First, taking advantage of the desirable economies of ship size, the fleet of container ships larger than those capable of transiting the expanded Panama Canal will continue to grow. Between 2005 and 2014, the average container ship size nearly doubled, increasing from 1,228 to 2,256 TEUs per ship (Tran and Haasis, 2015) and vessels near 20,000 TEUs are being ordered for construction.

Second, ports on the US west coast have started increasing service levels and lower turnover times in anticipation of greater competition from the expanded Panama Canal, despite the backup of cargo due to dockworker strikes across west coast ports. Railroads connecting the US west coast ports to the rest of the North America continent have also been examining the possibility of lowering freight rates in order to stay competitive. Furthermore, Canadian ports on the west coast, notably the Ports of Vancouver and Prince Rupert which are located directly on the Great Circle Route linking Northeast Asia and the North America west coast, are taking significant strides expanding operations to gain a bigger foothold in the Asia—North America shipping market.

Third, the Panama Canal has recently been challenged by the proposals of new shipping channels and improvements announced to the Suez Canal. The most prominent is a new shipping route through Nicaragua, known as
the Nicaragua Grand Canal (Figure 1). The Hong Kong Nicaragua Development (HKND) Group, which is in charge of the project, started construction in December 2014. The project is expected to be completed in 2019 (HKND, 2014). Competition for interoceanic shipping traffic does not only arise from the Nicaragua Canal. With location proximity and similar geographical features, several other Central American countries have been gauging the opportunities of constructing rail links, or dry canals, connecting their respective Pacific and Caribbean ends in the Central America isthmus. Finally, if the trend of global warming continues, then an Arctic route from Asia to the US east coast will become much more feasible.

The increase in the supply of maritime shipping and port/canal infrastructure capacity servicing Asia—US east coast will be accompanied by future changes in global trade patterns and volume. On the one hand, re-shoring of manufacturing is in its early stages of implementation in the US. Driven by increased wage rates in Asia and the utilization of robotics and other technologies which lower the costs of production in the US, the manufacturing reshoring trend is likely to have a dramatic impact on US import demand in the future. Another emerging technology is 3D printing which, after its widespread application, is expected to substantially reduce the demand for spare parts from overseas suppliers. Thus, combined manufacturing re-shoring and 3D printing may serve to lower the demand for Asia—US east coast transoceanic services.

On the other hand, global maritime trade will be shaped by the continuous economic prosperity and consequently growth of trade involving South American, Central American and Caribbean regions. Trade between these regions and Asia, in particular China, has grown explosively in recent years (OECD, 2010; ECLAC, 2012; Kotschwar, 2014), demanding more use of the Panama Canal. The use of the Panama Canal is also likely to increase by emerging African economies, which are taking the first-steps toward development through stable governments, the rule of law, and free, competitive markets. If a growing number of African nations continue on this economic development path, then there will be a new source for global maritime trade between those emerging African economies and major consumer markets such as the US and South American west coast regions, which would suggest an increasing demand for the use of Panama Canal.

Given all these changing trends, it is important for ports and canal operators, ocean-going liners, shippers, policy makers, and other
stakeholders to fully understand these impacts on the future supply-demand balance of interoceanic services in the Americas. However, only limited work has been done examining the impact of these factors on trans-oceanic maritime trade. Veldman et al. (2014) developed a logit model to assess the market shares of Asia—US east coast trade of the expanded Panama Canal, the Nicaragua Grand Canal and intermodal shipments through US west coast ports. Fan et al. (2012) quantified the impact of changes in container flows on the US logistic system caused by some of these changes in the trans-oceanic system. Ungo and Sabonge (2012) examined the competitiveness of the Panama Canal as compared to a variety of alternatives. Pagano et al. (2012) looked into the impact of the Panama Canal expansion on the Panama economy. Finally, Yip and Wong (2015) used scenario planning methods to examine how the Panama and Nicaragua canals may compete in the future.

In this paper, we make a first attempt to evaluate the plausible demand and supply distributions and the overall balance in the interoceanic maritime shipping system, which encompasses the west coast ports of North America, Panama Canal, Nicaragua Canal, and all proposed rail links across the Central American isthmus. We assume that traffic that may be diverted to the Suez Canal will eventually be re-routed through Panama as the Expansion is implemented. Since ports on the US east coast are in the process of getting ready for larger ships, we assume that at least some of the ports will be able to accommodate these ships. This paper will examine container traffic, with emphasis on East Asia—US east coast trade. The purpose of such analysis is to assess if sufficient or excess capacity would be provided with the boom of new infrastructure construction and growth of maritime trade.

