The Evolving Pattern of World Container Traffic Distribution

Olivier Joly, Arnaud Le Marchand

Maritime Transport, Globalisation, Regional Integration and Territorial Development
Research Seminar – University of Le Havre, Normandy
Le Havre, 3-4-5 June 2003
Session 5: The Port Economy

The Evolving Pattern of World Container Traffic Distribution

Olivier Joly
Associate Professor
CIRTAI UMR CNRS 6063
University of Le Havre, Normandy, France
olivier.joly@univ-lehavre.fr

&
Arnaud Le Marchand
Associate Professor
CERENE
University of Le Havre, Normandy, France
arnaud.lemarchand@univ-lehavre.fr

Abstract:

The evolving pattern of container traffic distribution is a highly stochastic phenomenon. Nevertheless, changes (hazard) in the distribution of port traffic do not seem to follow Gaussian laws. Shape of world container ports system, conceived as network geometry of container flows between ports explains both the interdependencies between ports performance and extreme fluctuations. Port traffic patterns are dependent results. The strength of interactions provokes a chaotic phenomenon within maritime container traffic network. External causes, even partial, need to be identified in order to evaluate local dynamics (for instance: shape of fluctuations for one given port by comparison with money fluctuations in the area (exchange rate volatility) or with the common trend in the range it belongs to). Otherwise, the continuity of container flows within the global maritime network could be more significant than singular 'port to port' interactions, given that network structures such as random, scale-free or hierarchical appear to be explaining factors.

Enhanced version by authors in March 2021 with added Figure 13bis, p.16.

1. Introduction: Various Factors

The determining factors of evolution and repartition of container traffics by ports and for each places, are multiple. Some factors are internal to each port system, and even from a local point of view, it is a complex phenomenon (Goulielmos, 2002). We cite productivity of handling operations, facilities for navigation, configuration of space, commercial politics and more widely the cohesion and the ‘click effect’ of the port community. The relations between these communities and the political decision-making centres[1] are summarized by the concept of governance of the port cities - matter in the mid-term and explain some factors of port performance that can be measured by containers flows.
Seen by the outside, we can use the term of ‘flexibility’ of a community to analyse its internal efficiency, and the notion of ‘reputation’ to empathize the perception of this flexibility by the external actors. However, a harbour place is not apart. The regional and national economies have obviously effects on the port traffic throughputs. The trade balance, the growth of income and all current trends cannot be ignored to characterize the path of a given seaport. In the same way, the degree of opening, and the mode of insertion into the global economy plays a role of major influence.
The strategy of major firms or even the strategy of relevant industrial districts are to be retained. If for instance, the firms were oriented towards exportation or delocalization, the consequences would not be the same for the port activity. In fact, we cannot consider the evolution of the ports independently of their context, which can be summarized into "situation and opening". However, between these key factors and the port efficiency, there are many retroaction loops[2]. Relations are not linear at this stage.
Lastly, the global maritime container network, seen as a worldwide techno-economical system, is another sphere of determining factors for each seaport and for ports as a whole. The strategy of container shipping lines companies should not be taken into account at this scale. The mix of competition and cooperation between each seaport nodes of this global network is influencing each harbour places. Maritime traffic influences the activity of the port. In fact, the overall state of the global port network, especially its shape and its degree of connectivity are making waves on each port nodes…

The container port performances are a very complex subject and it is not amazing if it appears sometimes as a lattice of unpredictable black boxes. We need to improve our knowledge about relations between this lattice and the fluctuations of the port nodes.

2. Pathways and random walks

These remarks, already well known, lead us to think that in a statistical approach, container port traffic throughputs are considered as a stochastic phenomenon. It does not mean random change for each port. We can always find a reason, or a bunch of reasons, to explain why a given port has its activity growing fast, slow or decreasing. This can be analysed as result of the evolution of the professional relations, or public policies, by firm strategies or local trade. Nevertheless, it is still difficult to forecast because of the complexity of interactions that are engaged behind a rate growth of container flow. The pathways of the port systems and territories matters, but there are bifurcations, and the growth of a port follows usually a very broken line. In fact, we can say there is a random walk of the throughputs.
We will show that the scale of traffic and the rank of one port among the others, are not explaining the rate growth. These variables are highly random like. That is compatible with the global distribution of the traffic that follows a Zipf-Pareto statistical distribution. This

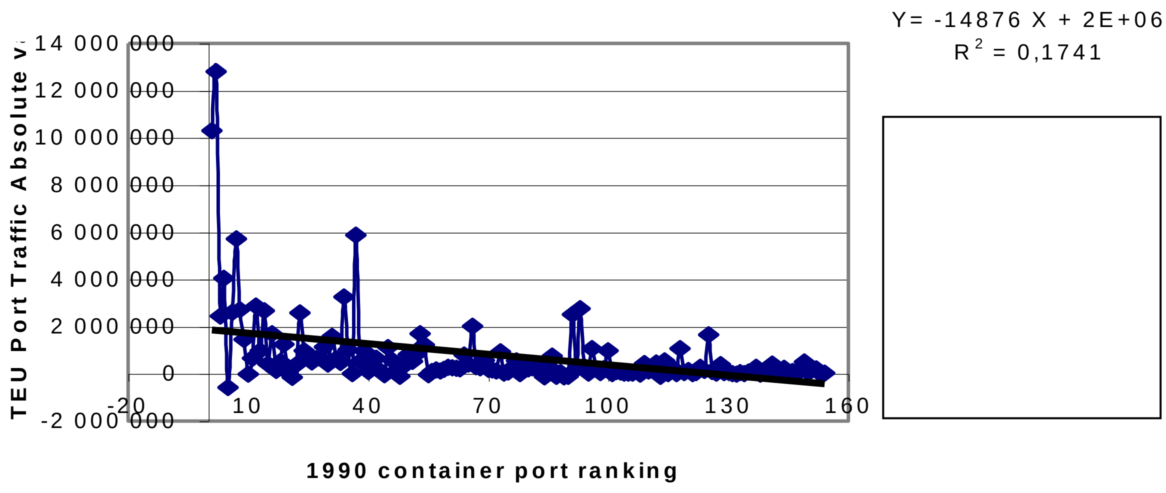
[1] as well as all the other problems
[2] for instance between opening and governance of the territories

phenomenon is explained by a network effect. Then, we will see that growth's fluctuations are non-Gaussian variables, with extreme values. This is due to a shape effect of the global maritime container traffic network. The spatial graph of global container's maritime traffic contributes to explain these characteristics (Joly, 1999).

3. Scale - free growth rates

It is clear that the rank of ports does not determine their future rate growth. Figure 1 shows that the rank of the 184 biggest seaports in the world in 1990 never explains their growth during the decade up to 2001. The coefficient of determination R^2 is near zero (Figure 2) for the rate, and very low and not significant for the absolute performances. Note that in 2001 data, some major container ports[3] as Gioia Tauro for instance, were not present in the 1990 data[4].

