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ARTICLES

EVALUATING THE IMPORTANCE OF BRAZILIAN PORTS USING GRAPH CENTRALITY MEASURES

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ABSTRACT. This study analyses the importance of Brazilian ports, based on the flow of non-containerized cargo in 2014, considering both national and foreign trades. For that, we study a non-traditional centrality, called layer centrality, which evaluates the importance of ports, based on how well they are connected to influential ports. This measurement was preliminarily proposed in 2011 and applied to a simple non-weighted network, though herein we extend it to weighted graphs. For comparison purposes, we also apply three traditional measures, namely degree, eigenvector, and flow betweenness centralities. Our findings show that the most impactful ports are private terminals *Ponta da Madeira* and *Tubarão*, although public ports, particularly *Santos*, are usually impactful for national trades. Moreover, we analysed the map for public ports and suggest a suitable location for a new public port.

Keywords: port evaluation, brazilian ports, centrality measures.

1 INTRODUCTION

Brazilian ports handle over 900 million tons of merchandise annually, which corresponds to more than 90% of the country's exports, according to the Special Secretary of Ports (*Secretaria Especial de Portos da Presidência da República*). Due to their strategic role in economic development, many studies evaluate Brazilian ports, most of which use Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) to measure efficiency (Chang and Tovar, 2014; Sanchez *et al.*, 2003).

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The present work also analyses Brazilian ports, however, using a network research perspective, to help identify systems' properties and vulnerabilities (Ercsey-Ravasz and Toroczkai, 2010). In this field of study, graph centrality measurements play a very important role, as they describe the ports' importance with respect to the network (Ercsey-Ravasz *et al.*, 2012). Since there are several different ways to evaluate this importance, many researchers have proposed and applied various centrality measurements to transport networks.

In this paper, we study and apply layer centrality, preliminarily introduced in Bergiante *et al.* (2011), which evaluates the importance of ports, based on how well they are connected to influential ports. Although originally proposed for non-weighted networks, herein we apply it to weighted networks. This centrality has a simple methodology, and presents intermediary characteristics between degree and eigenvector centralities, commonly used for port evaluation (Freire-Seoane *et al.,* 2013; Pais-Montes *et al.,* 2012). For comparison purposes, we also apply three popular measurements, namely, degree, eigenvector, and flow betweenness centrality (Joyce *et al.*, 2010).

This paper analyses the importance of each Brazilian port, considering the total amount of non-containerized cargo handled between January and December 2014, using multiple centrality measurements. This study helps to identify the system's characteristics and vulnerabilities, and fits the literature of maritime networks analyses at national and regional scale, which includes papers such as Castillo Hidalgo and Mohamed-Chérif (2017), McCalla *et al.* (2005), Tovar *et al.* (2015).

2 LITERATURE REVIEW

In this section, we first present background on Brazilian ports, and then port evaluation studies.

2.1 About Brazilian Ports

Historically, the private sector built most Brazilian ports, as consequence of public concession contracts, from 1950 to 1980. The Government incorporated them throughout the years, and in 1975 created a public company to control the port system, called *Portobrás* (Portos do Brasil, 2015). As a result, ports expanded their capacity, however without modernizing their structures and facilities. Thus, Brazilian ports became expensive and inefficient.

During the 1980's, Brazil suffered with great inflation, and many stability plans and reforms were implemented. One of them extinguished *Portobrás* in 1990, leaving the command of the ports' operations to the dock companies (Portos do Brasil, 2015). Few years later, the Port Modernization Law (Law 8630/1993) restructured the National Port System, enhancing port competitiveness and encouraging private investments.

This law represented a great advance theoretically, although in practice, ports' progress was heterogeneous. Certain ports received many investments and became efficient, whereas others did not develop much. This underdevelopment was consequence of labour issues, other legal requirements (e.g. health surveillance, customs requirements, etc.), and entry barriers (e.g. exorbitant start-up costs, scale economy, etc.).

Other laws have also targeted the system's improvement, competitiveness and legal security, such as law 12.815/2013 (ANTAQ, 2016). As a result, the private sector participation has been increasing, and equipment and procedures have been modernized. However, maritime transport is still considerably underused for local transport.

Today, there are 37 organized public ports, controlled by port authority and 169 private terminals, according to the National Waterway Transportation Agency (ANTAQ – *Agencia Nacional de Transportes Aquaviários*). Private terminals are private enterprises that explore port activities, authorized by the federal government. They include Private Use Terminals (TUPs – *Terminais de Uso Privado*) and Transhipment Cargo Point (ETC – *Estação de Transbordo de Carga*), which are port installation outside port areas, used for cargo transhipment. Hereinafter, we refer to public ports, TUPs, and ETCs as ports.

Many studies evaluate Brazilian ports, most using DEA. For instance, Bertoloto and Soares de Mello (2011) combined homogenization techniques and DEA to evaluate ports with different features, from 2007 to 2009. Sousa Junior *et al.* (2013) evaluated ports from the Northeast, providing two case studies: one for containerized cargo and the other for solid bulk cargo. Based on a different perspective, Caillaux *et al.* (2011) studied the most suitable route for containerized cargo, combining DEA with other techniques.