2 Conceptual model

Global interoceanic maritime trade patterns bear close relationship with the world's macroeconomic environment and spatial distribution of production and consumption centers worldwide. For example, the aforementioned reshoring of manufacturing back to the US, growing trade ties between Latin America and Asia, and economic development in Africa all affect the macroeconomic environmental evolution which determines the overall trade volumes between each origin-destination (OD) pair in the world. In the conceptual model, a continent (e.g., North America, South America) or a part of a continent that has strong economic clout and integration (e.g., East Asia, European Union) will be considered as one origin or destination. Let us first use Equation (1) to denote the relationship
between $Q_w$, which is the trade volume for OD pair $w$, and $M_w$, which is a vector representing the macroeconomic strength and other economic characteristics of the origin and destination regions of the OD pair $w$:

$$Q_w = Q_w(M_w)$$  \hspace{1cm} (1)

Shipping cost, inventory cost, and transit time represent three major factors in generalized transportation and logistics cost (GTLC), which determines the route-level maritime cargo demand, as shown in Equations (2)-(3).

In Equation (2), $C_{w,k}$ represents GTLC for route $k$ which belongs to OD pair $w$; $p^1_{w,k}$, $p^2_{w,k}$, and $t_{w,k}$ are the corresponding shipping cost, inventory cost, and transit time. In Equation (3), maritime cargo demand on route $k$, $Q_{w,k}$, is a function of both overall trade volume for OD pair $w$ and the route specific GTLC, $C_{w,k}$.

$$C_{w,k} = p^1_{w,k} + p^2_{w,k} + t_{w,k}$$  \hspace{1cm} (2)

$$Q_{w,k} = Q_{w,k}(Q_w, C_{w,k}) \quad \text{where } Q_w = \sum_{k \in K_w} Q_{w,k}$$  \hspace{1cm} (3)

where $K_w$ is the set of routes belonging to OD pair $w$.

On the other hand, the supply of trans-oceanic sea services depends on a variety of factors. Let $Q_{s,k}$ denote the supply of trans-oceanic sea services on route $k$. Then,

$$Q_{s,k} = Q_{s,k}(P_k, C_k)$$  \hspace{1cm} (4)

where $P_k$ is the total price charged for using transportation services through route $k$.

This includes all tolls, freight handling costs, and land transportation cost. $C_k$ is a vector of short term and long run costs associated with providing the service on route $k$. In an oligopolistic situation, which would be the case for trans-oceanic services, the prices charged on other routes factor into the decision of how much service to provide on a specific route of the same OD pair. Then the supply function becomes:

$$Q_{s,k} = Q_{s,k}(P_k, C_k, \mathcal{P}_{-k})$$  \hspace{1cm} (5)
where \( P_{-k} \) is the vector of prices for all competitive routes of the same OD pair. The total supply of trans-oceanic sea services for OD pair \( w \) is given by \( \sum_{k \in K_w} Q_k \). We have the following possible scenarios:

1. If \( \sum_i Q_{s,i} = \sum_i Q_{w,i} \), then supply equals demand. Market clearing prices and quantities will be obtained;
2. If \( \sum_i Q_{s,i} > \sum_i Q_{w,i} \), then there is excess supply with possible price wars, reductions in supply or price fixing among suppliers;
3. If \( \sum_i Q_{s,i} < \sum_i Q_{w,i} \), then there is excess demand with possible long wait times, higher prices and reductions in global trade.

### 3 Demand for trans-oceanic services

Whether moving by container ship, heavy lift vessel or tanker, maritime accounts for some 70 percent of all global trade by volume. In 2014, according to IHS Global Insight (2015), global trade monetary value stood at $20.6 trillion, global seaborne trade volume was about 9.24 billion metric tons. Trends in world seaborne trade are shown in Figure 2. As can be seen by the figure, world seaborne trade has steadily increased since 1980, except for recession years, such as 2009. World trade trends ultimately result in seaborne trade. Table 1 shows how these trade flows translate into flows of containers across different routes. Tables 2 and 3 illustrate these flows through the Panama Canal.

![Insert Figure 2 ‘World seaborne trade trend, in million tons loaded (Source: UNCTAD, 2014)’ about here](image)

### 4 Current supply of trans-oceanic sea service

#### 4.1 Panama Canal

Known as the spine of the Americas, the Panama Canal stands at approximately 80km long, linking the Atlantic and Pacific oceans. This canal enables ships traveling from Asia to the east coast of the US to shorten the distance by about 6 164 nautical miles or 13.5-day savings compared to the route around Cape of Good Hope. Since its completion a hundred years ago, the Panama Canal has become one of the two key conduits for international maritime trade (the other is Suez Canal), providing transit services to more than 815 000 vessels (ACP, 2015b). Currently the Panama
Canal handles 2.4% of seaborne world trade volume (in tons), including nearly 70% of all cargo to and from the US.