Figure 1. TEU port throughput according to (1990 to 2001) port ranking



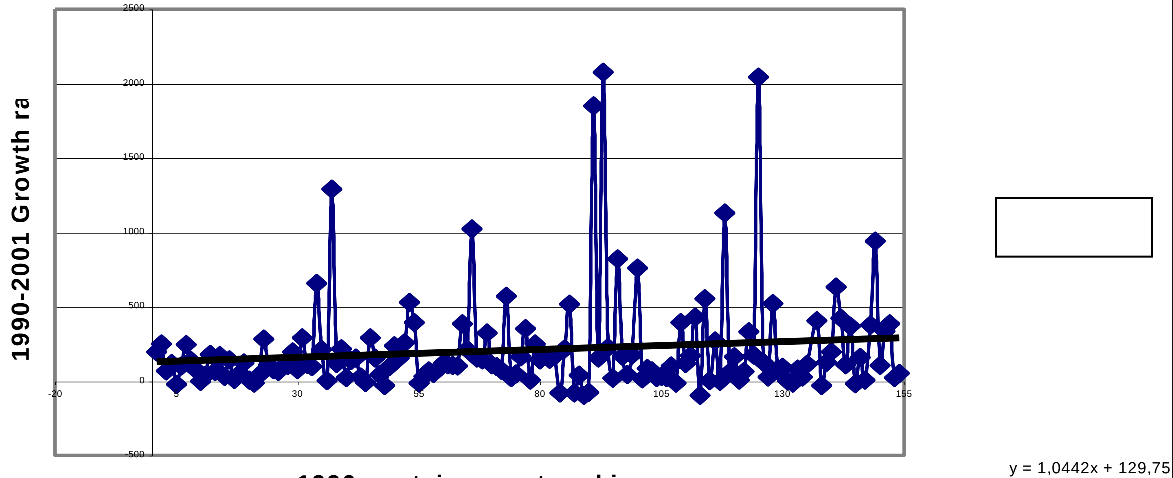
We can conclude from this simple estimate that rank and size are not discriminating factors. Same result is obtained for one year of variation. For instance, in 2001 some major ports have seen their traffics slightly decreasing, while smaller ports were growing. Such a result does not mean that size does not matter at all. It should be interpreted in relation with the Gibrat's statistical law as in industrial economics. The size of firms does not explain the growth rate. Therefore, we can assume that the evolution along the time is 'scale – free'. The advantages of size, (increasing returns, credit for new infrastructures), are in balance with the disadvantages (congestion, decreasing returns…). As written further, too many factors play a role in the competition, so the scale is only one key among others. This result is consistent with the attention paid to other studies on the institutions of the city-port communities. Because these institutions explain the port's flexibility and its ability to gain new container

[3] 'The port of Gioia Tauro is mainly a container terminal is nowadays one of the largest transhipment hub in the Mediterranean Sea (2003).

[4] Gioia Tauro Container Terminal did not exist yet in 1990!

flows. Furthermore, the major ports may continue to grow or not, depending on their efficiency and politics and not only from the past[5].

Figure 2. 1990-2001 Growth rate



Smaller ports can succeed to progress, depending on improvements and on a good context. The distribution of traffics is not definitely locked. What we qualify as ports' hazard the result of innovations in an open world. Innovations result from the complex interactions between flexibility, reputation and current trends.

4. The global distribution: the Zipf - Pareto statistical distribution

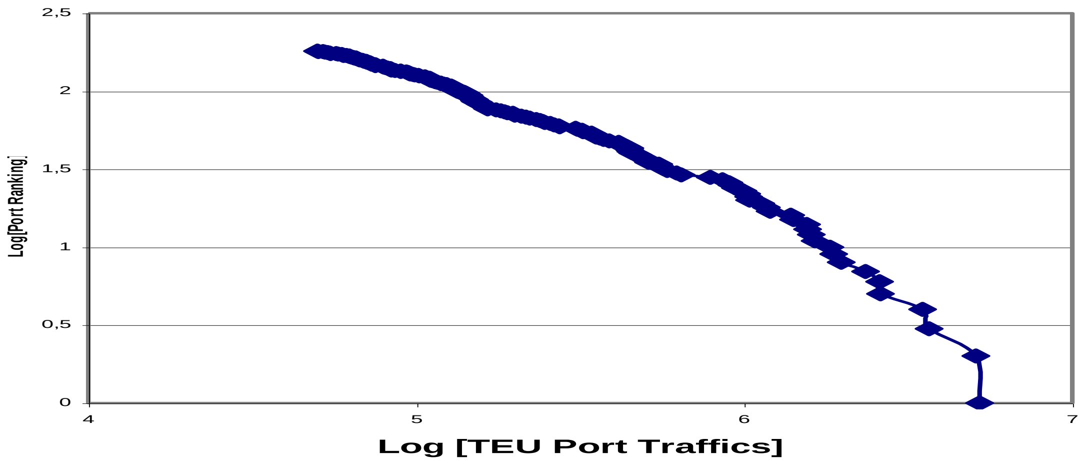
These previous observations are compatible with the distribution of traffic among ports, every year. This distribution is following, with a high degree of correlation, a well-known statistical law: the Pareto distribution. This law links the log of port rank with the log of size (measured by TEU Port Throughput).

We can notice (Figure 4) that the coefficient of adjustment is quite good, the convexity into the left part of the line is usual and can be explained by some noise on the data for the weak performances. Such a distribution has some remarkable properties. It is possible to obtain such a shape by random simulations. It is independent of the scale of analysis: It is 'a fractal distribution' (Mandelbrot, 1997; Zajdenweber, 2000).

One can note that if for the year 2001, we consider the 70 largest container seaports of the world, instead of the 280's; we find a correlation coefficient of 0.997. This may suggest the existence of 'a strong law among the core of the network'!

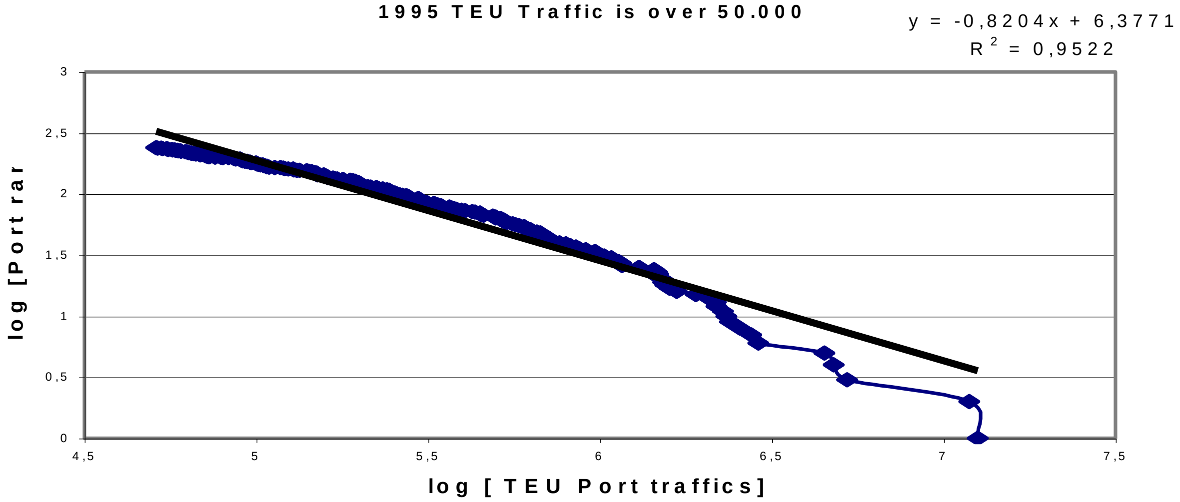
[5] as resumed in the observed absolute or relative size of the traffics

Figure 3. Rank - Size Law (ZIPF- Pareto) for 180 container ports wich 1990 TEU Traffic is over 50.000



