Panama Canal expansion: fuel economy and logistical risk

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Abstract Since cargo capacity increases faster than fuel consumption, the significantly larger capacity fleets which will accompany expansion of the Panama Canal will introduce additional fuel economies and cost savings. Enabling larger, more fuel-efficient vessels to carry cargo the entire distance from Asia to US east-coast ports allows vessel operators to realize significant and meaningful savings compared with the alternatives of using smaller Panamax vessels for the whole distance, or sending the cargo over the US land bridge by train or truck. Fuel savings are quantified along with the monetary savings based on various assumptions for the price of fuel. These savings are dramatic and will increase directly with the price of crude petroleum. Finally, microeconomic theory is deployed to determine how cost savings will be distributed between shipping customers and vessel operators.

Keywords New Panamax · Consumer and producer surplus · Logistical risk · Fuel economy · Pollutant emissions

1 Introduction

The substantial East Asia trade with US east-coast population centers uses both the Panama Canal and the US land bridge. When the Panama Canal was built, the lock dimensions were set at 1050 ft (320.04 m) in length, 110 ft (33.53 m) in width, and a draft of 41 ft (12.5 m).¹ Currently, vessels larger than Panamax size transporting cargo

¹Vessel Requirements, <http://www.pancanal.com/eng/maritime/notices/n01-05.pdf>, from the Panama Canal Authority.

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from East Asia destined for the east coast of the USA typically call on ports on the west coast of the USA where the cargo is off-loaded. The cargo then is either transferred to Panamax vessels for movement through the canal to an east-coast port, or via the US land bridge by rail or truck transport.

Modern Panamax vessels are significantly larger than nearly any ship afloat when the canal opened.² As the current world-wide container fleet ages, newer vessels placed into service frequently exceed Panamax dimensions. The number of new Panamax vessels in service will increase rapidly after 2015. Larger container vessels currently unable to transit the canal will be able to do so once the expansion project is completed. The expanded canal will be able to accommodate new Panamax vessels with lock dimensions of 1400 ft (426.72 m) in length, 180 ft (54.86 m) in width, and a draft of 60 ft (18.29 m).³

Given the economics of seaborne cargo, the preferences of vessel owners, enterprises that purchase the cargo for resale, and consumers who are the end users of the cargo, are that the goods be transported through the Panama Canal. Without the expansion, the Panama Canal Authority forecast the canal would have market share, experiencing a decrease in vessel transits despite increased trade between East Asia and the east coast of the USA.⁴

2 Increased cargo demand translates to logistical vulnerability to fuel costs

Increased vessel traffic is forecast to transit the canal after the third set of locks is in place. Our analysis will assess two alternative transportation routes: (1) current post-Panamax vessels that are unable to transit the canal, which currently call on US west-coast ports for cargo to be off-loaded and continue on its journey via the US land bridge using rail or truck transport and (2) new-Panamax vessels that will be able to transit the canal after expansion and continue their voyages to the US east-coast ports.

The amount of cargo transiting the Panama Canal from East Asia to the US east coast can be projected based on the Panama Canal Authority's forecasts. Figure 1 presents cargo transiting the Panama Canal under the nonexpansion scenario; Fig. 2 presents the data under the expansion scenario.

In the absence of the canal expansion, projected traffic volume would be increasingly diverted to the US land bridge as the canal reaches maximum capacity by 2017. Because overland modes, particularly truck, are the most expensive, fuel consuming, and pollution-generating options, the expansion project offers substantial benefits in

² Although the size of Panamax vessels varies, the maximum size possible to transit the Panama Canal is approximately 965 ft (294 m) length overall (LOA), 106 ft (32.3 m) wide (beam), and up to 39 ft (11.9 m) under the waterline (draft). Panamax vessels carry approximately 5,000 TEUs and are in the range of 50–60,000 deadweight tonnage (Kristensen 2006). One TEU is equal to what is known as a standard intermodal container with dimensions of 20 ft (6.1 m) in length, 8 ft (2.4 meters) in width, and a height from 4.25 ft (1.3 m) to 9.5 ft (2.9 m).

³ Panama Canal Authority (2009), ACP: Dimensions for Future Lock Chambers and "New Panamax" Vessels, <http://www.pancanal.com/common/maritime/advisories/2009/a-02-2009.pdf> and Panama Canal Authority (2010), *Vessel Requirements*, <http://www.pancanal.com/eng/maritime/notices/n01-05.pdf>, from the Panama Canal Authority.

⁴ Figure 16, p. 28, *Proposal for the Expansion of the Panama Canal: Third Set of Locks Project* (April 24, 2006).