Insert Table 1 ‘Estimated containerized cargo flows on major East-West container trade routes, in millions of TEUs (Source: UNCTAD, 2014)’ about here

Insert Table 2 ‘2014 Pacific to Atlantic cargo traffic along principal trade routes through the Panama Canal in million metric tons (ACP, 2015b)’ about here

Measuring the precise capacity of the Panama Canal is difficult and not a precise science (MARAD, 2013). This is because canal capacity is influenced by a number of factors, such as ship size, operation restrictions during a certain period in a day (e.g., nighttime), and weather conditions. The existing indicator of canal capacity is based on the Panama Canal Universal Management System (PCUMS), which converts each commercial ship to a unique PCUMS ton value to reflect the ship’s cargo-carrying capacity. Using this metric, the current annual capacity of the Panama Canal has been estimated to be over 300 million PCUMS tons. In addition, it was reported that the Canal already approached its maximum capacity in 2007, right before the global economic downturn (MARAD, 2013). Figure 3 shows the historic oceangoing traffic through the Panama Canal, in terms of both transits (in thousands) and PCUMS tons (in millions).

Insert Table 3 ‘2014 Atlantic to Pacific cargo traffic along principal trade routes through the Panama Canal in million metric tons (ACP, 2015b)’ about here

Insert Figure 3 ‘Panama Canal traffic history (Source: ACP, 2015a)’ about here

Because this study requires a combination of Panama Canal capacity with capacity of North America west coast ports and new wet/dry canals in the Central America isthmus, an alternative metric to PCUMS tons that commonly applies to all pertinent maritime infrastructure is needed for measuring capacity. Since our focus is container traffic and current traffic is very close to capacity, TEU throughput is used as a surrogate capacity measure. Following this, the current capacity for the Panama Canal is assumed 12 100 000 TEUs, which is the actual amount of TEUs transited through the canal (ACP, 2013).
4.2 North America west coast ports

Similar to the case of the Panama Canal, obtaining precise estimates of port capacities is difficult, and often require application of detailed simulation models, data on vessel arrival patterns, and service times (UNESCAP, 2007). Such detailed modeling is clearly beyond the scope of the present study. We instead take advantage of existing estimates. For the six ports in the US, i.e., Ports of Los Angeles, Long Beach, Oakland, Portland, Seattle, Tacoma, the port capacity estimates in terms of TEUs by Fan et al. (2012) is used for our analysis. The port capacity estimates for the two Canadian ports (Vancouver and Prince Rupert) are directly taken from the respective ports’ websites. As an alternative measure of port capacity, we also collect the port acreage information. As shown later, the acreage information can be helpful in obtaining future port capacity estimates as ports’ development plans indicate more often the expansion of land areas than explicit throughput capacity. Estimates of TEU capacity and current throughput of each of the ports is shown in Figure 4.

4.3 Suez Canal

As an important conduit for linking Asia, Europe, and Africa, the 193.3 km long Suez Canal is known as the throat of Europe. It shortens the shipping distance from Asia to Europe around Cape of Good Hope by about 8000 km (Suez Canal Authority, SCA, 2015). The Suez Canal extends from Port Said to Suez and connects the Mediterranean Sea with the Red Sea. It is one of the world's most important waterways. Only a small fraction of the traffic through Suez concerns Asia—US trade.

5 Future supply of trans-oceanic sea services

Predicting future capacity of trans-oceanic services is difficult. The most reliable related information, if it exists, should be collected from the planning and development reports of individual port/canal authorities. Similar to the existing capacity, projections of future capacity for ports are mostly made on the basis of TEU throughputs; in other cases in terms of future acreage of the port area. Because forecasts come from different agencies, the available port/canal capacity projection years are different, ranging from 2015 (for Port of Los Angeles) to 2023 (for Port of Prince Rupert). In this study, we look at capacity scenarios in year 2025, with the
assumption that the expanded port/canal capacity would remain between the reported projection year and 2025.

5.1 Panama Canal expansion

Over the past 18 years, the Panama Canal has undergone substantial modernization improvements. For example, the Gaillard Cut, the artificial valley linking Gatun lake (and therefore the Atlantic Ocean) and the Gulf of Panama (and therefore the Pacific Ocean), has been widened; new electrical and hydraulic equipment have been installed; the locks, lighting, communications and navigation control systems have also been improved. The result is a more efficient and safer canal with a relative small increase in its daily transit capacity. However, Canal traffic continues to grow, which is accompanied by the increase in ship size and the percentage of container ship traffic. Today, almost 50 percent of the ships transiting the Panama Canal are of Panamax size.

These improvements notwithstanding, the maximum capacity of the Panama Canal is being reached and the Canal is facing difficulty in handling a greater number of ships or cargo in the near future. The Panama Canal expansion project, with its core adding a new lane of traffic, is to overcome the forthcoming capacity shortage by allowing more and larger ships.

The new set of locks will allow the passage of container ships that carry 13000 – 14,000 TEU’s, as compared to the current maximum of 5100 TEU’s which are Panamax container vessels. The US east coast ports are currently in the process of getting ready to accept these larger ships. As a consequence, it is believed that the capacity of the Panama Canal will be doubled with the completion of the expansion. We assume that the capacity of the Panama Canal for handling container traffic will be twice the existing capacity after the expansion.