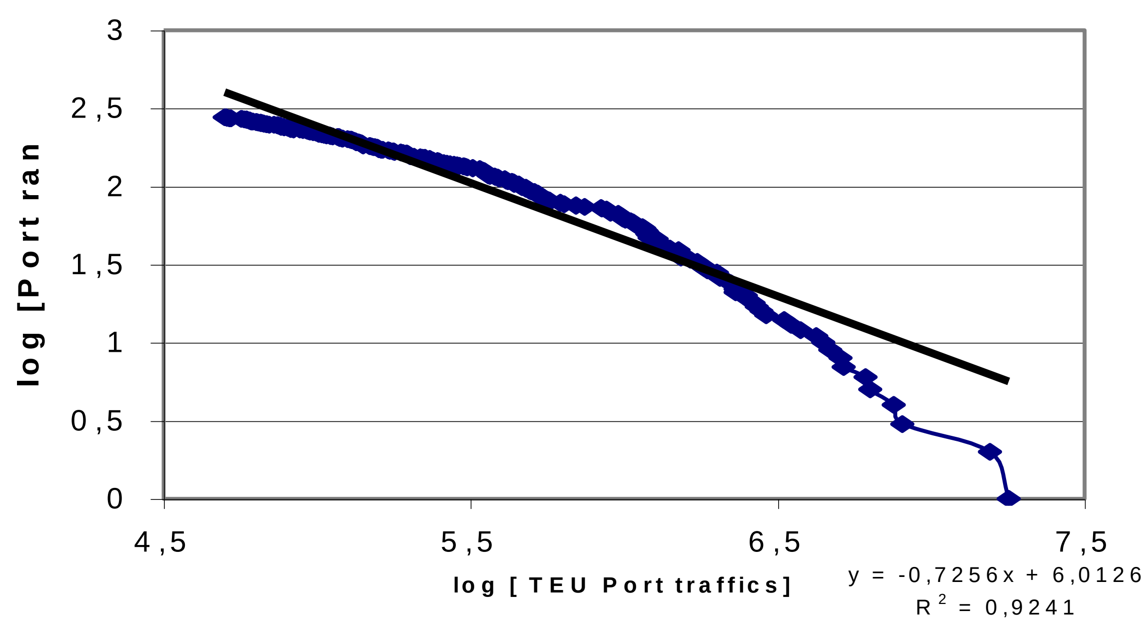
It is compatible with the possibility of very large extreme fluctuations. It suggests that we are in front of a chaotic and complex phenomenon (Mandelbrot, 1997 & Zajdenweber, 2000). It is a typical distribution among a large range of networks.
In addition, another technical point must be highlighted: the value of the parameter α^6 in the estimation is minor to one, which means that[7] there is no variance nor Esperance in such a distribution. There will be no convergence towards an average or a constant value for the variance among times. This leads us to the non-Gaussian fluctuations.

Figure 4. Rank - Size Law (ZIPF- Pareto) for 239 container ports wich 1995 TEU Traffic is over 50.000



[6] The shape parameter α determines the slope of the log-linear relationship between the (logarithms of) rank and size.
[7] a very important characteristic

Figure 5. Rank - Size Law (ZIPF- Pareto) for 278 container ports wich 2001 TEU Traffic is over 50.000



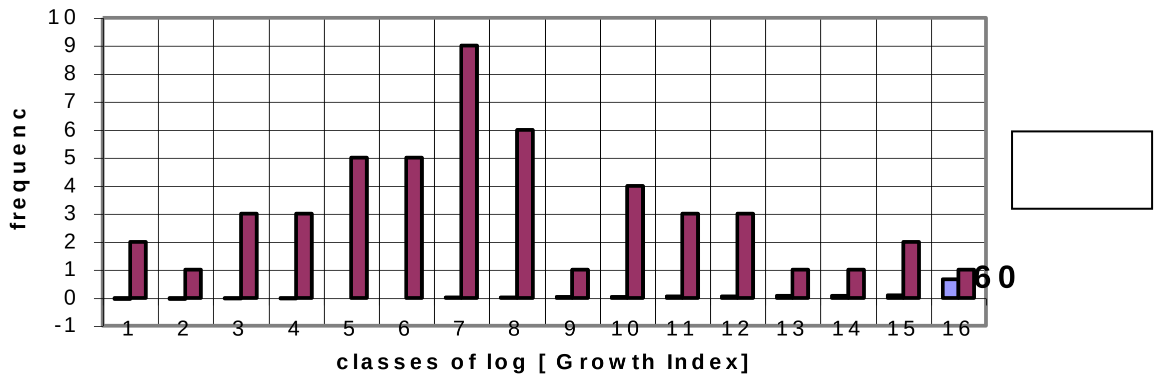
It should be note that during the year 2001 and for the first 70 world top ranking container ports, the coefficient of determination R^2 equal 0.99.

5. Bubbles of containers and extreme fluctuations

If we look at the growth rate of the 50 biggest container ports during the year 2001, it is very easy to check that it does not follow a Gaussian law. The rates are too much scattered, and the extreme fluctuations are really far from the average. The first rate is 390 %[8] the average is 10.2. Half the ports have negative rates. We have to represent the index of growth, rather than the rate.
One remarkable point is that even the log-Gaussian law cannot figurate this dispersion. The tails are too heavy, the extreme are too frequents and it is not possible to put on the same table, Tanjung Pelepas, which is note on the right at the rank 60 when all the rest of the index are quoted less than 15.

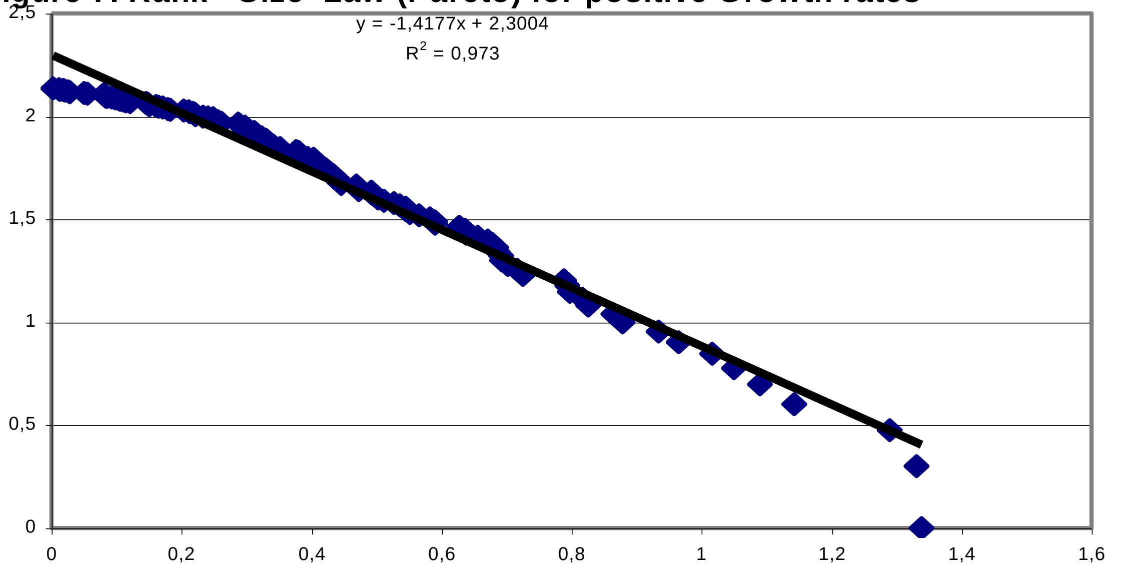
[8] According to the Tanjung Pelepas Container Terminal

