<u>*MSc in International Shipping, Finance and Management*</u>

RANKING OF WORLD PORTS: DETERMINANTS AND SYSTEM DYNAMICS

by

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CERTIFICATION OF THESIS PREPARATION

We hereby declare that this particular thesis has been written by us, in order to obtain the Postgraduate Degree (MSc) in International Shipping, Finance and Management, and has not been submitted to or approved by any other postgraduate or undergraduate program in Greece or abroad. This thesis presents our personal views on the subject. All the sources we have used for the preparation of this particular thesis are mentioned explicitly with references being made either to their authors, or to the URL's (if found on the internet).

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Abstract

This thesis constitutes a research and estimation of the mobility of the top 50 world port rankings, for a time horizon of 16 years (2002-2017). However, our study focuses on the mobility differences between two sub-periods, 2002-2009 and 2010-2017. Any ranking conditions displayed in this assignment refer solely to the containerized trade, since data collection and credibility are more feasible through the twenty-foot equivalent measurement units (TEU). Through application of the Markov Chain model and various mobility indices, we notice higher mobility (lower persistence) in the first era. Lower persistence is documented in inferior ranking positions as well, compared to higher ones. Additionally, higher probability for ranking deteriorations, in comparison to ranking improvements, is shown for both sub-periods. A supplementary goal of this thesis is the consideration of possible factors determining the overall ranking positions acquired during the data collection process. Few of the variables were proven significant, while others do not affect the port rankings considerably.

Introduction

The endeavor of measuring the competitiveness of the ports around the world is not something of great novelty. Many studies, in the form of non-academic and academic articles, have investigated the ports either individually or in groups just to determine the reasons behind their performance. Being preferable among hundreds of competitors is not an easy task, let alone sustain this preference over the years. This is the reason why this thesis will attempt to analyze the World Port Ranking of various ports, in order to realize their transitions and estimate their ranking persistence over time.

The thesis presented refers to the World Port Rankings, specifically of container ports. The reason behind this preference was data availability and data validity as well, due to the standardization of TEU measurement units. The topic to be analyzed is of great importance, since the literature review on the matter is scarce. However, actual data collection was not an easy task, since during previous years gradually fewer data are being kept in record. Through the analysis of an extensive data set that could be retrieved from sources like (UNCTAD, n.d.), (Lloyd's List Intelligence, n.d.) and (American Association of Port Authorities, n.d.), the goal was to notice throughout the years, which ports sustain their rank, which ones drop and/or rise and which exit or enter the top list. Such analysis is pertinent to the persistence and the transitions of the data collected.

Many researchers focus on how to measure sustainability, efficiency and competitiveness of the ports (most of the times not taking into account the aspect of long time horizon) with the assistance of various models that are reported in the literature section (AHP, DEA and many more). However, this is not the case here. The focus here is to measure possible transitions and capture any persistence of the container port rankings using panel data (regarding different ports for a long time period).

Based on world port rankings, this thesis will specialize on the properties of ranking dynamics during a certain time horizon. The methodology that will be followed is an application of the Markov Chain Model, in order to estimate a transition matrix based on which, several indices will be applied to capture the persistence of the system. Concerning the model used, the research done by Vasileios M. Koutras and Konstantinos Drakos: «*A migration approach for USA banks' capitalization: Are the 00s the same with the 90s?*» (Drakos, 2013) will be a useful guide and also followed closely, along with Sommers, P., & Conlisk, J. (1979): «*Eigenvalue immobility measures for Markov Chains. Journal of Mathematical Sociology, 6, 253–276.*» (Sommers, 1979) and Noris, J. (1998). «*Markov Chains. Cambridge University Press.*» (Noris, 1998)

Literature review

As mentioned in the introduction section, no previous literature exists for consultative purposes. Therefore, the papers that were reviewed and are presented here are solely for the purpose of indicating to the reader the method that is applicable in order to get the necessary results. The most valuable guide is the paper released by Vasileios M. Koutras and Konstantinos Drakos. Though their analysis was on the topic of banks (classification to various categories according to the banks' capitalization), the method that will be introduced to the next section is quite similar. Further papers using similar methodology are the following: P.A. Geroski, S.Toker, on the topic of top 5 manufacturing firms in UK (P. A. Geroski, 1994), Anna Lukiyanova, Aleksey Oshchepkov, topic of income mobility in Russian households (Anna Lukiyanova, 2011), and Joan Daouli, Michael Demoussis, Nicholas Giannakopoulos, on topic of educational mobility in Greece (Joan Daouli, 2010). Summon Kumar Bhaumik and John S. Landon-Lane also demonstrate a similar paper, studying the topic of debt ratings migration (Summon Kumar Bhaumik, 2013).

Despite the lack of literature, various models that measure port competitiveness and efficiency exist. A representative sample of such models is being presented below.

Dong-Wook Song and Ki-Tae Yeo made a competitive analysis regarding the Chinese container ports by using the model of Analytic Hierarchy Process or AHP (Yeo, 2004). China is a special case because of its rapid growth especially after 2001, when joined the international trade by becoming a member of the World Trade Organization (WTO). China plays an important role as a major importer of natural resources and major exporter of finished goods via the transportation of containerized cargo. That is one reason among others, why the researches focused on container ports, trying to measure their competiveness through the empirical method of AHP.

AHP was introduced by Saaty in 1980 and is a process of decision making and ranking priorities. What makes it even more useful is the fact that both tangible (quantifiable) and intangible criteria can be introduced in the model in order to make simple pairwise comparisons and extract any results. The methodology can be compressed in three simple steps: 1) Establishing decision-making hierarchy, 2) Determining weights on criteria and alternatives and 3) Evaluating overall ranking of alternatives. The ultimate goal is set at top level, that is what needs to be measured. In this research case was the port competitiveness. After the goal is located, the criteria in order to make our choice are being presented and last are the various alternatives which are linked to the above criteria and to the overall goal. Further to this process, the pairwise comparisons are done in order to conclude to the most decisive and conclusive criteria. A few mathematical equations take place in order to provide the necessary weights to these criteria. The final step is the assessment of the above process to decide the ranking.

There are plenty of other relevant case studies. Just to mention a few more, there is the most recent case of West African ports by (Ismael, 2015) in which port competitiveness is being measured, based on stakeholders perspective (Maria Rosa Pires da Cruz, 2013). This is probably the most well-known and commonly used model because of its simplicity and adaptability in every aspect of managerial and strategic implications.

Another well-known model is the data envelopment analysis (DEA) which is used to measure the performance efficiency of some entities. These entities in the model are called Decision Making Units or DMU. Basically, the previous known alternatives in the AHP model are now called Decision Making Units. It was introduced by Charnes, Cooper and Rhodes in 1978. DEA is a linear programming model, expressed as the ratio of the outputs to inputs. The desired goal is to attain maximum output and minimum input and the best score assigned to the most DEA models is the score of unity to the efficiency, meaning that the best DMU or alternative is selected in respect to other inefficient DMUs. A port will be more competitive when it presents greater relative effectiveness, which in terms derives from the chosen relative factors. The DEA model evaluates the effectiveness and the individual factors-DMUs and concludes to which of these factors is more suitable and appropriate. (C. Daofang, 2015)

Going further to the use of various models, there is also the DEMATEL model or decision making trial and evaluation laboratory model. DEMATEL basically functions as the AHP system with one basic difference, though. At the AHP the criteria assumed to be independent while this method identifies the interdependence of the criteria, thus it is essential to consider the direct relation of the chosen criteria. At the research of Min-Ho Ha and Zaili Yang, *the comparative analysis of port performance indicators: Independency and interdependency* was investigated with the use of AHP for the independency and the use of DEMATEL and ANP (analytic network process) for the interdependency (Yang, 2017). Such port performance matters present a multiple criteria decision making (MCDM) issue in nature, which means that these are problems that involve multiple criteria of both quantitative and qualitative features because they involve various interplays and interdependences within a cluster and between clusters at the same level or different levels. Therefore, it is essential to figure out the cause-effect relationship between the criteria.

As a last comment on these models and the many more that exist, the general use of non-quantifiable features in such researches brings the need of such models, capable of incorporating all kinds of data and presenting a well-established result.

Methodology - Data

Before moving on to the description of the methodology, let us briefly demonstrate the pathway from data collection to data utilization and retrieval of any results. Initially, all of the ports in our disposal were corresponded to a specific ID number. Our data arsenal was the rankings of the top 50 world ports, portrayed continuously from the year 2002 to 2017, with each port expressed by its ID number. Rankings were displayed with numbers from 1 (for first position) to 50 (for last position). However, two more ranking positions were eventually added after rank 50, in order to successfully depict the new entries and exits in our top 50 port list. Thus, rank 51 contains any exits from the system, while rank 52 any new entries. These data were exploited with the use of STATA in order to estimate a transition probability matrix, the main tool for studying the persistence of the system. Thereafter, MATLAB platform was utilized to accommodate further calculations for various mobility indices, which will be minutely explained later on.

Preliminary analysis

The core of the analysis will be the estimation of the mobility properties of the data collected. The data used refer to the world port rankings for a 16-year time period, from 2002 to 2017 and include the top 50 ports worldwide, concerning only the containerized trade in those ports. The final goal is to compare these properties across two sub-periods, which constitute the whole time span of the data. The milestone used to separate the initial time lapse into two periods was the global economic crisis of 2008, but in order to split the time horizon almost evenly, it was decided to take as reference point the next year of 2009, which also has plenty to provide regarding the recession in the shipping industry, the port economics and the economy in general. Thus, the two time periods to be compared in terms of persistence are 2002-2009 and 2010-2017.

From the construction of a transition probability matrix, important information can be extracted from its main diagonal. It denotes the probability that the ranking of a port remains the same between two successive periods. In terms of Markov chain terminology, this property is usually referred as "persistence". Thus, in this case, persistence will occur if a port maintains its position during the following year. On the contrary, the off-diagonal elements of the transition matrix describe the ability of a list unit to shift in different states between successive periods. For example, a port from the i^{th} to the j^{th} year will ascend or descend one or several ranks.

More precisely, all values above the matrix diagonal indicate the trend of the rankings to deteriorate, since those cell prices denote the probability for any port of the list to move further down between two successive periods. Consequently, all cells below the diagonal indicate the exact opposite, that is, the promotion of ports to higher ranking positions. In any case, the rank indicated by the rows of the matrix refers to the current period, while the rank of the column refers to the successive one. It is crucial to note though, that any value of row 51 indicates the probability of a port that exited the list to ascend to the rank indicated by each column during the next period, while the row 52 indicates the probability of a newcomer port to reach the ranking of the column during the successive year, which is the year of its entrance.

An extreme case exists, where all the off-diagonal elements equal zero. At this point, the complete persistence case takes effect, which would be described by a transition probability matrix coinciding with the identity matrix **I**. In the case of perfect persistence, the probabilities of remaining in the same rank between any two consecutive periods would equal unity for all ranks, therefore no transitions between two successive periods (and consequently between any two periods) would occur. (Drakos, 2013). However, just a glance at the lists of the top 50 world ports from 2002 to 2017 excludes any considerations of possible perfect persistence in the system. The overall rankings along the years, as shown in the figures below, illustrate a completely different image from year to year. Thus, a preliminary induction is that several alterations have happened during this 16-year period. The scope of this thesis is to study and analyze this exact behavior. Additionally, in every period, some ports that are not spotted during other years can be noticed. This phenomenon was captured in our analysis through the addition of the ranking positions 51 and 52, as mentioned previously.