5.2 North America west coast ports

In anticipation of future shipping traffic growth, several of the North America west coast ports have also reported their expansion plans. Among them, the most ambitious ones are by the Canadian Pacific gateway ports, Port Metro Vancouver and Port of Prince Rupert, which expect doubled traffic in the next 15 years.

Port Metro Vancouver, the largest port in Canada, estimates almost 4 million TEUs of additional capacity will be needed to meet Canada’s west coast container demand by 2030 (Port Metro Vancouver, 2015). The port is planning for expansion from the existing capacity of 2.7 million TEUs/year to a total of 7.2 million TEUs/year by mid 2020s.
The Port of Prince Rupert is the closest North American west coast port to Asia. For example, it is 36 hours closer to Shanghai than Vancouver and over 68 hours closer than Los Angeles (Prince Rupert Port Authority, 2015). Its 24-hectare (59-acre) Fairview container terminal, which was completed in September 2007 and commenced operations on October 31, 2007, is the first dedicated container terminal in North America, with an operational capacity to move 750000 TEUs per year. Upon completion of phase 2 of the Fairview container terminal, which is in the engineering design step and has an area of 32 hectares (80 acres) with a design capacity of 1.5 million TEUs/year, the container terminal will have a 2.25 million TEUs/year capacity.

On the US side, the middle harbor redevelopment project at the Port of Long Beach will combine two aging container terminals into one of the world’s most technologically advanced and greenest facilities. The project will double capacity while cutting air pollution in half. The nine-year, $1.31 billion project will upgrade wharfs, water access and storage areas, as well as add a greatly expanded on-dock rail yard. Construction is well under way; work on the project started in spring 2011 (Port of Long Beach, 2015). Despite limited physical area expansion, this is expected to double the container handling capacity at Long Beach.

The Port of Oakland will also see considerable capacity expansion due to a sweeping modernization and an expansion plan that converts the former Oakland Army Base to the Oakland Global Trade and Logistics Center, transforming the Port of Oakland into a world-class intermodal hub and international gateway (Oakland Global, 2015). A new break-bulk marine terminal will be built to increase the amount of materials coming through the waterfront. A new intermodal terminal will lead to port transit time savings, increased shipping volumes, and reduced transportation costs (Oakland Global, 2015). This will result in an additional area of 228 acres as part of the Port of Oakland (Port of Oakland, 2015). Because direct TEU capacity projections are not available, for simplicity we assume that the TEU capacity will increase proportionately with the increase in port acreage. This leads to a capacity of 4.17 million TEUs per year.

The other ports on the North America west coast have limited capacity expansion plans. The Port of Los Angeles, with new investment from several shipping liners, is expected to increase its TEU handling capacity from 11.2 million to 12.7 million per year (Port of Los Angeles, 2010). The Ports of Seattle, Tacoma, and Portland, have no new capacity expansion plans that have been reported. For these three ports, we will take their current capacity for the 2025 scenario analysis.
Ports on the US east coast and south are also in the process of expanding to accept the larger ships that will transit the Panama Canal.

5.3 Nicaragua Grand Canal

The idea of developing a Nicaragua Canal is the response to the anticipated increase in trans-oceanic ship size and maritime trade volumes (HKND, 2014). Even when taking into account the present Panama Canal expansion, there are still opportunities for additional new capacity on a much grander scale to transit container ships with size beyond 13000 – 14000 TEUs, which is the new-Panamax vessel size limit. If built, the Nicaragua Canal will be wider than the Panama Canal and be able to cater to the world’s largest cargo ships in existence today. The cost of the canal is estimated to be $50 billion. The construction has reportedly begun in December 2014 and is expected to take five years to complete (UNCTAD, 2014). However, questions have been raised about the viability of the project, including its environmental impact (Shaer, 2014). Having a precise estimate of the TEU handling capacity of the Nicaragua Canal is even more difficult than predicting future capacities for the Panama Canal and the North American west coast ports. For the Nicaragua Canal, the best relevant source we can find is the HKND’s own projection of ship traffic, which states the maximum ship transit capacity of 9153 per year (HKND, 2015). HKND further predicts the share of container ships in total transits to be 51% and 42% in 2020 and 2030. We therefore take the average for the 2025 analysis. In terms of ship size, Nicaragua Canal is mainly intended to provide transit for ships too large for expanded Panama Canal (HKND, 2015). In view that the largest container ships have capacity of 19300 TEUs (HKND, 2015) and the expanded Panama Canal can only accommodate container ships up to 13000 – 14000 TEUs (MARAD, 2013, ACP, 2015a), in the subsequent analysis we use 16000 TEUs as the ship capacity for estimating Nicaragua Canal TEU capacity per year, which amounts to $16000 \times 46.5\% \times 9153 = 68.09$ million TEUs.