Figure 6. 2000-2001 Log of Growth index



In fact, it is possible to find an adjustment: once again, the Pareto-Zipf law. If we take the index of variation for the 137 seaports, which have seen traffics, increase during 1990-2001 period. This property of the index's distribution means 'that we are in presence of extreme fluctuations, hyperbolics'. The parameters show that the variance of this index is infinite (Zajdenweber, 2000). So there is no convergence. Today it is similar to what we observe on the stock market exchange. One other remarkable point is that this result shows that the processes of localization in container traffics are not analysable in terms of the classical model of polarization, in which there is a stable equilibrium (Arthur, 1990).
This extreme dispersion of growth rate among the seaports has some correspondences. In the same way, by following the path of one port during a given time period, we can produce the same phenomenon. After years of growth, we can find a sudden stop or a negative rate. In fact, the path of any ports is always 'a broken line'.

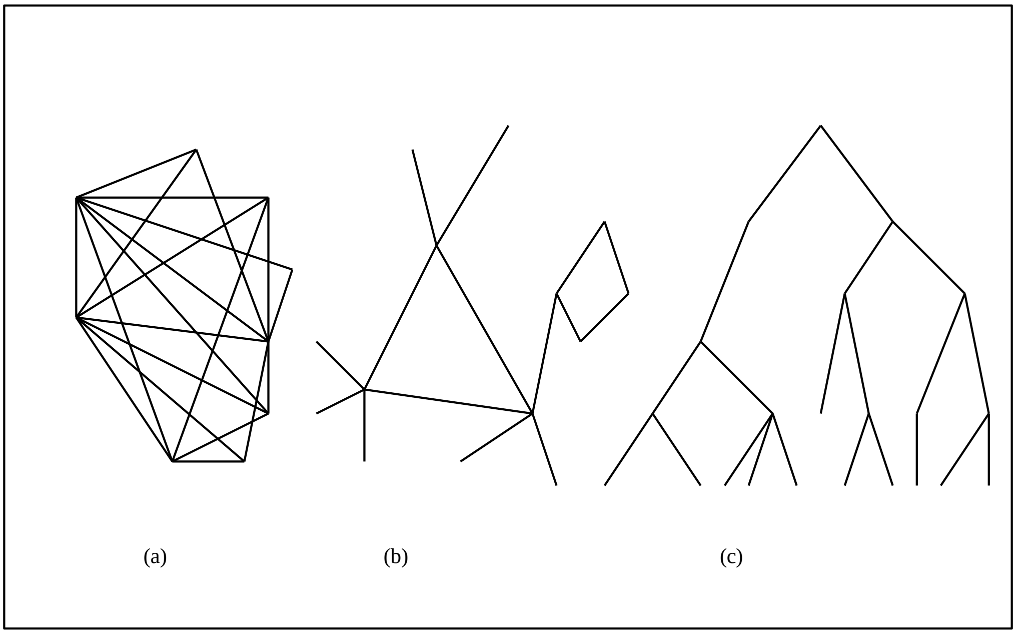
Figure 7. Rank - Size Law (Pareto) for positive Growth rates



It seems that the evolution of some ports can be analysed as bubbles on stock exchange. They can depend on expectations and evolutions of reputation. If a harbour place[9] gives proof of improving organization (for instance), shipping companies might establish new lines on this port, making new links. That decision puts the related local traffic to increase, but if the recorded performance is not sufficient or slow after a while, that can lead to 'corrections', which provokes decrease, via complex agglomeration effects (Scott, 2001). Over – reactions appear. This 'bubbles' can be called 'mimetic or rational bubbles'. If it begins on an information problem[10] and spread like fashions, because of reputation effects, we can call it mimetic bubble. Such a phenomenon can be studied using the tools of the economics of convention (Orlean, 2001). Because of the reputation effects (which are following the construction of ports perception) which established some of the rules of prediction shared by actors. If it follows real changes, like innovations or political events, we can call it 'Rational Bubbles'. Case[11] where new information leads to correction, or bifurcation, lies between these notions. In a network approach, this kind of 'over-reaction' may be caused by the co-dependencies among the port places[12]. These co-dependencies can explain why the 'Gaussian law' is overflowing. The performances are not to be taken isolated, and they can be cumulative, retroactive, and they reflect chaotic evolutions of reputations and traffics.
It is a network's effect on its connectivity.
The last decade was described by the concept of globalization. It is indeed 'a very hot context' for trade and maritime transport system, with important structural changes. The explosive upward trend in some Chinese ports are prominent examples, but they are not the only ones[13]. It is then conceivable that this context of fast evolutions, justifies the volatility of container flows and the pattern of distribution. It suggests some research should be focused on the links between this mobility and the volatility of other trends, like exchange rates.
However, the shape of the spatial graph relative to global structuring of maritime container traffics gives confirmations. Extreme fluctuations, stochastic evolutions can be explained by some properties of the maritime container traffic network. It links distinct port ranges, highly clustered through short - cuts with regular and random vertices. It is a scale-free network, allowing a small world graph according to Watts' theory (Watt, 1998) and it is also a 'related[14] graph'. In such network, 'between order and randomness', data spread very quickly. Therefore, movements are faster than in fully random or completely hierarchical networks, the anticipations are "kaleidoscopic" and in consequence, the local pathways are partly unlocked. Thus, opportunities and risks still exist for each port community. It explains why some maritime shipping companies reach uncommon hubs (Figure 8).

[9] i.e.: a seaport community
[10] Like a 'sun spot'
[11] i.e.; a seaport case study
[12] competition and cooperation
[13] See Gioia Tauro Container Terminal
[14] i.e.: connected

Figure 8. Network structures: (a) random, (b) scale-free and, (c) hierarchical (Stocker et al. 2001)



6. Seaports, flows, merchant vessels & global maritime container traffics

Let us remind of a few formulations that could provide a common basis for the understanding of the maritime transport system and allow comparisons between systems in different regions of the world.

Behind the term of global maritime container traffic network[15], we understand both a set of geographic locations namely container ports[16] that are interconnected - in the global container seaport system - by numerous segments of maritime routes and last but not least, by a set of 'interoceanic and transoceanic container flows' carried on by containerships. This suggests six main building blocks or major components:

(1) Ports of Origin,
(2) Segments of maritime routes,
(3) Respective channelled container flows,
(4) Relay-ports,
(5) Hub ports[17] and
(6) Ports of Destination – last call.

Thus, the name of 'maritime container traffic network' can be assigned to the framework of maritime routes within the world container seaport system and be used to describe tangible but invisible sea corridors.

A maritime route is not simply a single shipping link between two interchange or relay ports; a maritime route is a part of a larger maritime network of sea corridors, is made up of several maritime segments made up of single shipping links between 2 (or more) calling ports as well.

[15] or worldwide maritime container traffic network
[16] or container terminals
[17] That include the Sea-to-Sea Transhipment ports

Seaports or port nodes are points on the maritime network where both links, segments and routes converge, and often act as the focus for transport services and/or for the transhipment between two distinct modes of transport[18]. Lastly, channelled container flows were worn along maritime shipping links by the containerships. Aggregations of continuous container flows along links between two ports constitute inter and transoceanic container traffic flows.