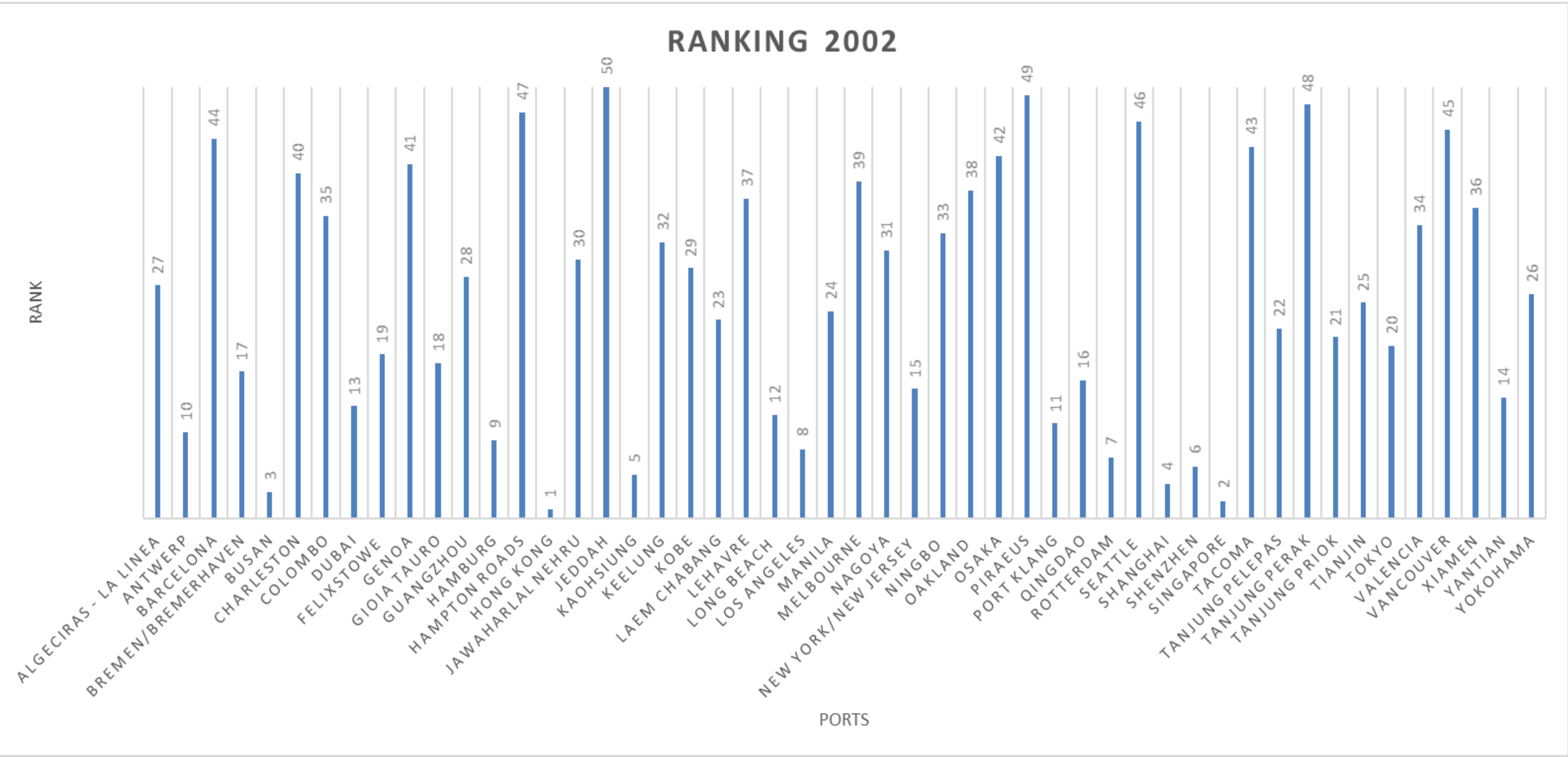

Figure 1: Top 50 ports of 2002

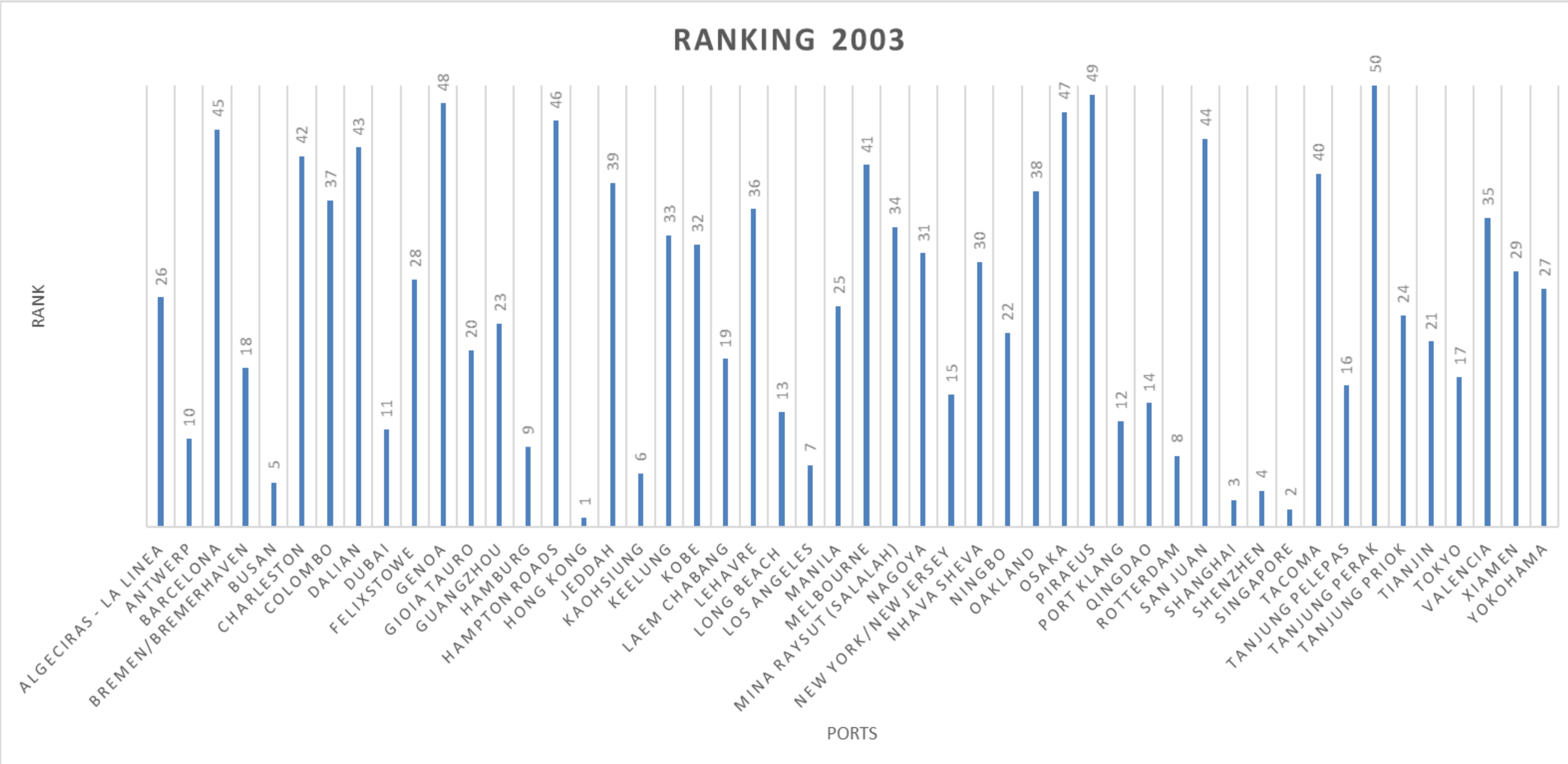

Figure 2: top 50 ports of 2003

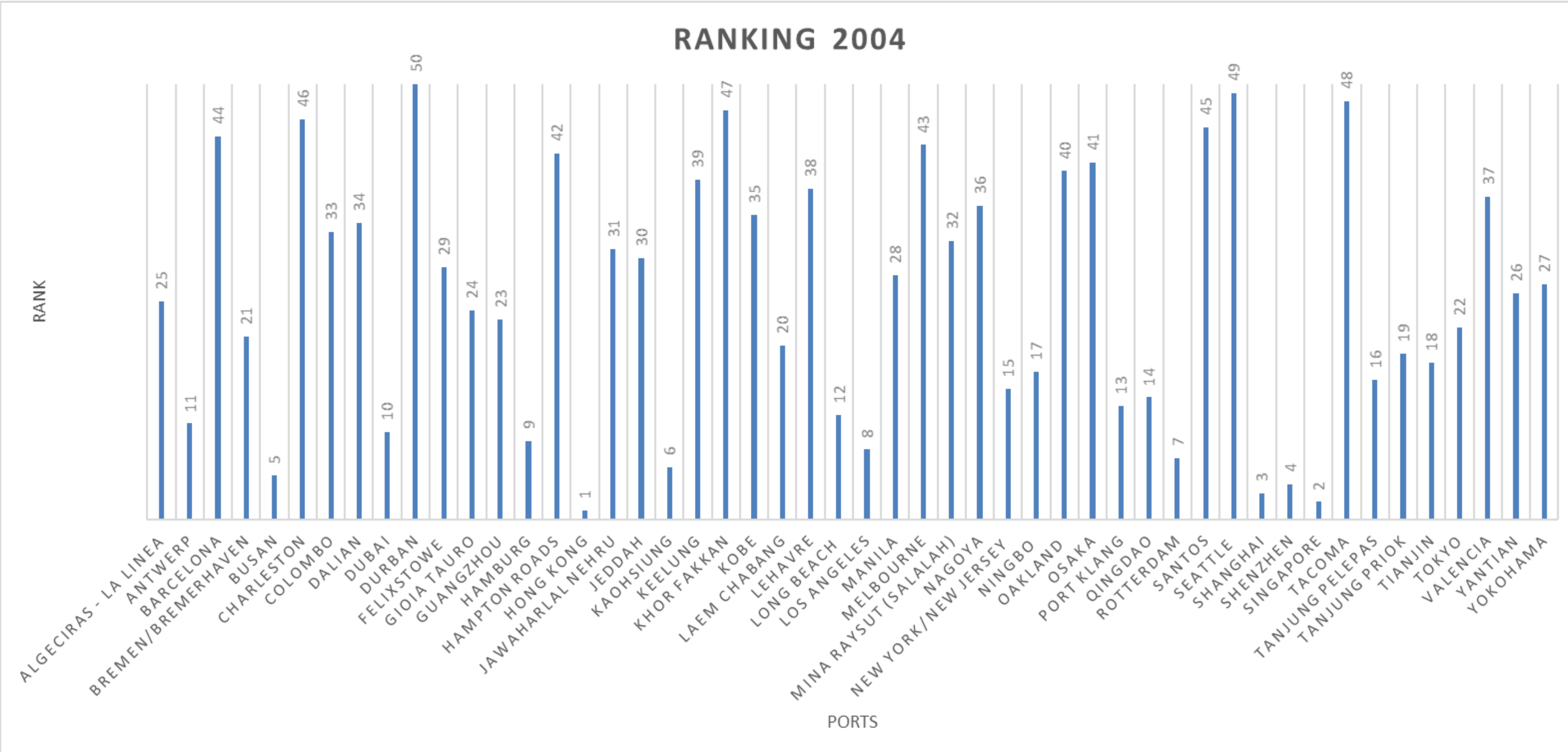

Figure 3: top 50 ports of 2004

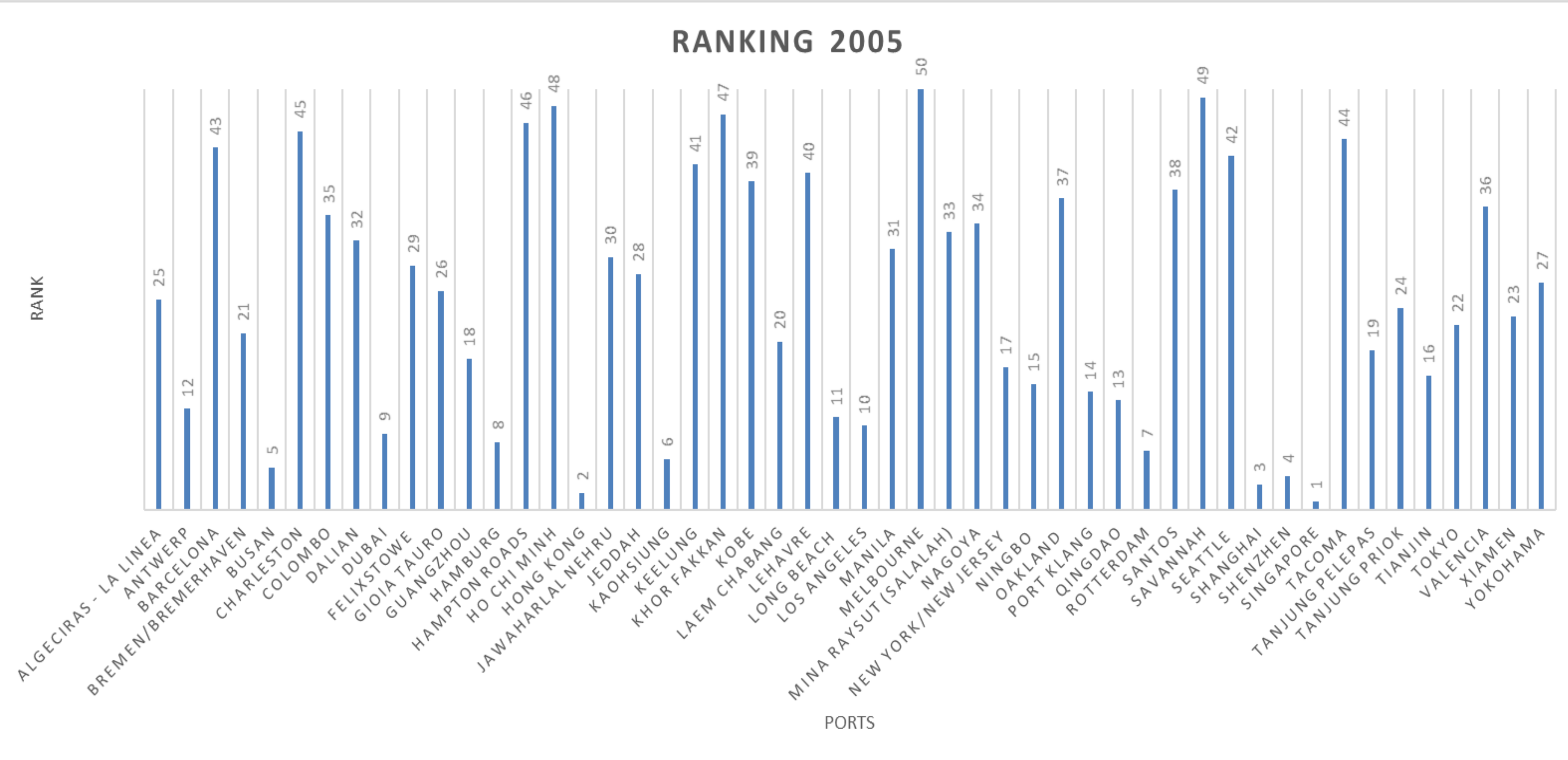

Figure 4: top 50 ports of 2005

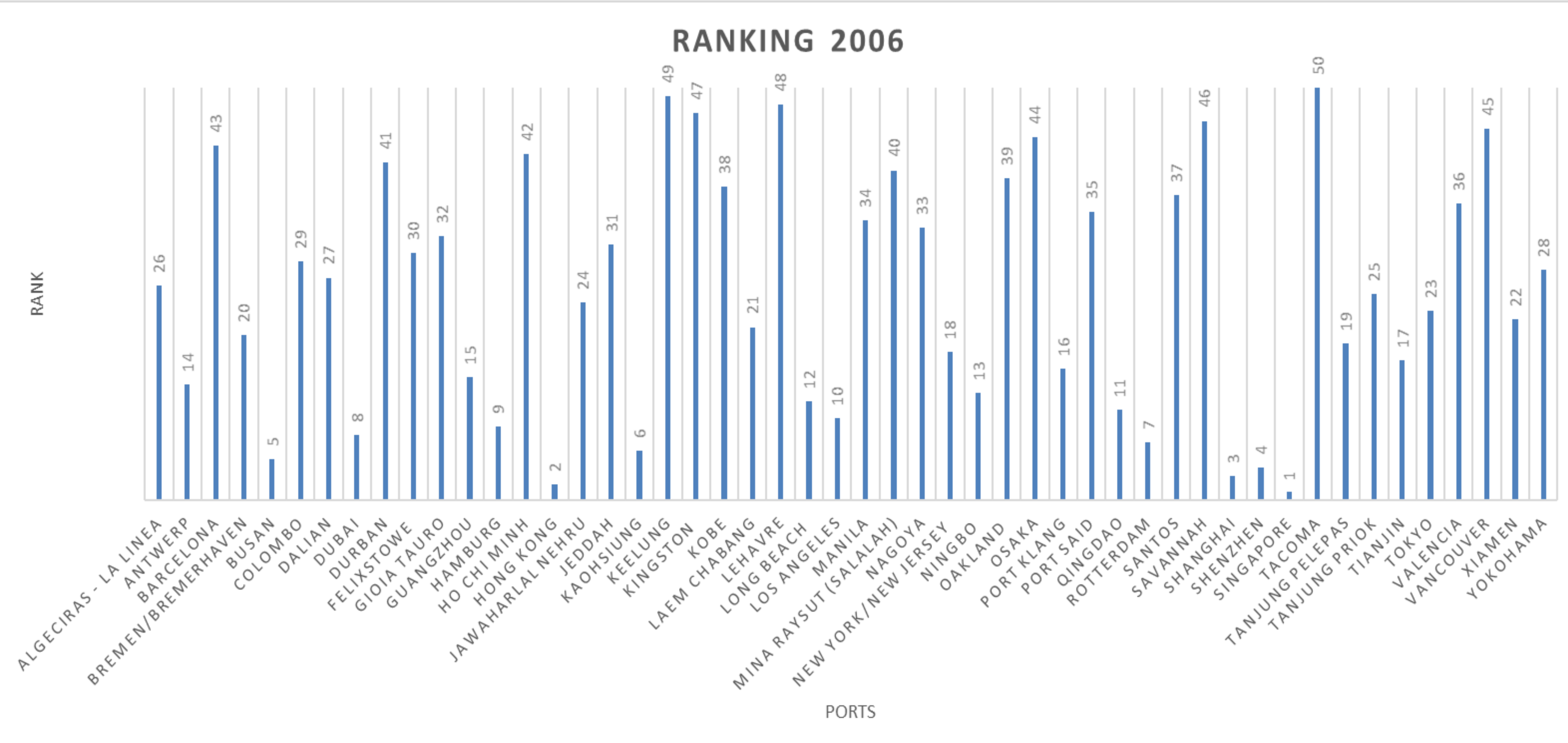

Figure 5: top 50 ports of 2006

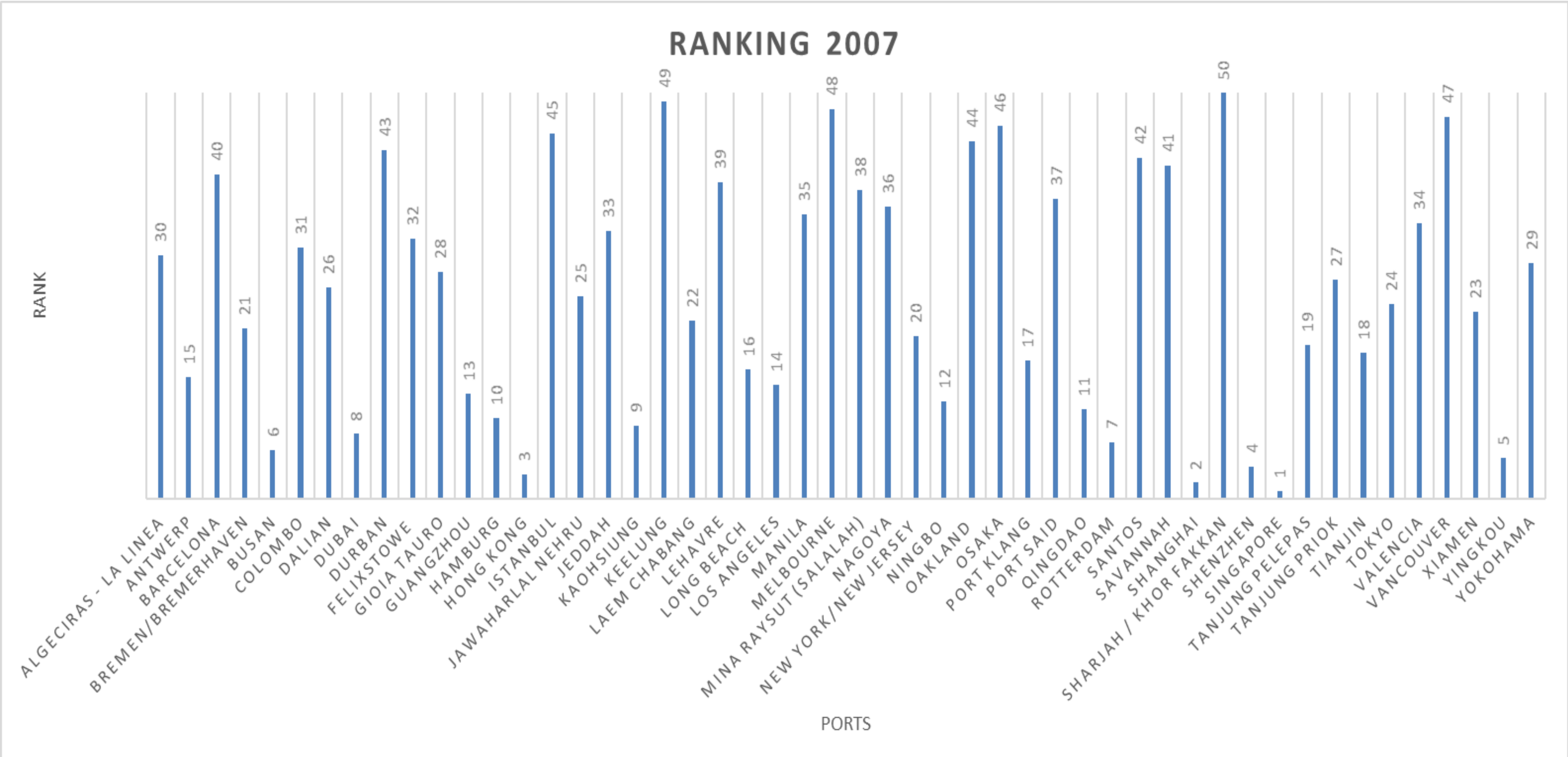

Figure 6: top 50 ports of 2007

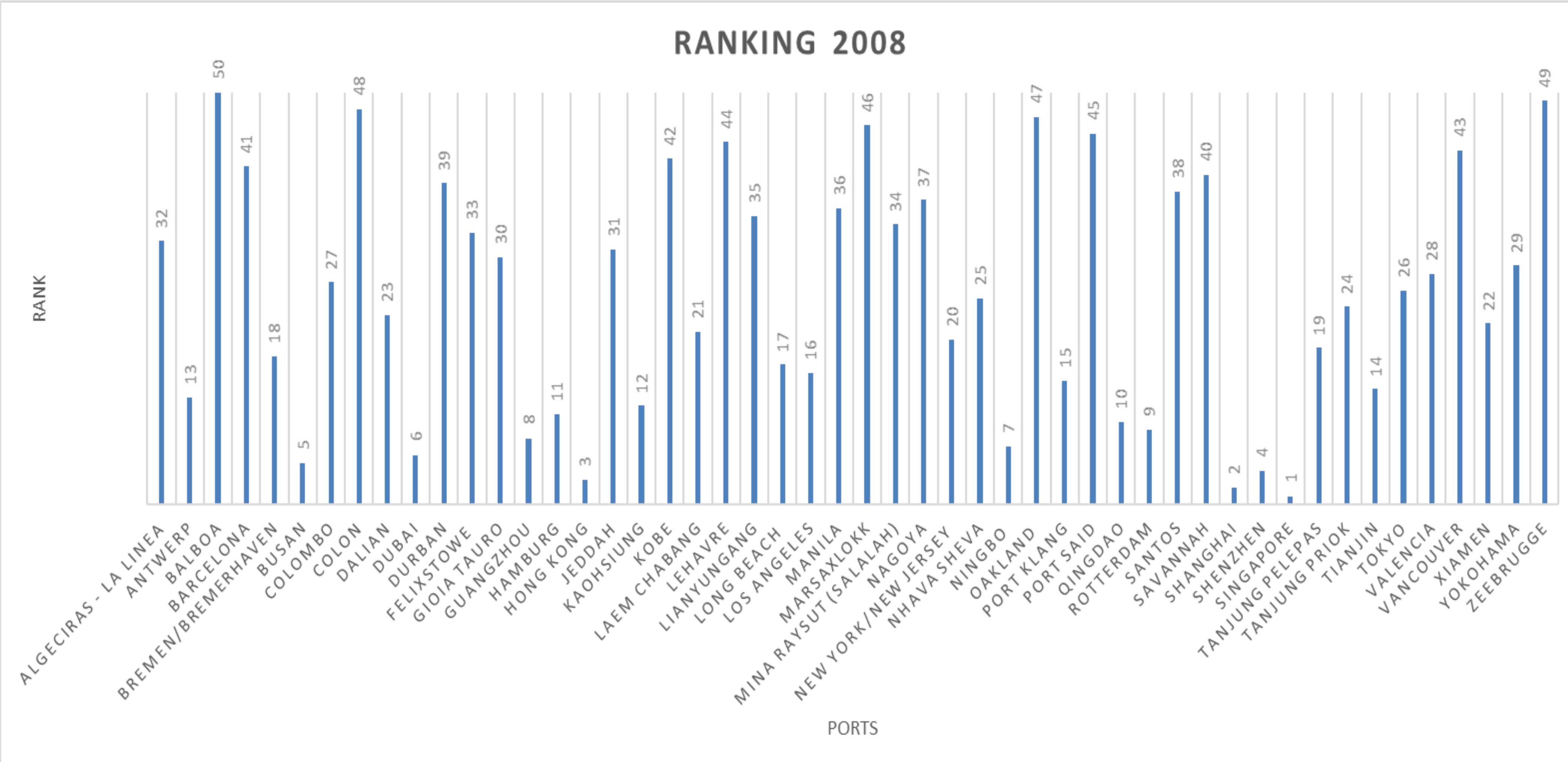

Figure 7: top 50 ports of 2008

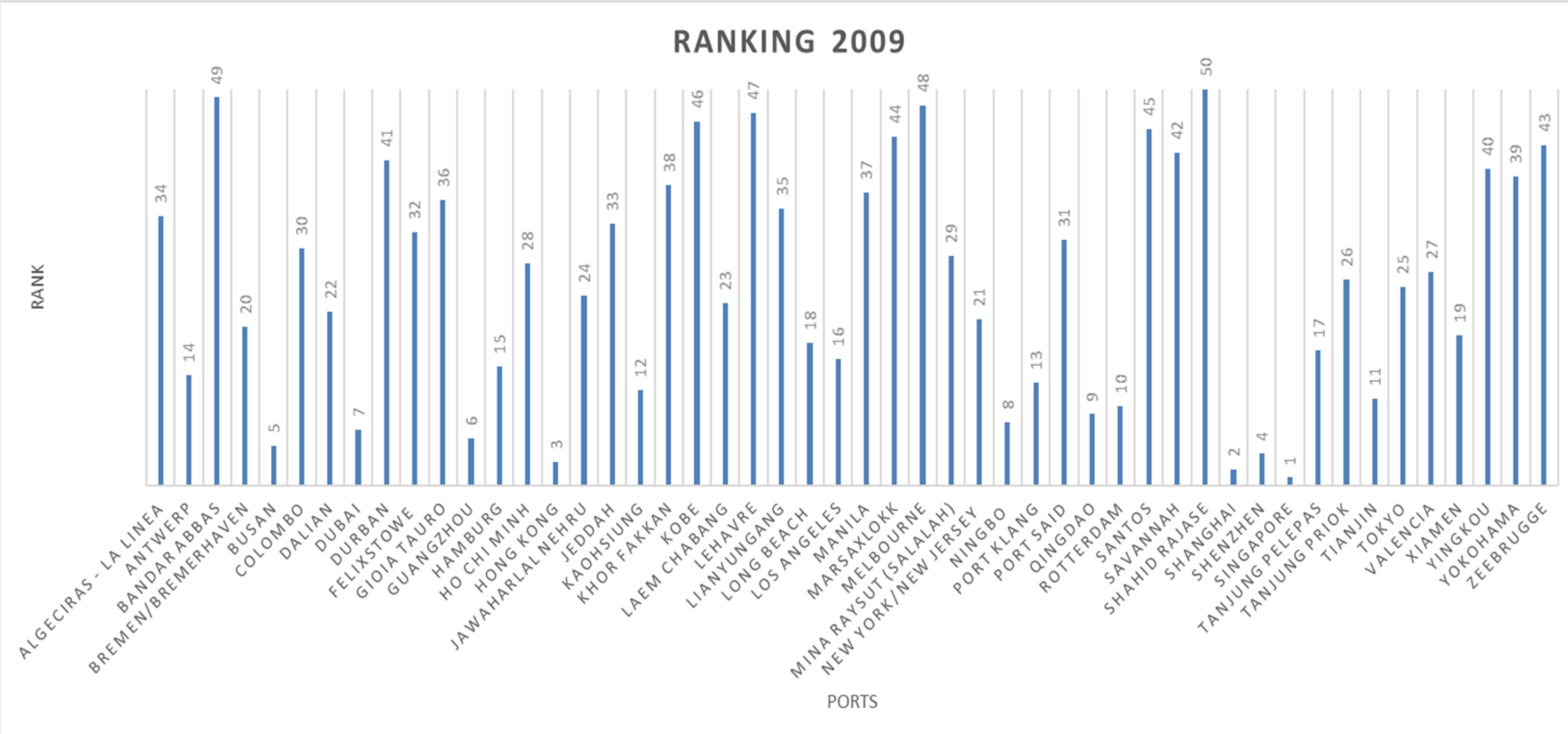

Figure 8: top 50 ports of 2009

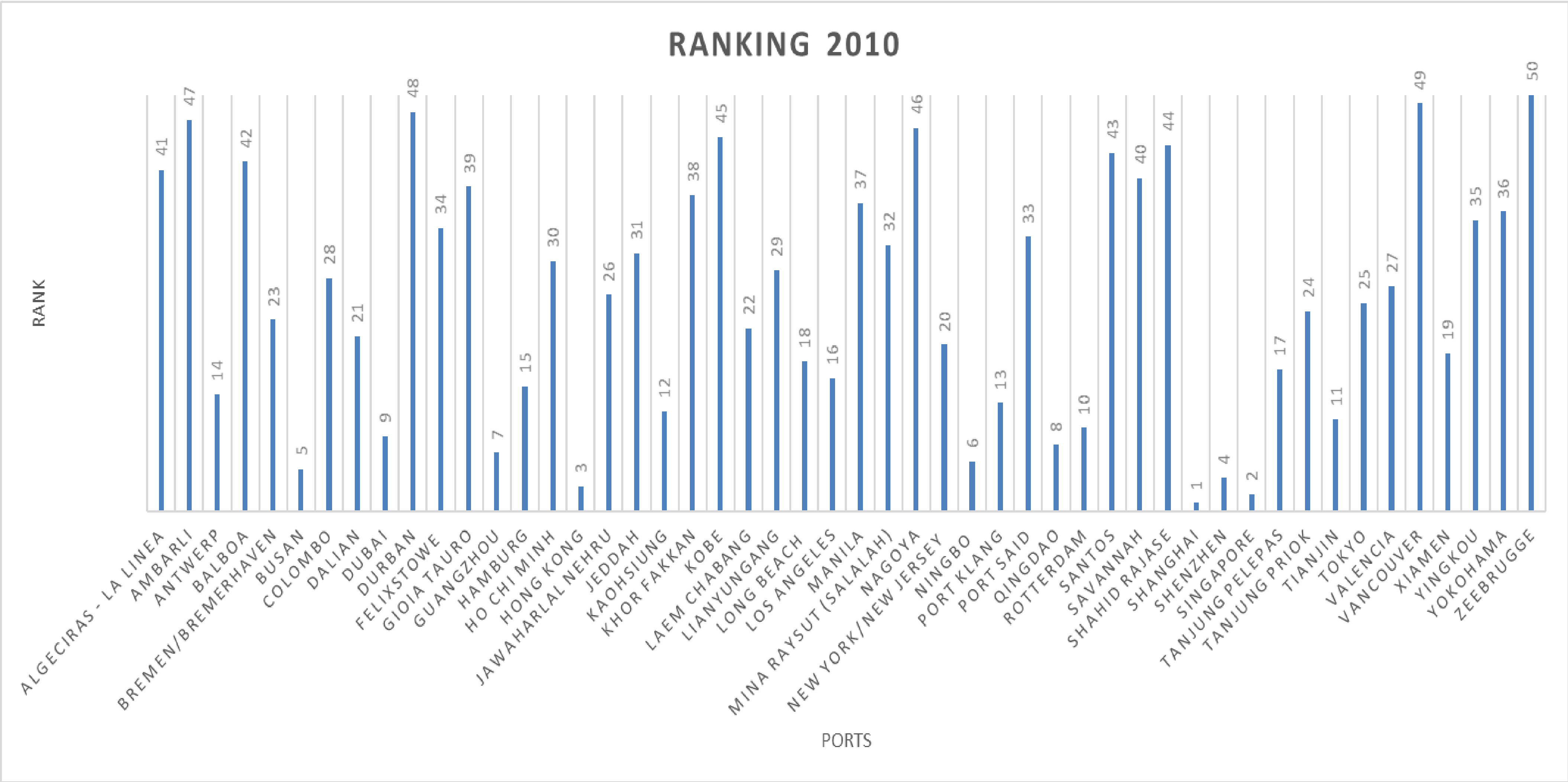

Figure 9: top 50 ports of 2010

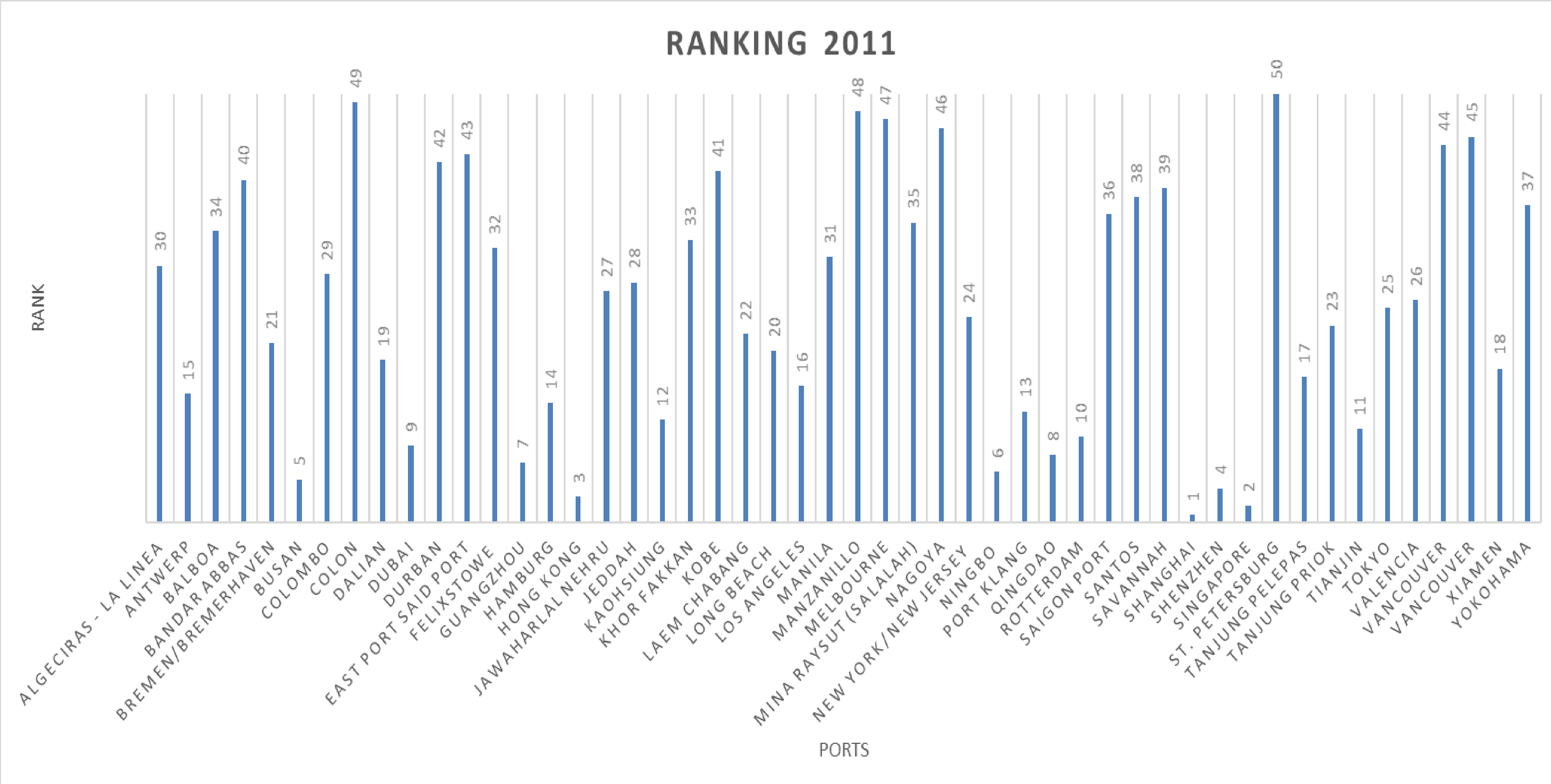

Figure 10: top 50 ports of 2011

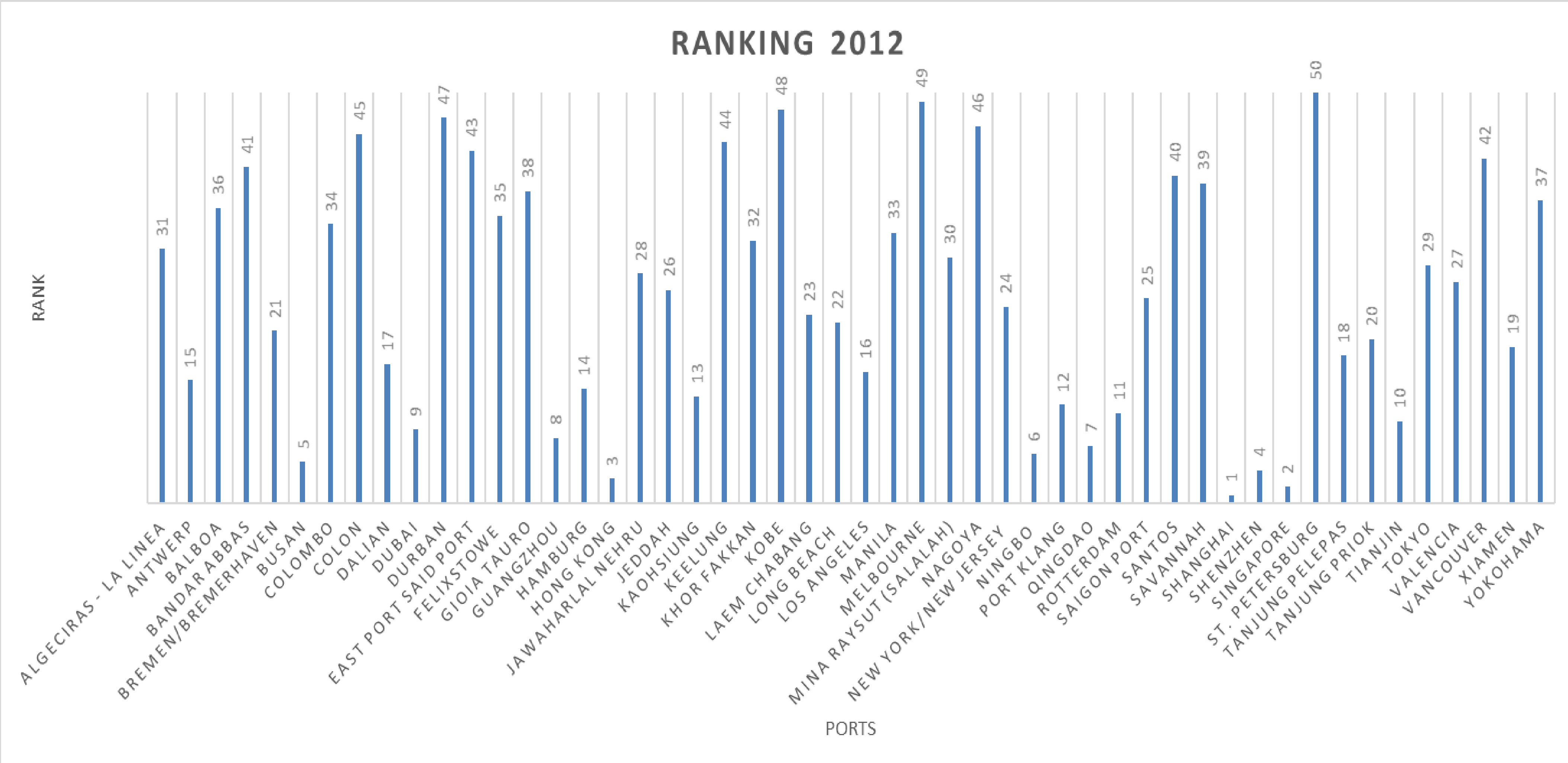

Figure 11: top 50 ports of 2012

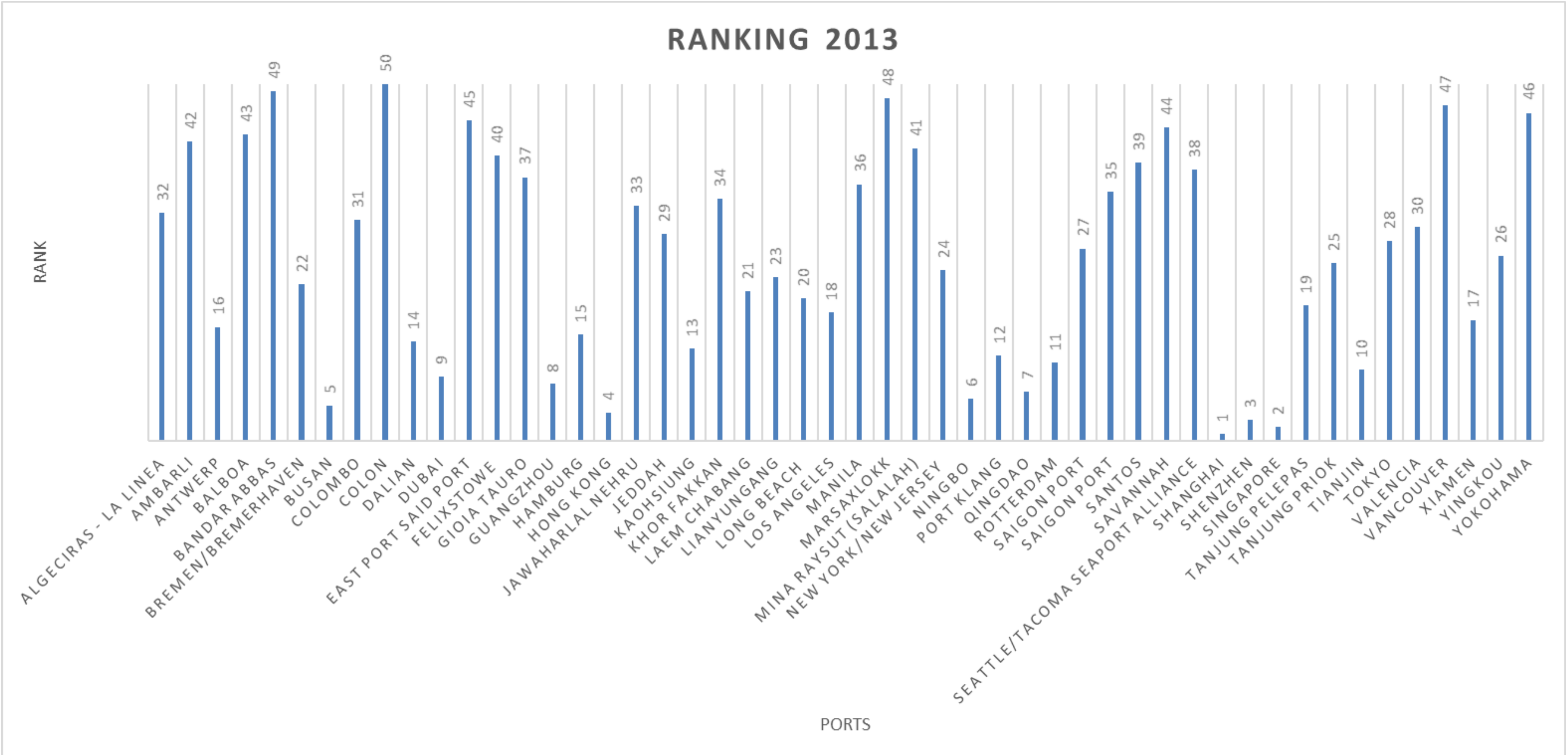

Figure 12: top 50 ports of 2013

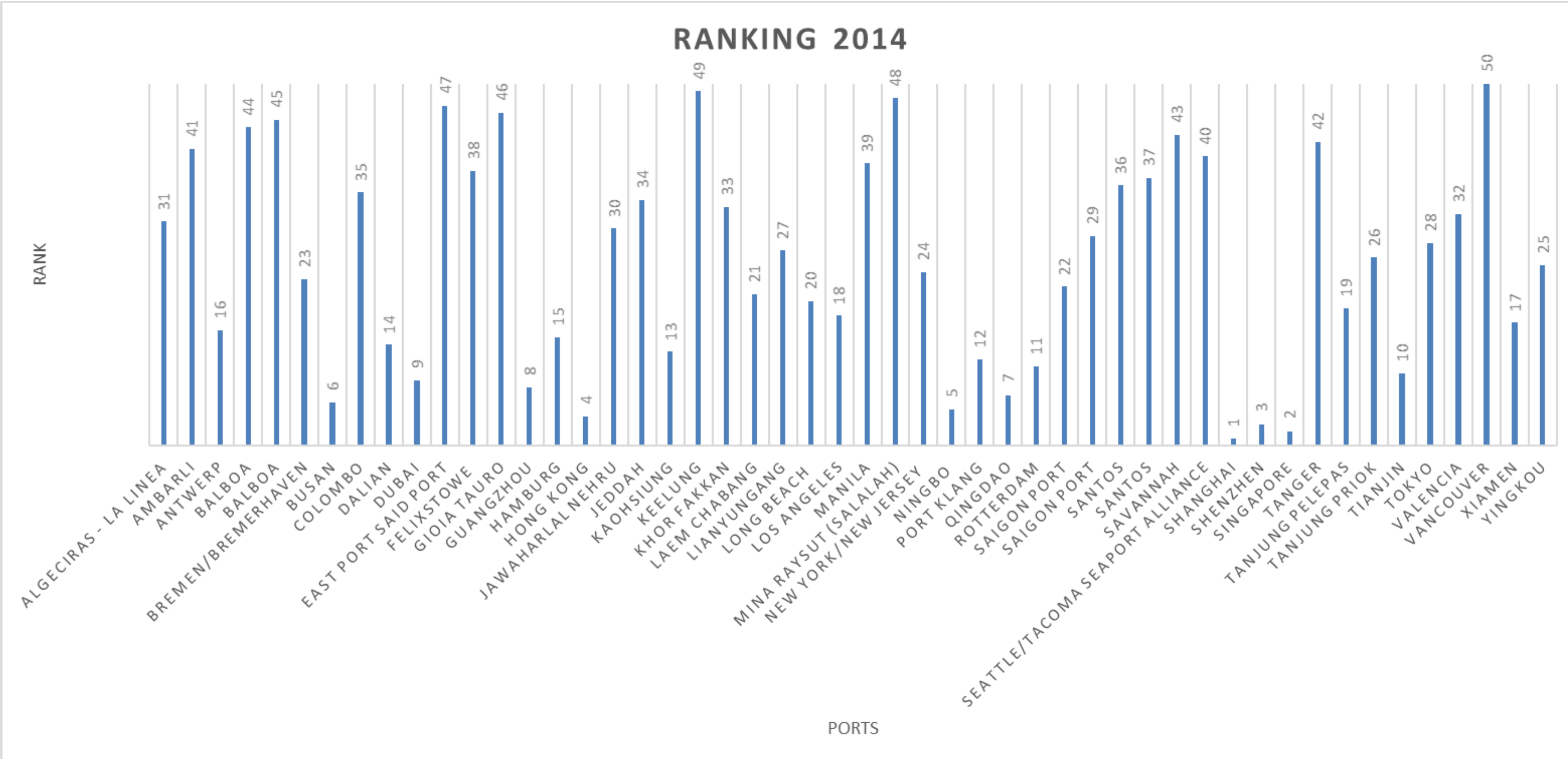

Figure 13: top 50 ports of 2014

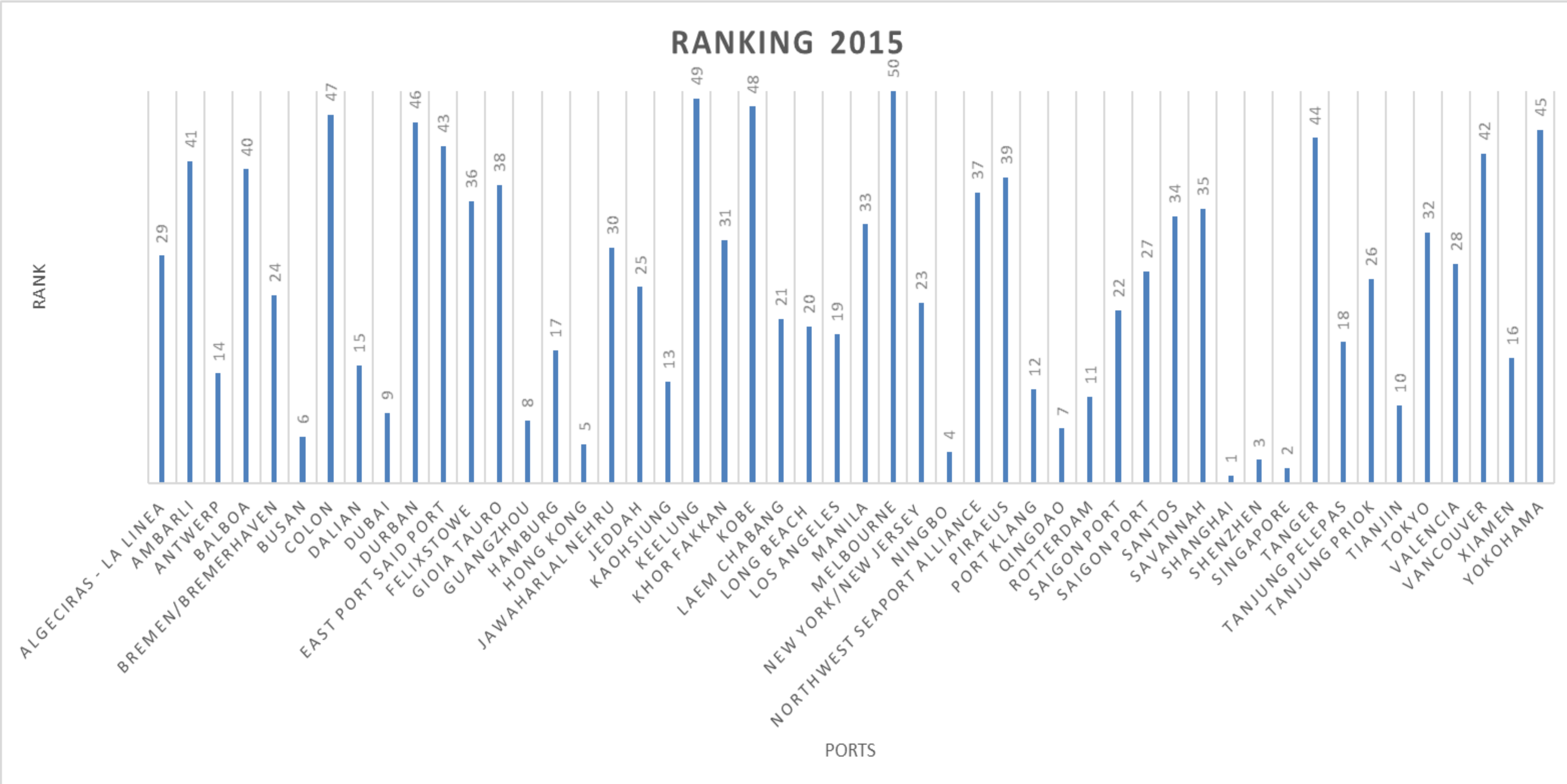

Figure 14: top 50 ports of 2015

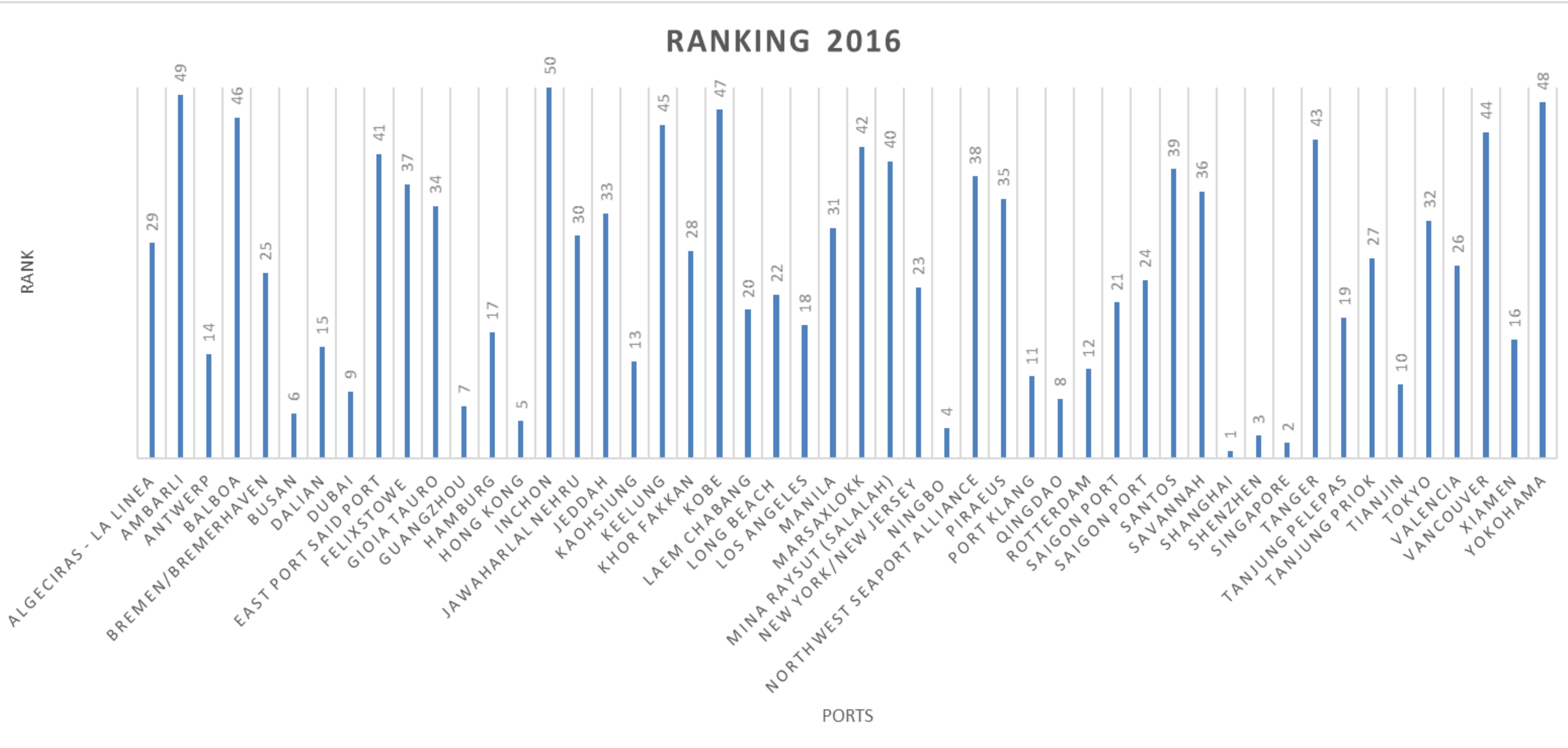

Figure 15: top 50 ports of 2016

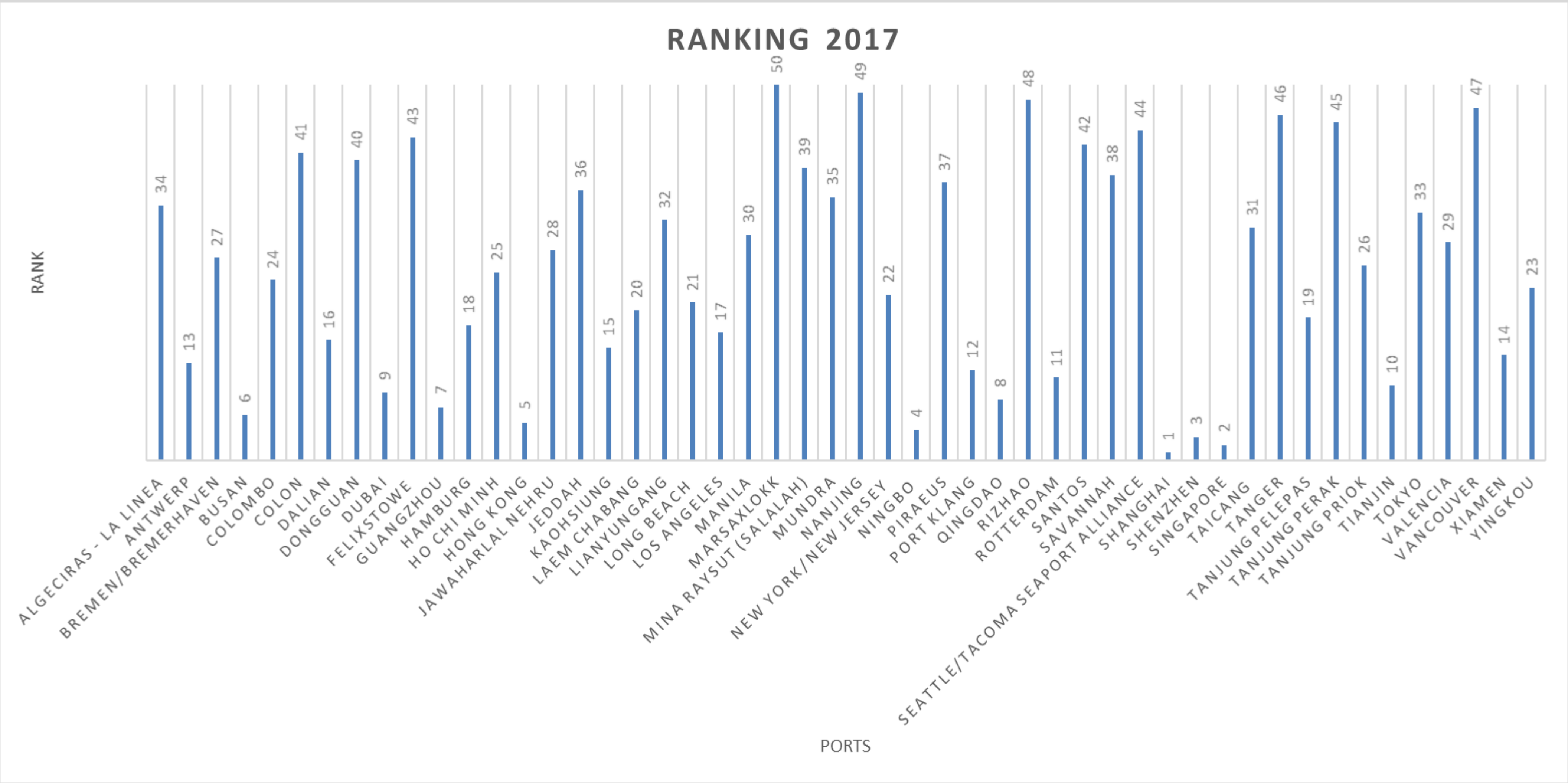

Figure 16: top 50 ports of 2017

Indices

Mobility indices

Several indices exist, separated in two main categories: Summary Mobility Indices, and Eigenvalue Based Indices. The former are computed based on the actual cells of the probability matrix, while the latter are expressed in terms of the eigenvalues of the empirical transition probability matrix under investigation.

Concerning the Summary Mobility Indices, these are the Immobility Ratio (IR), Moving Up (MU), and Moving Down (MD). The immobility ratio index depicts the percentage of ranking preservations out of all movements through the whole 16-year time period. The other two indices reflect the percentage of ranking changes, with MU indicating ranking improvements and MD ranking deteriorations. Each of the aforementioned indices assumes values between 0 and 1 (100%), representing the minimum and maximum possible value respectively. For instance, a hypothetical Immobility Ratio with value 1 corresponds to a transition matrix with absolute persistence. Additionally, any transition matrix with IR higher compared to another matrix, is characterized as more persistent. It is of essential significance that the sum of the three indices above equals 100, since it represents all movements of the ranked ports during the period of the research. The Summary Mobility indices are calculated as follows:

$$\boldsymbol{IR} = \left[\frac{\sum_{i=1}^{n} p_{ii}}{\sum_{i=1}^{n}\sum_{j=1}^{n} p_{ij}}\right] \boldsymbol{x}\, \mathbf{100} = \left[\frac{\sum_{i=1}^{n} p_{ii}}{n}\right] \boldsymbol{x}\, \mathbf{100}$$

$$\boldsymbol{MU} = \left[\frac{\sum_{i<j} p_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} p_{ij}}\right] \boldsymbol{x}\, \mathbf{100} = \left[\frac{\sum_{i<j} p_{ij}}{n}\right] \boldsymbol{x}\, \mathbf{100}$$

$$\boldsymbol{MD} = \left[\frac{\sum_{i>j} p_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} p_{ij}}\right] \boldsymbol{x}\, \mathbf{100} = \left[\frac{\sum_{i>j} p_{ij}}{n}\right] \boldsymbol{x}\, \mathbf{100}$$

Regarding the eigenvalue-based indices, the ones used here are the Prais–Shorrocks Index (Prais, 1955), the Sommers–Conlisk Index (Paul M. Sommers, 1979), the Shorrocks Index (Shorrocks, 1978) and the Half Life Index (Theil, 1972), which will be denoted as M_{PS}, M_{SC} M_S and M_h respectively. All indices, with the exception of the M_h, assume values in the [0,1] interval, with 1 denoting the highest degree of mobility and 0 the lowest. The M_h indicates the speed of convergence towards the equilibrium distribution Π ¼ lim $r \to \infty$ P^r. More precisely, it indicates how long it takes for the system to cover half of the deviation from equilibrium, and as such the half-life indicator ranges between zero (in the case of perfect mobility) and infinity (in the case of perfect immobility). Thus, a less persistent matrix would reveal a lower half-life value, in comparison to a more persistent one. The above indices are calculated by the following formulas:

$$\boldsymbol{M_{PS} = \frac{n - tr(P)}{n-1} = \frac{n - \sum_{i=1}^{n} \lambda i}{n-1}}$$

$$\boldsymbol{M_{SC} = 1 - |\lambda 2|}$$

$$\boldsymbol{M_S = 1 - |det(P)| = 1 - \left|\prod_{i=1}^{n} \lambda i\right|}$$

$$\boldsymbol{M_h = e^{-h}}, \textit{ where } \boldsymbol{h = \frac{-\,log2}{log|\lambda 2|}}$$

Finally, another index which is indirectly related to the eigenvalues of a matrix is the Singular Value Decomposition Index (SVD), which is calculated as follows:

$$\boldsymbol{M_{SVD} = \frac{\sum_{i=1}^{n} \sqrt{\lambda i}}{n}}$$

In the above formula, λi denotes the eigenvalues of the matrix **(P – I) ´ (P – I)**, where **P** is the main transition matrix. Obviously, due to the square root, only the positive eigenvalues are used here. The square roots of the positive eigenvalues of the matrix **(P – I) ´ (P – I)** are called *singular values* of **P**. So, what the above formula depicts is simply the average of the singular values of the transition matrix **P**. M_{SVD} assumes values in the [0,1] interval as well, with 1 indicating perfect mobility.

Distance metrics and indices

All indices mentioned above are very useful if one wishes to study the mobility of transitions on panel data. However, if the comparison of multiple probability matrices is the case, where each transition matrix depicts a corresponding time period, the aforementioned indices are not the only means that accommodate comparison purposes. As mentioned in the beginning, the final goal of this thesis is not to just interpret the dynamics of the port rankings during the recent years, but to segregate the accumulated data and compare different periods out of the whole time span that was selected, in order to see if they describe similar or dissimilar behavior of the between-states transitions. Therefore, the previous indices will be accompanied by additional tools, which serve the exact same purpose. It would be of special interest to compare the transition matrices P_{pre} (referring to the 2002-2009 period) and P_{post} (referring to the 2010-2017 period) by their proximity to the perfect immobility state. So, the point here is to compute the distances of P_{pre} and P_{post} matrices from the identity matrix **I**, in order to compare them with each other. The matrix with the lower distance would be the one with the higher persistence. The utilization of these extra metrics will contribute to the validation of any results drawn from the initial mobility indices, resulting to a more precise and confident outcome. Three of the most commonly used distance metrics, which are based on cell-by-cell differences, are the Euclidean distance: D_{L2} (Anil Bangia, 2002), the absolute deviations distance: D_{L1} (R. Israel, 2000), and the maximum distance: D_{Lmax} (Truck, 2004). Their formulas are indicated below:

$$\boldsymbol{D_{L2}(P,Q)} = \sqrt{\sum_{i=1}^{n}\sum_{j=1}^{n}\left(p_{ij} - q_{ij}\right)^2}$$

$$\boldsymbol{D_{L1}(P,Q)} = \sum_{i=1}^{n}\sum_{j=1}^{n}\left|p_{ij} - q_{ij}\right|$$

$$D_{Lmax}(P,Q) = \max_{1\le i,j\le n} |p_{ij} - q_{ij}|$$

The above metrics (D_{L2}, D_{L1}, D_{LMAX}) correspond to a special case of the more general formula (Randall Jackson, 2010):

$$D_{weight}(P,Q) = \left(\sum_{i=1}^{n} \sum_{j=1}^{n} p_{ij}^{r} \, |p_{ij} - q_{ij}| \right)^{1/p}$$

The parameters r and p vary from -1 to 1 and from 1 to infinity respectively. The distance metric indices D_{L2}, D_{L1}, D_{LMAX} occur when r=0, p=2 and r=1, p=infinite respectively. If r=p=1, the weighted absolute difference formula is formed:

$$D_{WAD}(P,Q) = \sum_{i=1}^{n} \sum_{j=1}^{n} p_{ij} \, |p_{ij} - q_{ij}|$$

However, there is an asymmetry met here since D_{WAD}(P,Q) does not equal D_{WAD}(Q,P). The following indices can be used to correct this anomaly:

$$D_{WAD}^{average}(P,Q) = 0.5(D_{WAD}(P,Q) + D_{WAD}(Q,P))$$

$$D_{WAD}^{max}(P,Q) = max\,(D_{WAD}(P,Q), D_{WAD}(Q,P))$$

In this study, the D_{WAD} average will be the one to contribute to our research, regarding the comparison between the two sub-periods. Lastly, a distance metric by Truck S. and Rachev T. (S. Truck, Changes in migration matrices and credit VaR- A new class of difference indices, 2006) , (S. Truck, Rating based modeling of credit risk: theory and application of migration matrices, 2009) will be of use in our analysis, based on the singular value decomposition indices of the mobility matrices. The formula is given as:

$$D_{SVD}(P,Q) = |M_{SVD}(P) - M_{SVD}(Q)|$$

It is of essential significance to note that any value of the aforementioned cell by cell difference and distance metrics is of no use on its own. Basically, these indices denote the distance of a matrix from the perfect immobility (the identity matrix). The point is to compare the values of these indices between the two mobility matrices introduced later on. The one with distance indices of lower value will be the one characterized with less mobility, thus with fewer ranking transitions through the years.