5.4 Central American rail links

Mexico, Guatemala, Honduras/El Salvador, Costa Rica, and Colombia each are betting on ‘dry’ canals, with cross-country rail lines connecting ports at each end of the Central America isthmus. Freight trains will speed containers from one ocean to the other without involving a water artery. More specifically, Mexico’s proposed rail link, located at the Isthmus of Tehuantepec, represents the shortest distance connecting the Gulf of Mexico and the Pacific. This rail link actually was an operational dry canal
from 1907, but was abandoned shortly after the opening of the Panama Canal (Rodrigue, 2015). It could be reopened as a logistics corridor. Guatemala’s $10 billion plans are aggressive: massive new ports on its Atlantic and Pacific coasts, five oil and gas pipelines, two rail lines, a highway, and industrial parks punctuating a 244-mile dry canal. Honduras has an even more ambitious rail construction plan jointly with El Salvador for a set of 10 rail lines linking two coasts, including a refinery and an oil pipeline. For Colombia, the most effective rail link would be between the ports of Cartagena and Buenaventura. However, its close proximity to the Panama Canal makes the option a difficult value proposition (Rodrigue, 2015). All the proposed dry canals are shown in Figure 5.

Estimation of the rail link capacities draws from the existing intercontinental rail line in Panama which has a handling capacity of 650 000 TEUs per year (Georgia Tech Logistics Innovation & Research Center, 2015). Note that the actual container traffic handled in 2012 was at its highest level, at 380 000 TEUs. The capacity of a rail link is relatively insignificant compared to that of the wet canals.

5.5 Suez Canal

The Suez Canal is in the process of expanding as well, widening the Canal to create two lanes of traffic. Some Asia—US east coast traffic is currently being diverted to Suez from Panama. But, this traffic is expected to return to Panama once the Panama Canal Expansion is complete.

6 Future supply-demand balance

In this section we investigate the potential balance/imbalance of trans-oceanic service supply and container traffic demand involving the North America west coast ports and the Central America wet/dry canals. These maritime infrastructure facilities are associated with many OD pairs, and the particular reason for us to jointly consider North America west coast ports and Central America canals is the potential route substitution for some ODs, notably Asia/Oceania-US east coast shipping traffic. Figure 6 demonstrates the different inflows into the North America continent through the west coast ports and through the Central America canals from the Pacific side to the Atlantic side. The dashed arrows denote the ODs with substitutable routes.
While it is ideal to perform detailed, route-specific analysis, such data are not available. Instead, we will look into the relative capacity and demand for the North America west coast ports and Central America canals separately, and all together as a whole.

We begin with projecting port/canal TEU demand in 2025. Three growth rates for shipping demand are considered, to represent different trajectories of future maritime trade. The first one comes from averaging the historic growth for world seaborne trade tonnage between 1970 and 2013 (UNCTAD, 2015), which turns out to be 3.25%. The second and third growth rates, 5% and 8%, are derived from UNCTAD (2014) information, reflecting medium- and high-growth paths. Since East Asia—US east coast traffic growth has averaged over four percent per year (IHS Global Insight, 2015), then the second growth rate seems to encompass a reasonable expectation for demand growth in the future.

We apply these growth rates to each port’s and the Panama Canal’s current TEU throughput, to generate 2025 TEU traffic projections. Although in reality different ports/canals may have non-homogeneous growth rates, the inter-port disparities may cancel out to a large extent when it comes to the system aggregate, which is the concern of this study. The current and projected demand values are then compared with the corresponding capacity supplies, determined in Section 5, for the North America west coast, Central America, and the system as a whole. The results are presented in Tables 4-6, with the demand-capacity ratios highlighted in bold.

First, let us focus on the North America west coast only (Table 4). Future capacity will fall short facing all demand growth scenarios, despite excess capacity under current demand. For the highest traffic growth, demand will exceed port capacities by 77%. The situation is quite the opposite looking at the Central America region only. As shown in Table 5, the only case with capacity shortage is when demand grows at 8% annually and only the Panama Canal is present. However, once the Nicaragua Canal is completed, canal capacities will far exceed projected demand, which would account for at most one third of the capacity provided. On the other hand, with the two wet canals, the effect of rail links on capacity provision is rather limited: the demand-capacity ratio changes only slightly.

The capacity shortage on the North America west coast and the capacity excess in the Central America isthmus combined together will result in net capacity surplus, as shown in Table 6 as well as Figure 7. Three scenarios are considered:
1) The trans-oceanic maritime infrastructure only consists of North America west coast ports that increase their capacity and the expanded Panama Canal. This is the baseline case;
2) The Nicaragua Canal is added;
3) The proposed rail links are added.

As already mentioned, the evaluation year is 2025.

Without the Nicaragua Canal and rail links, the expanded Panama Canal would be able to handle total shipping traffic in 2025, except when the demand grows really fast (at 8% rate annually). This suggests that, for some ODs that can use either the North America west coast ports or the Central America canals, such as shipping traffic between Asia and US east coast, Central America canals will hold a larger market share due to traffic diversion away from North America west coast ports. The shift of traffic to using canals is likely to be more even more prominent when additional capacity supplies in Central America. However, the utilization of system overall capacity will be low: with low or moderate demand growth the utilization rate will be no more than 45%.