Using theoretical concepts (Kansky, 1963) and network analysis tools that are often applied to inland goods transport networks, worldwide structuring of maritime container traffics has been studied using an original reliable source: Lloyd's Voyage Records data. Lloyd's Voyage Records is a weekly publication that enables to identify precisely worldwide from-port-to-port movements of numerous ocean-going merchant vessels[19] including conventional and part-modified conventional vessels carrying deck loads of containers and purpose-built cellular container vessels.
So we can locate where a container vessel was at a given time but also where it came from – its last port of call and where it was going to – its next stop, and all this over a given period. Almost 2000 successive sequences of port calls have been recorded[20].

7. The shape of the global container ports & shipping system

Graphs are a way of representing transportation networks linking ports together. According to graph-theoretic terms, the graph G is a set that contains two subsets of elements: (1) subset of vertices, and (2) subset of edges. An edge is an element of the graph G such as a continuous line between two distinct vertices. A vertex called a node or a point is an element of the graph such as a point of intersection of n edges.

Network geometry has become an important element in determining efficiency levels of container operations (Slack et al, 1996). One can see graph theory such as a starting point towards expected structural theory of network analysis centred on a set of geographical 'intertwined' locations (Capineri, 1993).
So we can consider 3 well-known network structures - useful in research into network topology and dynamics that are necessary to understand the evolution and behaviour of complex network systems (Stocker et al, 2002) – chosen from many other classical network structures such as Global, Regional Hub-and-Spoke or even Centralized networks (Figure 8) :

- Hierarchical network structure represents classical spatial patterns: equilibrium spatial systems based on the complementarity relationships between market areas and nested ranked centres. They consist of nodes with branching connections that form a typical tree-like structure. According to graph-theoretic terms, a tree is a connected graph[21] of at least two vertices such that graph does not contain any circuit (i.e.: finite path in which the initial vertex coincides with the terminal vertex of the path).

- Scale-free network consist of a few highly connected nodes that link the remaining sparsely connected nodes to the whole system (Stocker et al, 2002). In terms of the classical spatial patterns, we can consider that scale-free networks are closed to multi-centre networks (dynamic spatial systems, consisting of nodes with different functions

[18] i.e.: connections with inland (hinterland) transportation networks
[19] Vessels that appear in the records of the Lloyd's
[20] relative to 1990 & 1992 Autumn time periods
[21] i.e.: a graph that contains not isoled subgraphs associated with isolated subnetworks

that interact according to the circular cumulative mechanisms ruling the agglomeration and polarisation processes) (Rabino et al, 1997).

- Simulated random networks have no apparent structure when nodes are placed randomly; the distribution of the number of each node connections approximates a Poisson probabilistic distribution.

In order to make possible the qualification and measuring of the global maritime container traffic network's structure and attributes, a few topological indices[22] will be presented later.

8. Characterizing network geometry of container flows between ports: Findings

Anyway, Kansky wrote that the term of structure denotes the layout, geometry, or network pattern of transportation facilities or systems (Kansky, 1963). If these expressions imply a set of spatial relations between special components of global maritime container traffic network in respect with each other and to 'the whole organized', by measuring such relations, and according to Kansky, we should describe the structure of the global maritime container traffic network in technical terms. First, we present in the following two major data results relative to connected and strongly connected structure of global maritime container traffic network.

8.1. The global maritime container traffic network is connected[23]

The graph relative to world maritime container traffic network is a finite connected graph**.** During 1990 & 1992 autumn periods, it contained no significant isolated subgraphs[24] and finite number of elements. There are no significant disconnected maritime networks within the global 888 container ports network during the 1990 survey period - respectively within the global 915 container ports network during the 1992 survey period (Figure 9).

Figure 9: Related world maritime container traffic network

Maritime container network	Number of singular connected components	Calling Port nodes
1990 survey period	1 + (5)	888
1992 survey period	1	915

Note that during the 1990 survey period, except one major connected component grouping 880 container ports together, exactly 5 isolated subgraphs (3 made up of 2 isolated related ports component & 2 artefacts) have been identified and result from the original reliable Lloyd's Voyage Records source intrinsic data structure. They are not significant matter. Lastly, no artefacts are observed during 1992 survey period: all 915 observed ports belong to the only one connected component.
Never container ports[25] are isolated from any global maritime traffic exchange. We assume feasible maritime paths exist between any ports of origin and destination in the global maritime network.

[22] classical graph theory indices
[23] During the 1990 & 1992 autumn time periods
[24] i.e.: a subgraph S is graph wich is contained in the graph G such that very element of the subgraph S is an element of G and some elements of the graph G are elements of the subgraph S
[25] nor container terminals

8.2. Global maritime container traffic network is 'strongly connected'

'A connected graph' is said to be 'strongly connected' if for each pair of nodes i and j, there is a path starting at i and ending at j knowing that a path in 'a directed graph' is a sequence of some k nodes[26] with $k \geq 2$. 'The connected graph' relative to the world maritime container traffic network is almost strongly connected (Figure 10).

Figure 10: Strongly connected world maritime container traffic network

Maritime container network	1990 survey period	1992 survey period
Number of strongly connected components	**95** (1+6+88)	**75** (1+2+73)
Number of port nodes per strongly connected components	**788/1** + 2/6 + 1/88	**839/1** +2/2 +1/73

The results of the analysis indicate that according to 1990 survey period - within the major subset of 788 container ports[27] - any port or container terminal can be reached from any other port by following a path[28] consisting of a finite number of single maritime links.
According to 1992 survey period, number of ports increased up to 915 and ports belonging to the major strongly connected component also increased up to 839 (Joly, 1999).
Other strongly connected components relative to 1990 period: 88 strongly connected components with only one port and six with a pair of ports are not significant at all: Lloyd's Voyage Records intrinsic structure[29] distorts the results. Each of t these (88 + 6) minor components should not be considered as a 'terminal black hole or end-of the-world' in the one hand, or spontaneous traffic generating origin port, in the other hand... Same remarks are relevant for the 1992 survey period.
The structuring of global maritime container traffic network has one major strongly connected component of calling port call nodes within channelled container flows are blown along any maritime port-to-port links by the containerships, under constraints such as Estimated Time of Arrival[30], nautical access and above all, the commercial strategies of shipping companies[31].
Knowing that we have to apprehend the degree of connectivity of such global maritime container traffic network, the notion of 'connected graph' provides us result about the continuity of relations between vertices of the graph representing the network. However, be careful, this notion of 'connected graph' lumps together their nature: a link between two vertices is equal to any path that make possible to join these two points with several transits.
With the help of cycle and circuit notions[32], graph-theoretic concept of connectivity specifies the nature of relationships and links between points. In order to quantify connectivity we present further Indices alpha α, beta β and gamma γ knowing that some scholars have observed the limits of graph theory topological measurements[33] are often too weak to differentiate among transportation networks.

---

[26] node1, node 2, ... , node k
[27]namely major stongly connected component or major non – connected subgraph relative to major isolated network
[28]That is to say maritime routes, segments or combination of continuous direct links
[29]of calling port period sequences with missing logical feed-back
[30] ETA
[31] In other words: the shipping lines commercial ports strategies
[32] A circuit is a finite path within a 'directed graph', in which the initial vertex coincides with the terminal vertex of the path.
[33] and the difficulty to manage network with large number of nodes and edges

8.3. Connectivity measures of global maritime container traffic network

Indices alpha α, beta β and gamma γ are classical ratio measures of ''Whole Transportation Network'' expressing relations between distinguishable elements i.e. observed number of fundamental circuits / number of maximal circuits and edges / vertices (Kansky, 1963).