Fig. 1 Northeast Asia-US east coast containerized traffic pattern 2005–2025 in Million Panama Canal uniform measurement system (PCUMS) tons, alternative scenario without canal expansion. *Note:* years 2005, 2010, 2015, 2020, and 2025 obtained from review of (1) Fig. 28, Proposal for the Expansion of the Panama Canal: Third Set of Locks Project and (2) first full para figure, p. 40, Proposal for the Expansion of the Panama Canal: Third Set of Locks Project; remaining years developed as assumptions by authors

terms of lowered fuel costs and pollution abatement. With the expanded canal, the amount of cargo transiting the canal is projected to grow along with international trade. Expanding the canal ensures that as international trade continues to expand, fuel consumption and carbon emissions are both kept as low as feasible for any given trade volume.

Railroad and truck diesel fuel (distillate fuel oil no. 2) is a fractionally distilled petroleum product produced from crude petroleum by breaking it down into various component fuels, including kerosene (jet fuel), gasoline, diesel fuel, lubricating oil, etc. Trucks burn significantly more fuel per unit of work than trains, and truck diesel is also generally more refined and thus more expensive. Ships burn residual fuel oil no. 6, also

Fig. 2 Northeast Asia-US east coast containerized traffic pattern 2005–2025 in Million Panama canal uniform measurement system (PCUMS) tons, assuming canal expansion. *Note:* above market share data compiled as follows: years 2005, 2010, 2015, 2020, and 2025 obtained from review Fig. 28, Panama Canal Master Plan; and remaining years developed as assumptions by authors using the Master Plan's 5.6 % annual growth rate

known as bunker fuel, a thick tar-like substance left over as a byproduct of the refining process, which often must be preheated before it will flow through ship engines. This fuel is fundamentally different from the refined (and thus more expensive) diesel fuels burned by overland modes. To meet increasingly stringent emissions requirements, a cleaner distillate fuel is now normally mixed with conventional bunker fuel. Fuel costs are largely determined by the cost of crude petroleum (Table 1).

Linehaul costs are determined partly by fuel cost, and partly by the relative fuel economy of the particular technology. These levels are consistent with those computed by Mulligan and Lombardo (2011). MAN Diesel's (2009) operating data also yield similar figures. In turn, Harry Benford's classic methodology (1957, 1958, 1961, 1962, 1963, 1967, 1991a, 1991b, 1993; Benford et al. 1962), even though assuming a now obsolete high-pressure steam technology, yields very similar fuel consumption figures. Linehaul cost includes all operating costs, not only fuel, but also lubricating oil, maintenance, and labor costs. The largest 14,000 TEU new-Panamax vessels will burn more fuel but are also far more fuel efficient than 4000–5100 TEU Panamax vessels. Larger ships have this advantage in fuel efficiency even when operated at higher speeds, offering an additional practical advantage.

New-Panamax ships offer the lowest cost way to transport cargo a given distance. This advantage is amplified the more expensive crude oil becomes (Table 2). Fuel costs per kilometer are estimated for the four alternative transport modes under assumptions of petroleum costs ranging from \$30–210 per barrel.

Next, the distance required for each mode is factored into the analysis. A baseline one-way journey from Guangzhou to New York was selected for analysis. This compares a total distance through the canal of 20,778 km, with a trans-Pacific ship route of 13,275 km and either 4482 km by highway or 4860 km by rail (Table 3).

These distances are multiplied by the fuel consumption figures for each mode given in Table 2. This permits comparison of the linehaul cost for each mode as a function of hypothesized costs of crude petroleum (Table 4).

Finally, the cost differences can be computed (Table 5). The cost savings are simple linear functions of the hypothesized cost of crude petroleum. It becomes obvious that there will be significant savings from converting to the new-Panamax vessels the canal expansion will accommodate, and that the cost savings over railroad transport for the

Table 1 Comparative fuel and operating costs as a function of the price of crude petroleum

Date	Crude oil cost per barrel	Diesel fuel cost per gallon	Linehaul cost per TEU km			
			Truck	Rail IMX	Panamax (est)	New Panamax (est)
2002	\$28.85	\$1.37	\$1.13	\$0.24	\$0.15	\$0.14
2005	\$54.79	\$2.40	\$1.41	\$0.29	\$0.23	\$0.17
2020 low	\$59.61	\$2.61	\$1.49	\$0.31	\$0.26	\$0.18
2020 central	\$91.03	\$3.99	\$1.87	\$0.37	\$0.35	\$0.21
2020 high	\$157.18	\$6.88	\$2.66	\$0.49	\$0.56	\$0.29

