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► **To cite this version:**

César Ducruet. Maritime flows and networks in a multidisciplinary perspective. César Ducruet. Maritime Networks. Spatial Structures and Time Dynamics, Routledge Studies in Transport Analysis, pp.3-26, 2015, 9781138911253. halshs-01374937

HAL Id: halshs-01374937

<https://shs.hal.science/halshs-01374937>

Submitted on 11 Nov 2021

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Maritime flows and networks in a multidisciplinary perspective

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Pre-final version of the chapter published in Ducruet C. (Ed.) (2015) *Maritime Networks. Spatial Structures and Time Dynamics*. Routledge Studies in Transport Analysis, pp. 3-26.

It is almost inevitable when introducing a book about maritime networks to recall that more than 90 percent of world trade volumes are still supported by maritime transport. Seas and oceans occupy about 70 percent of the Earth's surface and coastal areas concentrated 16 and 39 percent of the world's total and urban populations respectively in the 1990s (Noin, 1999). This overwhelming importance is reflected by the great quantity of cultural, social, political, and scientific research about the sea in all its aspects. Dedicated sub-disciplines such as maritime history, geography, engineering, biology, and economics as well as institutions organise large-scale meetings to discuss the organisation and evolution of the sea as an ecosystem, a natural resource, and a vector of exchanges.

But what remains striking is that maritime transport has been much less studied than any other transport mode, especially from a network perspective. Existing research remains rather fragmented and scattered across the academic spectrum, which makes it difficult to review it exhaustively and to define any possible common framework. Five main reasons contribute to explaining such a fact: the dominance of a continental culture favouring studies of populated rather than “empty” spaces (Steinberg, 1999; Lewis and Wigen, 1999); the vague geographic distribution and morphology of maritime flows due to the absence of a track infrastructure (White and Senior, 1983; Rodrigue et al., 2013); the capture of most passenger and information flows by air transport and telecommunications since the second half of the 20th century; the continuous decline of maritime transport costs compared with other logistics costs; and the reluctance of scholars and experts to access and compile costly and hard to obtain maritime traffic statistics.

The World Seastems project No. 313847, funded by the European Research Council (ERC) over the period 2013-2018, is aimed primarily at compiling and analysing untapped historical records of global vessel movements over the contemporary period. Its international workshop held in June 2014 at the Paris Institute for Complex Systems (ISC-PIF), gathered many researchers with a similar focus, namely to provide a quantitative analysis of maritime networks in space and time. In so doing, the 20 chapters of the present book, written by 40 scholars from 12 countries and 10 academic backgrounds, offer a multidisciplinary perspective about one of the most vital pillars of world society.

The maritime network: late emergence of a multifaceted concept

A simple online search via *Science Direct* provided about 100 results for “maritime network” (as of 16 September 2014) compared with more than 10,000 results for road, global, or transport network, taking into account all scientific disciplines. Airline network scored 261, while trade, logistics, street, river, and railway ranged between 1,000 and 4,000 results each. Among maritime-related terms, “maritime network” scored less than maritime transport, trade, and traffic, shipping, port, or route, whereas “maritime transport” scored far below “road network”, thereby illustrating the paramount importance of roads for daily commuting and trucking. Such a situation echoes the work of Danisch et al. (2014) who in their analysis of word co-occurrences found that “global shipping network” occupied a peculiar, peripheral situation with regard to the graph theory community. As a matter of fact, many scholarly works using the term maritime (or shipping) network make no

reference to graph theory per se, in contrast to road, railway, air, and even river transport where network analysis had become a very common approach since the 1960s in the social sciences (Ducruet and Lugo, 2013).

As pointed out by Lemarchand (2000, pp. 1-2), “the literature on networks ignores maritime places [while] port and maritime actors do not refer much to the concept of network”. If the network traditionally describes technical systems made of material infrastructure, maritime routes exist on the map only so that the maritime network remains rather abstract, invisible, and decentralised, especially at the national scale where only a fragment of the network is perceived. The maritime network may refer to various realities according to different disciplines, such as trading linkages by sea organised by merchants in maritime history (Gipouloux, 2011; Tartaron, 2013), tactical or wireless communication networks between vessels in engineering, inter-firm alliances in maritime economics (Caschili et al., 2014), distribution of ocean carriers’ schedules, and physical flows of vessels between ports. With reference to the European *Motorways of the Sea* initiative, Baird (2010) even proposed to treat the floating deck of vessels just like road and rail infrastructure to favour integrated policies. In geography for instance, the maritime network had long been termed «system» (Bird, 1984, p. 26): “the ultimate system of maritime transportation is a true freedom of the seas whereby every port node can theoretically be linked to every other port node” (see also Slack, 1993).

The concept of “port system”, suggesting linkages between ports was found in many works, but “in their preoccupation with the development of land communications (...) the authors neglected the development of maritime space” (Rimmer, 2007, p. 76). In addition, the port system concept was used interchangeably to describe multiple realities such as port (or maritime) range, region, façade, or seaboard, and mostly at the national scale, leading to confusion. The phased model of port system evolution proposed by Rimmer (1967) initially incorporated maritime linkages contrary to earlier models (Figure 1.1), but without concrete empirical validation as subsequent works continued focusing on individual port traffics and port hinterlands. The classic distinction between a French school focusing on forelands and a Dutch school more interested in hinterlands (Weigend, 1956) led to distinct research pathways. For instance, the “port network” concept was proposed by Van Klink (1998) to describe the inland shift of port activities (Van Klink, 1998), but the same concept used in another context could also refer to a set of ports belonging to the portfolio of a given ocean carrier or terminal operator. When it comes to forelands, the French geographer André Vigarié (1979) proposed the concept of “port triptych” to think simultaneously the port itself, the hinterland (inland market area), and the foreland (overseas markets). Yet, out of 399 scientific articles published in major geography journals between 1950 and 2012, only seven mentioned foreland in their title, against 29 for hinterland; 12 mentioned “network” of which only five for maritime networks and seven for barge, hinterland, and other networks (Ng and Ducruet, 2014). Other concepts such as transport chain, logistics chain, commodity chain, and value chain became frequent to describe ports’ place in networks with a qualitative approach (see Robinson, 2002).

[Figure 1.1 here]

The emergence of a dedicated network vocabulary for describing maritime patterns and traffic came long after using more imaginary semantics. The French geographers René Perpillou (1959) and André Vigarié (1968), for instance, mentioned the constellation of ports and compared sea lanes to urban streets delivering flows of life in a city like arteries in a biological organism, respectively. Other concepts taken from other fields were gradually applied to maritime transport, such as corridor, loop, cycle, and hub. Graph-related concepts such as centrality and intermediacy were used about ports (Fleming and Hayuth, 1994) alongside studies of site and situation, carrier choice and selection factors, and port competition to explain the emergence of hubs at certain locations, but without yet applying network analysis to maritime flows, so that “a connectivity index is used for

airports (...) but does not exist for seaports” (de Langen et al., 2007, p. 31). This deficit became a growing issue, especially given that “the structure of [maritime] networks evolves over time [and therefore] the position of ports as nodes in the network also changes over time (...) understanding these changes is crucial for analysing the competitive position and growth prospects of (...) ports” (de Langen et al., 2002, p. 1). The conceptualisation of maritime transport as a network gave birth to many discussions that did not necessarily lead to empirical analyses of actual maritime flows, such as about security issues (Kristiansen, 2004; Angeloudis et al., 2007) or operations research on navigation safety, ship routing and scheduling, and optimisation (Christiansen et al., 2013; Windeck, 2013). Maritime economics barely refers to either graphs or networks in its central focus on management, pricing, markets, and finance, which is also true of wider transport economics (Zwier et al., 1994; Brooks et al., 2002; Leggate et al., 2004; Stopford, 2008).

