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ORIGINAL ARTICLE

The Nicaragua Canal: potential impact on international shipping and its attendant challenges

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Abstract The construction of an interoceanic canal in Nicaragua, a longstanding controversy, has once again become a source of concern in recent years, in both the global shipping industry and the world at large. Since the canal was green-lighted by the Nicaraguan government, scientists and specialists have sharply criticized its potential to inflict lasting environmental and societal damage. The vocal doubts raised by many experts regarding the canal's feasibility have resulted in several recent postponements of construction. Studies of the project's challenges and its potential impact on international shipping suggest that the canal will potentially have wide-ranging implications on vessel sizes, the global routing of maritime freight flows and port development along the Atlantic and Pacific coastlines. Many problems now hinder the project, from its economic and engineering viability to its environmental and safety hazards. This research provides a systematic analysis of the potential impact of the Nicaragua Canal on international shipping, as well as the various challenges the project faces.

Keywords Nicaragua Canal · Panama Canal · International shipping · Impact analysis

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Introduction

International shipping is an important mode of freight transportation. The Suez Canal, Panama Canal, and other artificial waterways have powerfully shaped global trade while producing immense economic advantages worldwide (Rodrigue et al. 2013). This record of economic benefit has long motivated the Nicaraguan government's desire to build an interoceanic canal of its own. In September 2012, a newly formed private Chinese enterprise, the Hong Kong Nicaragua Canal Development Group (HKND), proposed a 5-year construction plan at a cost of 50 billion U.S. dollars and signed a memorandum of understanding with the Nicaraguan government in which HKND committed to financing and building the project. In June 2013, the HKND Group received rights to build the canal and obtained a 100-year right to the franchise of the canal project (Andersen 2015).

The Nicaragua Canal would directly compete with the Panama Canal as the largest and longest interoceanic waterway connecting the Pacific with the Atlantic Ocean (Andersen 2015) (Fig. 1).

The remainder of the paper is organized as follows. The next section provides a review of the relevant literature in view of identifying knowledge gaps and presenting our research objectives. The third section investigates the potential impact of the Nicaragua Canal on international shipping with a particular focus on ship sizes, the routing of maritime freight flows, and regional port development. A detailed discussion of the future challenges facing the Nicaragua Canal project is presented in the fourth section. The last section contains the conclusions and avenues for further research.

Fig. 1 Final suggested route for the interoceanic canal in Nicaragua. *Source* Gross (2014)

Literature review and objectives of the study

Literature review

Intercontinental maritime and land corridors have become the main arteries of world trade. The world's transoceanic canals, in particular the Suez Canal and the Panama Canal, have shaped key maritime corridors, thereby contributing to global economic integration and world seaborne trade (Parke 2009; Obieta 2012). Scholars have undertaken academic research on the effects of these canals from economic, managerial, nautical, environmental, and legal perspectives.

With ship sizes getting bigger and bigger, the Suez Canal and the Panama Canal have been expanded to enhance capacity to accommodate larger ships and, as a result, some research has focused on the impact of these expansions. The opening of an additional set of larger Panama Canal locks in 2016, allowing container vessels of up to 14,000 TEU, intensified competition between the North American land bridge and the Panama Canal, particularly on the Asia–East Coast US route. Pagano et al. (2012) examined the economic impact of the canal's expansion on the economy of Panama through an Input–Output model. They found that an expanded canal and the associated sustained increase in traffic have significant impacts on export service activities and tourism. Fan et al. (2009) estimated prospective traffic flows through logistics channels for container shipments to US markets. Rodrigue (2010) focused on the impact of the expansion of the Panama Canal on shipping services. Kenawy (2015) identified the technology, trade, and industry developed in response to the new Suez Canal.

Due to the similarity in transport services, the world's canals and transport channels are challenged by other land and sea routes. Some scholars carried out studies on the competition between the Panama Canal and the North American rail land bridge (e.g. the Panama Canal Route Competitive Analysis Model applied in Ungo and Sabonge 2012), as well as between the Suez Canal and the Cape of Good Hope route. The position of the Suez route on many trade routes is being scrutinized by an ever-changing geography in world trade patterns and a search of shippers and shipping lines for routing flexibility. The Cape route could in the long run serve as an alternative to the Suez option on trades between Asia and South America, Asia and West Africa, and South America and East Africa (Notteboom 2012). In light of global warming, navigation of Arctic passages is likely to be realized, i.e. via the Northern Sea Route (NSR) and the Northwestern Passage. A growing number of studies analyse route competition and optimal route choice by comparing the Arctic routes to maritime shipping via the Panama Canal or the Suez Canal (Somanathan et al. 2007; Verny and Grigentin 2009; Schøyen and Bråthen 2011; Furuich and Otsuka 2015; Liu and Kronbak 2010). The NSR as a seafaring connection between Europe and Asia is highly unlikely to become economically viable for commercial shipping for a long time, and its impact on global shipping is expected to remain marginal (Kiiski 2017). In North America, the Northwestern Passage provides a similar Arctic maritime transport alternative, but also there the prospects are rather limited.