Determinants of rankings

An adjunct purpose of our study is the estimation of possible port characteristics determining the ranking positions used for the estimation of the matrices. For this objective, eight variables were utilized: harbor size, channel size, anchorage size, cargo pier size, max vessel size, repairs availability, dry-dock size and railway size. All aforementioned variables were chosen deliberately, since they constitute major features of a port's structure and any expansion would require significant amount of capital from port authorities.

A few words describing the above variables so that the reader can understand the reasoning behind these preferences:

1. **Harbor size**: it is determined not by just one factor, but by many, like the whole port area (shore), the berths of the port, the facilities, etc.
2. **Channel size**: channel size specifically constitutes a crucial factor, as the channel is the path followed by a vessel to the inner anchorage of a port or to the wharf/pier in order to proceed for cargo operations.
3. **Anchorage size**: similarly to the channel size, the anchorage depth is a determinant of the vessels that can be accommodated to this area due to size limitations.
4. **Cargo pier size**: the other alternative, other than the anchorage area is the cargo pier, where a vessel is taken from the channel it follows. Again, its depth and dimensions are

crucial parameters to determine what kind of vessel can be accommodated in the cargo pier.

5. **Max vessel size**: this variable depends on the length, beam and draft of the vessel that can enter the port and use its facilities. Since previously the depth was taken into consideration, where higher depths can accommodate vessels with higher drafts, this is not enough to check whether the vessel can berth or anchor in the port, thus making its physical dimensions an equally important factor.
6. **Repairs availability**: it is essential for a shipping company to know where its vessels can undertake major or minor repairs, depending on the situation. There are not few occasions where vessels going for cargo operations and ending up doing some repairs as well.
7. **Dry-dock size**: Dry-dock is related to any repair, major or minor, needed by the vessel. Dry-docks accommodate special and intermediate surveys as well, something that has to be done to every vessel every 5 and 2.5 years respectively, so it can be ready to sail again without severe penalties.
8. **Railway size**: the size of railway facilities in the adjacent inland of the port gives the port the advantage of high speed transportation of cargo, contributing to its overall performance.

The value interval for each of these variables was segregated into classes, so that each port could belong in a category, regarding each variable. More precisely, the categories for all variables are indicated below:

Harbor size → large, medium, small, very small

Channel size → large, medium, small, very small

Anchorage size → large, medium, small, very small

Cargo pier size → large, medium, small, very small

Max vessel size → large, medium

Repairs → major, moderate, limited, emergency only, none

Dry-dock size→ large, medium, small

Railway size→ large, medium, small

Relevant information and data considering the above variables for every port were obtained from National Geospatial – Intelligence Agency (Agency, 2009, 2010, 2011 ,2012, 2013, 2014, 2015, 2016, 2017). However, data availability covers a period from 2009 to 2017, thus our analysis attempts to document any determinants of port rankings during the specific time window. Let us briefly demonstrate the methodology followed here. Initially, every port included in the top 50 lists from 2009 to 2017 was placed in a category for each of the aforementioned variables, based on its average values through the years. Afterwards, and for each category of every variable, the average rank of the ports was computed, in order to document if the class of each variable affects the ranking positions (the superior the category, the higher the ranking position).

Results

Transition probability matrix

Cell by cell commentary

The first step of the analysis is to observe the actual cell values of the transition matrix. The matrix is depicted below in the figures 17-19. Every row and column from 1-50 depicts the ranking positions of a port. However, every rank expressed in columns refers to the successive year, while every coinciding cell with any row displays the probability of the specific port to move from the position of the row to the position of the column between adjacent periods. For example, the cell (5,7) shows the probability of a port to move from the 5^{th} rank to the 7^{th} from one year to another, on average. Rows and columns 51 and 52 work similarly, referring however, to exits and entries on the list, respectively. Any cell of the row 51 would express the probability of a port that exited the list during the current year to ascend to the rank indicated by the columns of the matrix, the year after. The cells of the row 52 portray the probabilities of a port entering the list next year, to reach the ranking stated by each column.

A major property of the matrix is its main diagonal, which is highlighted. Clearly, this is not the case of perfect persistence, as described in the methodology section. There is a pattern of higher values almost until the 21st ranking position of the matrix. Lower values are noticed until the 30th place, while the rest of the values are close to zero. This is a logical and anticipated result, since a port, high up in the ranks is more likely to retain its place next year, rather than to move upwards or downwards, in comparison to a port of lower ranking position. On the other hand, the rest of the ports are supposed to fluctuate more, simply because they will be trying to ascend in the ranking or they will not catch up with the development pace of close competitors and fall of the rankings eventually.

The off diagonal values are higher as the ranking drops and deviate more and more from the main diagonal. This constitutes clear indication of higher mobility in lower ranks, since each port has higher probability to ascend or drop to more distant ranking positions. Some ports have higher off diagonal values in ranks above the one they occupy at that time, indicating that there is a tendency to move upwards next year, while others have higher off diagonal values in ranks below the ones that they currently hold, thus giving a signal of moving downwards in the next year. Nothing of course is certain until the next year comes, however this is the concept of the transition probability matrix, to get an indication of future movements. When looking at the last places, for example the 48th place, it has a probability of exiting of 35.71%, while the 50th place has a probability of 72.72%, very likely to be excluded from the top 50 during the next year.

Furthermore, something interesting to comment on is the fact that the off diagonal values of each rank, becomes zero pretty quickly, even for the lower ranked ports. This means that any movements possible in the next year are due to occur in the proximity of the current position. This is also a logical assumption as the data collected indicate the same thing and it is rather unlikely in real life, a port not so recognizable to be preferred all of sudden unless drastic changes took place. And the other way around, it is highly unlikely for a reputable port high in the ranks to fall many places at once. This process of moving many positions up or down could be feasible only after more than one year.

Considering the rows 51 and 52, which portray the exits and entries of the list respectively, their corresponsive cells start to acquire significant values after the 23rd position, with row 52 showing a significant value at the rank 5 as well (cell (52.5)). This means that on average, ports that exited the top list, have chances to ascend up to 23th place during the successive year. Additionally, ports that enter our list can make it up to the 23rd place as well. However, it is also possible for the latter to ascend specifically to the 5th rank. This value could possibly be the result of a port that occupied the 5th position ceasing operations for a period of time, before rejoining our list. The probabilities that any of the aforementioned ports reach higher ranking positions during a single year are non-existent (except for the 5th position regarding the entries of the system). Of great interest is the value of the cell (51.52), which displays the possibility of a port that exited the list rejoining the year after. The value of the cell is 69.77%, thus a very likely event.

Lastly, a section of the transition probability matrix requiring further commentary is the column 51. Portraying any imminent exit from the list, this column displays significant values from the rank 21 and bellow, meaning that on average, the event of an exit during an adjacent period is possible for ports ranked below the 21st position of the top 50 list, but for not all of them. However, there is also a significant value documented in the 5th position, possibly explaining the value of the cell (52,5) mentioned above.

RANK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	**86.67**	13.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	13.33	**80**	6.67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	6.67	**80**	6.67	6.67	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	13.33	**80**	6.67	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	6.67	**66.67**	20	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	6.67	13.33	**60**	13.33	0	6.67	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	**53.33**	33.33	13.33	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	20	26.67	**40**	6.67	6.67	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	20	**60**	13.33	0	6.67	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	13.33	**60**	20	0	0	6.67	0	0	0	0
11	0	0	0	0	0	0	0	0	0	20	**40**	33.33	0	0	6.67	0	0	0
12	0	0	0	0	0	0	6.67	0	0	0	20	**40**	20	6.67	0	6.67	0	0
13	0	0	0	0	0	0	0	6.67	0	0	13.33	20	**40**	13.33	6.67	0	0	0
14	0	0	0	0	0	0	0	0	0	0	7.15	0	14.28	**35.71**	28.58	14.28	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	26.67	6.67	**40**	13.33	13.33	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	**46.67**	20	6.67
17	0	0	0	0	0	0	0	0	0	0	0	0	0	6.67	13.33	6.67	**26.67**	40
18	0	0	0	0	0	0	0	0	0	0	0	0	0	6.67	6.67	6.67	6.67	**13.33**
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	20
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.67	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13.33
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.67	6.67	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.67
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	1.54	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 17: Transition probability matrix for period 2002 – 2017 (part 1)

19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	6.67	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26.67	26.67	6.67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	6.67	0	0	0	6.67	0	0	0	6.67	0	0	0	0	0	0	0	0
0	**33.33**	20	13.33	6.67	13.33	6.67	0	0	0	0	0	0	0	0	0	0	0
6.67	20	**26.67**	13.33	6.67	6.67	0	0	0	0	0	0	0	0	0	0	0	0
6.67	6.67	26.67	**20**	26.67	0	0	0	0	0	0	0	0	0	0	0	0	0
6.67	6.67	13.33	33.33	**13.33**	13.33	0	0	6.67	0	0	0	0	0	0	0	0	0
6.67	0	0	0	13.33	**20**	26.67	26.67	0	0	0	0	0	0	0	0	0	0
0	0	7.15	0	0	0	**21.43**	14.28	21.43	7.15	7.15	0	0	0	7.15	0	0	0
0	0	0	0	6.67	6.67	20	**6.67**	26.67	0	13.33	6.67	0	6.67	0	0	0	0
0	0	0	6.67	0	13.33	0	26.67	**20**	13.33	0	13.33	0	0	0	0	0	0
0	0	0	0	6.67	0	0	13.33	6.67	**6.67**	20	13.33	13.33	6.67	6.67	0	0	0
0	0	0	0	0	0	0	0	7.15	7.15	**21.43**	7.15	7.15	14.28	0	21.43	0	0
0	0	0	0	0	7.15	0	0	0	21.43	0	**14.28**	7.15	21.43	0	0	0	7.15
0	0	0	0	0	0	0	0	6.67	13.33	6.67	13.33	**6.67**	6.67	26.67	6.67	6.67	6.67
0	0	0	0	0	0	0	0	6.67	13.33	0	0	6.67	**6.67**	26.67	20	20	0
0	0	0	6.67	0	0	0	0	0	0	0	6.67	26.67	13.33	**0**	0	6.67	20
0	0	0	0	0	0	6.67	0	0	6.67	6.67	0	6.67	20	13.33	**0**	13.33	6.67
0	0	0	0	0	0	0	0	0	0	20	6.67	0	0	0	0	**6.67**	13.33
0	0	0	0	0	0	0	0	0	0	7.15	0	0	0	0	21.43	0	**7.15**
0	0	0	0	0	0	0	0	0	0	0	0	6.67	0	6.67	0	0	20
0	0	0	0	0	0	0	0	0	0	0	0	0	0	13.33	13.33	0	0
0	0	0	0	0	0	0	0	0	0	0	6.67	0	0	0	0	6.67	13.33
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.67	0
0	0	0	0	0	0	0	0	0	0	0	6.67	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.67	6.67	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.67	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	6.67	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	2.33	2.33	0	2.33	0	0	0	0	2.33	0	0	0	2.33	0
0	0	0	0	3.07	1.54	4.62	1.54	0	1.54	0	1.54	1.54	1.54	0	1.54	4.62	1.54

Figure 18: Transition probability matrix for period 2002 – 2017 (part 2)

37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	Total
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.67	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.67	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.67	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	14.28	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.67	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.67	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.67	0	100
0	0	7.15	0	0	0	0	0	0	0	0	0	0	0	7.15	0	100
0	0	0	0	7.15	0	0	0	0	0	0	0	0	0	14.28	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
0	0	6.67	6.67	0	0	0	0	0	0	0	0	0	0	6.67	0	100
0	0	6.67	0	6.67	0	0	0	0	0	0	0	0	0	6.67	0	100
26.67	0	6.67	6.67	0	0	0	0	0	0	0	0	0	0	13.33	0	100
28.58	21.43	7.15	0	0	0	7.15	0	0	0	0	0	0	0	0	0	100
13.33	6.67	6.67	0	0	6.67	6.67	6.67	6.67	6.67	0	0	0	0	6.67	0	100
13.33	**13.33**	6.67	20	0	0	0	6.67	6.67	0	0	0	0	0	6.67	0	100
6.67	6.67	**6.67**	0	20	6.67	0	20	0	0	0	0	0	0	6.67	0	100
13.33	6.67	20	**0**	20	13.33	0	0	0	6.67	0	13.33	0	0	0	0	100
0	0	0	6.67	**0**	0	13.33	6.67	0	6.67	0	20	20	0	20	0	100
0	6.67	0	13.33	0	**0**	0	6.67	0	20	20	0	0	6.67	13.33	0	100
0	6.67	6.67	20	6.67	0	**20**	0	6.67	6.67	0	0	0	13.33	6.67	0	100
0	7.15	0	0	0	14.28	14.28	**0**	7.15	7.15	21.43	0	0	7.15	21.43	0	100
0	6.67	0	0	6.67	0	13.33	6.67	**6.67**	6.67	6.67	6.67	0	6.67	26.67	0	100
0	0	0	0	6.67	6.67	0	6.67	20	**0**	0	0	6.67	6.67	46.67	0	100
0	0	0	0	6.67	0	6.67	0	0	6.67	**6.67**	6.67	6.67	0	60	0	100
0	0	7.15	0	0	21.43	0	7.15	7.15	0	7.15	**0**	7.15	7.15	35.71	0	100
0	0	0	0	0	7.70	7.70	7.70	7.70	7.70	0	0	**15.38**	7.70	38.46	0	100
0	0	9.10	0	0	0	0	9.10	9.10	0	0	0	0	**0**	72.72	0	100
0	0	0	2.33	2.33	4.65	0	0	0	0	2.33	6.98	0	0	**0**	69.77	100
0	4.62	1.54	4.62	3.07	3.07	3.07	4.62	6.16	6.16	7.69	7.69	10.76	10.76	0	**0**	100

Figure 19: Transition probability matrix for period 2002 – 2017 (part 3)

Mobility indices

Summary mobility indices

Let us continue the analysis of the first matrix by discussing the results from the first category of mobility indices, the Summary mobility indices. It consists of the Immobility Ratio (IR), Moving Up (MU), and Moving Down (MD). The results are the following:

- ❖ IR = 0.2487, MU = 0.3045, MD = 0.4468

As noticed, the sum justifiably equals 100% probability. The immobility ratio captures the overall constancy of the system throughout the 16 years. 24.87% is not a small percentage to consider, especially when taking the high competitiveness among the ports under consideration. 30,45% of the movements had an upward tendency while almost half of them constituted deteriorations (44.68%). One possible explanation of the high downward percentage may be the fact that after the 21st place, much more volatility is observed and it seems that there is a bigger tendency towards falling than rising.

Eigenvalue Based Indices

In total, five of these indices were presented in the methodology section. The three of them: M_{PS}, M_{SC} and M_S take values in the interval of [0,1] and the theory dictates that the closer to unity, the higher the mobility, with the value of 1 stating perfect mobility. The findings are the following:

- ❖ M_{PS} = 0.7514, M_{SC} = 0.0113, M_S = 1

From the above values, someone could claim that the results are contradictory, simply because, two of the indices are close to unity, with the M_S actually equaling unity, and the other close to zero. Indeed, there is a misunderstanding here, which has to do with the construction and use of the indices individually. The values of the indices should not be compared to each other in the case of one matrix. Their contribution to our research derives from the comparison between same indices (same scale of values) of different transition matrices. When the time comes to compare and comment on the two split matrices, then the M_{PS}, M_{SC} and M_S will be compared with the corresponding indices of the other mobility matrices, in order to capture any mobility differences between the sub-periods. Whichever is closer to unity will designate the matrix with the higher mobility.

The next index of this category is the M_h, which denotes the time needed for the system to cover half of the deviation from equilibrium. The half-life index has a range between zero and infinity, with the former meaning total mobility and the latter total immobility. Its result in this case is 60.9932, which individually does not give any information, except that there is no perfect mobility nor immobility. Therefore, it should be commented further when the two matrices come forth for comparison.