The diversity of maritime data analyses

Before analysing maritime transport as a network, graphical representations of maritime flows long remained broad estimates of amount and geographic distribution (Scarborough, 1908; Siegfried, 1943; Alexandersson and Norström, 1963; Central Intelligence Agency, 1973). Still in 2014, a geophysics paper reported “a lack of knowledge in the actual global distribution of the ships, i.e. vessel density, and its evolution over time due to economics or other causes” (Tournadre, 2014). This situation was already deplored in the 1940s when early economic geographers such as Ullmann (1949) provided an innovative cartography of maritime routes connecting the United States, claiming that maritime flows were useful to “take the pulse of world trade and movement” (see also Figure 1.2). Such a call did not, however, have many followers. Foreign trade statistics served to analyse overseas connections or maritime forelands of single ports such as Toronto (Kerr and Spelt, 1956), Genoa (Rodgers, 1958), Victoria (Britton, 1965), Clyde (Desbarats, 1971), Halifax and Saint John (Patton, 1961), Irish Sea ports (Andrews, 1955), and ports in the countries of Norway (Sommers, 1960), England (Bird, 1969; Von Schirach-Szmigiel, 1973), and Sweden (Von Schirach-Szmigiel, 1978). Such studies grew scarce until a recent revival based on the Chinese case (Wand and Ng, 2011). Accurately calculating and representing ship traffic densities on a larger scale demanded enormous data collection and extraction from printed reports on vessel movements such as on a world square grid (McKenzie, 1975). Until the 2000s, analyses of global maritime flows were bound to diagrams and simplified maps using United Nations (van den Bremen and de Jong, 1986) or other data (Fossey and Pearson, 1983; Rodrigue, 2004). Nevertheless in the 1980s, a few works mapped the nodal hierarchy of ports based on small data samples (Marti, 1981; Marti and Krausse, 1983) using trade data to/from United States ports (Figure 1.3).

[Figure 1.2 here]

[Figure 1.3 here]

It is only recently that scholars from various backgrounds, through interdisciplinary collaboration, have produced more elaborate representations of maritime flows on a larger scale, often from unexpected research domains. One of them is climatology, which made particular use of *log books* that reported weather conditions during ship voyages, as in the *Climatological Database for the World's Oceans (CLIWOC)* project for the period 1750-1850 (Herrera et al., 2003), affiliated with similar projects such as ICOADS, RECLAIM, and *Old Weather* (see Figure 1.4). The same data also was used by historians to analyse technological progress in terms of sailing speed (Ronnback, 2012). The extraction of archival records provided unprecedented knowledge of transatlantic slave voyages over the period 1500-1900 (*Transatlantic Slave Voyages* project), and trade flows across the Oresund Strait for the period 1634-1857 (*Sound Toll* project)¹. In other fields such as

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Other sources are worth mentioning although they have not yet been studied, such as the archives of the Suez Canal Authority, where every ship reported the precise content and value of its cargoes as well as the origin and

anthropology and archaeology, the lack of knowledge on precise maritime circulations could be overcome by looking at sailing distances to explain the spread of languages in Australasia (Coupé and Hombert, 2005), demographic migrations in the Caribbean (Friedman et al., 2009), the diffusion of techniques (Leidwanger, 2013), and sea-land accessibility in the Roman Mediterranean (Scheidel, 2013).

[Figure 1.4 here]

Other themes and issues included the effects of network centrality on maritime warfare based on the queuing theory (Fewell, 2003), geospatial analysis of maritime piracy (Leymarie et al., 2014), modelling of optimal shipping routes to prevent collisions and oil spills (Höglund and Meier, 2012), simulation of attacks on the intermodal shipping network (Earnest et al., 2012), calculation of a composite index of global urban accessibility based on raster data including maritime flows (Nelson, 2008) (see Figure 1.5), and the mapping of traffic densities based on ship detection (Tournadre, 2014), voluntary observing ships (Vettor and Guedes Soares, 2014), and Automated Identification Systems (AIS) (Le Guyader et al., 2011). Measuring the environmental impacts of shipping also provided among the most detailed and aesthetically advanced maps of global maritime flows, focusing on ship emissions (Corbett and Winebrake, 2008; Halpern et al., 2008; Leonardi and Browne, 2010). Specific commodity flows in relation to United States ports using MARAD data were mapped also using Geographical Information Systems (GIS) methods combined with Google Earth 3D visualisations (Shen et al., 2013) (see Figure 1.6). In maritime geography, scholars proposed mapping the service networks of ocean carriers based on schedule data (Robinson, 1998; Comtois and Wang, 2003; Frémont and Soppé, 2004; Rimmer and Comtois, 2005; Frémont, 2007, 2010) but still without direct engagement in network science, although some visualisations already underlined the centralisation of links around certain hubs (Figure 1.7). Another example is in maritime economics where disaggregated data of shipments served to measure the effect of maritime networks, services structure, and port infrastructure variables on maritime transport costs (Martinez-Zarzoso et al., 2011).

[Figure 1.5 here]

[Figure 1.6 here]

[Figure 1.7 here]

A recent surge in maritime network analysis: towards a convergence?

Maritime networks for many years did not fit well into the traditionally “planar culture” of graph theoretical approaches of the academic literature (Ducruet and Beauguitte, 2014). In the 1960s, the vast majority of network analyses focused on planar graphs (no crossing between links, or edges, without creating a node, or vertex) such as power grids, road networks, etc. The only exception was the PhD dissertation of Ross Robinson (1968), deeply rooted in graph theory, geography and regional science, for its application to the analysis of the maritime network within Vancouver port and with other British Columbia ports (see Figure 1.8): “it is possible to define the spatial patterns of functional relationships between ports by examining the linkages which are sustained by the inter-port shipping movements of foreign trade vessels. Such an analysis provides not only an accurate measure of the linkages themselves but also clarifies the relationships between ports, the spatial organisation of port functions and the functional status of individual ports within the total group (...) The system of ports operating interdependently may now be regarded in abstract form as a set of points or nodes in a network, a transportation network in which the lines or links in the network are in fact ‘imaginary routes’” (Robinson, 1968, pp. 95-97). A port network development model was also proposed to depict four phases that may apply to other regions of the world (Figure

1.8). Strangely enough, and even after its partial publication in a renowned journal a few years later (Robinson, 1976), that pioneering work found no followers until the 1990s, mainly due to the wider shift from quantitative to behavioural approaches in the social sciences (Ducruet and Beauguitte, 2014; Ng and Ducruet, 2014). It was only in the 1990s that scholars began to analyse maritime flows using a dedicated network methodology, just like airline or multinational firms networks; there was another unpublished PhD dissertation, this time on the North Atlantic region based on carrier schedule data (Helmick, 1994), but with no reference to Robinson's initial breakthrough.

[Figure 1.8 here]

Starting with a simple count of vessel calls at world ports (Brocard et al., 1995), and a preliminary paper on the matter (Joly, 1995), another pioneering work was the PhD dissertation of Olivier Joly (1999) who provided the first-ever network analysis of maritime container flows at the global scale, revealing the bipolar structure of the global maritime network centred upon Europe and Asia (Figure 1.9). The fast-growing field of complex networks recorded its first paper about maritime networks in 2007, which described the topological structure of container shipping networks in China (Xu et al., 2007) and later on, the world (Deng et al., 2009; Hu and Zhu, 2009; Doshi et al., 2012); these works were based on carriers' schedules and collaborations with physicists. Most of the time such works looked at the small-world and/or scale-free network structure of container flows (see also Hu and Zong, 2013), with reference to drastically different concepts and literatures than those of scholars interested in operations research and optimisation. The latter school recently provided many applications of the hub allocation model to container flows among Asian ports (Low and Tang, 2012; Asgari et al., 2013; Jiang et al., 2015). Research on marine bioinvasions benefitted from globally available AIS data tracking the real-time position of vessels through growing collaboration between biology and physics (Kaluza et al., 2010; Concepcion et al., 2010; Keller et al., 2011; Seebens et al., 2013) (see Figure 1.10).