Although the interoceanic canals and transport channels brought huge commercial benefits, their shipping activities have negatively impacted the marine environment (Ibáñez et al. 2002; Shefer et al. 2004; Miller and Ruiz 2014). At present, scientists and scholars have conducted extensive academic research regarding the Nicaragua Canal's environmental impact. Since the Nicaragua Canal project officially received government approval, most scientists and scholars have voiced grave concerns, harshly criticizing the environmental damage caused by the canal (Huete-Perez et al. 2013, 2015, 2016; Meyer and Huete-Pérez 2014; Gross 2014; Laursen 2015). Some scholars hold different views, however, emphasizing that the negative impact of the canal project on the environment should not be exaggerated (Condit 2015; McCrary 2015).

Knowledge gaps

As a shipping channel, the essential purpose of the construction of the Nicaragua canal is to provide a maritime shortcut between the Atlantic Ocean and the Pacific Ocean. At present, the Panama Canal Authority is the sole provider of such a service to the global shipping and trade community. The dream of constructing a Nicaragua canal can be traced back to the 16th century, but no concrete construction plans were developed for another three centuries due to a lack of technological knowledge, means, and concrete market demand. In the 19th century, the US was pushing for such a canal and in 1890 dredging works started at the San Juan River in Nicaragua (Reeves 1923). However, the work was suspended in 1893. In 1899, the US installed an Isthmian Canal Commission to investigate two routes: one via Nicaragua and one via Panama. The Commission report came out in 1901 and favoured the Nicaragua route. However, the US Senate finally voted for the Panama route, in large part because of a sharp decrease of the asking price for the real estate properties owned by the French New Panama Canal Company (Clayton 1987). It should be noted that France began with the construction of the Panama Canal in 1881, but ceased works due to a high mortality among workers (from yellow fever, malaria, and accidents) and major engineering problems. The US finally made the great trans-isthmian in Panama between 1904 and 1914. In the late 1920s, US interest in the Nicaragua Canal resurged as capacity concerns over the Panama Canal would urge for a second interoceanic waterway. The plans to construct the Nicaragua Canal were shelved in 1931 due to a combination of factors. The Great Depression eased the fears for future capacity shortages at the Panama Canal. Furthermore, the enormous construction costs and fears over nearby active volcanoes (fuelled by some deadly eruptions in the late 1920s) were not helpful in terms of moving ahead with the project (Bailey 1936).

About 80 years later, the realization of the Nicaragua canal was resuscitated by the concession given to the HKND Group. However, not much research has been done on the shipping attributes of the Nicaragua Canal in the current global trade and shipping environment. The uncertainty of the Nicaragua canal's shipping service was analysed by Chen and Liu (2016). Yip and Wong (2015) used scenario analysis to predict the possible future role of the Nicaragua canal. However, there was particularly little related research discussing the impact of the Nicaragua canal on international shipping and the risks or challenges faced by the construction and operation of the canal. This paper aims to narrow these research gaps.

Methodology and research objectives

The paper mainly makes use of comparative data analysis to analyse the maritime economic and technical characteristics of the proposed Nicaragua Canal and the existing Panama Canal and Suez Canal. On the basis of the comparative analysis, the potential influence of the Nicaragua canal on international shipping and the main attendant challenges are discussed. All data were obtained from official websites, existing literature, and research reports. This research is developed to achieve the following objectives:

- Analyse the potential impact of the development of the new interoceanic Nicaragua Canal on international shipping services.
- Identify and clarify the future challenges presented by the proposed Nicaragua Canal project.
- Provide systematic managerial insights regarding the construction and development of such a massive maritime canal from the perspective of international shipping.

Potential impact on international shipping

From a technical standpoint, the proposed canal would have the greatest water depth, allowing much bigger ships to pass through. This capacity will likely have an impact on the size of ships deployed, the routing of maritime freight flows, and regional port system development. Whether the Nicaragua Canal can smoothly run and operate continues to be a point of contention and a source of worry. In this section, we discuss the potential impact of the project on global oceanic shipping should the canal open for service.

Ship size development

The Nicaragua Canal will have a minimum water depth of 26.9–29.0 m, thus able to accommodate vessels with a draft of 24–26 m, which are too large to pass through the Panama Canal (Andersen 2015). With these water depth conditions, the canal can accommodate all existing and planned container ships (note that the current largest ship capacity is about 22,000 TEU and a series of ships with a unit capacity of 23,500 TEU are on order to be deployed by MSC and CMA CGM), 320,000 DWT VLCC (very large crude oil carriers), 400,000 DWT bulk carriers, and other mega-vessels (Andersen 2015). When we set aside all other factors and consider only the canal's technical conditions, the Nicaragua Canal surpasses by far the capacities of both the Panama and the Suez Canals in terms of serving larger vessels (Table 1).