Lastly, there is the Singular Value Decomposition Index (SVD) or M_{SVD}. The value of the index is 0.7724. One reasonable remark here is that the value of M_{SVD} is close to the one of M_{PS}. This is an indicator that the two metrics contribute similar information for the mobility matrix. So, the results of the M_{PS} are being verified in a way by the singular value decomposition index.

Distance metrics and indices

There is no point analyzing any findings from cell to cell difference and distance metrics yet, since the value intervals here are not specific and can theoretically reach infinity. Consequently, the only way to retrieve any conclusions from these metrics is to use them for comparison purposes, which will be done in the comparison section of this thesis.

Transition probability matrix for period 2002-2009

As mentioned in the methodology section, the main purpose of our research is the segregation of the port rankings data in two intersections, in order to compare the transition dynamics between these time periods. This task will include comparison of the mobility indices but also some commentary on cell by cell difference indications. Just like in the previous matrix, the rows and columns 51 and 52 denote the exits and entries of the top 50 ranking board, respectively.

Cell by cell commentary

The main diagonal of the matrix is of great importance, as it is indicative of the persistence of the matrix. Just like in the previous matrix, the diagonal shows higher values in higher rankings, meaning that it is more possible for a port to retain its position between two successive years, if it is ranked in a higher position. On average, the ports with lower annual throughput seem to be less persistent in their rankings on the top 50 list. This could be explained by the fact that the differences between the throughput capacities are less significant for the smaller ports, so more easily caught up from competitors. For example, on average, it is easier for the 40th port to ascent (or deteriorate) ranking positions than the 5th one.

The cells below (moving up) and above (moving down) the main diagonal follow the reverse pattern, as expected. While moving down in the ranking, the persistence is diminishing, resulting in higher values for the cells close to the main diagonal. With the deterioration of rankings, higher values are getting gradually more distant from the main diagonal. This verifies the conclusions from the main diagonal, indicating higher mobility in lower positions. The above observations can be detected at the figures 20-22, shown below.

Similarly to the first matrix, the cells indicating the exits and entries seem to assume values after 23rd and 25th ranking positions. So, on average and between successive years, any port that exited the top 50 list, cannot ascend above the 23th ranking position. Any new entry can ascend up to the 25th place. There is a possibility though for a new entry to ascend to the 5th place specifically, like in the first matrix of our analysis. Another common feature with the initial transition matrix is the value of the cell (51,52) which also leads to the assumption that the event of rejoining for a port that exited the list of the previous period, is very likely (60% probability).

Regarding the 51^{st} column, the matrix displays significant probabilities for imminent exits for ports currently occupying positions below the 25^{th} one, which is lower in comparison to the first transition probability matrix (21^{st} position).

RANK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	**85.71**	14.29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	14.29	**71.43**	14.29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	14.29	**71.43**	0	14.29	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	14.29	**85.71**	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	**66.67**	33.33	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	14.29	14.29	**42.86**	14.29	0	14.29	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	**42.86**	42.86	14.29	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	28.57	28.57	**14.29**	14.29	14.29	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	28.57	**28.57**	28.57	0	14.29	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	28.57	**28.57**	28.57	0	0	14.29	0	0	0	0
11	0	0	0	0	0	0	0	0	0	28.57	**14.29**	42.86	0	0	14.29	0	0	0
12	0	0	0	0	0	0	14.29	0	0	0	14.29	**14.29**	28.57	14.29	0	14.29	0	0
13	0	0	0	0	0	0	0	14.29	0	0	28.57	28.57	**0**	28.57	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	16.67	0	16.67	**16.67**	16.67	33.33	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	57.14	0	**28.57**	0	14.29	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29	0	**28.57**	42.86	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28.57	0	**0**	57.14
18	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29	14.29	14.29	0	**0**
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28.57
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29	14.29	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	3.33	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 20: Transition probability matrix for period 2002-2009 (part 1)

19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	14.29	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	42.86	14.29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42.86	14.29	0	0	0	14.29	0	0	0	14.29	0	0	0	0	0	0	0	0
0	**28.57**	42.86	0	0	14.29	0	0	0	0	0	0	0	0	0	0	0	0
0	14.29	**14.29**	14.29	14.29	14.29	0	0	0	0	0	0	0	0	0	0	0	0
14.29	0	14.29	**14.29**	28.57	0	0	0	0	0	0	0	0	0	0	0	0	0
14.29	0	0	42.86	**14.29**	14.29	0	0	0	0	0	0	0	0	0	0	0	0
14.29	0	0	0	0	**0**	42.86	42.86	0	0	0	0	0	0	0	0	0	0
0	0	16.67	0	0	0	**16.67**	16.67	16.67	16.67	0	0	0	0	0	0	0	0
0	0	0	0	14.29	0	28.57	**0**	14.29	0	0	14.29	0	14.29	0	0	0	0
0	0	0	0	0	14.29	0	28.57	**28.57**	14.29	0	14.29	0	0	0	0	0	0
0	0	0	0	14.29	0	0	0	14.29	**0**	28.57	14.29	28.57	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	**33.33**	16.67	16.67	16.67	0	0	0	0
0	0	0	0	0	14.29	0	0	0	14.29	0	**0**	0	28.57	0	0	0	14.29
0	0	0	0	0	0	0	0	14.29	0	0	14.29	**14.29**	0	28.57	14.29	0	14.29
0	0	0	0	0	0	0	0	14.29	14.29	0	0	0	**0**	42.86	14.29	14.29	0
0	0	0	14.29	0	0	0	0	0	0	0	0	14.29	14.29	**0**	0	14.29	14.29
0	0	0	0	0	0	0	0	0	14.29	14.29	0	0	28.57	14.29	**0**	28.57	0
0	0	0	0	0	0	0	0	0	0	14.29	0	0	0	0	0	**14.29**	14.29
0	0	0	0	0	0	0	0	0	0	14.29	0	0	0	0	28.57	0	**14.29**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	16.67	0	0	33.33
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29	0	0
0	0	0	0	0	0	0	0	0	0	0	14.29	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16.67	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	14.29	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	6.67	6.67	0	6.67	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	3.33	0	0	3.33	0	3.33	3.33	0	0	3.33	6.67	0

Figure 21: Transition probability matrix for period 2002-2009 (part 2)

37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	Total
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	16.67	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	16.67	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	28.57	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	14.29	14.29	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
42.86	0	14.29	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
28.57	14.29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	16.67	0	0	16.67	0	0	16.67	0	0	0	0	0	0	0	**100**
14.29	**14.29**	0	28.57	0	0	0	0	14.29	0	0	0	0	0	14.29	0	**100**
0	14.29	**0**	0	42.86	0	0	28.57	0	0	0	0	0	0	0	0	**100**
14.29	14.29	0	**0**	14.29	28.57	0	0	0	0	0	28.57	0	0	0	0	**100**
0	0	0	14.29	**0**	0	28.57	0	0	0	0	14.29	14.29	0	28.57	0	**100**
0	14.29	0	0	0	**0**	0	0	0	42.86	14.29	0	0	0	28.57	0	**100**
0	0	16.67	33.33	0	0	**16.67**	0	0	0	0	0	0	16.67	0	0	**100**
0	0	0	0	0	0	14.29	**0**	14.29	14.29	28.57	0	0	14.29	14.29	0	**100**
0	14.29	0	0	0	0	0	14.29	**0**	0	14.29	0	0	0	42.86	0	**100**
0	0	0	0	14.29	14.29	0	14.29	14.29	**0**	0	0	0	0	42.86	0	**100**
0	0	0	0	14.29	0	14.29	0	0	14.29	**14.29**	0	0	0	42.86	0	**100**
0	0	16.67	0	0	16.67	0	16.67	0	0	0	**0**	0	16.67	33.33	0	**100**
0	0	0	0	0	14.29	14.29	0	0	14.29	0	0	**28.57**	0	28.57	0	**100**
0	0	20.01	0	0	0	0	0	0	0	0	0	0	**0**	79.99	0	**100**
0	0	0	6.67	6.67	0	0	0	0	0	0	6.67	0	0	**0**	60	**100**
0	3.33	0	0	0	3.33	3.33	6.67	10.00	3.33	6.67	10.00	13.34	13.34	0	**0**	**100**

Figure 22: Transition probability matrix for period 2002-2009 (part 3)

Mobility indices

Summary mobility indices

Similarly to the main mobility matrix, the preliminary analysis will include commentary on the results of the summary mobility indices. The values attained are 0.1785 for IR, 0.3264 for MU and 0.4951 for MD. A first remark is the pretty low value for the immobility ratio, already indicating lower persistence for the first sub-period. More precisely, through the years 2002 to 2009, 17.85% portrays the percentage of the rank upkeeps, 32.64% the percentage of rank accessions and 49.51% the percentage of rank deteriorations. The sum of the indices logically equals 100, as it represents the sum of all movement probabilities through the time horizon.

It is interesting to note the significantly low value for IR, which denotes pretty low persistence for our matrix. So the basic conclusion here is that the ranking of the top 50 ports presents perceptible changes between the years 2002 and 2009. It yet remains to compare these results to the ones of the following mobility matrix (2010-2017). Before that though, it would be useful to compare it with the initial matrix. Clearly the Immobility Ratio has decreased almost by 30%. On the contrary, the other ratios experienced an increment. Almost half of the vector consists of ranking deteriorations, which is quite a large percentage. A preliminary explanation could be the higher competitiveness before the years of the immense crisis.

Eigenvalue Based Indices

The eigenvalue indices for this matrix acquire the following values:

- $M_{PS} = 0.82157$, $M_{SC} = 0.0224$, $M_S = 1$

As mentioned above, these values do not contribute much at this point. However, they constitute the main tools for the upcoming matrix comparison.

Considering the half-life index, it reaches the value of 30.5961. With a value range from 0 to infinity, all this index has to contribute for now is the conclusion that we refer to a matrix which is neither perfectly immobile nor mobile, in which case the M_h would display values approximating infinity and 0 respectively.

Moving to the singular value decomposition mobility index, we notice a value of 0.8584. It is pretty interesting the fact that similarly to the main matrix, the M_{SVD} takes value close to the M_{PS} index. Thus, these two indices offer similar results yet again.

Distance metrics and indices

Lastly, the distance and cell by cell difference indices will be presented in the comparison section, since they lack the ability to determine the mobility of a matrix without a common point of reference.

Transition probability matrix for period 2010-2017

Cell by cell commentary

Now it is time to check upon the last sub-period sample, depicted at the figures 23-25. Concerning the main diagonal of the second transition matrix, higher values are noticed at the beginning, which become minimal while moving down to lower ranking positions but not as fast as in the 2002-2009 matrix. Of special interest here are the values of the cells (1,1), (2,2) and (9,9), which all equal 100. This can be translated that from 2010 to 2017, the first, second and ninth port of our top 50 list have retained their positions. To be more specific, what the matrix portrays in that case is that the possibility for those 3 ports to remain at the same position for any adjacent period (year), is 100%. None of the previous matrices have presented similar results in their main diagonals, thus this might be a preliminary indicator of lower mobility for this matrix.

The rest of observations regarding cell values follow the same motive as the previous matrices, with significant values on the cells close to the main diagonal in the beginning of the matrix, which gradually diverge from the diagonal. Just like in previous cases, this leads to the induction of higher ranking mobility in lower positions of the list.

Regarding the ranking positions 51 and 52, some differences are noticed in comparison to previous cases. More precisely, the cells of the row 51 (exits) gain significant values after the rank 35, much lower than in the matrix of the first era. Additionally, no value is being documented in row 52 higher than rank 23. Consequently, the outcome of ascension of a newcomer port to the 5th rank is possible only during the 2002-2009 era.

Any values for the column 51 are noticed below the 21st position, same as in the initial matrix (except the cell (5.51)) but higher in comparison to the matrix of the first era.

RANK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	**100**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	**100**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	**85.71**	14.29	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	14.29	**71.43**	14.29	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	14.29	**71.43**	14.29	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	14.29	**85.71**	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	**71.43**	28.57	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	28.57	**71.43**	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	**100**	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	**85.71**	14.29	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	14.29	**57.14**	28.57	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	28.57	**57.14**	14.29	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	14.29	**71.43**	0	14.29	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	14.29	**42.86**	42.86	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29	**42.86**	28.57	14.29	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	28.57	0	**57.14**	0	14.29
17	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29	0	14.29	**42.86**	28.57
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29	**14.29**
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28.57	42.86
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 23: Transition probability matrix for period 2010-2017 (part 1)

19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57.14	14.29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28.57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	**42.86**	0	28.57	0	14.29	14.29	0	0	0	0	0	0	0	0	0	0	0
14.29	14.29	**42.86**	14.29	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	14.29	28.57	**28.57**	28.57	0	0	0	0	0	0	0	0	0	0	0	0	0
0	14.29	28.57	14.29	**14.29**	14.29	0	0	14.29	0	0	0	0	0	0	0	0	0
0	0	0	0	28.57	**42.86**	14.29	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	**14.29**	14.29	28.57	0	14.29	0	0	0	14.29	0	0	0
0	0	0	0	0	0	14.29	**14.29**	42.86	0	28.57	0	0	0	0	0	0	0
0	0	0	14.29	0	14.29	0	28.57	**0**	14.29	0	14.29	0	0	0	0	0	0
0	0	0	0	0	0	0	28.57	0	**14.29**	14.29	0	0	14.29	14.29	0	0	0
0	0	0	0	0	0	0	0	14.29	14.29	**14.29**	0	0	0	0	42.86	0	0
0	0	0	0	0	0	0	0	0	14.29	0	**28.57**	14.29	14.29	0	0	0	0
0	0	0	0	0	0	0	0	0	28.57	14.29	14.29	**0**	14.29	14.29	0	14.29	0
0	0	0	0	0	0	0	0	0	14.29	0	0	14.29	**14.29**	14.29	14.29	28.57	0
0	0	0	0	0	0	0	0	0	0	0	14.29	28.57	14.29	**0**	0	0	28.57
0	0	0	0	0	0	14.29	0	0	0	0	0	14.29	14.29	14.29	**0**	0	14.29
0	0	0	0	0	0	0	0	0	0	14.29	14.29	0	0	0	0	**0**	14.29
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16.67	0	**0**
0	0	0	0	0	0	0	0	0	0	0	0	14.29	0	0	0	0	14.29
0	0	0	0	0	0	0	0	0	0	0	0	0	0	28.57	14.29	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29	14.29
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	14.29	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29	14.29	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.76	0
0	0	0	0	6.06	3.03	6.06	3.03	0	0	0	0	3.03	3.03	0	0	3.03	3.03

Figure 24: Transition probability matrix for period 2010-2017 (part 2)

37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	Total
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29	0	**100**
0	0	0	0	14.29	0	0	0	0	0	0	0	0	0	14.29	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	14.29	0	**100**
0	0	14.29	0	0	0	0	0	0	0	0	0	0	0	14.29	0	**100**
14.29	0	0	14.29	0	0	0	0	0	0	0	0	0	0	28.57	0	**100**
33.33	33.33	0	0	0	0	16.67	0	0	0	0	0	0	0	0	0	**100**
14.29	14.29	0	0	0	0	14.29	14.29	0	14.29	0	0	0	0	0	0	**100**
14.29	**0**	14.29	14.29	0	0	0	14.29	0	0	0	0	0	0	0	0	**100**
14.29	0	**14.29**	0	0	14.29	0	14.29	0	0	0	0	0	0	14.29	0	**100**
14.29	0	42.86	**0**	28.57	0	0	0	0	14.29	0	0	0	0	0	0	**100**
0	0	0	0	**0**	0	0	14.29	0	14.29	0	14.29	28.57	0	14.29	0	**100**
0	0	0	14.29	0	**0**	0	14.29	0	0	28.57	0	0	14.29	0	0	**100**
0	14.29	0	14.29	14.29	0	**28.57**	0	14.29	14.29	0	0	0	0	0	0	**100**
0	14.29	0	0	0	28.57	14.29	**0**	0	0	14.29	0	0	0	28.57	0	**100**
0	0	0	0	14.29	0	14.29	0	**14.29**	14.29	0	14.29	0	14.29	14.29	0	**100**
0	0	0	0	0	0	0	0	16.67	**0**	0	0	16.67	16.67	50.00	0	**100**
0	0	0	0	0	0	0	0	0	0	**0**	14.29	14.29	0	71.43	0	**100**
0	0	0	0	0	28.57	0	0	14.29	0	14.29	**0**	14.29	0	28.57	0	**100**
0	0	0	0	0	0	0	14.29	14.29	0	0	0	**0**	14.29	57.14	0	**100**
0	0	0	0	0	0	0	0	16.67	0	0	0	0	**0**	83.34	0	**100**
0	0	0	9.52	0	0	0	0	0	0	0	4.76	0	4.76	**0**	76.19	**100**
0	6.06	3.03	3.03	6.06	6.06	3.03	3.03	3.03	6.06	9.09	9.09	6.06	6.06	0	**0**	**100**

Figure 25: Transition probability matrix for period 2010-2017 (part 3)

Mobility indices

Summary mobility indices

As done previously, the analysis of the summary mobility indices comes first. One can say that the preliminary induction of lower mobility for the 2010-2017 sub-period is being verified here, since the Immobility Ratio is 0.3077, the highest noticed so far. Therefore, the impression given by the vector itself was correct, without any statistics applied. The period 2010-2017 exhibited less mobility than the other two cases. One possible explanation to this could be the aftermath of the crisis, since one of its effects, besides the high recession in every aspect of the economy, seems to be the mere stabilization of the port rankings. However, it is not reasonable to assume that the crisis was the only cause. Many factors may determine the mobility of the matrix, but the general economic recession probably caused the higher ranked ports to retain their position and generally deteriorated the transition mobility, possibly due to the lack of market liquidity, thus restrictions for further investments in the port industry. As a consequence, port authorities and operators struggle more to augment their TEU handling capacities, so ranking changes are noticed less frequently through the years after the crisis. On the contrary, one could claim that the economic recession could also constitute a reason for more ranking fluctuations. This does not seem to be the case here, though.