Figure 11. Graph-Theoretic Measures of Whole Transportation Network: Global maritime container traffic network

	1990 Survey period	1992 Survey period
K Cyclomatic number	3772	4251
Indice α	0.0096	0.0101
Indice β	5.2409	5.6448
Indice γ	0.0118	0.0123

The K cyclomatic number[34] is an arithmetic comparison between the number of port nodes, the number of maritime links between 2 calling ports and the number of strongly connected components[35].
In the 1992 survey period, completely interconnected network[36] would accept a K_{MAX} equal to 417.241. One can use K to determinate index α as an indicator of trellis or lattice and the geometry of the network as an adjusted form of K ratio[37]. Index α[38] can be interpreted as a percent of maximum connectivity of World maritime container traffic network. Values of index α are closed to 0: 0.0096% and 0.0101% (Figure 11) for each survey period according to K values: Connectivity of global maritime container traffic connected network is very weak. A few container ports related by connected network are belonging to circuits. 'Global maritime container traffic network trellis'[39] is loose. So assessment of the number of alternative paths within the world maritime traffic[40] blown along shipping links by the containerships demonstrates that the whole structuring of world maritime container traffic network is very weakly jointly liable by circuits or alternative circular paths.
7
Index β is the simplest form of connectivity measure, which is written as ratio between number of direct links, and number of port nodes, networks with complicated structure will have high values ofβ, whereas networks with a simple structure will have low values (Kansky, 1963). β could appear to be weak to differentiate among transportation networks.

Figure 12. From-port-to-port connections & container ships movements' empirical data

From-port-to-port Relationships	1990 Survey period	1992 Survey period
Directed from-port-to-port connections without transit (Arcs)	4 654	5 165
Directed from-port-to-port containerships movements	12 625	14 563
Calling Port Nodes	888	915

34 In a connected graph, the K cyclomatic number is equal to the maximum number of fundamental circuits.
35 i. e.: non-connected subgraphs
36 with complete connected graph with equal number of direct port-to-port links and port nodes
37 between observed number of circuits and maximum theoretical number of circuits
38 when the value is multiplied by 100
39 Or lattice
40 Namely maritime circulation of container merchant vessels

Therefore, index β equals 5.24 during 1990 period and 5.64 during 1992 period, its whole scale is from zero to ∞ (for non-planar graphs such as air or maritime transportation graphs). It indicates that in the global maritime network, each container port is connected without transit to five ports. It is a kind of average degree of nodal incidence for the network that equals 5. This index β can also be partially improved by the 'observed directed[41] from-port-to-port containerships movements' data' instead of 'directed from-port-to-port connections' without transit (Arcs). It indicates that during 50 days – long 1990 autumn period and 50 days – long 1992 autumn period, calling ports are reached by respectively almost 14 and 16 containerships! Connectivity of the global maritime container traffic related network is still very weak. However, index β results do not seem to be efficient and Gamma index γ provides furthermore relevant results.
Index gamma γ is a quotient of the observed number of edges to the maximum number of edges that lower limit is zero and upper limit is one assigned to all completely connected networks whether they have 5 or 5.000 vertices (Kansky, 1963)[42].
Our results for such indicator of trellis geometry of network: γ equal 0.0118 and 0.0123[43] for the two survey periods 1990 and 1992!
Thus, γ is almost invariant between the 2 periods; it quantifies direct links within the whole network. So it indicates, by comparison with 'a theoretical ideal and fully interconnected network'[44], that only a few calling ports are related without transit: 1.18% out of 888 ports and 1.23% out of 915 ports for the 2 survey periods 1990 and 1992!
This translates into the fact that to link all the container ports of the world within an existing connected network, the 'direct interport relationships'[45]are not predominant: some transhipment ports relationships constitute a valid observation.

To conclude, our connectivity measurement underlines the structuring of global maritime container traffic network that is not jointly liable nor by maritime directed connections, nor circuits and alternative circular paths. In fact, a multipolar worldwide core of highly interconnected container ports wherein transhipment and traffic distributive operations are intensive appears linked to most of the remaining sparsely connected container ports.

9. An 'Invariant Core' for the Global Maritime Network (1990&1992 periods)

The configuration of the global maritime container traffic network seems to accept a core of highly interconnected hub container ports linking the remaining sparsely connected service container port nodes to the entire maritime traffic system. According to O'Kelly and Miller's review and synthesis, a hub network consists of three major components occupying a unique geographic location and these essential elements of singular hub transportation networks are located on the earth's surface in geometric patterns:

- 'service nodes' such as points of specific location from which flows can originate and into which only flows which are destined for that specific location can enter;

[41] i.e.: oriented vessels movements data
[42] Note that Kansky named ratio 1/ γ: 'Degree of Connectivity'.
[43] so close to 0
[44] That is to say with complete connected graph bearing equal number of direct port-to-port links and port nodes
[45] i.e.: port-to-port links without transit

- ‘hub nodes’ that have the characteristics of services nodes (i.e.: they can be flows origin and destination) but also allow the passage of through-flows or transshipment flows that are not intended to that location;

- Lastly, ‘arcs’[46] that connect the service nodes and hub nodes must have the two following properties:
    (1) Every ‘service node port’ must be connected to, at least, one hub port node;
    (2) A valid path must exist between all ‘hub port nodes’.

These properties ensure that feasible path will exist between all origins and destinations in the network (O’Kelly et al, 1994).

Figure 13: World Container Ports distribution according to The i port’s incidence degree: d(Port i)

Survey Period \ d(Port i)	>100	]50, 100]	]10, 50]	]0, 10]
1992	1% (5 ports + 2 nautique transit points)	3% (28 ports)	26% (234 ports)	70% (646 ports)
	d (Port i) > 10 ≈ 30% (269) which 25% (North-western Europe: A), 17% (Mediterranean: B), 16% (USEC, Caribbean & Gulf Coast: C) & 14% (Far East Asia: F)			which 46% as d (Port i) ≤ 2
1990	1% (4 ports + 2 nautique transit points)	3% (25 ports)	24% (212 ports)	72% (645)
	d (Port i) > 10 ≈ 28% (243) which 29% (A), 21% (B), 14% (C) et 14% (F)			which 47% as d (Port i) ≤ 2

Incidence degree (of a given vertex) is a graph theoretical measure of individual elements of transportation networks, which provides the number of edges from a given vertex to each of the other vertices. Port incidence degree d(Port i) provides total number of from-port-to-port links from a given port to each of the others (Figure 13).