[Figure 1.9 here]

[Figure 1.10 here]

Geographers also provided various studies of hub-and-spokes systems in liner shipping networks at the regional level using elements of graph theory and spatial analysis, such as for the Caribbean basin (Veenstra et al., 2005; McCalla, 2004), Canary Islands (Tovar et al., 2015), Mediterranean basin (Cisic et al., 2007), northeast Asia (Ducruet et al., 2010a), and southern Africa (Fraser et al., 2014). Global-level analyses also gradually became prominent about the container business to map nodal regions (Wang and Wang, 2011; Ducruet and Notteboom, 2012) and evaluate network vulnerability with reference to interoceanic canals (Ducruet, 2015), also based on multiple fleet types and the concept of multigraph or multiplex graph (Ducruet, 2013). Economists as well recently started to investigate the correlation between centrality and accessibility measures of port nodes and their broader traffic attributes (Wang and Cullinane, 2008; Lam and Yap, 2011; Li et al., 2015; Xu et al., 2015), such as macro-scale analyses of country pairs based on their maritime connectivity (Fugazza et al., 2013). In the same vein, Ducruet et al. (2014a) used a multilevel analysis to show the influence of port centrality on average ship turnaround times globally. In particular, degree centrality and hub position of ports (as measured by the clustering coefficient) speed up their cargo handling operations while the volume of container throughput has the opposite effect, but this is even truer in richer countries.

Another avenue of research has been to unravel the regionalism of maritime flows. A wide variety of network clustering methods has been used in various contexts, such as the Atlantic (Ducruet et al., 2010b) and the world (Ducruet and Zaidi, 2012; Ducruet et al., 2014b) to detect the influence of geographic proximity on the distribution of flows or the emergence of a cohesive region such as Europe. Complementary views were offered by the study of particular regions such as the Korean

Peninsula (Ducruet et al., 2009), the East Asian maritime corridor (Ducruet et al., 2011a), the Le Havre-Hamburg range (Plasschaert et al., 2011), the East-West maritime corridor (Tran and Haasis, 2014), Greece (Tsiotas and Polyzos, 2014), and North Africa (Mohamed-Chérif and Ducruet, 2015). Graph theoretical methods as well as social network analysis (SNA) revealed the backbone of maritime flows and emergent hub ports (Cullinane and Wang, 2012; Montes et al., 2012; Gonzalez-Laxe et al., 2012; Freire Seoane et al., 2013; Wang and Cullinane, 2014). The global maritime network was also analysed through its complementarity with the global airline network regarding their respective and mutual connectivities (Parshani et al., 2010; Ducruet et al., 2011b; Woolley-Meza et al., 2011) and the spread of infectious diseases (Tatem et al., 2006), and with the global road network to estimate cost effects on port and route performance (Tavasszy et al., 2011; Wang et al., 2012).

Perspectives and structure of the book

Although the late application of network analytical methods to maritime transport flows has been somewhat counterbalanced by a growing number of empirical studies, this book addresses several unresolved issues. First, most studies remain static, so that the dynamic properties of change in maritime network organisation and spatial distribution remain unclear. Second, the majority of recent works have focused on flow patterns but without explicit reference to any theoretical model, be it spatial or statistical. Third, the maritime network is not an isolated entity floating in an abstract space or defined only by its costs or benefits. It is a component of the society we live in, and as such its analysis should consider its local and regional embedding.

This first part of the book, *Introduction to Maritime Network Analysis*, addresses the aforementioned issues in both theoretical and practical ways. Chapter 2, by Anne Bretagnolle, particularly stresses the emergence of city-systems throughout history, defined as networks of cities linked by certain transport modes, including maritime transport, although it lost its ability to move information and people in the second half of the 20th century. Chapter 3, by Antoine Frémont, complements the previous chapter in that it concerns maritime transport actors (shipping lines) and how the CMA-CGM has evolved alongside technological and managerial transformations in the container business. Chapter 4, by Marc Barthelemy, focuses on the concept of spatial network and how it is analysed in the current transdisciplinary literature. It implicitly raises a crucial question: how can maritime networks contribute to such a fast-growing, mainstream research arena?

The second part of the book, *Modelling Past Maritime Networks*, comprises five chapters all concerned with the specific difficulties of using old data sources to map and analyse maritime networks. The lack of knowledge on actual Bronze Age maritime routes created the opportunity for Ray Rivers, Carl Knappett, and Tim Evans to simulate the distribution of inter-island maritime links in the Aegean Sea based on archaeological records and spatial models (Chapter 5). When route data does exist, problems are all but eliminated as new ones emerge, as seen in the other contributions. This was particularly well discussed and overcome by Mélanie Fournier in her visualisation experiment of Venice's maritime trade during the Middle Ages (Chapter 6); by Silvia Marzagalli when creating a new database on 18th century shipping flows allowing her to map, among other things, the distribution of French seaborne trade in the world (Chapter 7); by Liehui Wang, Theo Notteboom, and Lei Yang, who show the convergence or divergence of British and Japanese maritime colonial networks in 1920s China based on local archives (Chapter 8); and by César Ducruet, Sébastien Haule, Kamel Ait-Mohand, Bruno Marnot, Zuzanna Kosowska-Stamirowska, Laura Didier, and Marie-Anne Coche, who have extracted and mapped thousands of vessel movements from the world's biggest source of shipping information, *Lloyd's List*, to represent major shifts of maritime activity since the late 19th century to the present (Chapter 9).

The third part, composed of five chapters, is entitled *Topology and Spatial Distribution of*

Maritime Networks. These works all apply wider statistical and spatial models of networks and trajectories to massive maritime data. The analysis by Frédéric Guinand and Yoann Pigné (Chapter 10) of daily connectivity changes in the global container shipping network is a very innovative approach that sheds new light on seasonal and cyclical dynamics in liner shipping as well as on temporal graphs, a novel approach to maritime networks with huge potential to zoom on particular events and nodes. The following work by Laurent Etienne, Erwan Alincourt and Thomas Devogele (Chapter 11) provides a critical analysis of real time vessel positioning data based on radar information or AIS to identify peculiar ship behaviour within aggregated maritime trajectories, an approach which has direct implications for port and maritime security. The identification of clusters in the global maritime network by Charles Bouveyron, Pierre Latouche, Rawya Zreik, and César Ducruet (Chapter 12) allows us to better define the functional specialisation of port nodes within a system of interlocked components connected by various fleet types, with cores, peripheries, and brokers. Another way to link maritime networks with mainstream network analytical research is shown by Serge Lhomme (Chapter 13) who measures the vulnerability of liner shipping networks to random or targeted failures of port nodes. This work sheds new light on the geographic dimension of network dereliction under certain attack scenarios, taking into account the weight of links and nodes as well as possible traffic shifts due to rerouting. Lastly, Michael Gastner and César Ducruet (Chapter 14) question the statistical structure of global cargo ship traffic with reference to well-known models such as scale-free and small-world networks. They also emphasise noticeable changes over time in the distribution of the port hierarchy that correspond to important technological breakthroughs in the industry.