Source: TEMS (2008), p. 5, exhibit 4. Panamax and new-Panamax figures estimated by authors through interpolation. Figures for 2020 include a 2 % premium for ULSD fuel (Notteboom 2011). These levels are consistent with those computed by Mulligan and Lombardo 2011

Table 2 Fuel consumption and linehaul cost per km

	5,100 TEU Panamax vessel	14,000 TEU New-Panamax vessel	Truck	Train	units
Fuel consumption	0.03331	0.02087	0.19992	0.11825	kg/TEUkm
Conversion to gallons/TEUkm	0.0102	0.0064	0.0612	0.0362	gal/TEUkm
Crude oil cost					
\$30.00	\$0.12	\$0.08	\$0.80	\$0.45	\$/TEUkm
\$40.00	\$0.16	\$0.10	\$1.07	\$0.60	\$/TEUkm
\$50.00	\$0.20	\$0.13	\$1.34	\$0.75	\$/TEUkm
\$60.00	\$0.24	\$0.15	\$1.61	\$0.90	\$/TEUkm
\$70.00	\$0.28	\$0.18	\$1.87	\$1.05	\$/TEUkm
\$80.00	\$0.32	\$0.20	\$2.14	\$1.20	\$/TEUkm
\$90.00	\$0.36	\$0.23	\$2.41	\$1.35	\$/TEUkm
\$100.00	\$0.40	\$0.25	\$2.68	\$1.50	\$/TEUkm
\$110.00	\$0.44	\$0.28	\$2.94	\$1.65	\$/TEUkm
\$120.00	\$0.48	\$0.30	\$3.21	\$1.80	\$/TEUkm
\$130.00	\$0.52	\$0.33	\$3.48	\$1.95	\$/TEUkm
\$140.00	\$0.56	\$0.35	\$3.75	\$2.10	\$/TEUkm
\$150.00	\$0.60	\$0.38	\$4.01	\$2.25	\$/TEUkm
\$160.00	\$0.64	\$0.40	\$4.28	\$2.41	\$/TEUkm
\$170.00	\$0.68	\$0.43	\$4.55	\$2.56	\$/TEUkm
\$180.00	\$0.72	\$0.45	\$4.82	\$2.71	\$/TEUkm
\$190.00	\$0.76	\$0.48	\$5.08	\$2.86	\$/TEUkm
\$200.00	\$0.80	\$0.50	\$5.35	\$3.01	\$/TEUkm
\$210.00	\$0.84	\$0.53	\$5.62	\$3.16	\$/TEUkm

Source: prepared by authors. Fuel consumption computed with EEDI Calculation Tool (Danish Shipowners' Association 2014)

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Table 3 Distances

Canal transit	English to metric conversion			
Distance via canal Guangzhou to NYNJ				
11,219	nm	20,777.59	km	1 nm=1.852 km
Distance Guangzhou to Los Angeles				
7,168	nm	13,275.14	km	
Distance Highway LA-NY (Mapquest 2012)				
2,785	sm	4,482.023	km	1 sm=1.609344 km
Distance RR LA-NY (Rand McNally 2000 Commercial Atlas & Marketing Guide (131st ed.) p. 27)				
3,082	sm	4959.998	km	

Source: prepared by authors

Table 4 Total fuel consumption and linehaul cost per TEU

	New-Panamax via land bridge truck	New-Panamax via land bridge RR	Panamax via Canal	New-Panamax via Canal
Fuel consumption (kg/TEU)	1,173	864	692	434
Conversion to gallons/TEU	359	264	212	133
Crude oil cost per barrel	Linehaul cost per TEU			
\$30.00	\$227	\$87	\$26	\$10
\$40.00	\$302	\$117	\$34	\$13
\$50.00	\$378	\$146	\$43	\$17
\$60.00	\$453	\$175	\$51	\$20
\$70.00	\$529	\$204	\$60	\$23
\$80.00	\$604	\$233	\$68	\$27
\$90.00	\$680	\$262	\$77	\$30
\$100.00	\$755	\$291	\$85	\$33
\$110.00	\$831	\$320	\$94	\$37
\$120.00	\$906	\$350	\$102	\$40
\$130.00	\$982	\$379	\$111	\$43
\$140.00	\$1,057	\$408	\$119	\$47
\$150.00	\$1,133	\$437	\$128	\$50
\$160.00	\$1,208	\$466	\$136	\$53
\$170.00	\$1,284	\$495	\$145	\$57
\$180.00	\$1,359	\$524	\$153	\$60
\$190.00	\$1,435	\$553	\$162	\$63
\$200.00	\$1,511	\$583	\$170	\$67
\$210.00	\$1,586	\$612	\$179	\$70

Source: based on authors' calculations

Los Angeles to New York leg of the journey are even more dramatic, being slightly more than twice as great. The savings over interstate trucking for the US land bridge leg are significantly greater.