Using different methodologies, Padilha and Ng (2012) investigated the spatial evolution of dry ports in the State of São Paulo, and found that they have not been able to develop with the country's economic growth, due to institutional and infrastructural obstacles. Ng *et al.* (2013) also investigated development of dry ports in four Brazilian States and how institutional framework affects their bureaucratic and logistical roles.

2.2 Port Evaluation

According to Lagoudis *et al.* (2017), most port studies focus on port selection, efficiency, performance and competitiveness. However, this paper adopts a different perspective, as we analyse the importance of each port to the transport network. Among the first papers to adopt this perspective in maritime transport are Ducruet *et al.* (2010) and Kaluza *et al.* (2010). As in the present study, both papers used graph tools, including centrality measurements.

However, Kaluza *et al.* (2010) studied ships, instead of ports. The authors developed conclusions with regard to ships, and took important steps toward understanding patterns of global trade and bioinvasion. On the other hand, in Ducruet *et al.* (2010), the authors did evaluate ports, however, they focused on changes over a 10 year-period. Their target was to verify to what extent hub-and-spoke strategies modified maritime networks' structures.

More recently, other papers also have analysed the evolution of port systems, using graph tools. For instance, Freire-Seoane *et al.* (2013) and Pais-Montes *et al.* (2012) analysed port system evolution before and after the 2008 financial crisis, using centrality measurements and other graph tools as well.

In contrast to such studies, our analysis is static, focusing on the importance of each port to the system. Moreover, we do not use other graph tools, besides centrality measures. On the other hand, we use four different centralities, measuring different types of importance, which also differs from the aforementioned studies.

3 CENTRALITY MEASURES

In the present study, we apply three traditional centrality measures, namely, degree, eigenvector, and flow betweenness centralities, briefly described in 3.1. Layer centrality is explained separately, in 3.2.

First, however, let us introduce some necessary definitions and concepts. In this work, $G(V;E)$, or simply G, denotes a simple undirected weighted graph on n vertices where V is the vertex set, $V = \{v_1,\ldots,v_n\}$ and E is the set of weighted edges $[v_i, v_j]$, formed by pairs of vertices from V, i.e., $v_i, v_j \in V$. Each edge of G has an associated value, called a weight.

Graphs can be represented by adjacency list or adjacency matrix. In our case, we opted for the representation through the adjacency matrix, which will be more convenient for the purposes of this work (three of the four centrality measures used here can be extracted directly from the matrix). For a weighted graph, as in our case study, the adjacency matrix of G, $A(G) = [a_{ij}]$, is the square matrix of order n, such that $a_{ij} = \omega_{ij}$, where ω_{ij} is the value associated to the edge $[v_i, v_j]$, if v_i and v_j are adjacent and $a_{ij} = 0$, otherwise.

Since edges in our graphs have no orientation, (undirected graphs), $a_{ij} = a_{ji}$ and the matrix is symmetric.

3.1 Traditional Centrality Measures

Degree centrality has been proposed by Freeman (1979). It corresponds to the number of direct connections that each element establishes with the others, which is called the vertex's degree. In transport networks, it represents the degree of usage for each element.

The degree centrality of a vertex v_i, denoted by $C_D(v_i)$, is calculated by summing the values in the corresponding row in the adjacency matrix, as in (1).

$$C_D(v_i) = d(v_i) = \sum_{j=1}^{n} a_{ij}, \qquad \text{where } v_i \in V \tag{1}$$

In this paper, we also apply the eigenvector centrality, which corresponds to the linear combination of the centralities of connected vertices (hereinafter called neighbours) (Bonacich and Lloyd, 2001). Hence, an element u is regarded as more central than another element v if u's neighbours are more central than v's neighbours, even if u and v have the same degree.

Using the adjacency matrix, the eigenvector centrality of a vertex v_i is defined as x_i, where x_i is the i-th coordinate of the unit positive eigenvector associated to the spectral radius (greatest eigenvalue) of $A(G)$. In other words, $C_{ev}(v_i) = x_i$, where $x = (x_1, \ldots, x_n)$ satisfies equation (2), or $Ax = \lambda x$, in matrix notation. In (2), λ corresponds to the greatest eigenvalue of the adjacency matrix, whereas x correspond to the unit positive eigenvector associated with λ.

$$\lambda x_i = a_{i1}x_1 + a_{i2}x_2 + \ldots + a_{\in}x_n \tag{2}$$

Another traditional measure is the betweenness centrality, based on the concept of geodesic path, i.e., the smallest number of edges connecting two vertices in a graph. Basically, this centrality measures the proportion of geodesic paths that pass through each vertex. However, there is no guarantee that two elements choose the geodesic path between them (Everton, 2012). Moreover, this centrality does not consider the edges' values.

Thus, Freeman *et al.* (1991) proposed the flow betweenness centrality, which considers any path between two vertices, as well as the edges' values. This centrality, considered an extension of betweenness centrality, represents the importance of a vertex in the flow between the other vertices (Freeman *et al.*, 1991).