The last part of the book, *Maritime networks and regional development*, provides a closer look at the local embedding of maritime flows. Ronald Halim, Jan Kwakkel, and Lorant Tavasszy (Chapter 15) use simulation and spatial econometric methods to show direct connections between port traffic, maritime network design, trade, and economic development by choosing different parameters and scenarios in their global network model. An exploratory analysis of Pacific Rim port regions is proposed by César Ducruet and Hidekazu Itoh (Chapter 16) to seek the local socio-economic determinants of maritime connectivity in a network composed of different fleet types. Territorial factors thus play an important role as seen with the tendency for richer, more urbanised regions specialised in the tertiary sector to be more dominant in the network and to centralise higher-valued flows. At the country level, David Guerrero, Claude Grasland, and César Ducruet (Chapter 17) revisit the gravity model by comparing trade flows to maritime container flows on country pairs. They particularly highlight the facilitation of trade by shipping frequency, especially for manufactured goods, and the geographic essence of this relationship notwithstanding a number of outliers among countries. By linking spatial economics with spatial statistics, network analysis, and GIS, Igor Lugo provides a novel approach to systems of cities (Chapter 18) based on the case of Mexico, where urban nodes as well as port locations are connected via road segments. Such a combined approach has important implications for further understanding multimodal urban centrality and accessibility. The analysis by Nora Mareï and César Ducruet (Chapter 19) of the network configuration of maritime container flows in three different regions of the world discuss the respective influences of regional integration processes and carrier/port selection and competition dynamics on port hierarchies. A new measure of intra- versus extra-regional vessel circulation allows us to detect noticeable differences in the way such basins are organised and have evolved in recent decades. The last contribution to this part and to the book by César Ducruet, Sylvain Cuyala, Ali El Hosni, and Zuzanna Kosowska-Stamirowska (Chapter 20) re-explores the longstanding port-city issue by measuring the influence of urban demographic size on the spatial pattern of global maritime flows between 1950 and 1990. Larger cities maintained their overwhelming dominance in terms of centrality, but at the same time, port hierarchy and urban hierarchy gradually became less overlapped.

Acknowledgements

The research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP/2007-2013)/ERC Grant Agreement n. [313847] 'World Seastems'.

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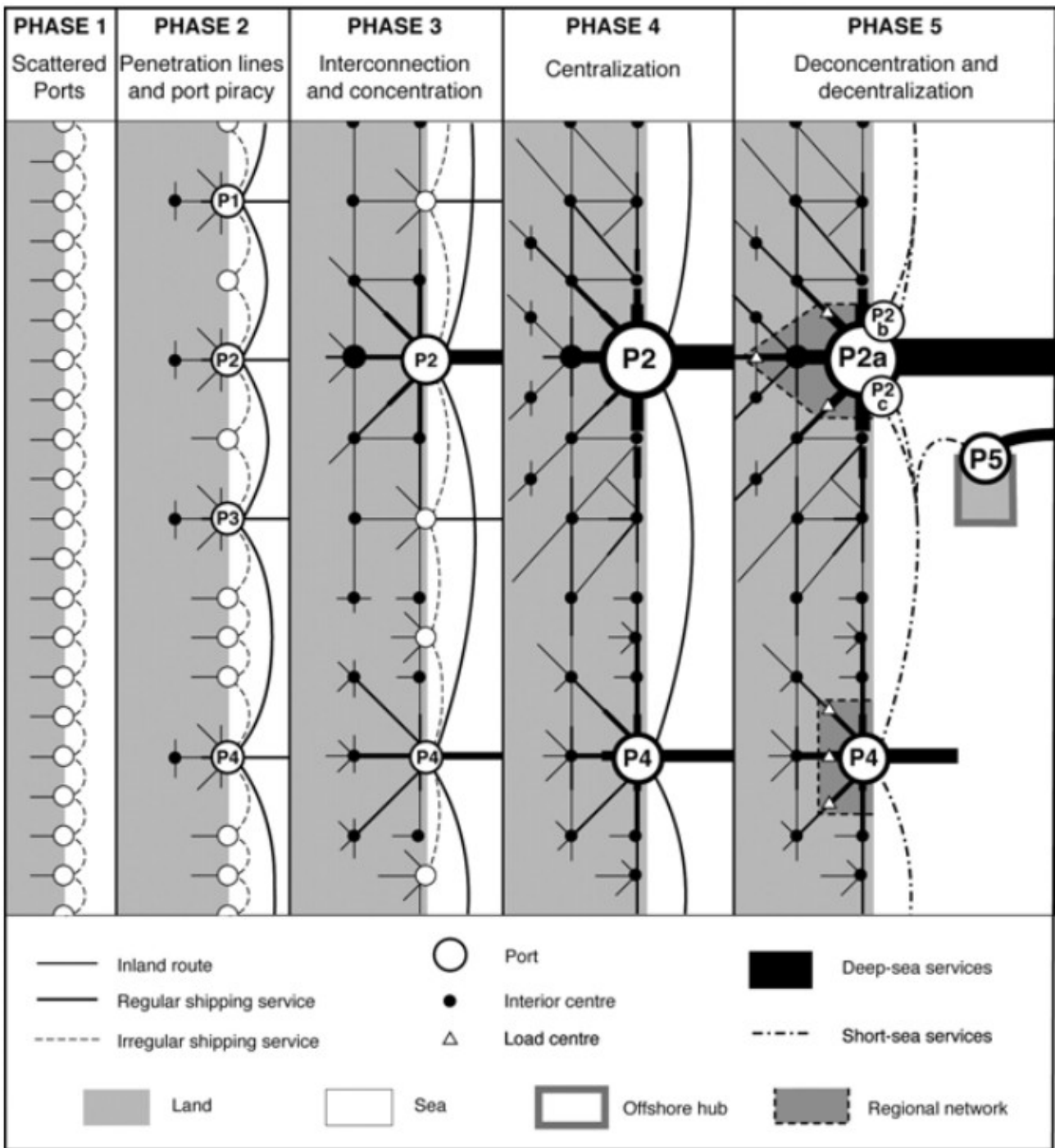


Figure 1.1 Spatial model of the evolution of a port system including maritime linkages
Source: Rimmer (2007).

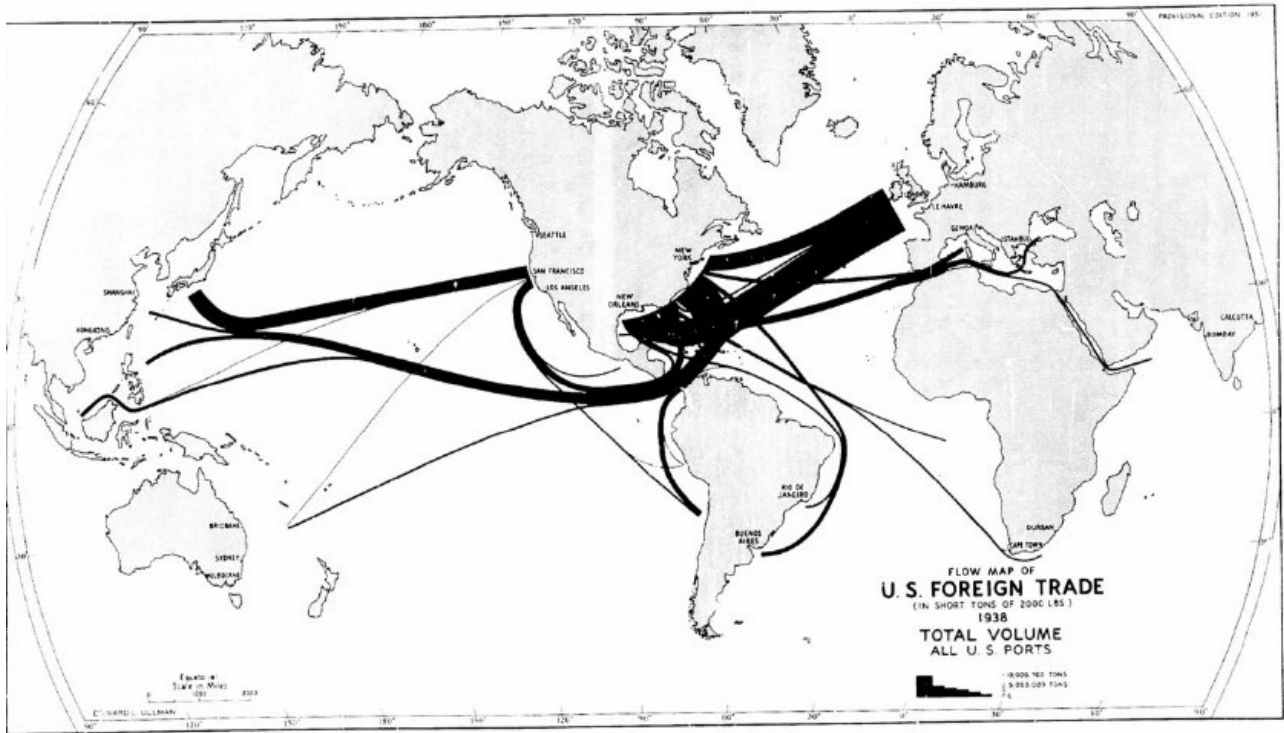


Figure 1.2 A cartography of US maritime trade, 1938.
 Source: Ullman (1949).