The results suggest that additional canal capacity, for example a second wet canal, seems to be needed if a likely high demand growth is possible through 2025 and beyond. However, such a second wet canal, if built, should be a much smaller one than the planned Nicaragua Canal. This places a question mark on how the sheer $50 billion capital investment in the Nicaragua Canal could be recovered through toll collection in a reasonable timeframe. In addition, the Panama Canal has begun analyzing the possibility of adding a fourth set of locks in the future depending on future seaborne demand requirements.
Conclusions and future research

The analysis in Section 6 suggests that in the foreseeable future substantial capacity redundancy will likely appear after the completion of the Panama Canal expansion and the construction of the Nicaragua Canal. Given that there are only a few competitors in the market, possible outcomes include pricing and other market structure issues such as cartels. In the case of cartels, history indicates that eventually the agreements break down. So, a possible outcome is a period of instability until demand catches up with supply.

This analysis is a first step toward understanding the market for trans-oceanic services in the future. However, much additional work is needed to fully understand the impact of changes in supply and demand in the future. On the supply side, an understanding of the potential for the Suez Canal to play a much larger role in Asia-East Coast trade is needed. Currently, only about six percent of this trade transits the Suez Canal. With much larger ships and slow steaming because of the economics of shipping, the Suez route may become far more competitive in the future. The Panama Canal may decide to construct the fourth set of locks sooner rather than later. Mexico may further develop the ports of Lazaro Cardenas and Manzanillo. Rail improvements from these ports will make a land bridge to the US feasible, further increasing competition for trans-oceanic services. Over the long term, an arctic route may also become feasible, if global warming continues. On the demand side, reductions in demand caused by the nascent reshoring movement in the US and 3D printing may reduce the demand for these services. Growth in trade from other regions such as South America and Africa may supplant some or all of this demand.

This analysis has only dealt with container traffic, which accounts for 47% of PCUMS tons from Asia to the US East Coast. Other traffic including bulk, tank, and general cargo also should be included in the analysis. In addition, two approaches to this analysis seems feasible in the future. One is to continue the scenario approach presented in this paper by adding in the additional demand and supply alternatives that may occur in the future. All traffic, not just container traffic could be included in the
analysis. A simulation model could be developed with probabilities attached to each future scenario.

The insights obtained from the scenario based approach could then be used as the building block for a more sophisticated mathematical modeling based approach, which enables simulation of systematic response to maritime infrastructure capacity investment and pricing changes in a more comprehensive fashion. The core of the mathematical modeling based approach is a computational model that combines interregional commodity shipments with transportation network flows on major global trade routes. The computational model would be composed of two principal modules:

- Global multi-region Input-Output (GMR-IO) module
- Global transportation network (GTN) module

The GMR-IO model would be an interregional commodity shipment model to predict exports and imports of commodities between each pair of trading regions (including trading within a region itself). Commodities could be segmented by industrial sector: agriculture, mining, electronic equipment, etc. Conceptually, the GMR-IO module could be represented by a system of equations, each of which capturing flow balance for a given sector and a given region:

Development of the GTN model could be based on the assumption that shippers desire to minimize their total GTLC which, same as in the scenario-based approach, encompasses shipping costs and transit time. For intermodal routes (e.g., maritime plus rail transport), shipping cost needs to cover seaborne as well as in-land shipping expenses. In order to obtain transportation network flows that are consistent with reality, the model could follow the classic treatment in the literature and explicitly consider dispersion of commodity flows among pairs of trading regions by introducing an entropy function.

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Figure 1. Panama Canal and the proposed Nicaragua Canal (Source: Google Map)

Figure 2. World seaborne trade trend, in million tons loaded (Source: UNCTAD, 2014)

Figure 3. Panama Canal traffic history (Source: ACP, 2015a)
Figure 4. Current TEU capacity and throughput of North America west coast ports

Figure 5. Proposed rail links in the Central America isthmus (Rodrique, 2015)
Figure 6. An illustration of part of the OD flows using the North America west coast ports and Central America canals

Figure 7. Total system capacity under the three scenarios and their relative magnitudes with total system demand
Table 1. Estimated containerized cargo flows on major East-West container trade routes, in millions of TEUs (Source: UNCTAD, 2014)

<table>
<thead>
<tr>
<th>Year</th>
<th>Transpacific</th>
<th>Europe Asia</th>
<th>Transatlantic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Asia-North America</td>
<td>North America-Asia</td>
<td>Asia-Europe</td>
</tr>
<tr>
<td>2009</td>
<td>10.6</td>
<td>6.1</td>
<td>11.5</td>
</tr>
<tr>
<td>2010</td>
<td>12.3</td>
<td>6.5</td>
<td>13.3</td>
</tr>
<tr>
<td>2011</td>
<td>12.4</td>
<td>6.6</td>
<td>14.1</td>
</tr>
<tr>
<td>2012</td>
<td>13.1</td>
<td>6.9</td>
<td>13.7</td>
</tr>
<tr>
<td>2013</td>
<td>13.8</td>
<td>7.4</td>
<td>14.1</td>
</tr>
</tbody>
</table>