The expanded Panama Canal will allow for lower-cost transport of freight which would otherwise be diverted to the US land bridge. Most of this cost saving comes from differences in fuel consumption, thus facilitating a comparison of pollutant emissions. Table 6 presents the most important pollutants generated from burning 1 kg of the two most commonly used diesel fuels.

Figure 3 compares the total 2011–2025 fuel consumption and carbon emissions for new-Panamax containerships routed through the canal compared with overland carriage for the Los Angeles to New York leg by truck and by train. Ship transport consumes the least fuel and emits the lowest overall level of pollutants, but pollutant emissions increase by a lower margin for truck and train transport because these modes burn fuels which are cleaner and more refined, but also more expensive. Figure 4 provides the same comparison for other climate-change causing pollutants.

Even with the significantly greater distance required to use the canal, fuel consumption and pollutant emissions are significantly lower than with the land bridge. Use of

Table 5 Linehaul cost advantage per TEU

Crude oil cost	New-Panamax versus Panamax	New-Panamax versus land bridge RR
\$30.00	\$15	\$77
\$40.00	\$21	\$103
\$50.00	\$26	\$129
\$60.00	\$31	\$155
\$70.00	\$36	\$181
\$80.00	\$41	\$206
\$90.00	\$46	\$232
\$100.00	\$52	\$258
\$110.00	\$57	\$284
\$120.00	\$62	\$310
\$130.00	\$67	\$335
\$140.00	\$72	\$361
\$150.00	\$77	\$387
\$160.00	\$83	\$413
\$170.00	\$88	\$438
\$180.00	\$93	\$464
\$190.00	\$98	\$490
\$200.00	\$103	\$516
\$210.00	\$108	\$542

Source: based on author's calculations

the canal with fuel-efficient new-Panamax vessels has a similar advantage in terms of pollutant emissions overall, but by a lower margin due to the higher levels of impurities found in bunker fuel. Increasingly stringent regulations increase the cost of practical bunker fuel, but tend to amplify its environmental advantages without seriously compromising its overwhelming cost advantages.

3 Allocation of benefits between cargo shippers and ship operators

Canal cost savings may be concentrated in higher profit margins for ship operators or lower freight costs borne by cargo shippers, or some combination of the two, but it is unambiguous that there will be benefits distributed among both groups. How these

Table 6 Diesel fuel emissions in g/kg

Pollutant	Truck and rail emissions (ULSD distillate oil no. 2)	Ship emissions (ULSD residual fuel oil no. 6)
CO ₂	3206	3114
NO _x	2.00	18.70
SO ₂	0.10	7.35
CO	0.50	1.93
HC	0.02	2.75
Particulates	0.05	9.94

Source: EEDI calculation tool (Danish Shipowners' Association 2014)

Fig. 3 Total 2011–2025 fuel consumption and CO₂ emissions, New Panamax Ships versus Alternative Land Transport (million kg). Source: authors' calculations with EEDI calculation tool (Danish Shipowners' Association 2014, based on Mulligan and Lombardo 2011)

benefits will be distributed among cargo shippers and vessel operators depends on the two groups' supply and demand elasticities. If ship operators have low supply elasticities, they will not increase transport supply much in response to reduced costs. In this case, if cargo shippers have high demand elasticity, they will want to ship more cargo in response to lower costs, raising the revenue and profits of ship operators. If cargo shippers have low demand elasticity, they will not want to increase shipments much in response to lowered costs, and benefits will be spread more-or-less equally across both groups. If ship operators have high supply elasticities, they will increase supply significantly in response to reduced costs. Then, if cargo shippers have high demand elasticities, they will ship more cargo, increasing revenue and profits for ship operators, as the cargo shippers also benefit from additional capacity and lowered prices. If cargo shippers have low demand elasticities, they will not ship so much more cargo in

Fig. 4 Total 2011–2025 emissions of other global climate-change causing pollutants New Panamax Ships versus Alternative Land Transport (million kg). Source: authors' calculations with EEDI calculation tool (Danish Shipowners' Association 2014, based on Mulligan and Lombardo 2011)

response to price reductions, but will benefit from the lowered prices. These implications are presented in Table 6.

