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To cite this version:

César Ducruet, Hidekazu Itoh. Spatial Network Analysis of Container Port Operations: The Case of Ship Turnaround Times. Networks and Spatial Economics, 2022, 10.1007/s11067-022-09570-z . halshs-03719064

HAL Id: halshs-03719064
https://shs.hal.science/halshs-03719064
Submitted on 10 Jul 2022

Spatial network analysis of container port operations: the case of ship turnaround times[1]

César Ducruet[2]
French National Centre for Scientific Research (CNRS), Paris, France
cdu@parisgeo.cnrs.fr

Hidekazu Itoh
Kwansei Gakuin University, Japan
hito@kwansei.ac.jp

Abstract

This research investigates the determinants of ship turnaround times at about 2,300 container ports between 1977 and 2016, based on nearly 3 million daily vessel movements. It adopts a multilevel approach combining territorial and network indicators to characterize ports, and proposes a new methodology calculating shipping delays. Main results reveal that port connectivity, Gross Domestic Product per capita, the number of vessel calls, and island location foster efficient port operations. Conversely, urban population, voyage delays at sea, maximum ship size, and upstream location increase turnaround time. While average turnaround time and inter-port sailing time have both regularly declined, operational and technological changes in the ports and maritime sector - especially after the 2007/8 global financial crisis - accelerated intra-port time and slowed down inter-port time. This relational and spatial approach also underlines the geographic differentiation of ship times nationally and regionally, as it is far from being randomly distributed on the globe.

Keywords: complex networks; congestion; connectivity; containerization; liner shipping networks; port cities; ship turnaround time; uncertainty

1. Introduction

The rise and fall of ports have long relied on their ability to ensure efficient vessel accommodation and cargo handling (Jackson, 1985). Seaports of the 19th century were already competing by providing fast transit between sea and land (Marnot, 2005). Such aspects are

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[1] This Working Paper is the previous version of the article published in *Networks and Spatial Economics* (2022), https://doi.org/10.1007/s11067-022-09570-z

[2] Corresponding author

even more crucial in recent decades, with the acceleration of global trade and the advent of containerization (Bernhofen et al. 2013). Containerization was specifically applied to maritime transport to facilitate cargo handling and save time and cost (Levinson, 2006). The time that ships spend in a port thus has become increasingly crucial, especially for shipping companies, although it remains poorly documented in official reports (de Langen et al., 2007). The current COVID-19 pandemic had tremendous impacts in terms of supply chain disruption and port congestion worldwide (Merk et al., 2022), thereby confirming how the speed of port operations is vital for global transport and economic development.

While it is recognized that “port efficiency” as a whole may facilitate trade (Clark et al., 2004) and local economic development (Doi et al., 2001; Haddad et al., 2010), the time factor lags behind other port performance indicators in the academic literature (Tongzon, 2001; Itoh, 2002). It is often discussed in broader researches on supply chain efficiency (Hummels 2001; Nordas et al., 2006), port choice behavior (Itoh et al., 2002; Tiwari et al. 2003; Tongzon and Sawant 2007), and congestion issues in ports (see Notteboom, 2006; Vernimmen et al., 2007; Yan et al., 2009; Jones et al., 2011; Leachman and Payman, 2012), but systematic empirical studies remain scarce (Suarez-Aleman et al., 2014).

This article wishes to tackle this lacuna by providing a spatiotemporal analysis of vessel turnaround times across ports of the world in the last four decades. The main objective is to further understand the determinants of ship times in ports. In particular, this research innovates by adopting a relational, or network, perspective. Port connectivity studies have become popular in the last decades (Ducruet, 2020), but the relationship between maritime centrality and ship times has not been investigated yet. It is based on the idea that port operations are increasingly influenced by exogenous realities, such the position of ports in value-driven chain systems (Robinson, 2002). One first hypothesis is that a strong centrality will accelerate port operations. Another facet of this relational perspective is the possibility to put in relation port time and delays at sea, namely the difference between expected berthing time and actual berthing time (see Premathilaka, 2018), in the global container shipping network considered as one comprehensive system. Related to this, a second hypothesis is that sailing delays increase bottlenecks, congestion, and thus port time, as a cascading effect throughout the network, which is made of interconnected ports and dependency chains (Stergiopoulos et al., 2018; Talley and Ng, 2016).

Another innovation of the present research is to confront ship times with the territorial attributes of places in which ports operate. Although port competition studies considering ship times may include such elements, like policy measures and hinterland connections, they often remain theoretical or focused on a small sample of ports (see Zondag et al., 2010). Maritime networks belong to the class of spatial networks (Barthelemy, 2015), with nodes being characterized by geographic and socio-economic characteristics at different levels. Those include the national economy, in terms of investment potential in efficient port infrastructure. It also includes more local attributes, especially about the urban location itself. The urbanized area may act as a constraint for port operations, but at the same time, the urban economy constitutes a crucial market for maritime trade (Ducruet et al., 2020a). Ports situated within dense urban environments have higher probabilities to face congestion than ports situated in smaller urban settlements. Other locational factors also play a role, ports being in a more or less favorable situation to accommodate larger vessels. Spatiotemporal models of port evolution well depicted the demise of upstream seaports (Bird, 1963), while modern transshipment hubs, which provide state-of-the-art facilities and adequate berth depth, often locate on peninsulas and small islands (Fleming and Hayuth, 1994; Rodrigue and Notteboom, 2010). Last but not least, ship time is thought to be differentiated across world regions, depending on socio-economic development levels, but its geographic distribution is not well-known.

Our research covers the period between 1977 to 2016, namely since the Open Door Policy of China and a few years before the current pandemic. Despite the latter event, which is affecting ports and supply chains to such an extent that it fosters a paradigm shift in container shipping (Merk et al., 2022), the search for regularities in the distribution and evolution of port time remains necessary. One main reason is that there is hope for the pandemic to cease and for port operations to resume, thereby going back to a state of global "synchronization" among transport terminals (Rodrigue, 1999). Past regularities may survive to shocks, as it will be examined in this research from diverse angles, namely the escalation of ship size and the 2009 global financial crisis.

The remainders of this article are organized as follows. The second section reviews the existing literature on ship time in diverse scientific disciplines. It is followed by a third section introducing the data and methodology serving the global analysis of ship time in container ports. The fourth section provides preliminary results of ship time evolution and its geographic distribution. Main results lie in the fifth section, where the determinants of ship time are analyzed. The last section discusses the lessons learned for research and practice and provide conclusions as well as pathways for further research.

2. Literature review

As underlined by Goss (1967), a vast literature addressed port time issues back in the 1950s to finds ways reducing lengthy port operations and overall sea transport costs. Scholars particularly focused on the relationship between ship size and loading time (see Heaver and Studer, 1972; Edmond and Maggs, 1976; Robinson, 1978), being aware that many external factors may distort their correlation, such as weather, dock labor, and market conditions, the relative importance of time to vessel operations, and the number of berth changes: "*the rate at which a cargo is handled, even for ships with the same types of cargo, is different for different cranes, on different berths, and in different ports, and is subject to a large range of random factors. So too is turnround time in port*" (Robinson, 1978, p. 161). Scholars studying ship times at ports dominantly adopt a monographic approach, focusing on a single port or terminal, with very rare comparative studies. Another characteristic of time-related port studies is to discuss mainly the operational dimension within the port or terminal.