Table 1 Comparison of Panama, Suez, and Nicaragua Canals. *Sources* Authors' compilation based on data of panacanal.com, suezcanal.gov.eg.HKND

	Previous Panama Canal*	Expanded Panama Canal*	Previous Suez Canal**	New Suez Canal***	Nicaragua Canal
Beginning service year	1914	2016	1869	2015	–
Length (km)	77	77	193	193	276
Maximum container vessel size (TEU)	5000	14,000	18,000	24,000	> 25,000
Maximum vessel size (thousand DWT)	65	180	200	280	400
Maximum vessel draft (m)	12.04	15.2	17.7	20.1	24–26

*The maximum vessel size on the Panama Canal is determined by the lock capacity

**The figures relate to the year 2009. In 2009, the Suez Canal was deepened from 18 to 20 m, allowing ships of up to 58 feet draft (about 17.7 m) to pass through

***Since August 2015, the New Suez Canal is in operation with a new parallel canal of 35 km in length in the middle part. The water depth now reaches 23 m at the shallowest section allowing ships with a draft of up to 20.1 m

Hence, the superior water depth of the Nicaragua Canal could in principle lift a barrier to a further enlargement of vessel scale currently imposed by the nautical limitations of the Suez Canal and the Panama Canal (Table 2).

At present, large bulk and tanker ships generally transit around the Cape of Good Hope to carry out international bulk shipping services without the limitation of water depth. The opening of the Nicaragua Canal would allow most of these superlarge dry bulk ships and tankers to pass through the canal, which would support the opening of new shipping routes and maritime markets for existing and future large-scale bulk vessels and tankers.

International maritime freight

The opening of the Suez and Panama transoceanic canals shortened the shipping voyage between Western and Eastern countries (Rodrigue et al. 2013; Notteboom 2012). The Nicaragua Canal would further shorten trading distances between Asian and American ports. For example, the Nicaragua Canal would shorten the distance from Shanghai to Baltimore by 4000 km, when compared with a route passing through the Suez Canal, and by 7500 km when compared with a Cape of Good Hope route (Andersen 2015).

Because almost all existing large ships would be able to pass through the Nicaragua Canal, it stands to become an important component of international shipping routes and its existence could benefit the world's main trading countries and regions, especially in Asia and the Americas.

Given its nautical characteristics, the Nicaragua Canal would allow for more extensive possibilities and combinations of maritime freight services in the trans-

Table 2 Evolution of ship sizes. *Sources* Author's compilation, partly based on Yip and Wong (2015), panacanal.com, suezcanal.gov.eg.HKND

Vessel type	Generation	Typical ship	Year	TEU/DWT	LOA (m)	Beam (m)	Draft (m)
Container ship (TEU)	1st generation	Early containership	1956	500–800	137	17	9
		Fully cellular	1970	1000–2,500	200	20	9
	2nd generation	Panamax	1980	3000–3400	215	20	10
		Panamax max	1985	3400–4500	250	32	12.5
	3rd generation	Post Panamax	1988	4000–5000	290	32	12.5
		Post Panamax plus	2000	6000–8000	285	40	13
	4th generation	New Panamax	2004	12,500	300	43	14.5
	5th generation	Post new Panamax	2006	15,000	366	49	15.2
		Triple E	2013	18,000	400	59	15.5
		Triple E plus*	2015	19,000–24,000	400–415	59–62	15.5–18
		*Nicaragua***	*> 2020*	*> 25,000*	*> 415*	*> 62*	> *18*m
Bulk carrier (DWT)	1st generation	Handysize	1960	28,500	169	27.2	10
	2nd generation	Handymax	1965	50,000	190	32.2	12.6
	3rd generation	Panamax	1970	76,300	225	32.2	12.2
	4th generation	Capesize	1975	172,000	289	45.0	17.8
	5th generation	Ultra cape	1990	365,000	343	63.0	22.8
Tanker (DWT)	1st generation	Panamax	1914	70,000	230	32.2	13.7
	2nd generation	Aframax	1959	115,000	250	44	14.8
	3rd generation	Suezmax	1963	155,500	274	47	17

Table 2 continued

Vessel type	Generation	Typical ship	Year	TEU/DWT	LOA (m)	Beam (m)	Draft (m)
	4th generation	VLCC	1966	300,000	323	60	21
	5th generation	ULCC	1968	400,000	380	68	24.5

*It concerns vessels with about the same dimensions as the Triple E class of Maersk Line, but with a higher optimized TEU capacity. This higher capacity is obtained through a combination of adding additional layers of containers below and above deck, adding one additional container row (which increases the vessel's beam by some 2.5 m) and/or adding one additional container bay (which affects the LOA); see also Probst (2016)

**It concerns a possible further upscaling of container vessels after 2020. The water depth conditions of the Nicaragua Canal would allow it to accommodate containerships of more than 25,000 TEU; vessels larger than 14,000 TEU cannot pass through the expanded Panama Canal, while the limit of Suez is estimated at 24,000 TEU based on the maximum permissible beam (the current maximum draft of 20.1 m does not pose any problem for container ships). LOA (Length Overall) is the maximum length of a vessel's hull measured parallel to the waterline

Table 3 Potential international maritime freight characteristics for the Nicaragua canal. *Sources* Author compilation based on Andersen (2015), Yip and Wong (2015), Chen and Liu (2016)