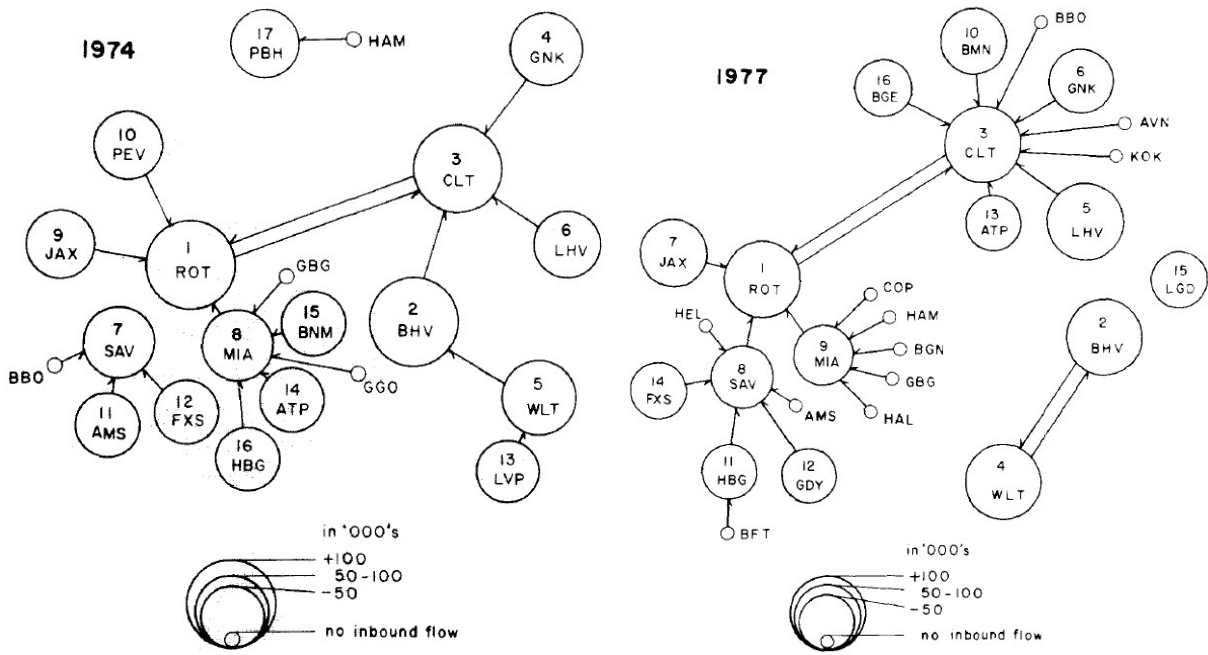


Figure 1.3 Nodal hierarchy of US-European ports in maritime container flows, 1974 and 1977. Source: Marti and Krausse (1983).

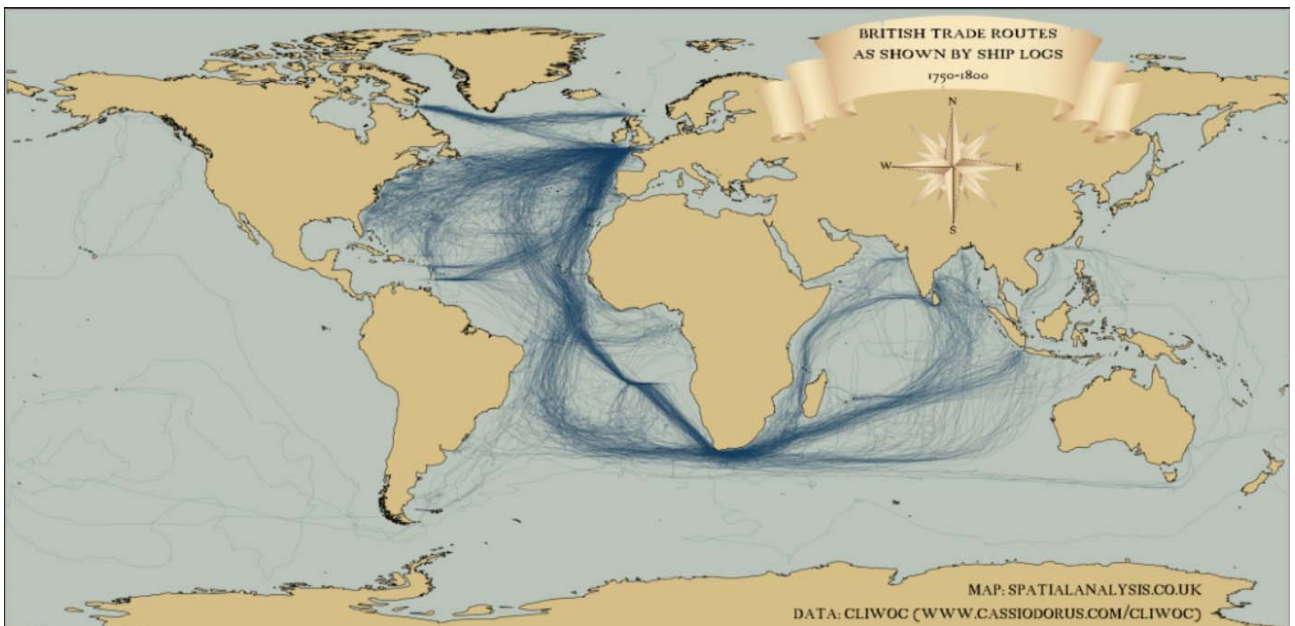


Figure 1.4 Map of British vessel flows based on log books, 1750–1800. Source: James Cheshire (2012).