Percentage change 2012-2013 4.6 7.6 3.1 1.8 5.8 3.6

Table 2: 2014 Pacific to Atlantic cargo traffic along principal trade routes through the Panama Canal in million metric tons (ACP, 2015b)

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>EC US</th>
<th>EC Canada</th>
<th>EC Central America</th>
<th>EC South America</th>
<th>West Indies</th>
<th>Europe</th>
<th>Africa</th>
<th>Middle East</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia</td>
<td>26.09</td>
<td>0.51</td>
<td>3.18</td>
<td>1.82</td>
<td>2.27</td>
<td>0.29</td>
<td>0.03</td>
<td>0.00</td>
<td>34.19</td>
<td></td>
</tr>
<tr>
<td>WC US</td>
<td>0.70</td>
<td>0.23</td>
<td>0.12</td>
<td>0.63</td>
<td>0.20</td>
<td>2.85</td>
<td>0.10</td>
<td>0.22</td>
<td>5.07</td>
<td></td>
</tr>
<tr>
<td>WC Canada</td>
<td>0.19</td>
<td>0.00</td>
<td>0.24</td>
<td>0.78</td>
<td>0.27</td>
<td>3.56</td>
<td>0.38</td>
<td>0.19</td>
<td>5.61</td>
<td></td>
</tr>
<tr>
<td>WC Central America</td>
<td>4.48</td>
<td>0.17</td>
<td>0.72</td>
<td>1.24</td>
<td>0.51</td>
<td>1.80</td>
<td>0.97</td>
<td>0.12</td>
<td>10.03</td>
<td></td>
</tr>
<tr>
<td>WC South America</td>
<td>13.35</td>
<td>0.64</td>
<td>0.87</td>
<td>2.20</td>
<td>0.75</td>
<td>8.92</td>
<td>0.14</td>
<td>0.32</td>
<td>27.18</td>
<td></td>
</tr>
<tr>
<td>Oceania</td>
<td>0.66</td>
<td>0.01</td>
<td>0.12</td>
<td>0.01</td>
<td>0.04</td>
<td>0.48</td>
<td>0.00</td>
<td>0.00</td>
<td>1.32</td>
<td></td>
</tr>
<tr>
<td>Other routes</td>
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<td>0.02</td>
<td>1.02</td>
<td>0.63</td>
<td>0.36</td>
<td>0.45</td>
<td>0.01</td>
<td>0.03</td>
<td>3.30</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>46.26</td>
<td>1.57</td>
<td>6.28</td>
<td>7.31</td>
<td>4.40</td>
<td>18.35</td>
<td>1.63</td>
<td>0.88</td>
<td>86.70</td>
<td></td>
</tr>
</tbody>
</table>

Note: EC = East Coast; WC = West Coast.
Table 3: 2014 Atlantic to Pacific cargo traffic along principal trade routes through the Panama Canal in million metric tons (ACP, 2015b)

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Asia</th>
<th>WC US</th>
<th>WC Canada</th>
<th>WC Central America</th>
<th>WC South America</th>
<th>Oceania</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC US</td>
<td>Asia</td>
<td>58.68</td>
<td>0.57</td>
<td>0.15</td>
<td>9.92</td>
<td>19.75</td>
<td>1.77</td>
<td>90.83</td>
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<td>WC US</td>
<td>0.64</td>
<td>0.17</td>
<td>0.00</td>
<td>0.13</td>
<td>0.29</td>
<td>0.01</td>
<td>1.24</td>
</tr>
<tr>
<td>EC Central America</td>
<td>WC US</td>
<td>1.23</td>
<td>0.04</td>
<td>0.00</td>
<td>0.15</td>
<td>0.50</td>
<td>0.02</td>
<td>1.95</td>
</tr>
<tr>
<td>EC South America</td>
<td>WC US</td>
<td>2.01</td>
<td>1.33</td>
<td>0.23</td>
<td>2.70</td>
<td>8.48</td>
<td>0.15</td>
<td>14.88</td>
</tr>
<tr>
<td>West Indies</td>
<td>WC US</td>
<td>2.06</td>
<td>1.35</td>
<td>0.04</td>
<td>1.84</td>
<td>1.78</td>
<td>0.00</td>
<td>7.07</td>
</tr>
<tr>
<td>Europe</td>
<td>WC US</td>
<td>0.29</td>
<td>4.52</td>
<td>0.42</td>
<td>1.93</td>
<td>4.88</td>
<td>0.30</td>
<td>12.34</td>
</tr>
<tr>
<td>Africa</td>
<td>WC US</td>
<td>0.00</td>
<td>0.67</td>
<td>0.72</td>
<td>0.07</td>
<td>0.19</td>
<td>0.24</td>
<td>1.89</td>
</tr>
<tr>
<td>Middle East</td>
<td>WC US</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.32</td>
<td>0.00</td>
<td>0.33</td>
</tr>
<tr>
<td>Other routes</td>
<td>WC US</td>
<td>0.89</td>
<td>0.78</td>
<td>0.09</td>
<td>2.49</td>
<td>1.29</td>
<td>0.10</td>
<td>5.64</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>65.80</td>
<td>9.43</td>
<td>1.65</td>
<td>19.22</td>
<td>37.48</td>
<td>2.59</td>
<td>136.17</td>
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</tbody>
</table>