Maritime freight	Main cargo types	Main marine cargo logistics characteristics
Container shipping	Industrial products, agricultural products, etc.	Asia's industrial products transported to North America
		Cereals, sugar cane, soybeans, and other food crops shipped in container from the U.S. and Brazil to East Asia
		Other agricultural and animal husbandry products from the Americas shipped in container to East Asia
Dry bulk shipping	Iron ore, grain, coal, etc.	Brazil iron ore to East Asia, especially China
		Grain bulk shipping from the U.S., Brazil, and other places to Asia
		Coal product shipping from the U.S., Venezuela, Columbia to East Asia
Tanker shipping	Crude oil, chemicals, liquid biofuels, etc.	Crude oil or chemical shipping from Venezuela, the U.S., and other places to East Asia
		Biofuels shipping service from the U.S. and Brazil to East Asia

Pacific markets. This could include hub-and-spoke based service networks or direct services with mainline vessels, depending on the operational considerations of the vessel operators and specific customer requirements in terms of frequency, reliability, and transit time. Furthermore, shipments between the west coast of the United States and Europe, and between the east and west coasts of the United States, could also possibly use the canal. In this manner, the Nicaragua canal would potentially influence the future of the international shipping market for containers, dry bulk cargo, oil, and other primary categories of goods. The future freight features of the Nicaragua Canal are shown in Table 3.

Container shipping

Container shipping is currently the main source of income for the world's interoceanic canals. For example, the Panama Canal assumed around 4% of the world's container cargo traffic in 2014. In the 15 years following the U.S. handover of the canal to Panamanian administration, in 1999, container shipments grew to account for 23% of transits and 47% of tolls for the Panama Canal (ACP 2014).

Both Nicaragua and Panama Canals would serve similar container transportation markets. Taking the shipping market between Asia and American ports as an example, two main types of container cargoes will dominate this market after the opening of the Nicaragua Canal: industrial products transiting from China and other Asian countries to the North American consumer markets and trade flows of grain, sugarcane, soybeans, and other agricultural products from Brazil and the United States to Asian countries, as well as other American farmed goods, shipped to East Asian regions as food or raw material cargo. Container transportation of grains has developed rapidly between the Americas and Asia in recent years, mainly to meet the trends towards smaller and standardized shipment batches of grain (Prentice and

Hemmes 2015) and to obtain a more balanced import/export container flow on the Asia–America trade route (Rodrigue and Notteboom 2015). Animal protein consumption has increased in Asia along with an overall rise in the Asian standard of living. The Nicaragua Canal would enable American agricultural and animal products to be shipped more effectively to Asian markets.

Dry bulk shipping

As for the North American dry bulk shipments of iron ore, grain, coal, and other raw materials to Asian countries, the Nicaragua Canal will compete fiercely with other transport channels, i.e. the route via the Panama Canal for shipments using east coast and gulf coast ports, and routes that combine a landside transport segment using north American rail freight services to west coast ports with onward deep-sea bulk shipping.

Australia, Brazil, and South Africa are the main exporters of iron ore and coal. The international iron ore trade is mainly carried out by bulk shipping from the above countries to China, Japan, the European Union, and elsewhere. Brazil is the world's second largest iron ore exporter after Australia, accounting for about 26% of total world exports in 2016. China and Japan are major iron ore importers, accounting for around 71 and 9% of total global imports in 2016, respectively (UNCTAD 2017). Iron ore is the most important trade commodity between Latin America and Asia. The very large bulk carriers deployed on the Brazil–China/Japan trade now follow a route that goes via the Cape of Good Hope to the northern coast of Australia before heading north to East Asia.

Voyages between Brazil and China—and other Asian countries—are very lengthy, increasing both shipping time and costs, and weakening Brazil's competitiveness in the iron ore trade compared to Australia. China, the world's largest importer of iron ore, received 63.7% of its imports from Australia and about 20.1% from Brazil in 2015 (Russell 2016). The Nicaragua Canal would accommodate much larger Asia-bound iron ore ships and slightly reduce shipping route distances. However, the competitiveness of the Nicaragua Canal to accommodate the Brazil–East Asia dry bulk trade will largely depend on the future toll for transiting the canal. The current pricing practices of existing interoceanic canals show that canal transit fees are typically set to discourage ship operators from choosing (longer) alternative shipping routes. A good example is the competitive pricing strategy of the Suez Canal Authority: they actively monitor and compare the total ship operating costs of the Suez Canal route versus the route via the Cape of Good Hope when deciding on the transit fees (Notteboom 2012). One can expect that also the Nicaragua Canal operator would develop similar pricing strategies to attract ship visits on O-D relations where the canal is in a good position to effectively compete.