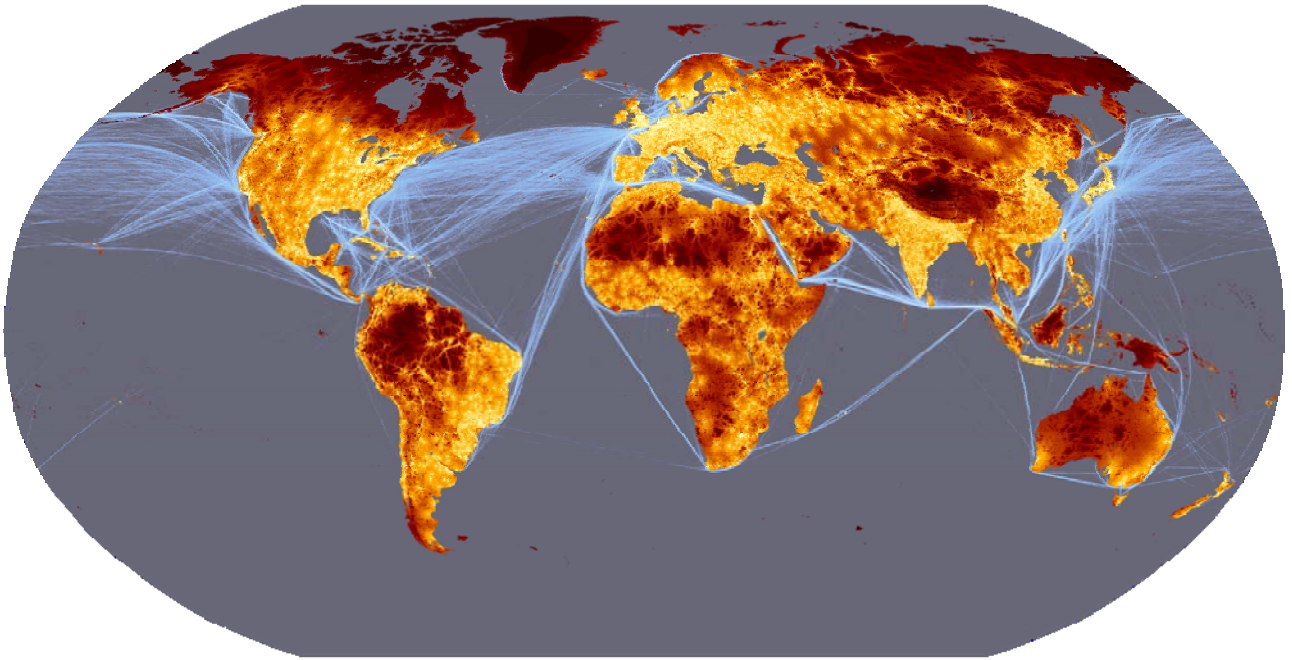


Figure 1.5 A global map of urban accessibility.
 Source: Nelson (2008).

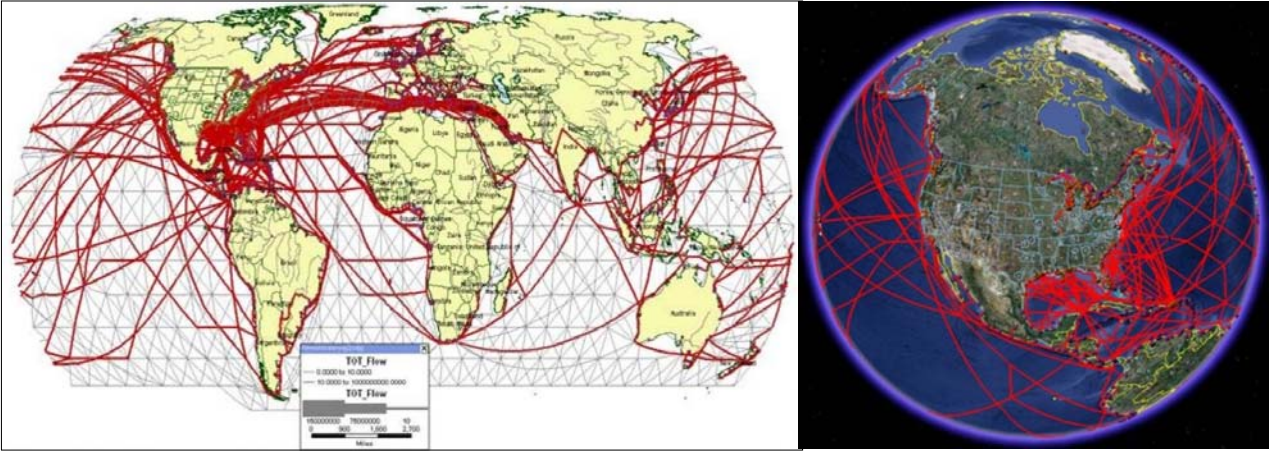


Figure 1.6 World distribution of US maritime trade in 2D and 3D, 2002.
 Source: Shen *et al.* (2013).

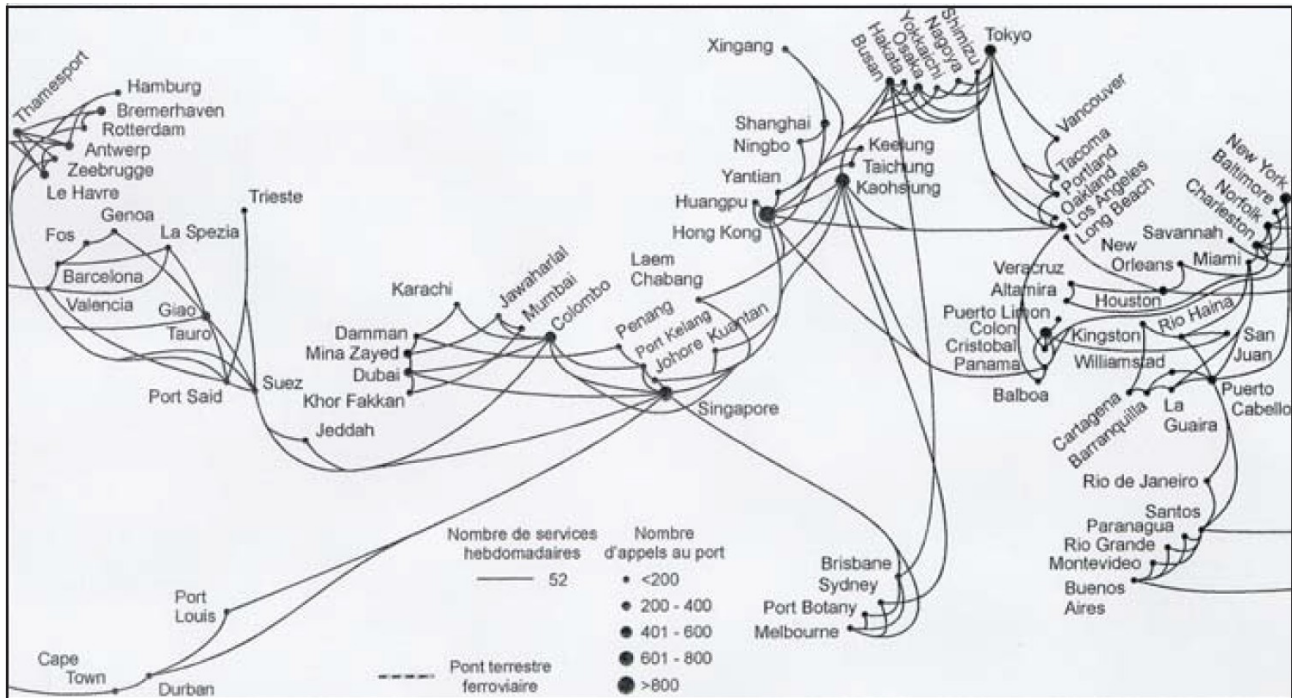


Figure 1.7 The port network of Evergreen based on schedule data, 2000.
 Source: Comtois and Wang (2003).

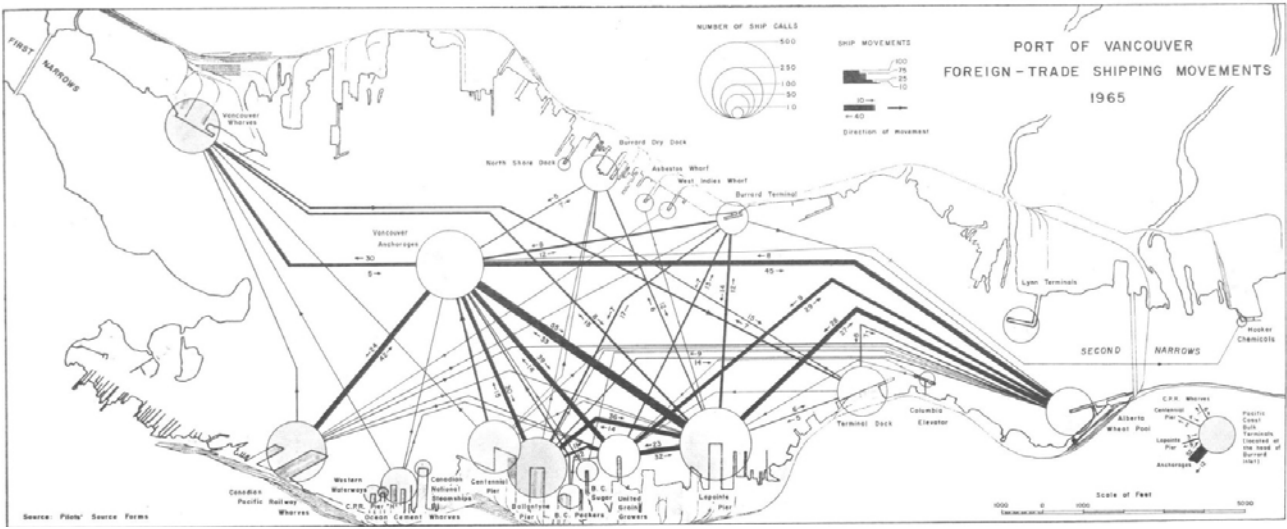


Figure 1.8 The foreign trade shipping network of Vancouver (a), British Columbia ports (b) and related spatial model (c)