It shows that:

- Relay – ports[47] as d(Port i) ≤ 2 (including ‘service node ports’) represent a ports subset of 70 to 72% from total number of ports which do not belong to the core;

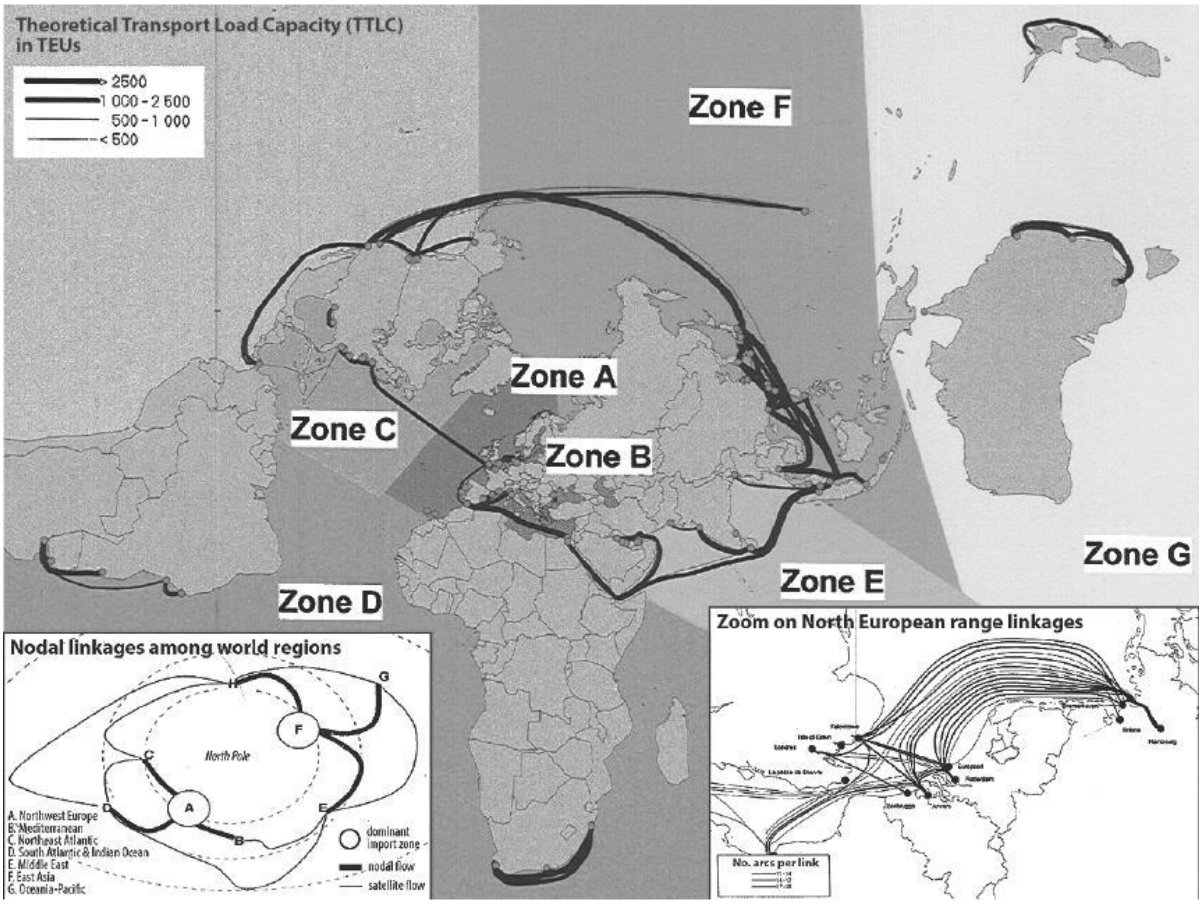
- Other Port incidence degree results provide 3classes of container ports which d(Port i) belong to]10, 50],]50, 100] & >100, constitute major part of ‘the invariant container ports core’ and represent minus 30% from total number of ports.

Within this minor subset, one can find major hub and load – centre ports[48] that reaches sufficient volumes to sustain high efficiency shipping in a high density trade corridors with high connectivity level[49], the former ports might be regarded as ‘Mega terminals’ (Robinson, 1998) - except the 2 world main nautical transit points: Panama Canal & the Straits of Gibraltar.

[46] That is to say directed links without transit
[47] As common seaports
[48] 1+3=4% of the overall ports
[49] d(Port i) belonging to]50, 100] & d(Port i) >100

It is clearly outstanding that 'the spatial significant[50] re-distribution of channelled container flows' is operated by a few container terminals and ports but with a wild range of local characteristics. Partial analysis of 2001 results seems to present a less than 200 container ports core which keep less than 25% (North Western Europa: A), less than 17% (Mediterranean: B), less than 16% (USEC, Caribbean & Gulf Coast: C) & more than 14% (Far East Asia: F) geographical distribution[51].

Figure 13 bis: World Maritime Container flows in 1992 and Underlying Structure (Joly, 1999)[52]

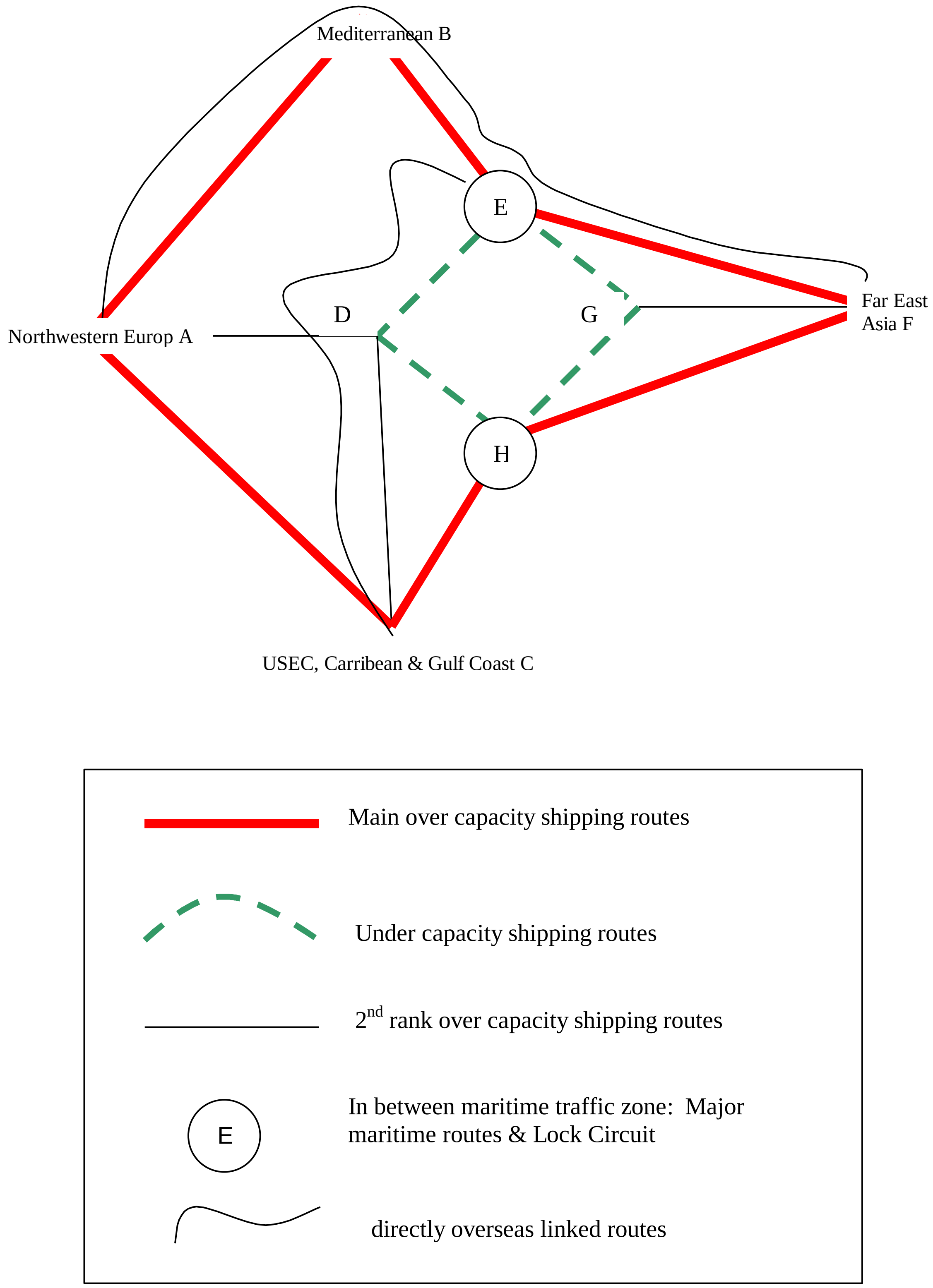


50 Considered on a global scale

51 Sea below in the added Figure 13bis by O. Joly 2021 showing the representation of the geographical division of maritime areas according to the 1988 Reed's Marine Distances Table.