The bulk grain market from North America to Asia is very large, with agricultural production in the United States and Brazil making these countries the world's leading exporters of grain. For example, in 2016, the U.S. was responsible for about 22% of global exports, with East and South Asia responsible for as much as 34% of the global imports of grains (UNCTAD 2017). Although container shipping of grains from North America to Asia has been growing rapidly, bulk shipping will continue to be the main mechanism, because of its low costs and large transport capacities. Currently, between the U.S. Gulf and the Far East, grain transport mainly utilizes Panama vessels (60,000–80,000 dwt) and Handymax vessels (50,000–60,000 dwt), and their routes pass through the Panama Canal. The Panama Canal facilitates between 14 and 20% of the world's grain freight (ACP 2014). The Nicaragua Canal would offer more options to bigger bulk vessels while at the same time reducing shipping route distances. Moreover, ships would no longer have to travel south to bypass the Panama Canal, needing only to pass through the Nicaragua Canal and travel north directly to the Pacific Ocean. From the perspective of time and distance, the Nicaragua Canal will potentially greatly benefit the grain bulk shipping market from North America to Asia.

Additionally, the Nicaragua Canal will facilitate coal exports from Venezuela to Asia. China, India, and Japan are the world's major importers of coal, accounting for over 65% of total world imports (BP 2015). The proposed canal will allow the choice of larger carriers for more coal supplies, which could encourage an increase in the coal exported from the eastern U.S., Venezuela, and Colombia to the steel and power industries in Asia.

Tanker shipping

The opening of the Nicaragua canal will facilitate international tanker shipping between the Americas and Asia, primarily by delivering crude oil and chemicals from Venezuela and the U.S., as well as biofuels from the U.S. and Brazil to markets in East Asia.

The Americas have very rich oil reserves, with the current proven reserves reaching about 87 billion tons, accounting for about 33% of the world's total oil (BP 2015). Venezuela is Latin America's most important oil-producing nation; its most abundant resource is oil, ranking first in the world in 2014 and accounting for 17.5% of the world total (Table 4). Although the Americas have rich oil reserves, the Panama Canal's capacity constraints have prevented the passage of large tankers. VLCCs shipping oil from the Caribbean and the Gulf of Mexico have not as yet

Table 4 Total proven oil reserves in the Americas. *Source* BP (2015)

Area	Country	End of 1994		End of 2004		End of 2014	
		Billion barrels	Share of total (%)	Billion barrels	Share of total (%)	Billion barrels	Share of total (%)
North America	US	29.6	2.6	29.3	2.1	48.5	2.9
	Canada	48.1	4.3	179.6	13.1	172.9	10.2
	Mexico	49.8	4.5	14.8	1.1	11.1	0.7
South and Central America	Venezuela	64.9	5.8	79.7	5.8	298.3	17.5
	Others	16.6	1.5	23.7	1.7	31.5	1.9

been a viable alternative, as ships must cross the Atlantic, sail around the Cape of Good Hope, and then through the Indian Ocean to get to China, India, Singapore, Japan, and other Asian countries, significantly lengthening shipping distances and time and reducing the American oil trade competitiveness. Currently, the oil imports of China, India, Singapore, and Japan from the Americas constitute about 12, 20, 13, and 5% of their total oil imports, respectively, with the vast majority of their oil imports coming from the Middle East and Africa (BP 2015).

By providing a high-capacity maritime passage between the Atlantic and Pacific Oceans, the Nicaragua Canal would offer a shorter transport route between the oil-producing countries in the Americas and the Asian markets. If the canal transit fees turn this distance advantage into lower ship operating costs for the canal route vis-à-vis the currently used routes, the canal would facilitate the growth of oil and liquid bulk trade of Venezuela, the United States, and other American countries to Asian regions. To encourage its shale gas and shale oil revolution and to bolster its energy exports, the U.S. government abolished a 40-year ban on the export of crude oil at the end of 2015, preparing the U.S. to become a major energy exporter in the future (Aruga 2016). The main American refineries and natural gas ports are located along the Gulf Coast. In the future, VLCC and VLGC (Very Large Gas Carrier) transportation to China, Japan, and other East Asian countries would likely benefit from the Nicaragua Canal, which is closer than the Panama Canal and will allow much larger vessels to transit the canal. However, the routing options offered by the global transport system and the shipping industry are only some of the factors affecting global oil trade patterns. The economic geography of oil demand and supply, the oil price on the world market (and related trading), regional differences among production costs, energy (transition) policies, and geo-political and geo-economic considerations also affect trading patterns and routing decisions. For example, Ji et al. (2014) demonstrate that the current global oil trade network can be divided into three trading blocs, i.e. the ‘South America–West Africa–North America’ trading bloc, the ‘Middle East–Asian–Pacific region’ trading bloc, and ‘the former Soviet Union–North Africa–Europe’ trading bloc. Using complex network theory, they found that geopolitics and diplomatic relations are the two main reasons for this regional oil trade structure. The power of a new canal to (re)shape global trade patterns is therefore very limited. A canal as part of a global transport system can enhance the fluidity of trade flows and increase routing flexibility.

Furthermore, the United States and Brazil have very advanced technologies for the production of biofuel using sugar cane, corn, and other crops as raw materials. The two countries are the world’s first and second largest producers of biofuel, accounting for 43 and 24% of world biofuel production, respectively (BP 2015). Both nations actively push their biofuel exports. Brazil has created energy industry partnerships with China, Japan, India, and other Asian countries, and the United States is actively expanding its fuel, biodiesel, and other biofuel exports to the Asian consumer market (Huang et al. 2012). For this kind of liquefied bulk cargo shipping, the Nicaragua Canal could facilitate a convenient and stable biofuel delivery to Asian regions.