FOREIGN-TRADE SHIPPING NETWORK

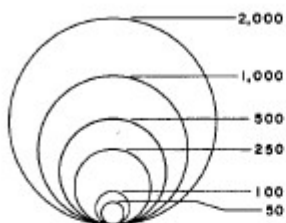
B.C. PORTS

1965

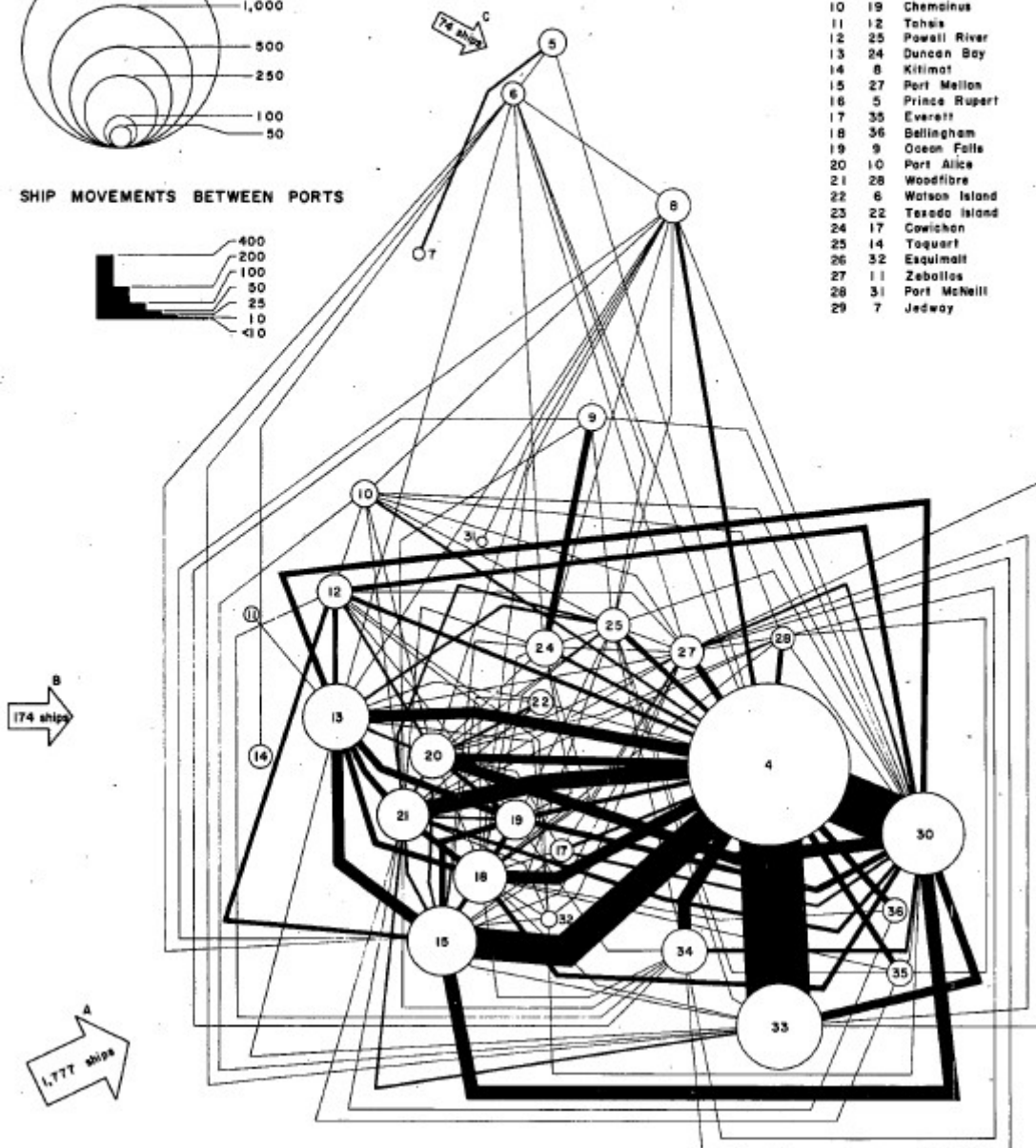
NETWORK PORTS AND ENTRY POINTS (Ranked according to number of ship calls)

	Rank	Code	Port
ENTRY POINTS	1	A	Fairway
	2	B	Cape Beale
	3	C	Triple Island
NETWORK PORTS	1	4	Vancouver
	2	30	Fraser River
	3	33	Seattle
	4	15	Victoria
	5	13	Port Alberni
	6	18	Crofton
	7	21	Harmac
	8	34	Tecoma
	9	20	Nanaimo
	10	19	Chemainus
	11	12	Tahsis
	12	25	Powell River
	13	24	Duncan Bay
	14	8	Kitimat
	15	27	Port Mellon
	16	5	Prince Rupert
	17	35	Everett
	18	36	Bellingham
	19	9	Ocean Falls
	20	10	Port Alice
	21	28	Woodfibre
	22	6	Watson Island
	23	22	Tesado Island
	24	17	Cowichan
	25	14	Toquart
	26	32	Esquimalt
	27	11	Zebollis
	28	31	Port McNeill
	29	7	Jedway