Two research directions gradually expanded this scope and scale, however. One is a corpus of studies on the ocean transit times of carriers, as time rather than cost had become a paramount selection factor for shippers (Wilmsmeier et al., 2013). Scholars compared the time performance of liner shipping firms in terms of uncertainty (Saldanha et al., 2006; Slack et al., 2018) while others applied mathematical modeling to a wide set of components such as total voyage time, voyage time at sea, voyage time in port, average port time, vessel speed, and liner shipping network design (Moon and Woo, 2014; Wang and Meng, 2012; Qi and Song, 2012; Alvarez, 2012). The other direction is more firmly rooted in the "classic port performance" school, looking, for instance, at the factors influencing time efficiency such as container loading rate, containers loaded per vessel, and waiting times (Sanchez et al., 2003), the analysis of the relationship between port characteristics (of which cargo delay during customs procedures) and maritime transport costs (Wilmsmeier et al., 2006), and the analysis of the components of vessel time in ports together with the determinants of port inefficiency, such as customs clearance, container handling charges, and cargo handling restrictions (Clark et al., 2004).

There are important challenges to international comparison. While port and terminal authorities may have different regulations in terms of operating hours, official port statistics do not always explain the true meaning of turnaround time, i.e. including or not channel navigation and queuing time in addition to the time spent inside the port itself. The smaller the sample of ports, the wider the spectrum of variables becomes available (for a useful review, see Le-Griffin and Murphy, 2006): dwell time, berth length utilization rate, crane utilization rate, crane productivity, etc. The growing availability of extensive maritime data, however, allowed scholars to propose comparative studies of port congestion. AbuAlhaol et al. (2018), for instance, used Automatic Identification System (AIS) data to measure port congestion levels in Halifax, Hong Kong, and Singapore. A port congestion model was proposed by Ma and Zhu (2021), also based on AIS data, with direct berthing rate and average anchorage time as indicators of port congestion. Other works better relate with the environmental impacts of prolonged ship times, in terms of energy efficiency and port emissions.

3. Data and methodology

The preparation of relevant data is thought as a multilevel analysis (Table 1) where each indicator is expected to have a positive or negative effect on average turnaround time (ATT) and standardized dispersion of turnaround time (CVTT). After introducing the calculation of ATT and CVTT itself, we discuss the role and relevance of chosen indicators, classified into "territorial environment" and "liner shipping network".

3.1 Measuring average and dispersion of vessel turnaround time at ports

The global database used in this study was obtained from the *Lloyd's List*. It provides information about the daily movements of the entire world fleet of fully cellular container vessels, on the basis of four months a year between 1977 and 2016. No less than 2,765,192 vessel movements were computed in this analysis. The average turnaround time (ATT) at our 2,328 ports corresponds to the average (yearly) difference between the day of arrival and the day of departure. The standardized dispersion of ship turnaround time (CVTT) is the standardized value of dispersion of turnaround time at ports by their ATTs. The enormous advantage of this data is to avoid collecting and harmonizing dispersed information from distinct port and terminal authorities, as such an information would not be available with the same units, definition, and overtime. Vessel movements not related with cargo handling, such as repair and bunkering, were excluded for the sake of comparability. The study period allows us to analyze important changes in the way containerization has spread and how ports adapted to such successive technological diffusion "waves" (Guerrero and Rodrigue, 2014), from the era of handy size vessels to the one of megaships.

We also aim to confront average (ATT) and dispersion (CVTT) of turnaround time with two simple facets of port activity, namely total vessel traffic by the number of vessel calls, and maximum vessel capacity measured in deadweight tons, which is a proxy index of container terminal capacity. The effects of these two indicators can be either positive or negative, as large ports may be more congested than small ports, but at the same time, may possess more suitable equipment to handle large vessels and ensure smooth turnaround time.

3.2 Territorial indicators

One first indicator related with the territorial environment is at country level, namely the Gross Domestic Product (GDP) per capita in current dollars. Although it remains not directly related with port operations, it has the advantage of being available from the World Bank database for the entire study period. Another advantage is to indicate the probability for ports to be backed by a more or less dynamic economy. We are aware of its limits, as richer countries may not necessarily have a dynamic port activity, and poorer countries may host an efficient port financed by, for instance, private external actors as in the case of terminal concessions. GDP thus remains a proxy for the general economic performance in which ports operate. Trade variables are also introduced, i.e., values and volumes of export and imports, and trade values for GDP. However, these variables are at country level, and affected by the size of the economy. Therefore, they are indexed by the average of countries on years and by their own yearly trends. Trade data are from World Economic Outlook, World Trade Organization (WTO) and Taiwan National Statistics.

Other territorial indicators are at the subnational level, or city and region. The population of the host city was chosen as a proxy for potential congestion around the port. In the literature and as said above, port cities have grown by expanding urbanization and moving out port facilities, which relocated at either smaller urban settlements or greenfield sites (Ducruet et al., 2020b). It is thus hypothesized that ship turnaround time (average and dispersion) will be higher if the city is large and lower if the city is small. In reality, certain large and densely populated port cities managed to sustain very efficient port operations, such as Hong Kong, while others, such as Manila, suffer from combined urban and port congestion (see Saeed and Larsen, 2016). Each port was attributed to a city, based on the extent of urbanization or urban morphological area. Population data was obtained from the databases Geopolis (1980-1990), World Gazetteer (2010), Population Statistics (1977-2005), and Citypopulation (2010-2016) to cover the whole study period.

Locational characteristics were attributed to ports as dummies to depict their situation as downstream, upstream, island, and coastal. Coastal ports are neither upstream nor downstream, while upstream, downstream, and coastal ports may be island or not. Such dummies are used to test, mainly in the case of upstream and downstream ports, the influence of deep-water access (or not) on port operations. As numerous transshipment ports locate on islands, we use the island dummy to test this fact.

3.3 Network indicators

Based on vessel movement data, we constructed a global port-to-port matrix where nodes are ports and links are inter-port voyages. The matrix only considers direct links between ports along the sequence of calls. In the case of pendulum services for instance, port pairs are thus segments or parts of the entire voyage. The calculation of shipping delays and shipping speeds is based on the orthodromic distances between ports. Shipping delays are calculated as follows. Actual shipping time for each inter-port movement is the difference between day of departure and day of arrival. Theoretical shipping time is the orthodromic distance divided by 37.4

kilometers per hour (i.e. 20 knots for containerships) divided by 24 hours. Shipping delay is thus the average of the absolute differences between actual shipping time and theoretical shipping time at the ports of arrival. The higher the shipping delay, the more ports receive vessels too early or too late; the closer to zero, the more actual shipping time is in line with speed and distance.

We measured the centrality of ports in four complementary ways, based on complex network framework. Degree centrality counts for each port the number of its adjacently connected neighbors in the graph. It is a measure of connectivity that partially corresponds to the definition of the hub, i.e. a node with many links in the case of a high degree. In complement, betweenness centrality counts the number of shortest paths on which each port is located. It is more a global accessibility measure, which complements the degree as it reflects the "intermediacy" defined by Fleming and Hayuth (1994) as the ability of transport nodes to be well inserted in the networks of transport actors. In addition, the hub function is the clustering coefficient, a well-known measure in social network analysis. It calculates for each port the proportion of connected neighbors in the total maximum number of connected neighbors. Values closer to zero indicate a strong hub function, as the port is a crucial node through which shipping flows should pass to connect other neighboring nodes. Values closer to one indicate the opposite, i.e. a port that is surrounded by high-density linkages and therefore does not act as a pivotal node. Lastly, the bridge function focuses on the clustering coefficient of links. For each port, it is the average clustering coefficient of its links to/from other ports. This clustering coefficient is low for links being crucial to connect nodes at its both ends. Ports with high bridge functions are those that are essential to connect neighbors with each other through such crucial links.