Regional port system

The Nicaragua Canal has the potential to impact the development of port systems in the Atlantic and Pacific oceans.

First, it could impact the North American regional port system, which has three coastal port groups: the Pacific port group (the U.S. West Coast), the Atlantic port group (the U.S. East Coast), and the Gulf of Mexico port group. The Nicaragua Canal would facilitate dry bulk shipping from the Gulf of Mexico to Asia. If the Far East-to-America exports go smoothly using all-water routes (Pacific Ocean, Nicaragua Canal, Atlantic Ocean), cargo will probably have fewer chances to transit through U.S. West Coast ports. As a result, the canal may negatively impact the development of those ports, while ports on the US East Coast and in the Gulf of Mexico may have more opportunities to develop.

Second, in terms of the Central American and Caribbean regional port system, the Nicaragua Canal could create an additional high-capacity transshipment passage for the foreign trade of the nations in this area. The canal has the potential to become an important cargo channel to Venezuela, Colombia, Cuba, and other countries in the region, and it could therefore invoke competition with existing and planned transshipment facilities along the Panama Canal (i.e. Balboa, Manzanillo, Colon, and the planned Corozal terminal complex) and the Caribbean (e.g. Freeport Bahamas and Kingston Jamaica). The surrounding regions are less economically developed, but the new canal could bring more foreign trade to these nearby countries. Thus, the canal has the potential to effectively stimulate the development of the ports in this region.

Caribbean facilities have capitalized on opportunities to establish themselves as transshipment hubs for the region (Rodrigue 2010). In the presence of the Nicaragua Canal, mega-ships could easily induce new hub-and-spoke systems. One could imagine the Caribbean port industry consisting of three major segments:

- Modern world-class transshipment facilities in the western Caribbean, such as Kingston container port in Jamaica, Caucedo port in Dominican Republic, and Freeport in Bahamas;
- Sub-regional hub ports such as Kingston Wharves in Jamaica, Port of Spain in Trinidad, and Point Lisas in Trinidad. These facilities would act as gateways to the Eastern and Southern Caribbean, as well as the Caribbean rim of South America;
- Caribbean feeder service facilities, such as Bridgetown Port in the Dominican Republic, Port of St. John in Antigua, Port of Castries in St. Lucia, and Port of Havana in Cuba. These ports could provide services to smaller vessels moving cargo between smaller ports of the Eastern Caribbean.

Third, the Nicaragua Canal would likely have an impact on South American regional ports. Ports in the region are not as advanced as those in North America, and their railway systems are unable to achieve cross-strait interactions. The canal could create value added by offering improved connectivity between both sides of

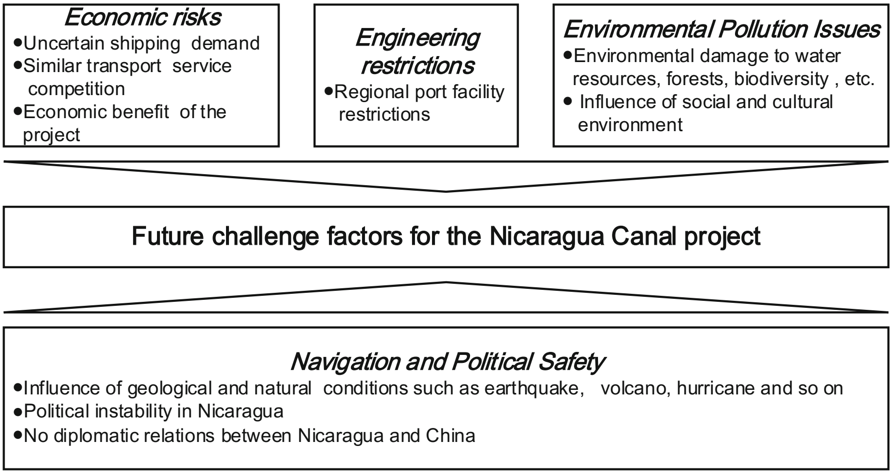

Fig. 2 Major challenge factors facing the Nicaragua Canal project

South America and it might therefore impact the layout and development of the ports in this region.

Future challenges for the canal project

The above discussion assumes that the canal will meet the technical requirements of larger ships and will be priced in a competitive way vis-à-vis the Panama Canal, the North American rail land bridges, and even the Suez Canal route. However, international trade and shipping are influenced by many complex external factors, the interactions of which vastly increase the challenges of the construction and operation of the canal (Fig. 2).