Basic microeconomic theory informs us that elasticities for both groups are relatively higher in the short run than in the long run. Given enough time, shipping firms can adjust to changes in demand by optimizing fleet size, either through leasing or new construction. Similarly, given enough time, shipping customers can relocate production either to minimize transportation costs or take advantage of lower-cost resource and/or labor availability, whichever is more critical.

However, at any point in time, firms operate in the short run, facing longer-lasting constraints determined by past decisions. The location the maritime industry occupies in Table 7 will be largely determined by business cycle fluctuations. In the late stages of an unsustainable expansion which precedes a recession, international trade (transportation demand) increases faster than shipping firms can lease or build larger fleets (supply). This would put the industry in quadrant III during late-stage expansions. When a recession or slowdown hits, the industry faces excess capacity, as supply has been increasing, and often continues to increase, more rapidly than demand for capacity, which often falls, putting the industry in quadrant I. Thus, over the business cycle, we can expect the industry to toggle between quadrants I and III of the table.

4 Risk alleviating and aggravating factors

The principal risk-alleviating factor canal expansion offers for international trade is reduced fuel consumption. In addition to reducing costs overall, reliance on ship transport also reduces the impact of fluctuations in the price or availability of petroleum and related uncertainty to which overland transport remains far more vulnerable. This is somewhat ironic in that marine transportation is highly fuel-intensive, though significantly less fuel-consuming in absolute terms, than alternatives.

Although the main advantage from substituting new-Panamax for smaller Panamax vessels comes from fuel economy, there is also a benefit through lower labor costs. New-Panamax vessels carry two to three times as much cargo with at most only

Table 7 Allocation of benefits according to supply and demand elasticity

		Supply elasticity	
		Low	High
Demand elasticity	Low	Equally beneficial to both cargo shippers and ship operators: small increase in both consumer and producer surplus	Benefit cargo shippers more than ship operators: large increase in consumer surplus compared to relatively small increase in producer surplus (<i>recession</i>)
	High	Benefit ship operators more than cargo shippers: large increase in producer surplus compared to relatively small increase in producer surplus (<i>business cycle late-stage expansion</i>)	Equally beneficial to both cargo shippers and ship operators: large increase in both consumer and producer surplus

Source: prepared by authors

marginal increases in crew size. The larger vessels are also less vulnerable to most weather. Transaction costs for new-Panamax vessels are reduced due to the fewer sailings to handle the same volume of cargo compared with the more numerous voyages for smaller ships.

After new-Panamax vessels begin using the expanded canal, west-coast ports currently overburdened by transferring cargo to Panamax vessels for transit through the canal or transfer to the land bridge may improve efficiency in the face of lowered demand.

Some risk-aggravating factors also need to be considered which can potentially increase shipping costs and the costs of final goods. General use of new-Panamax ships implies a logistical bottleneck of greater dependence on fewer sailings of larger vessels. Operating a smaller number of larger vessels exposes shipping firms and insurers to the possibility of less frequent, but more catastrophic losses. The canal remains a choke point, offering less redundancy than the trans-Pacific routes and the land bridge against either natural disaster or terrorist attack. However, this redundancy is greatly improved by the third set of locks.

Only two east-coast ports can currently handle new-Panamax vessels due to their extraordinary draft, Norfolk and New York/New Jersey. For the New York/New Jersey port, the roadbed of the Bayonne Bridge is being raised 19.5 m to provide a 65.5-m clearance for larger vessels. East- and gulf-coast ports may face capacity and inefficiency constraints, and will increasingly face tight scheduling tolerances. Although smaller new-Panamax vessels can use numerous other east-coast ports, many of which plan expansion projects to take advantage of increased traffic through the canal, this also introduces the potential for east- and gulf-coast terminal overcapacity in anticipation of higher volume. Every TEU diverted from the land bridge to the canal lowers demand for transcontinental highway and rail infrastructure but also creates new demand for infrastructure specifically serving east- and gulf-coast ports.

5 Conclusion

Ocean transportation offers better fuel economy and lower pollutant emissions compared with land transport. Additionally, truck and train cargo transportation along the US land bridge threatens to overwhelm existing highway and rail systems and limit economic growth. The alternate transportation route of easterly transit of the Panama Canal will reduce overland traffic congestion and enhance economic development by maintaining freight flow efficiency.

The more the Panama Canal expansion project captures market share, the greater will be its impact in relieving clogged highway and railroad arteries in the USA and lowering costs of transport over competing modes, as well as improving time performance. More importantly, every kilometer the freight is carried via sea instead of by either interstate highway or rail will reduce both fuel consumption and climate-changing pollutant emissions.

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