4. Preliminary results

4.1 General trends

Our preliminary results in Figure 1 show a global improvement of about 1 day on average during the first decade 1977-1986, from more than 2 days to about 1.5 days for vessels to stay in ports. This confirms the development of containerization at major ports in advanced countries and the expansion of container shipping networks. The next two decades 1987-2007 are remarkably stable and oscillate around 1.5 days of ATT, meaning that the effects of technological (and wider, economic and trade) changes did not apparently affect the global average. As it will be showed later (see Figure 5), certain ports have worsened while others have improved in terms of ATT. A tremendous change occurred in the last period 2008-2016, as global ATT dropped from about 1.62 in 2008 to 0.54 in 2016. This can be directly attributed to the effects of the global economic downturn between 2007 and 2010 on the shipping and ports sector. Struck by falling demand, major shipping lines reorganized their fleet (often through new alliances) by pursuing further economies of scale (Notteboom et al., 2021). A minority of evermore larger containerships gradually replaced the bulk of smaller ones, calling at fewer ports, and resulting in faster cargo handling (see Wilmsmeier et al., 2013 for the case of Latin America).

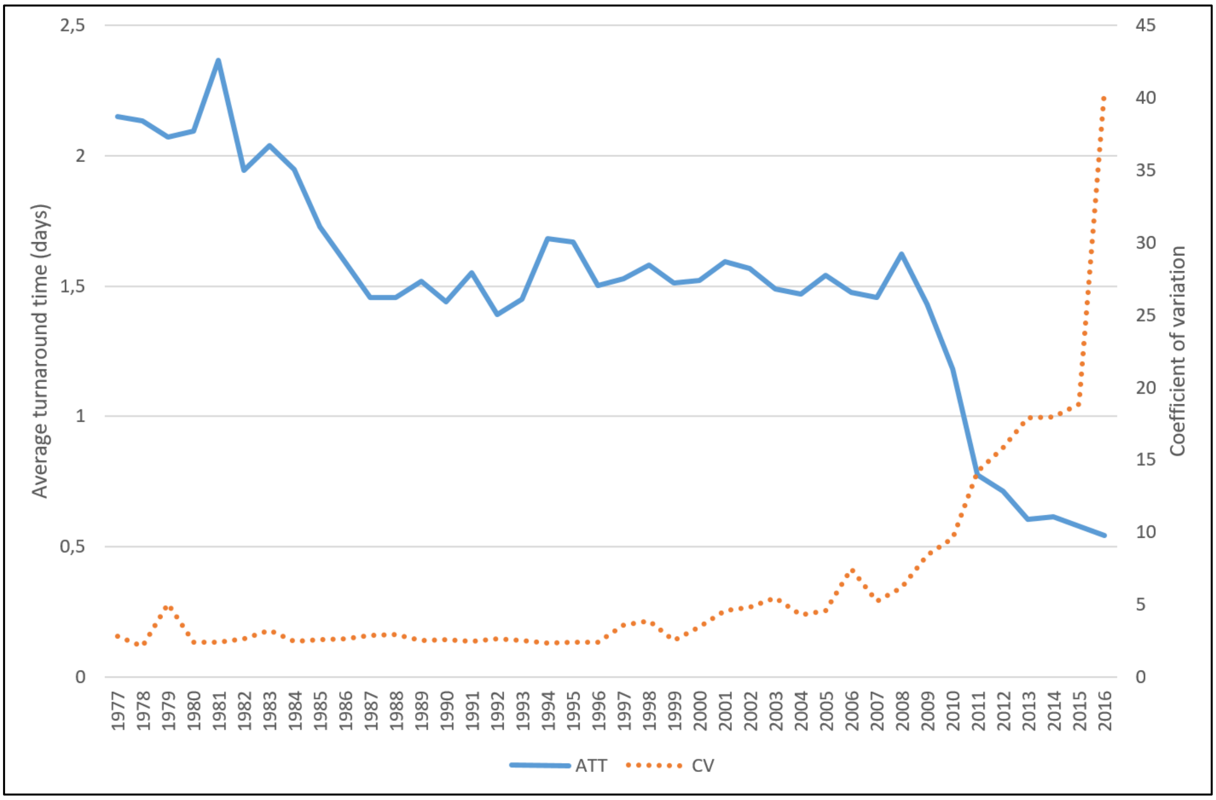

Figure 1: Global evolution of ship turnaround time, 1977-2016

One useful preliminary result is the calculation of the correlation coefficient between actual and theoretical shipping times (Figure 2). One can observe that the correlation had been highly significant until the mid-1990s, at a time when larger containerships were released on the market. Between the mid-1990s and the global financial crisis in 2008, the correlation decreased because of rapid container terminal developments and growing imbalances in the structure of shipping networks and hub-system. From the crisis to the end of the study period, the correlation remained stable and moderately significant, around 0.3-0.4. Technological change and network reconfiguration have clearly impacted ship times.

It is worth noticing that actual shipping time (or ocean transit time) went through a peculiar evolution over the study period (Figure 3). We observe a gradual decrease of average shipping time from 3.5 days to two days between 1977 and 2000, followed by a modest increase up to 2.5 days in 2008. A drastic change occurred in 2009 when shipping time literally jumped to 4.2 days within one year, decreased gradually to 3.6 days in 2015 and jumped again to 6.3 days in 2016. As such, shipping time is clearly reflecting technological change in the shipping industry as a response to global economic and trade evolutions. The introduction of larger vessels on the market already caused slower shipping speeds between 2000 and 2008, but the 2009 turn is directly attributable to the global financial crisis. This event motivated shipping lines to adopt the strategy of slow steaming to save fuel costs, and palliate the lowering speed by further economies of scale using larger ships (Notteboom and Cariou, 2013).