Table 4. Port capacity and demand on the North America west coast (in 10^6 TEUs): current and 2025 projections

<table>
<thead>
<tr>
<th>Port</th>
<th>Capacity</th>
<th>Demand</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current</td>
<td>2025</td>
<td>Current</td>
<td>2025</td>
<td>3.25%</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>growth rate</td>
<td>growth rate</td>
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<tr>
<td>Log Angeles</td>
<td>11.04</td>
<td>12.70</td>
<td>7.87</td>
<td>11.55</td>
<td>14.13</td>
<td>19.81</td>
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<tr>
<td>Long Beach</td>
<td>9.64</td>
<td>19.28</td>
<td>6.73</td>
<td>9.88</td>
<td>12.09</td>
<td>16.95</td>
</tr>
<tr>
<td>Oakland</td>
<td>3.23</td>
<td>4.17</td>
<td>2.35</td>
<td>3.44</td>
<td>4.21</td>
<td>5.91</td>
</tr>
<tr>
<td>Seattle</td>
<td>3.01</td>
<td>3.01</td>
<td>1.59</td>
<td>2.34</td>
<td>2.86</td>
<td>4.01</td>
</tr>
<tr>
<td>Vancouver</td>
<td>2.70</td>
<td>7.20</td>
<td>2.83</td>
<td>4.15</td>
<td>5.07</td>
<td>7.12</td>
</tr>
<tr>
<td>Prince Rupert</td>
<td>0.75</td>
<td>2.25</td>
<td>0.54</td>
<td>0.79</td>
<td>0.96</td>
<td>1.35</td>
</tr>
<tr>
<td>Tacoma</td>
<td>3.01</td>
<td>3.01</td>
<td>1.89</td>
<td>2.78</td>
<td>3.40</td>
<td>4.76</td>
</tr>
<tr>
<td>Portland</td>
<td>0.71</td>
<td>0.71</td>
<td>0.18</td>
<td>0.26</td>
<td>0.32</td>
<td>0.45</td>
</tr>
<tr>
<td>Total</td>
<td>34.09</td>
<td>52.33</td>
<td>23.97</td>
<td>35.18</td>
<td>43.05</td>
<td>60.36</td>
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<tr>
<td>d/c ratio</td>
<td>0.70</td>
<td>1.03</td>
<td>1.26</td>
<td>1.77</td>
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<td></td>
</tr>
</tbody>
</table>

Note: d/c ratio means total demand/capacity ratio. Same in Tables 5 and 6.
Table 5. Canal capacity and demand in Central America (in 10^6 TEUs): current and 2025 projections

<table>
<thead>
<tr>
<th></th>
<th>Capacity</th>
<th>Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current</td>
<td>2025</td>
</tr>
<tr>
<td>Pan Canal Expansion only</td>
<td>12.10</td>
<td>24.20</td>
</tr>
<tr>
<td>d/c ratio</td>
<td>1.00</td>
<td>0.73</td>
</tr>
<tr>
<td>Pan Canal Exp + Nicaragua Canal total</td>
<td>--</td>
<td>92.92</td>
</tr>
<tr>
<td>d/c ratio</td>
<td>--</td>
<td>0.19</td>
</tr>
<tr>
<td>Pan Canal Exp + Nica Canal + Dry Canals total</td>
<td>--</td>
<td>102.04</td>
</tr>
<tr>
<td>d/c ratio</td>
<td>--</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Table 6. Total port/canal capacity and demand (in 10^6 TEUs): current and 2025 projections

<table>
<thead>
<tr>
<th></th>
<th>Capacity</th>
<th>Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current</td>
<td>2025</td>
</tr>
<tr>
<td>Scenario 1 total</td>
<td>46.19</td>
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<td>Scenario 2 total</td>
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<td>144.61</td>
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<tr>
<td>Scenario 3 total</td>
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</tr>
<tr>
<td>Scenario 1 d/c ratio</td>
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<td>0.69</td>
</tr>
<tr>
<td>Scenario 2 d/c ratio</td>
<td>--</td>
<td>0.37</td>
</tr>
<tr>
<td>Scenario 3 d/c ratio</td>
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<td>0.34</td>
</tr>
</tbody>
</table>