52according to César Ducruet. La spatialité des réseaux maritimes : Contributions maritimes à l'analyse des réseaux en géographie. Géographie. Université de Paris 1 Panthéon-Sorbonne, 2016.

Figure 14 : 8 Main world maritime container traffic zones & Shipping routes: Scale-free network structure



10. Structuring of world maritime container traffic network closed to scale-free

The main ports of the world, considered as a whole, admit a hierarchical spatial structure. Ranges or Regions hierarchy are then considered as a structure in their own right whose different parts are linked by predominance relationships (Medda et al, 2000). Using 'the dominant-flow approach' as pioneered in 1961 by Nystuen and Dacey that involves a prior rule to define the 'centrality' of a place within a system (Rabino et al, 1997), it makes possible to underline bipolarisation and organization into a hierarchy of 8 main world maritime traffic zones from A to H[53]) in both terms of:

- the import and export dominant maritime areas and port ranges,
- In addition, the satellite[54] maritime areas (Figure 14) and port ranges (Joly, 1999)[55].

However, within a given seaport range, there are many non – predominant ports which are directly linked without any size determinism to various non – closely related port ranges (Figure 14), even directly connected to single overseas container ports within a non-adjoining port range and such configuration define scale-free network structure (Watts, 1999 & Stocker et al, 2002). First part of this assumption is close to the 5th phase of Hayuth's 5 phases model for containerized port systems relative to: 'New direct service lines to some peripheral ports emerge, while the ocean trade route network is still composed of a relatively few consolidated long-distance routes' (Wang, 1998). It follows that this configuration could well be useful to describe the early steps of scale-free network structure.

11. Concluding remarks

The main results can be summarized as follows:

(a) There is some degree of correlation between scale-free network structure of global maritime container traffic network and evolving pattern of world container traffic distribution. So because of the scale-free structure of this network and its strongly connected whole shape[56], data and traffic flows spread quicker and easier than within classical hierarchical network or within weakly connected networks.

(b) This degree of correlation between the scale-free network structure of global maritime container traffic network and the evolving pattern of world container traffic distribution could be an explanation for non – Gaussian fluctuations & an explosive growth of container maritime traffic throughputs.

[53] With reference to the practical and gobal spatial division of maritime areas proposed by the Reed's Marine Distances Table Editions.
[54] or 2nd rank maritime areas
[55] See JOLY, O. (1999) The Structuring of maritime traffic networks: Location of interconnected seaport platforms in North Western Europe.
[56] Namely integrating the 'invariant core'of highly interconnected hub container ports linking the remaining sparsely connected service container port nodes to the whole maritime traffic system

In response, that is why port activities are complex and partly scale-free. One single recognized ‘’shipping line operator’’ or even one unique new comer can always open an unprecedented maritime service on one specific market segment. Consequently, the concerned port community will gain new trades. The related global maritime network exhibits these changing properties[57].
Finally, in this paper[58], we try to associate statistics and graph tools. This research could be continued by improving the understanding of traffic evolution within complex network systems. Furthermore, it will give keys to appreciate numerous seaport cases.

Bibliographie (as in June 2003)

MANDELBROT, B. (1997) Fractales, hasard et finance. Paris, Champs – Flammarion

ZAJDENWEBER, D. (2000) Economie des extrêmes. Paris, Nouvelle Bibliothèque Scientifique, Flammarion

ARTHUR, W. B. (1990) Silicon Valley locational clusters: When do incrasing returns imply monopoly. Mathematical Social Science 19, 1990

SCOTT, A. (2001) Les régions et l'économie mondiale. L'Harmattan

ORLEAN, A. (2001) Le pouvoir de la finance. O. Jacob

WATTS, D. J. (1998) Small worlds: The dynamics of networks between order and randomness. Princeton University Press, 262 p.

GOULIELMOS, A. M. (2002) Complexity theory applied to management of shipping companies. Maritime Policy & Management. Vol.29, n°4, pp. 375-391

KANSKY, K. J. (1963) Structure of transportation networks, Relationship between network geometry and regional characteristics. 1963, University of Chicago, Chicago, 155 p.

O’KELLY, M. O.; MILLER, H. J. (1994) The hub network design problem – A review and synthesis. Journal of Transport Geography 1994 2(1) 31-40

RABINO, G. A.; OCELLI, S. (1997) Understanding spatial structure from network data: Theoretical considerations and applications. CYBERGEO, N°29, 26/06/97

MEDDA, F.;NIJKAMP, P.; RIETVELD, P. (2000) Hierarchies of spatial networks systems. New Contributions to Transportation Analysis in Europe. In BEUTHE, M.; NIJKAMP, P. (Ed.) New Contribution to Transportation Analysis in Europe. Aldershot, Ashgate, pp. 151-167

[57] so called ports’hazard

[58] This paper was presented in Le Havre, June 5, 2003 at the 5th session, Research Seminar ‘Maritime Transport, Globalisation, Regional Integration and Territorial Development’.

ROBINSON, R. (1998) Asian hub/feeders nets: the dynamics of restructuring. Maritime Policy & Management. pp. 21-40

SLACK, B.; COMTOIS, C.; SLETMO, G. (1996) Shipping lines as agents of change in the port industry. Maritime Policy & Management. Vol.23, n°3, pp. 289-300

TOGZON, J. L. (1995) Systematizing international benchmarking for ports. Maritime Policy & Management. Vol.22, n°2, pp. 171-177

FLEMING, D. K. (1997) World container ranking. Maritime Policy & Management. Vol.24, n°2, pp. 175-181

STOCKER, R.; CORNFORTH, D.; BOSSOMAIER, T. R. J. (2002) Network Structures and Agreement in Social Network Simulations. Journal of Artificial Societies and Social Simulation. Vol. 5, no. 4

CAPINERI, C. (1993) Italian geography and networks: a bibliographical essay. Flux 11 January – March 1993

WANG, J.J. (1998) A container load center with a developing hinterland: A case study of Honk Kong. Journal of Transport Geography. Vol.6, n°3, pp. 187-201

Data sources:

Containerisation International Yearbooks, 1989 to 2001

Lloyd’s Voyage Records, autumn 1990, 1992, 1993

JOLY, O. (1999) Structuring of maritime traffic networks: Location of interconnected seaport platforms in North Western Europe. PhD Thesis Transport Geography & Planning. University of Le Havre Normandy, le Havre, France, pp.652. ISBN: 9782729541576