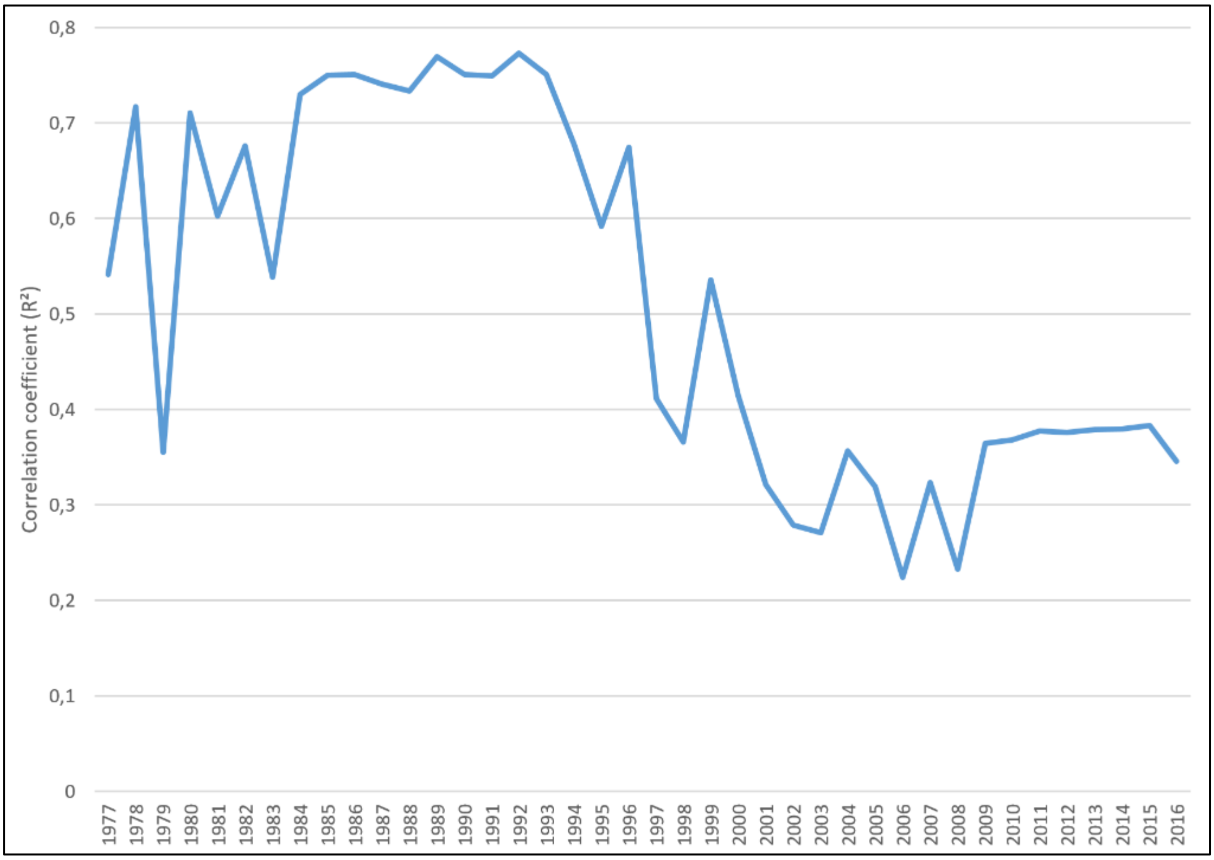

Figure 2: Correlation between actual and theoretical shipping times, 1977-2016

The year 2016 is a special case marked by shipping industry turmoil, for example, Hanjin Shipping Bankrupt in 2016 by container freight-cutting competition, a medium-term consequence of the financial losses caused by the 2008/9 crisis. Because of the alliance restructuring of container shipping companies and M&A (merger and acquisition) of them since 2014, the number of major shipping company and of alliances decrease 17 to 10, and four to three respectively. For example, three Japanese shipping companies had announced to merge their container divisions in October, 2016 (April 1st 2018 operation started). In comparison, the evolution of the average length of links[3] went through a parallel trend until the years 2006-2008, followed by rapid decline. Shorter distances in the late period suggest a growing importance of hub-feeder systems as a consequence of further shipping network rationalization and concentration.

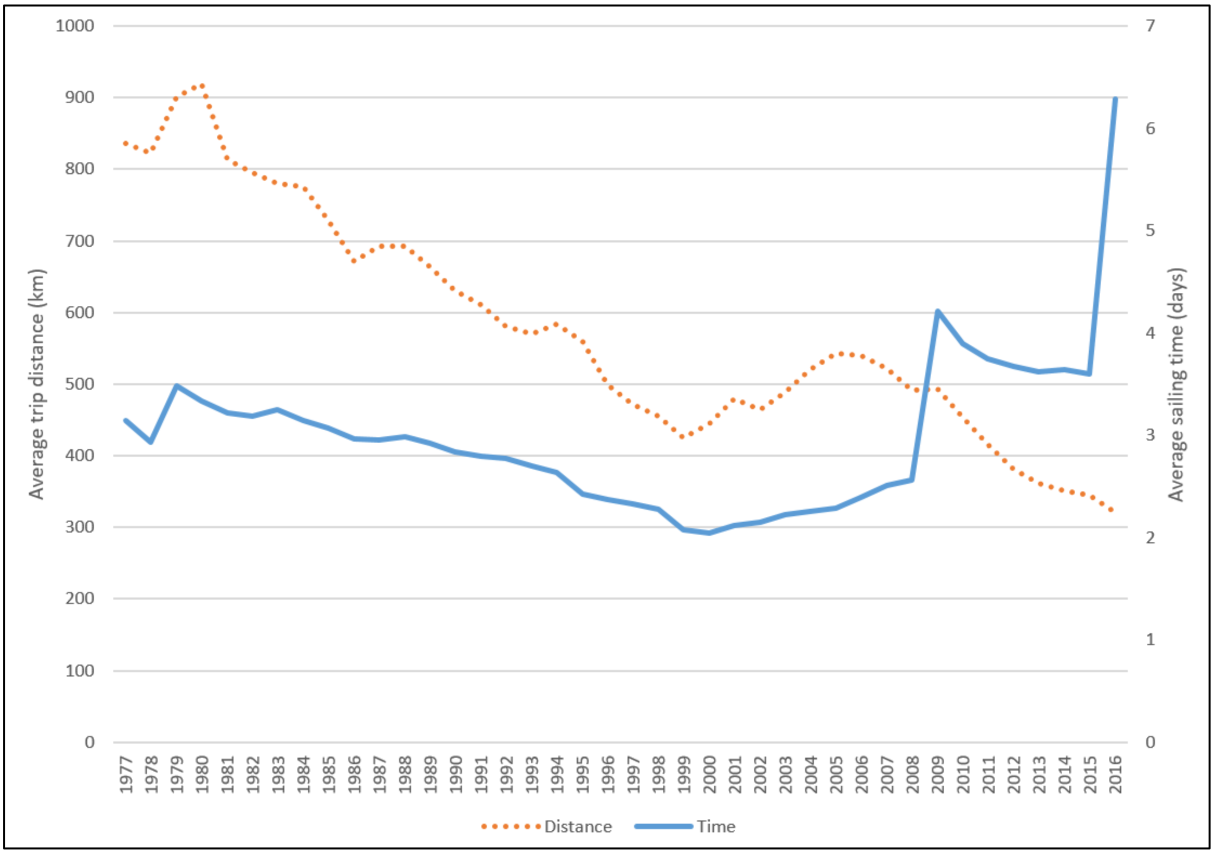

Figure 3: Average inter-port time and distance, 1977-2016

4.2 Geographic distribution of ship times

The evolution of ATT per world region (Figure 4) is a first step into the understanding of ship time distribution across the world. While all regions resemble the world trend presented in Figure 1, one can observe interesting discrepancies. All regions have had a high ATT in the early period compared with their own average, except West Asia, which improved sooner than other regions, shifting to 1.5 days in 1982 already. Another early improvement is North

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[3] The length of inter-port links is measured by the orthodromic (or “great-circle”, spherical) distance, namely the shortest distance between two connected ports at the surface of the Earth.