Economic risks

The Nicaragua Canal project faces substantial economic risks. First, it is uncertain whether there will be room in the future for the deployment of post New Panamax vessels to connect the Atlantic and the Pacific Oceans. At present, the world's largest container ships are deployed on the Asia–Europe trades, with typical ship sizes ranging from 14,000 to 22,000 TEU. The use of such large ships is supported by the route's massive container flows, the long sailing distances, and the availability of ports and terminals on both sides of the trade route well equipped to receive such mega-ships. Existing research shows that containerships above 18,000 TEU have a lower economic effectiveness, as they cannot be economically viable without the support of proper technical conditions at the calling ports, and a broader supply chain coordination and inland transport integration (Drewry 2015). In recent years, both North American East Coast ports and Latin American ports had to engage in large-scale investment programmes in dredging, terminal infrastructure, and hinterland access to be ready for the arrival of New Panamax ships in the wake of the Panama Canal extension. While the adaptive capacity of ports (and the willingness to invest) in dealing with increasing vessel size is generally higher than initially thought (Notteboom 2016), geographical, nautical, and trade-related conditions of many ports in these regions pose a natural upper limit on the maximum ship size they can accommodate in the future. The Nicaragua Canal will have the possibility to welcome container vessels of well above 18,000 TEU. However, given the above discussion, it remains doubtful whether port operators and governments will be prepared to engage in another even costlier port upgrading round to move beyond the New Panamax vessel size of up to 14,000 TEU. In other words, the Nicaragua Canal could end up only transiting container vessels that can also pass through the Panama Canal, thereby not being able to fully utilize its nautical advantage over the Panama Canal.

Second, the Nicaragua Canal will have to compete with the Panama Canal, the Suez Canal, and other transportation channels. As mentioned in the previous paragraph, the limitations of the U.S. East Coast port system mean that the Nicaragua Canal will be obliged to compete with the Panama Canal for the traffic of similarly sized container ships. Moreover, the Nicaragua Canal will also be faced with competition from the U.S. railway system. Asian manufacturers often choose the combined mode of sea–rail transportation for goods shipments to the United States, as this mode of transport has certain timesaving advantages. Furthermore, other North American and Mexican land bridges, as well as dry canal projects pursued by several Central American countries, would also offer niche alternatives for cargo transportation.

In addition, globalization is not a static process, for comparative advantages are always changing. China's status as the world's manufacturing powerhouse has begun to waver. China's rising labour and business costs have caused a number of factories to transfer to Southeast and South Asian countries (Rodrigue 2010; Chen and Liu 2016; Chen et al. 2016). On eastbound routes, the sea–land bridge combined transport solution passing via West Coast ports can save time albeit with higher costs, while all-water shipping via the Nicaragua canal would involve a slightly shorter distance than the same passage transiting the Panama Canal. However, as the world's manufacturing centres shift from China to Southeast and South Asia, the westbound all-water route via the Suez Canal seems to become more competitive.

In summary, the Nicaragua Canal's goal of serving mega-vessels will not be easy to realize. Fierce competition from both the Panama Canal and the Suez Canal, coupled with high initial investment costs, suggests that the economic outlook of the Nicaragua Canal project is not optimistic (Chen and Liu 2016; Chen et al. 2016). The Nicaragua Canal's investment cost is as high as 50 billion dollars, which is, respectively, about 9 and 6 times that of the Panama and Suez Canal expansion projects (Andersen 2015). Due to this cost disadvantage, the Nicaragua Canal's future toll rate strategy will face fierce competition. An overly high canal toll will increase cost pressures on the passage of ships, and the canal may thereby risk losing the shipping market. By contrast, a lower toll strategy will make the project unlikely to ever recover its huge investment cost.

Engineering restrictions

The Nicaragua Canal's effective operation will be determined by large ship navigation technology and port engineering facilities and conditions. Currently, Pacific and Atlantic port depths cannot accommodate the expected mega-sized Nicaragua-type ships. Containership sizes, for instance, have continued to increase in the past few decades, with the current largest ship weighing in at more than 22,000 TEU. These large ships have already created operational challenges, even for European and Asian mega-ports with good water depths (Drewry 2015). Due to the limitations of global container shipping demand and port engineering conditions, future containerships would need to be limited to maintain reasonable efficiency (DNV 2012).

For a long time, limited by the Panama Canal, the U.S. East Coast mainly served 3000–5000 TEU container vessels. In the future, the main Mexican Gulf–Caribbean–Atlantic Ocean port hubs, such as Savannah, Hampton Roads, Kingston, Freeport, Caucedo, Cartagena, and New York, may receive Nicaraguan Canal transshipments, but their port facilities might limit their ability to effectively service these massive ships. Widening the Panama Canal allowed bigger ships to arrive at these regional ports, which involved investments in dredging navigation channels and upgrading bridges. The new conditions of these port hubs allow serving ships of up to 10,000–14,000 TEU but simply cannot reach the technical requirements for accommodating ships of over 20,000 TEU, imagined by the Nicaragua Canal project. The success of the 20,000 + TEU-class containerships cannot be guaranteed in the canal's market environment (Chen and Liu 2016; Chen et al. 2016).