Moving to the rest of the mobility indices, the MU ratio takes the value of 0.2793 and the MD ratio the value of 0.41306, significantly lower than the corresponding values of the 2002-2009 matrix. As always the sum of summary mobility indices equals 100%, a percentage including all possible movements through the whole time period. Almost half of the main diagonal assumes large values, which indicates, as shown above, a higher persistence through consequent years. At lower ranks there is always higher mobility, as it seems, with the tendency to move to even lower ranks, until the exit of rank 51.

Eigenvalue Based Indices

The first three eigenvalue-based indicators assume the following values:

- $M_{PS} = 0.69243$, $M_{SC} = 0.0093$, $M_{S} = 1$

These are the lowest values noticed so far. This remark is expected to be determinant during the actual comparison between the matrices. The half-life index takes the value of 74.18484 and the

M_{SVD} the value of 0.7226, close to the M_{PS}. At the next chapter all these indices will be analyzed and utilized accordingly in order to retrieve more instructive results.

Distance metrics and indices

As mentioned in previous cases, further analysis regarding the distance and cell by cell difference metrics will be done in the comparison section of this thesis.

Matrices Comparison

The next and most essential part of this study consists of the comparison between the two matrices, which refer to each of the time periods of 2002-2009 and 2010-2017. Additionally, a comparison will also be made between each matrix and the original one, which portrays the whole time horizon from 2002 to 2017. The comparison section will contain extended analysis between the summary mobility indices, eigenvalue-based indices, cell to cell difference indices and distance mobility indices of all matrices presented above. In order to achieve direct comparability of the two sub-periods, the last two categories of mobility indices will be of great value among the others, since those indicators express the distance from the same reference point, the identity matrix. As stated in the methodology section, the identity matrix reflects perfect persistence, thus the matrix with the lower index value is closer to the absolute immobility.

Let us start the comparison with the summary mobility indices. The IR for the sub-period 2002-2009 takes the value of 0.1785, lower than the 0.3077 of the successive 8-year period. This indicates higher mobility for the first matrix, meaning more ranking transitions for the corresponding period. Considering the MU ratio, first sub-period portrays higher value (0.3264>0.2793). This implies more upward transitions for the years 2002-09, meaning more ports have ascended ranks in the top 50 list. Same pattern applies for the MD ratio (0.4951>0.41306), thus more ports have also been demoted during the first time lap subsection in comparison to the second one. It should also be documented that ranking deteriorations exceed ranking improvements for both eras. The results so far verify the expectations from the preliminary analysis, that 2002-2009 matrix presents lower persistence. Moving on, the eigenvalue-based indices for all periods are indicated on the following tables:

➢ **<u>2002-2017 period:</u>**
$\boldsymbol{M_{PS}}$ → 0.75142
$\boldsymbol{M_{SC}}$ → 0.0113
$\boldsymbol{M_{S}}$ → 1
$\boldsymbol{h}$ → 60.9932
$\boldsymbol{M_{SVD}}$ → 0.772439

Table 1: Eigenvalue-based indices for the period 2002 - 2017

➢ **<u>2002-2009 sub-period:</u>**
$\boldsymbol{M_{PS}}$ → 0.82157
$\boldsymbol{M_{SC}}$ → 0.0224
$\boldsymbol{M_{S}}$ → 1
$\boldsymbol{h}$ → 30.5961
$\boldsymbol{M_{SVD}}$ → 0.8584

Table 2: Eigenvalue-based indices for the sub-period 2002 - 2009

➢ **<u>2010-2017 sub-period:</u>**
$\boldsymbol{M_{PS}}$ → 0.69243
$\boldsymbol{M_{SC}}$ → 0.0093
$\boldsymbol{M_{S}}$ → 1
$\boldsymbol{h}$ → 74.18484
$\boldsymbol{M_{SVD}}$ → 0.7226

Table 3: Eigenvalue-based indices for the sub-period 2010 - 2017

At this point, we should recall the value interval for the eigenvalue-based indices, which varies between 0 and 1, with 1 indicating perfect mobility. The same applies for the singular value decomposition index. The half-life indicator assumes values from 0 to infinity with the latter expressing perfect immobility. Considering the sub-periods comparison, M_{PS} index indicates higher mobility for the pre-crisis period (0.82157) in contrast to the second period (0.69243), resulting to the same conclusions drawn from the summary mobility indices comparison. Similar results are also assumed from the M_{SC} and M_{S}. Actually, M_S seems to be the exact same number, however this is not accurate. The difference in decimals was miniscule, resulting both to coincide with unity. The first matrix (2002-2009) denotes higher values on those indices. Based on the theory applied here, this leads to the conclusion of higher mobility (or lower persistence) for the pre-crisis period. Lastly, the comparison of the half-life indicator paints the same picture, giving a higher value for the second sub-period (2010-2017) which means lower mobility. Therefore, the system for this time period needs more time to cover half of the convergence from the equilibrium (74.18484>30.5961), a remark which totally agrees with all the previous indicators applied during the comparison procedure.

Finally, it is time to comment on the indices that were not of any significant value individually, since they require a common reference point in order to accommodate comparison purposes. We refer to the *cell by cell indices*: D_{L1}, D_{L2} and D_{Lmax}, the *difference in distances*: D_{WAD} (trans matrix), D_{WAD} (ident. matrix), $D_{WAD\ AVERAGE}$, $D_{WAD\ MAX}$ and lastly, the *Singular value based distance* (D_{SVD}). The findings are presented at the tables below:

➢ **<u>2002-2017 period:</u>**
Absolute deviations distance DL_1 → 7,813.82
Euclidean distance DL_2 → 628.6381
Maximum distance DL_{max} → 100
D_{WAD}(trans matrix) → 135,011.628
D_{WAD}(ident. matrix) → 390,665
$D_{WAD\ AVERAGE}$ → 262,838.314
$D_{WAD\ MAX}$ → 390,665
D_{SVD} → 0.772439

Table 4: Cell by cell and distance indices for the period 2002 - 2017

➢ **<u>2002-2009 sub-period:</u>**
Absolute deviations distance DL_1 → 8,543.41
Euclidean distance DL_2 → 694.573
Maximum distance DL_{max} → 100
D_{WAD}(trans matrix) → 154,894.9165
D_{WAD}(ident. matrix) → 427,138
$D_{WAD\ AVERAGE}$ → 291,016.4583
$D_{WAD\ MAX}$ → 427,138
D_{SVD} → 0.8584

Table 5: Cell by cell and distance indices for the sub- period 2002 - 2009

➢ **<u>2010-2017 sub-period:</u>**
Absolute deviations distance DL_1 → 7,200.46
Euclidean distance DL_2 → 626.3231
Maximum distance DL_{max} → 100
D_{WAD}(trans matrix) → 144,945.2912
D_{WAD}(ident. matrix) → 359,996
$D_{WAD\ AVERAGE}$ → 252,470.6456
$D_{WAD\ MAX}$ → 359,996

D_{SVD} → 0.7226

Table 6: Cell by cell and distance indices for the sub- period 2010 - 2017

Regarding the two sub-periods, higher mobility is observed where the higher distances occur. Thus, higher mobility is detected at the first sub-period (2002-2009), since every distance metric assumes higher values for the corresponding transition matrix. The D_{SVD} index assumes higher value for the 2002-2009 period as well (0.8584>0.7226). Given that the particular index is based on the singular value decomposition index (M_{SVD}), it contributes identical information, with higher values indicating higher mobility. Consequently, D_{SVD} validates any conclusions drawn from the rest of the distance metrics. Just a supplementary note here is that the initial matrix, covering the whole 16-year time horizon, assumes distances from **I** somewhere between the ones of the sub-period matrices. Such behavior is totally logical and anticipated, considering that the persistence of this transition matrix could be speculated as an average of the persistence describing each of the sub-period matrices.

Determinants

All results from the analysis demonstrated in the methodology section, regarding the ranking determinants, are portrayed in the following table:

Variables	Classifications	# of ports	Average port rank
Harbor size	large	29	26.63
	medium	23	31.28
	small	12	29.91
	very small	5	41.6
Channel size	large	6	34.21
	medium	36	30.11
	small	23	27.93
	very small	4	40.66
Anchorage size	large	23	28.67
	medium	23	28.21
	small	19	30.59
	very small	1	43.8
Cargo pier size	large	3	16.78
	medium	37	29.19
	small	21	32.65
	very small	7	33.33
Max vessel size	large	36	27.96
	medium	31	32.78
Repairs	major	32	28.83
	moderate	13	27.62
	limited	20	32.22
	emergency only	0	0
	none	3	46.79
Drydock size	large	20	26.99
	medium	17	24.79
	small	12	30.14
Railway size	large	10	29.71
	medium	27	32.54
	small	20	26.08

Table 7: Determinant variables

As noticed, the variables channel size, drydock size and railway size do not contribute any results, since no connection seems to exist between classification improvement and ranking anode. On the contrary, the sizes of cargo pier and of the biggest vessel that can enter the port, apparently display a positive correlation with the average ranking of the ports. Harbor and anchorage size and repairs do not present strong positive correlation, however an average ranking improvement can be detected, while gradually moving to higher classification categories of the variables.

Interpretation of results

The major conclusions that arise from this research are:

- The higher persistence levels in the top ports of the ranking lists (at least for the time window utilized in this thesis), in comparison to the persistence observed in lower positions.
- The difference between the port ranking dynamics of the two successive time periods (2002-2009, 2010-2017), indicating the latter as the less mobile one.

A possible explanation concerning the first conclusion is the fact that the majority of the top ports of our lists are located in China, North Korea and Singapore. Those countries, especially China constitute the major finished or semi-finished goods exporters, thus supporters of the containerized trade. Given this, it is quite anticipated for those ports to achieve the highest levels of twenty-foot equivalent units (TEU) handling capacities, with the ports of other countries not threaten their position. Consequently, the top positions of the ranking lists are more stagnant in comparison to lower rankings, which display higher mobility.

Furthermore, another possible explanation could be the fact that shipping companies and charterers were more willing to operate in ports capable of providing services of high quality and quantity. That is why the top 10 almost always retained their ranks with not much risk of losing positions from inferior ports. Of course, the fact that these remained at the top, is not only part of their unparalleled quality. Business in shipping was going to historical lows in almost every sector. So, to think of it, on the one hand any shipper wants to cooperate with a reputable port, but on the other hand there was not so much cargo to move around the globe (low demand for shipping), thus keeping the ports and generally the business at a steadier state.

In research of additional factors explaining the aforementioned findings, the cascade effect that characterizes greatly the containerized market, could also contribute. More precisely, the cascade effect refers to the construction and use of continuously bigger container ships, which gradually replace the smaller ones. The former mother vessels seize to serve main routes and are placed in smaller ones, parts of the hub and spoke system of containerized trade. The new mother vessels (mostly triple E type) take over the major routes. Most of the ports that acquire the highest positions in our lists are part of those major routes, thus they accommodate those vessels, achieving tremendous amounts of TEUs handling. As a consequence, this can explain the fact of stagnation in the higher ranking positions, given that those throughputs are much harder to be surpassed by competitors.

Higher mobility during the pre-crisis period could be the result of various factors. In contrast to the after-crisis period, ports enjoyed market liquidity, thus many opportunities for further investments. Especially in the port industry, investments like terminal expansions, purchase of infrastructure equipment and dredging can enhance greatly the port's ranking position among competitors. Quicker and more efficient TEU handling techniques, more spaces for container storage or bigger capacities in berthing areas contribute to much higher yearly TEU handling capabilities, which was the criterion for the port rankings in this thesis. Consequently, expansions of this kind could result to higher mobility of the top 50 world port ranking list. However, these kinds of investments require tremendous amounts of capital from the port authorities. Thus, a reasonable explanation for the deterioration of mobility for the after-crisis period seems the lack of financial assets to fund the aforementioned investments. Thereat, stagnation is observed from 2010 to 2017, always in comparison to the previous 8-year period.

Notwithstanding, the port authorities are not the only players determining the port's performance. Other parties like terminal operators come forth and make investments in the port industry as well. Such players can be stevedore companies (dedicated in the terminal operations), vertically integrated shipping companies, or financial institutions that make investments in the particular industry. More precisely, the aforementioned parties can enter the port industry through concession agreements with the port authorities. Such agreements are also accompanied with performance goals guaranteed from the terminal operator to the port authority, considering the TEU handling capacities during a designated period of time. These companies invest huge amounts of capital for any superstructures in the port area that will accommodate those goals. Superstructures include bridges, roads, warehouses etc. Consequently, it would be a reasonable assumption that the after crisis period (2010-2017) could not support financially such investments from the part of terminal operators, thus concluding to the general stability of the ranking transitions for this sub-period.

Furthermore, a port’s performance also depends on various hinterland operations. These include any transport and distribution activities that connect the port with its customers. Inland operations can be part of the port´s activity, but also can depend on investments from third parties, like inland ports. Especially in the case of gateway ports, where the port victuals the local area, in order for the port efficiency to augment, investments from public authorities must also take place. Otherwise, the port has reached the peak of its performance, since the local area cannot sustain higher levels of commodity trade. Given the financial stagnation after 2009, the amount of relevant investments dropped dramatically, leading to the particular result from the comparison of the two sub-periods.

Epilogue

Based on the Markov Chain Model, we conduct a research on the transition dynamics concerning the top 50 container world port rankings. This is done for a time horizon of 16 years (2002-2017), through the estimation of a transition probability matrix. However, our study focalizes on the comparison between two sub-periods: 2002-2009 and 2010-2017. Our main purpose here is to compare these two eras in terms of persistence. Though the estimation of transition matrices for both eras and the application of several mobility indices, we document higher mobility for the first period (pre-crisis) and thus, higher persistence for the post-crisis period. All indicators converge for this result, increasing the validity of any conclusions. Higher mobility is noticed for lower ranking positions in both eras. On the contrary, higher ranks are steadier, something that apparently does not change after the economic crisis emerges. Moreover, results show that on average, and between successive years, the event of a port that exited our list rejoining, is very likely. This result is derived from the actual value of the cell (51.52) of each matrix, which portrays the probability for the aforementioned event.

Regarding the determinants of the ports rankings, cargo pier size and maximum vessel size contribute to the formation of those rankings, while other variables, such as channel, dry-dock and railway size do not present any correlation. Harbor, anchorage and railway size seem to slightly determine any ranking for the ports, without leading to an unquestionable result.

Appendix

Figures:

Tables:

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