America, which started with relatively low ATT values in 1977. Other regions are marked by the turning point of 1992 (Africa, Europe, Latin America, and Oceania), when ATT becomes lower than the study period average. While East Asia's improvement occurred earlier, in the late 1980s already, it experienced contrasted internal dynamics between 1994 and 2002, with the Hanshin earthquake (Kobe) in 1995 and the fast rise of South Korean ports (Busan, Gwangyang). East Asia has in common with North America to have witnessed a growing ATT from the mid-1990s to the mid-2000s. This had to do with the rapid development of trans-Pacific trade whereby larger ships were deployed to cope with long-distance shipping (China effect). North America's West Coast ports were not always prepared to welcome such larger ships, especially due to the technical limitations of the Panama Canal, often causing congestion, which was accentuated by trade imbalance and issues of empty container repositioning. Last but not least, Africa stands out by its higher ATT than other regions, due to lower technological standards at port terminals (Sequeira and Djankov, 2008; Nyema, 2014). The gap between Africa and other regions even widened between 2005 and 2010, as Africa's ATT reached about 3.0 days on average.

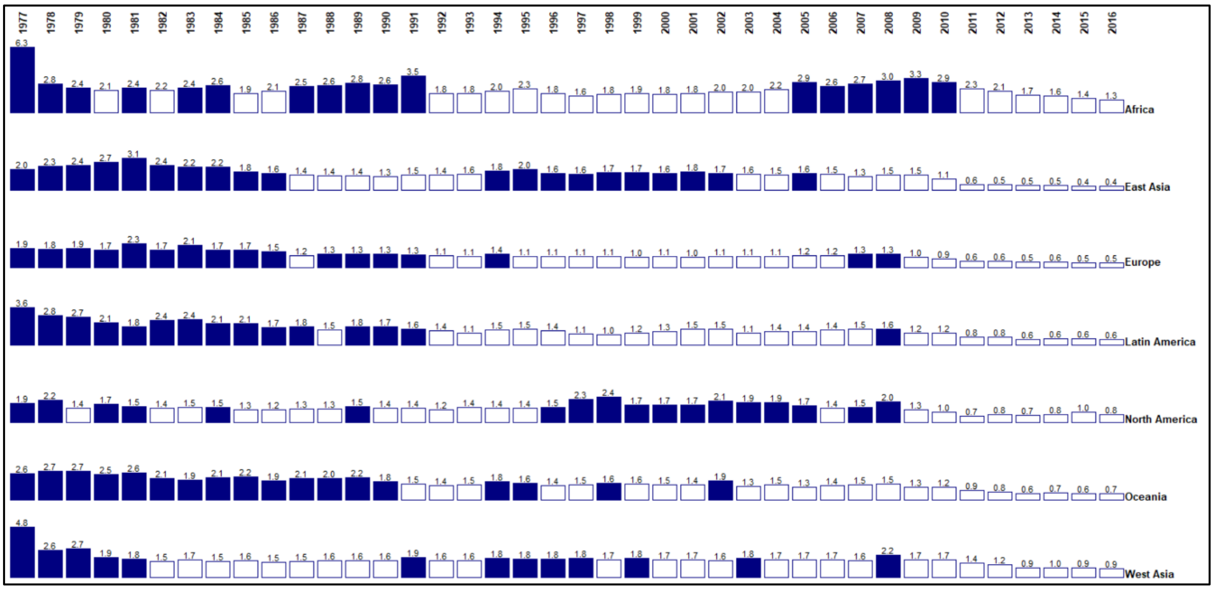


Figure 4: Average ship turnaround time by world region, 1977-2016 (unit: days)

N.B. dark bars represent values over than each region's average

The distribution of voyage delays between and within world regions also confirms the influence of geography on shipping and port operations (Figure 5). A recurrent pattern applies to the first three decades, with longer delays along routes connecting East Asia and Oceania (1977-2006). The three largest routes connecting North America are the most reliable (with Europe, East

Asia, and Latin America) in this period. In the second and third periods, the triangle linking Europe, Africa and West Asia also exhibits among the lowest delays. In terms of intraregional delays, the three dominant economic poles of the world (Europe, East Asia and North America) are also the least impacted by delays in the last two periods. This occurs despite the aggravation of intercontinental delays in the last period, mainly due to the effects of the global financial crisis.