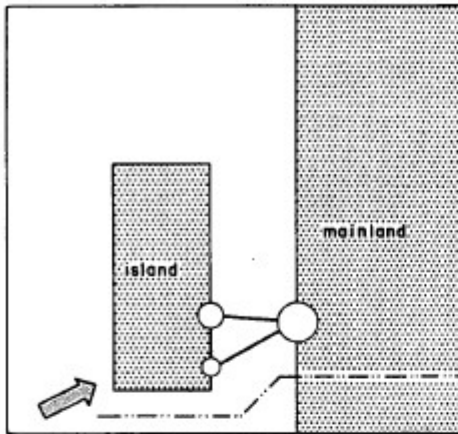
NUMBER OF SHIP CALLS



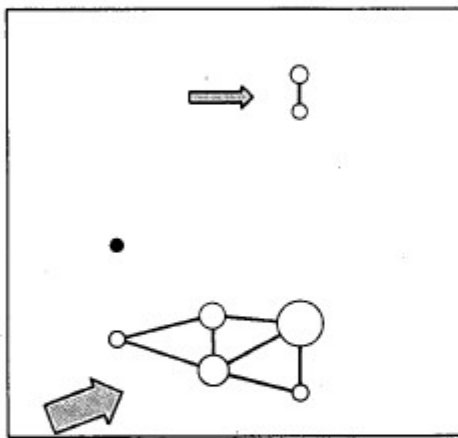
SHIP MOVEMENTS BETWEEN PORTS



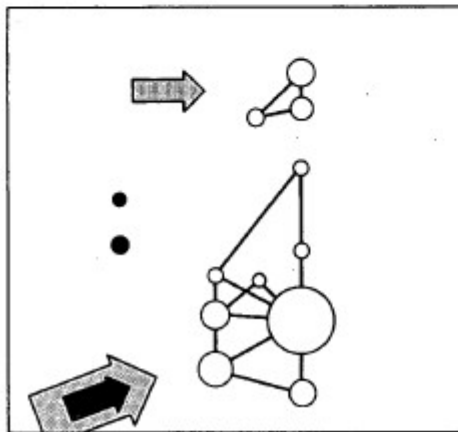
PORT NETWORK DEVELOPMENT



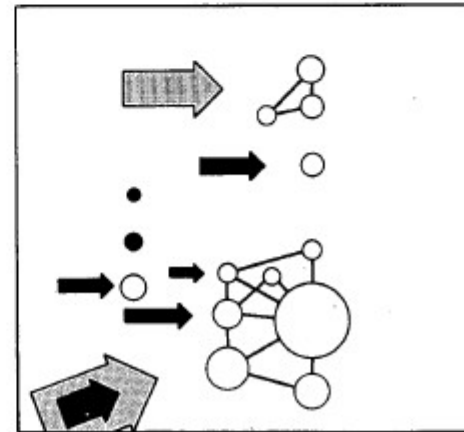
I. SIMPLE NETWORK









II. NETWORK EXTENSION



III. NETWORK INTENSIFICATION



IV. NODAL CENTRALIZATION

-  Volume (G.R.T.) of general shipping
-  Volume (G.R.T.) of specialized shipping
-  International boundary
-  Shipping linkages between ports
-  Ports shipping foreign-trade tonnages
-  Obsolescent ports

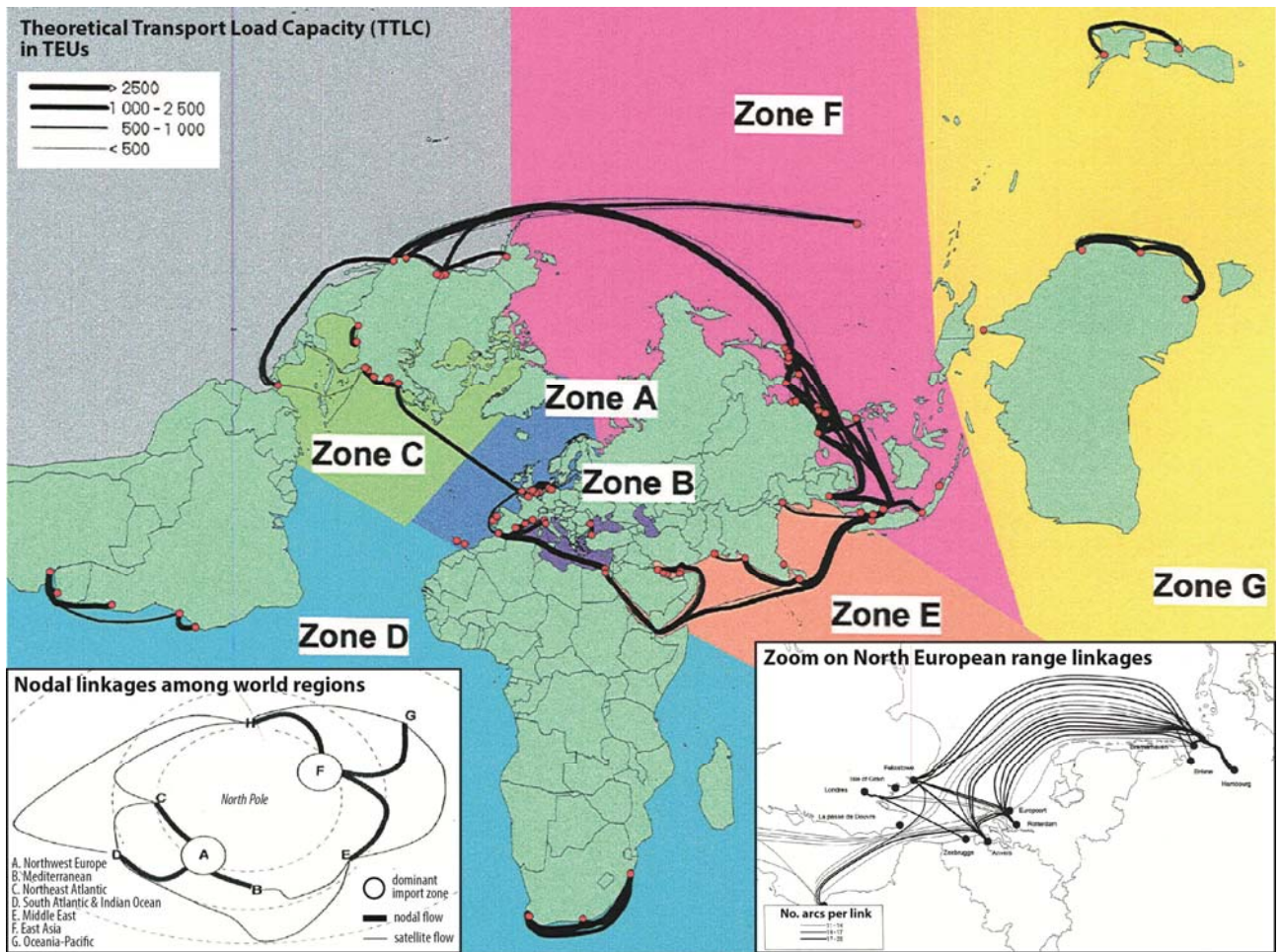


Figure 1.9 Modelling and mapping global maritime container flows on various scales, 1992. Source: Joly (1999).

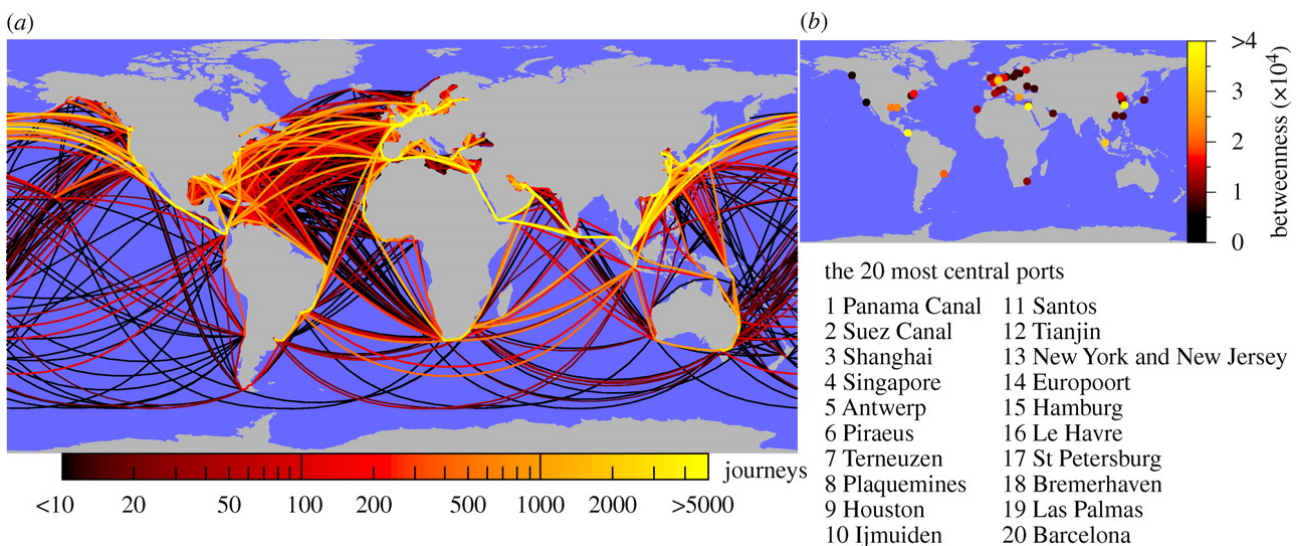


Figure 1.10 Distribution and density of world maritime flows based on AIS data, 2007.