Environmental pollution issues

The Nicaragua government's planned canal route crosses Lake Nicaragua, the country's largest freshwater lake. Canal dredging and shipping activities will have a serious impact on the lake's water quality and ecological environment. Shipping activities between the Atlantic and the Pacific coast and the construction and operation of coastal deep-water ports will seriously affect the development of biodiversity and the protection of endangered species (Huete-Perez et al. 2016). The Nicaragua canal shipping activities will bring serious negative effects to the surrounding tropical rain forest, forest wetlands, natural and biosphere reserves, and other ecological systems, and shipping ballast water could also cause marine biological invasion. The cost to Nicaragua's natural ecological environment cannot be ignored (Huete-Perez et al. 2013; Meyer and Huete-Pérez 2014; Chen and Liu 2016; Chen et al. 2016). Meanwhile, the canal project will also destroy local archaeological sites, disrupt the lives of indigenous people, and cause damage to other social environments (Huete-Pérez et al. 2015). Thus, scientists warn that the extent of ecological and social damages caused by the canal project could forever change Nicaragua's ecosystem and social structure, potentially in a catastrophic manner (Huete-Perez et al. 2013; Meyer and Huete-Pérez 2014; Chen et al. 2016). The government and stakeholders will face serious challenges in enforcing environmental protection of the canal project. Specific and reasonable responses and solutions need to be identified and put forward to reduce the canal's negative impact on the natural environment and social structure.

Navigation and political safety

The proposed canal is located in a region of active seismic and volcanic activity. It is also in the path of Caribbean hurricanes, which might present a major hazard to the future navigation of the Nicaragua Canal. It should be further considered that when the United States invested in building an interoceanic canal in Central America a century ago, the U.S. eventually gave up the Nicaragua Canal project and opted for the Panama Canal precisely because of these canal navigation safety factors (Chen and Liu 2016; Chen et al. 2016; Greene 2009).

In addition, Nicaragua is politically unstable, has slow social and economic development, and remains one of the poorest countries in Latin America. The country faces the long-term arduous task of improving its economic and social stability, and of resolving its hostile border disputes with its neighbour, Costa Rica. Additionally, Nicaragua has no diplomatic relations with China, which is a potentially large risk to Chinese investors. The Chinese government has repeatedly and officially warned Chinese companies not to get involved in this risky project in any way (MOFCOM 2012). At the same time, Panama has cut ties with Taiwan in June 2017 and is forging stronger relations with China. Panama's policy reversal with respect to Taiwan may be linked to China's massive investment in the area around the Panama Canal. The stronger economic and diplomatic exchanges between China and Panama potentially undermine the plans for the realization of the Nicaragua Canal.

Conclusions

In this study, we analysed the controversial issue of the Nicaragua Canal in Central America from the perspective of its shipping and port attributes. A significant part of previous research has mainly concentrated on the environmental assessment of the canal, while our paper analysed the canal issue from a *maritime* perspective, further expanding the academic research in this field. The paper identifies and discusses the most important aspects to be considered regarding the Nicaragua Canal's potential impact on international shipping and its attendant impediments. This research can help the Nicaragua Canal's authorities and stakeholders to make appropriate decisions and devise reasonable strategies on canal construction and development.

The essential purpose of constructing an interoceanic canal is to serve international maritime transportation, and the feasibility of the Nicaragua Canal is affected by many complex factors. Even when we set challenges and restrictions aside and we only consider the project's expected technical and nautical characteristics, the Nicaragua Canal would still impact shipping operations such as ship sizes, the routing of maritime freight flows, and regional port development.

However, the project's feasibility is undermined by economic, engineering, safety, environmental, and political obstacles.

We conclude that the Nicaragua Canal could cause international shipping to exhibit different characteristics as follows.

Regarding ship sizes, the canal's technical conditions can accommodate mega-ship of well above 18,000 TEU. Even so, due to shipping demand limitations and port restrictions, we expect that the canal might end up servicing container ships that can also transit via the new Panama Canal locks. Large bulk carriers and oil tankers will experience a similar scenario, as the Nicaragua Canal is technically able to serve these huge ships, albeit in competition with multiple other alternatives. Whether big bulk and tanker ships will choose this canal depends mainly on the transportation economy of the canal and its pricing policy.

The opening of the new canal can facilitate cargo transportation between Asia and the Americas and offer more routing flexibility to shipping lines and cargo owners, which is conducive to the development of maritime trade between Asia and the Americas.

The Nicaragua Canal will potentially have significant effects on the regional port system, allowing Asia-to-the-Americas shipping to use all-water transportation routes. U.S. West Coast ports may be used less, but East Coast and Gulf of Mexico ports will have more development opportunities. At the same time, the canal will have a positive impact on Central and South America and the Caribbean regions. However, the extension of the Panama Canal is already resulting in similar effects, so it remains uncertain whether an additional canal can further intensify the changes that are already taking place in the regional port system.

The canal project is rife with shipping service uncertainties and challenges, as well as high economic and environmental costs. Given these high levels of uncertainty, we recommend future studies focusing on two main issues. First, specific and reasonable responses and solutions need to be identified and put forward to reduce the canal's negative impact on the natural environment, social structure, indigenous issues, and navigation safety. Second, further study should develop reasonable technical and economic evaluations of ship type, shipping route network design, and regional port hub selection in the context of the Nicaragua Canal and its competitors.

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