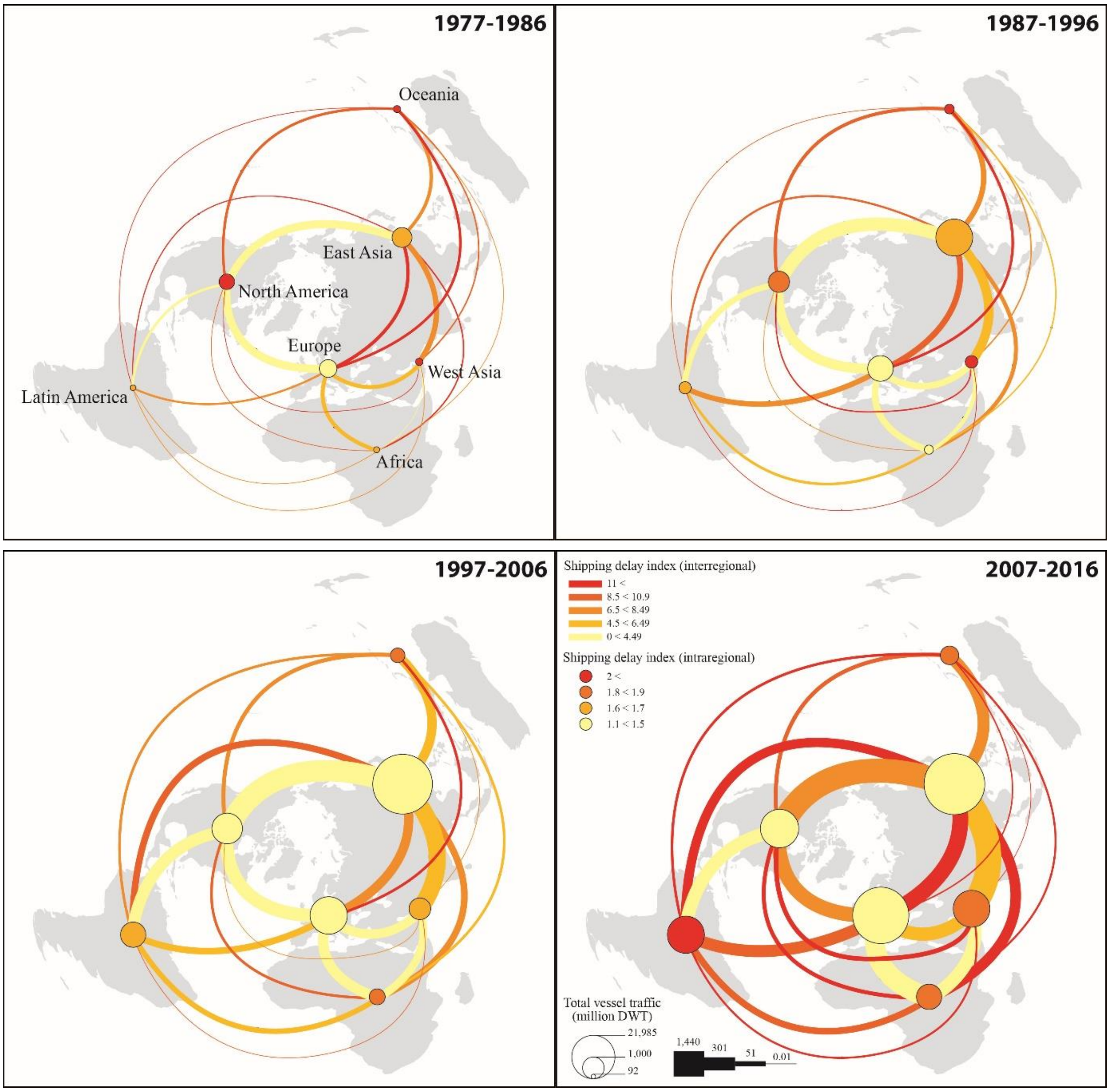


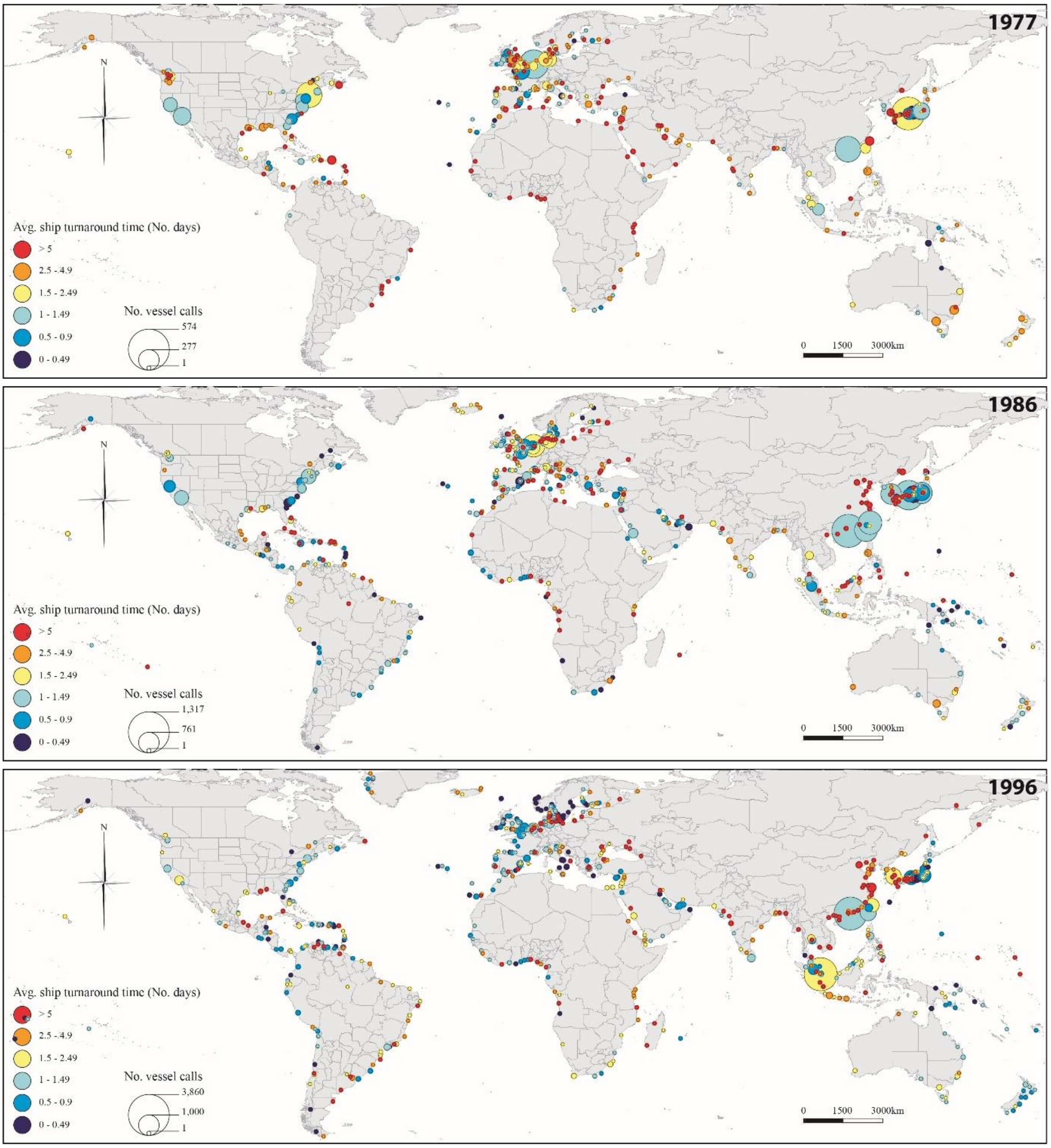
Figure 5: Shipping delays among and within world regions, 1977-2016

The analysis of ATT at port level (Figure 6) every decade allows for a more detailed discussion about its changing geography. In 1977, the largest ports (by the number of ship visits) concentrate in the northern hemisphere and exhibit lower ATT than their southern, often smaller, counterparts. There are discrepancies within the same region or country. For instance, New York, the largest US port, has a higher ATT than California ports and other East Coast ports, while Kobe, Japan's largest port, is in a similar situation compared with Osaka, Nagoya (the most efficient among large world ports), and Yokohama. Hong Kong and Singapore. Rotterdam is the world's second largest port and is more efficient than Kobe or New York. Except for Le Havre, Barcelona and Valencia handle ships within less than a single day on average. Europe's major ports fall in the class of moderately efficient ports, like Hamburg, Bremerhaven, Antwerp, London, Southampton, and Genoa.

In 1986, most of the large East Asian ports have improved their ATT, while smaller ports in western Japan and China lag far behind, in the class of very inefficient ports (i.e. ATT of more than five days on average). This is also the case of North and Latin American ports, while the Caribbean is marked by heterogeneity. In Europe, Le Havre maintained itself in the class of very efficient ports, joined by London and Antwerp, while Valencia became Europe's most efficient port among the larger ones.

The year 1996 shows for Europe a persisting divide between efficient ports in the west and inefficient ports in the east (mainly Baltic sea, including Russia), revelatory of political differences and their impact on the conduct of trade and shipping operations (Ledger and Roe 1996). Such differences are also apparent in East Asia, where Chinese ports continue to be the least efficient ones compared with the Asian Tigers and Japan. Busan, Keelung, and Singapore have seen their ATT slightly rising compared with 1986. The aforementioned gap between US west and east coasts becomes well apparent, as west coast ports saw their ATT rising, notably due to growing trans-Pacific trade and Panama Canal limitations.

In 2006, the global pattern resembles the one of 1996, except for the European division which had become blurred with the ongoing EU integration, following the collapse of the USSR and the socialist block. All major East Asian ports keep improving their ATT, the Japanese ones being the most efficient, while Chinese ports, despite their huge traffic growth since 1996, all remain in the classes of least efficient and inefficient (more than 2.5 days of ATT on average) except Hong Kong (0.5-0.9 days). It is only in 2016, at a time when global ATT becomes the lowest in all world regions, that Chinese ports as well reach similar ATT levels than their regional counterparts. Elsewhere, the map confirms the inefficiency of most African ports, despite many exceptions over the west coast, and of special cases such as Cuba and northern Russia. This analysis underlines the varying importance of the national context in port operations, as the same country is marked by more or less ATT similarity among its ports. The macro-regional level is also important, as seen with Africa, but much less in the case of East Asia, with reference to the contrast between Chinese ports and surrounding hubs.



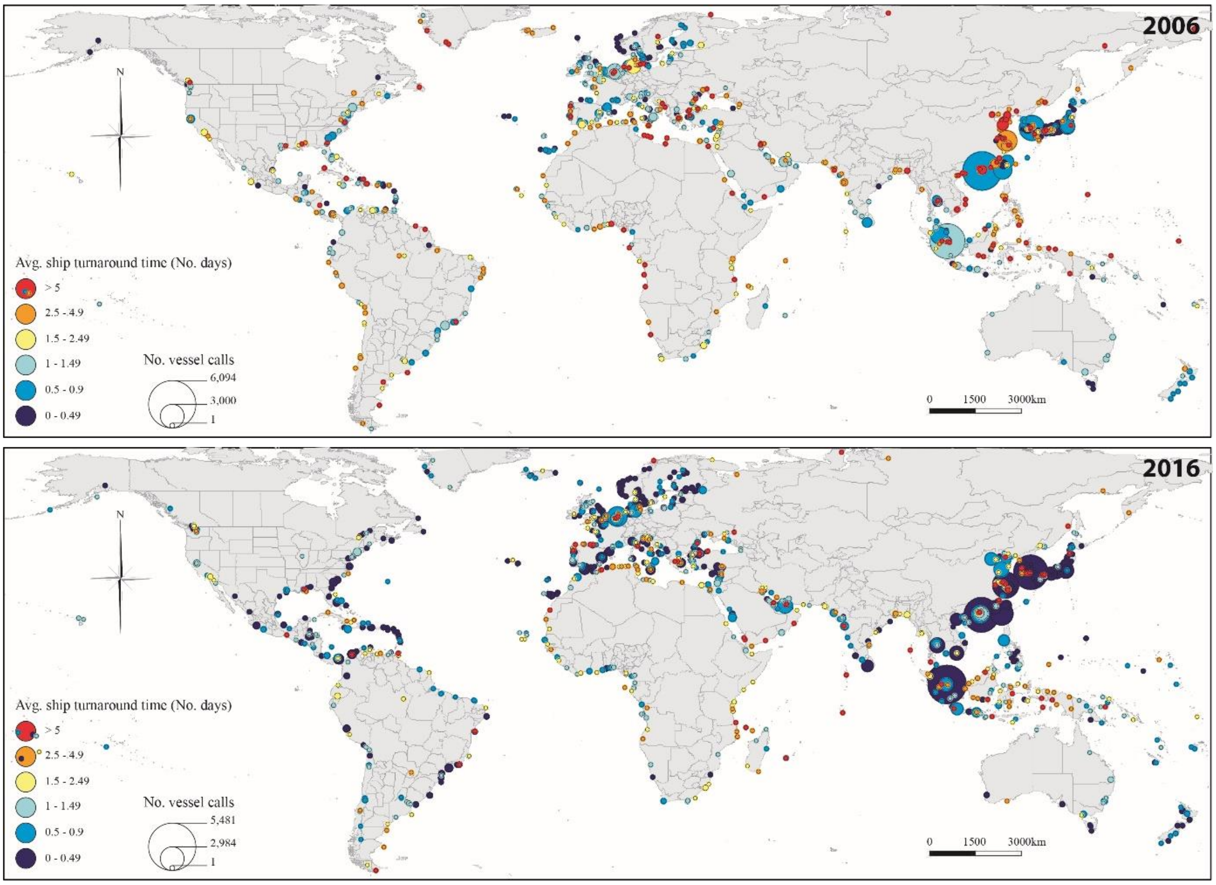


Figure 6: Average ship turnaround time at world ports, 1977-2016

5. The determinants of ship times in ports

To investigate the factors influencing ship turnaround time at ports, we run a regression analysis with indexes (Table 1) for three dependent variables; a) average values of ship turnaround time at port (ATT), b) the ratio of ATT at ports for yearly global ATTs' average, and c) standardized dispersion of ship turnaround time at ports (CVTT), i.e., standard deviation of turnaround time at port (SDTT) divided by their ATT, or coefficient of variance (CV) of their ship turnaround time. Several reasons motivate such an approach. First, the size of the unit of analysis is quite diverse because of city and region (size effect), and the ATTs had been decreasing (cf. Figure 1). However, the parameter of year dummy was negative, but statistically insignificant on preliminary testing. Therefore, we run a regression not only on actual ATTs but also on the ratio of ATT, to get rid of yearly changes of ATT (temporary effect) and check for stable effects. Second, although ATT shows the standardized (leveling) anchoring time at ports, ATTs do not consider the dispersion (fluctuation) of their duration times at ports. For example, because major hub ports handle not only big container ships on trunk lines but also smaller ships for feeder services, the ATTs will be lower (law of large numbers), but SDTT (or CVTT) will be relatively bigger (the correlation between ATT and CVTT is statistically significant and slightly negative (-0.086)). Third, because container shipping services are scheduled, contrary to general cargo, inducing the shift from labor-intensive to capital-intensive industry at ports, the dispersion of ship turnaround time is also an important index for discussing the fluctuation or uncertainty of ship movements.

Based on the results (Table 1), the model fitness for c) CVTT is highly better than a) ATT and b) ATT ratio because ATT is relatively fragile, as some ports have only one or two vessel calls a year. On the other hand, CVTT is a dimensionless index. The signs and values of parameters on a) ATT and b) ATT ratio are almost the same, so that temporal changes of ATTs (Figure 1) would be mostly explained by continental characteristics (Figure 4). Despite geographic inequalities (continental dummy) showed previously, and as suggested by Figure 5 (world distribution of ATT by port), the container technology had spread, until recently, more and more evenly in terms of global technical standards. East Asian ports show more inefficiency than others, but European ports (baseline) are the most efficient. In addition, ports in Oceania and West Asia show less operational uncertainty.

Another interesting aspect is the port hierarchy. The number of ship calls (vessel traffic) has a negative influence on ATT. This means that busier ports, on average, manage to overcome congestion by efficient (faster) port operations. In contrast with ATT, vessel traffic has a positive influence of CVTT for different handling duration times at ports with various ship sizes. On the other hand, although maximum vessel capacity increases ATT, it does not affect (or insignificantly) the handling fluctuation of port operations. Welcoming larger vessels allows creating economies of scale, as larger vessels often mean larger terminals and more modern port facilities. This stands in contrast with the early work of Heaver and Struder (1972), in which "*regressions certainly support the general hypothesis that ship loading time increases with the size of the vessel*" (p. 41). Our results are in accordance with the fact that "*bigger ships need to select highly productive calling ports that provide less time in port*" (Moon and Woo, 2014). The negative influence of the number of calls and of the maximum vessel size is also a possible exemplification of the hub function of ports. Transshipment ports typically welcome the largest vessels along the main trunk lines (mother vessels) while they also act as redistribution platforms through high-frequency calls with smaller vessels (feeder vessels).

The role of hub functions is well confirmed by two of the three centrality indicators, namely degree centrality (K) and inverse clustering coefficient (invCC), which have a negative and a positive influence on ATT respectively, and therefore go along with faster port operations. The most significant effect is observed with degree centrality, with a negative effect on ATT. On the other hand, degree centrality has a positive influence on CVTT because of various connections with adjacent, diverse ports. In addition, the positive influence of the inverse clustering coefficient on ATT means that hub functions lower ship times.

Variables		**a) ATT**		**b) ATT ratio**		**c) CVTT**	
pop ratio for yearly global average		0.024	***	0.023	***	-0.024	***
GDP per capita		-0.013				0.160	***
The share of trade value for GDP		0.106	***	0.126	***	0.021	***
Continental dummies	Africa	0.063	***	0.079	***	-0.020	***
	East Asia	0.201	***	0.209	***	0.043	***
	Latin America	0.039	***	0.044	***	0.008	
	North America	0.027	***	0.021	***	-0.009	*
	Oceania	0.027	***	0.025	***	-0.040	***
	West Asia	0.037	***	0.041	***	-0.033	***
Location dummies	island	-0.036	***	-0.038	***	0.056	***
	upstream	0.064	***	0.073	***	-0.008	*
	downstream	0.058	***	0.058	***	0.007	
Total traffic (calls)		-0.086	***	-0.090	***	0.098	***
Vessel capacity (MAXDWT)		0.107	***	0.144	***		
Degree centrality (K)		-0.209	***	-0.256	***	0.203	***
Betweenness centrality (BC)		0.084	***	0.101	***	-0.118	***
Inverse Clustering coefficient (invCC)		0.093	***	0.080	***		
Link clustering coefficient (linkCC)						0.283	***
Average of shipping delay time		0.056	***	0.085	***	-0.014	***
Dispersion of shipping delay time		-0.077	***	-0.067	***	0.262	***
Adj. R2		0.105		0.140		0.678	

Table 1: Influencing factors to ship turnaround time

*Note) parameters are standardized. "Europe" is baseline for continental dummy. "Coastal" is baseline for location dummy. * 10% significant, ** 5% significant, *** 1% significant.*

Conversely, ports with high betweenness centrality (BC) tend to have higher ATT. As a matter of fact, betweenness centrality is calculated in a totally different manner than degree and (inverse) clustering coefficient, namely at the level of the entire network rather than at the local (adjacent nodes) level. Ports with high betweenness centrality are those with a strong accessibility on all possible shortest paths in the network. Although this property should apply to transshipment hubs, which act as both interregional and intraregional redistribution platforms, in our results the global accessibility does not reduce turnaround time. Local transshipment is more crucial to turnaround time. Certain global ports may be well positioned along trunk lines, but do not act as transshipment hubs locally. This would imply that gateway ports are less time-efficient than hub ports. On the other hand, the accessibility highly reduces the fluctuation of turnaround time at ports (CVTT) because of more balanced operation and efficient network position between interregional and intraregional ship movements. In addition, link clustering coefficient (linkCC) has a positive influence on CVTT, as an effect of dense short sea-shipping connections with neighbors augmenting ship movement fluctuations.

Longer voyage delays tend to increase ATTs, but very slightly decrease CVTTs. The more the actual voyage deviates from the theoretical voyage, the slower is the terminal operation. This result is in accordance with our hypothesis on cascading effects, and confirms previous literature on schedule reliability and its close relationship with port congestion effects (Notteboom, 2006; Vernimmen et al., 2007; Wang and Meng, 2012; Hasheminia and Jiang, 2017). In addition, the dispersion of voyage delay time does not only affect ATTs but also CVTTs, and it is the biggest factor responsible for fluctuations at ports following the link clustering coefficient (linkCC). This result is in line with our expectations, since container shipping is organized as a chain operation between ports connected via maritime networks. The operation delay at previous port for schedule causes uncertainty of sea shipping towards next port, forcing the terminal operator to change its operation schedule.

In terms of territorial factors, the island location (location dummy) fosters faster port operations on average as hypothesized earlier. Numerous hub ports locate on islands, which are less hinterland-driven in terms of cargo throughput. Upstream ports tend to have slower operations. Such locations are more constrained than coastal ports (or island ports), especially in terms of vessel queuing and channel access issues, although special cases do exist like Antwerp and Hamburg (Notteboom, 2016), notwithstanding massive investment in dredging operations. Yet, upstream ports have slightly less fluctuations because of the limitation of ship size (homogenous fleet). When it comes to cities, our results confirm the assumption that ports situated in larger urban areas have slower terminal operations (higher ATTs). Large port cities have a higher probability for congestion effects as they constitute the immediate hinterland of the port, with limited options other than trucking to connect port and city. Such aspects constituted the core idea of port-city separation models (Bird, 1963; Hoyle, 1989) and of the challenge of the periphery (Hayuth, 1981). Congestion effects as well as lack of space for efficient port operations and further port expansion in the urban core forced the shift of modern port terminals away from large (of which upstream) cities.

Other territorial factors are also important for explaining ATT and CVTT levels and their evolution. Richer countries (GDP per capita, country level) support slightly faster operations at ports on average, but the dispersion of terminal operation at advanced regions is higher. However, trade specialization (the share of trade value for GDP, country level) has a positive influence on ATT and CVTT, i.e. increased inefficiency and fluctuation in port operations for various trade partners with different shipping routes and connections.

4. Conclusion

This research investigated the determinants of time efficiency among world container ports based on untapped vessel movement data over the period 1977-2016. It adopted a spatial network perspective where links and nodes are characterized by various attributes, from urban population to port connectivity and voyage delays. Another innovation of our research is its multi-level approach, as ports are envisaged at the city, country, and world levels. Our results are in line with the existing literature in a sense that cities, upstream location, and shipping delays constrain port operations. They also shed new light on turnaround time by showing that hub functions, economic wealth, traffic size (calls), and island location foster efficient operations. Although average turnaround time has improved globally, regions and ports of the world remain highly differentiated.

Further research may try to include more variables, such as actual port throughput, transshipment share, port and logistics infrastructures, intermodal connections, water depth, and deviation distance from main trunk lines. The consideration of port governance would also be possible, using dummies for private, public, etc. One crucial indicator to add would be the level of urban traffic congestion (excessive driving time), available for certain (port) cities of the world[4]. Shipping flows may be categorized amongst mother vessel traffic and feeder vessel traffic. Based on fewer years of reference, the multi-level analysis would be enriched by the inclusion of several other country-level indicators such as the liner shipping connectivity index (LSCI), the port infrastructure quality index (WEF), and the logistics performance index (LPI) provided by international organizations. Updating the dataset would prove useful to verify whether the observed regularities have persisted up to the COVID-19 crisis that still lingers on.

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Level/Classification		**Variable**	**Definition**	**Expected effect**
City		Urban population	No. inhabitants of the morphological area	(+) or (-)
Country	Economic size	GDP	Gross Domestic Product per capita (in current dollars)	(+) or (-)
	Trade	Export	Export volumes and values at country	(-)
		Import	Import volumes and values at country	(+)
		Trade value	Amount of trade at country	(+) or (-)
Continent		Continent dummy	7 continents	(+) or (-)
Time		Year dummy	1977-2016	(-)
Land	Geography	Location dummies	Upstream	(+)
			Downstream	(-)
			Coastal	(-)
			Island	(-)
	Ship time	Average of ship turnaround time (ATT)	Average difference between arrival date and departure date	
		Standardized Dispersion of ship turnaround time (CVTT)	Standardized Dispersion of ship turnaround time (Coefficient of variation (CV) for standard deviations (SD) of ship turnaround time)	
	Port profile	Total traffic	No. of vessel calls	(+) or (-)
		Vessel capacity	Maximum vessel capacity (DWT)	(+) or (-)
Sea	Network	Degree centrality	No. of adjacently connected neighbors	(-)
		Betweenness centrality	No. of occurrences on all shortest paths in the graph	(-)
		Clustering coefficient	Proportion of connected neighbors	(-)
		Link clustering coefficient	Average proportion of connected neighbors at links	(-)
	Shipping	Shipping delay index	Average difference between actual sailing time and theoretical sailing time on links	(+)
		Shipping speed variation	Average standard deviation (SD) of days/km on links	(+)

Appendix 1: Selected indicators and their expected effect on ship turnaround time