Let $m_{i,j}$ be the maximum flow from vertex i to vertex j, and $m_{i,j}(v)$ the maximum flow from vertex i to vertex j, passing through v. The flow betweenness centrality is shown in (3).

$$C'_F(v) = \frac{\sum_{v \neq i \neq j \neq v} m_{i,j}(v)}{\sum_{v \neq i \neq j \neq v} m_{i,j}} \tag{3}$$

There are other centrality measures that could be calculated, such as Katz-centrality, originally proposed by Katz (1953), improved by Grindrod and Higham (2013), among others, and based on the premise that vertices are considered important if they are linked to other important vertices or if they are highly linked. Another possibility is the clustering coefficient, calculated for each vertex, as the number of triangles that pass through that vertex, relative to the maximum number of triangles that could pass through that vertex. In our case, it would be necessary to choose from several definitions of weighted clustering coefficient proposed in the literature, e.g., Barrat *et al.* (2004), Holme *et al.* (2007), Saramäki *et al.* (2007) and Zhang and Horvath (2005).

However, our target is to analyse the Brazilian port system using a recently proposed centrality measure, with desirable properties for our case study, as explained herein. Thus, we compare this centrality only with popular centrality measures that present similar characteristics, to simplify the comparative analysis.

3.2 Layer Centrality

Layer centrality, preliminarily introduced in Bergiante *et al.* (2011), takes the importance of neighbours into consideration, using, however, a simpler and more intuitive method than the eigenvector centrality.

This centrality, unlike the others described in the previous paragraph, does not assign a value to each vertex, but assigns an ordering to the set of vertices, allowing to identify which vertices are more central in the network.

The first step of the layer methodology is to identify the vertex with the smallest degree, calculated in (1), and ranking it in last place. We then exclude, from the adjacency matrix, the row and column associated with this vertex, and we recalculate the remaining vertices' degrees. By doing so, we remove the vertex from the matrix, thus we do not rank it again, but we also eliminate its connections to the other vertices, in which case, the vertices that are connected to this element also loose these connections. Thence, we repeat this process, ranking vertices from bottom to top. If more than one vertex has the same degree, we rank them in the same position, and exclude their rows and columns from the matrix, together. As previously stated, this centrality provides only a ranking. However, this may not be a major limitation, as plenty of studies are based solely on rankings.

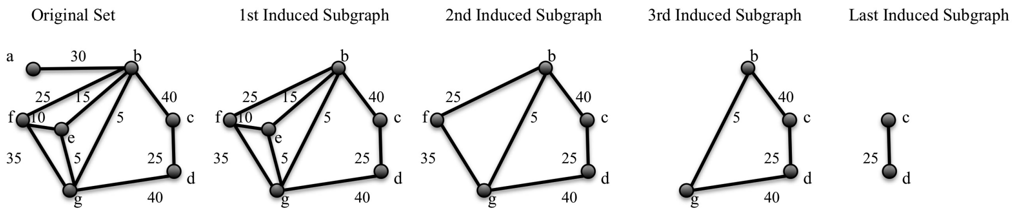
The ordering of the vertices is obtained recursively and this procedure could be described with the Algorithm 1.

Algorithm 1

Input: Graph G
Output: Final Order Centrality
Procedure
    $j = 1;\ X_j \leftarrow \emptyset$
    $\delta \leftarrow min\{d(v_i); 1 \leq i \leq n\}$
    $\Delta \leftarrow max\{d(v_i); 1 \leq i \leq n\}$
    While $(\Delta \neq \delta)$ do
        For each $i \in V(G_j)$
            if $d(v_i) = \delta$ then $X_j \leftarrow X_j \cup \{v_i\}$
        End-for
        $G \leftarrow G[V - X_j]$
        $j \leftarrow j + 1;\ X_j \leftarrow \emptyset$
        $\delta \leftarrow min\{d(v_i); 1 \leq i \leq n\}$
        $\Delta \leftarrow max\{d(v_i); 1 \leq i \leq n\}$
    End-while
    Return $V(G_j), X_{j-1}, X_{j-2}, \ldots, X_1$
End-procedure

We should highlight that, when applied to trees, i.e., connected acyclic graphs (Bondy and Murty, 2008), layer centrality resembles the algorithm based on the proof of Jordan's (1869) theorem, for finding the centre of trees (Hedetniemi *et al.*, 1981). In other words, a tree's best-ranked vertex (or two best-ranked vertices) in the layer centrality is proven to be its centre.

Figure 1 presents an illustrative example for layer centrality. The first illustration represents a weighted undirected graph $G = (V, E)$, where $V = ?\{$a, b, c, d, e, f, g$\}$ and $E = ?\{$[a,b], [b,c], [b,e], [b,f], [b,g], [c,d], [d,g], [e,f], [e,g], [f,g]$\}$. Moreover, the edges' weights are $\omega_{ab} = 30, \omega_{bc} = 40, \omega_{be} = 15, \omega_{bf} = 25, \omega_{bg} = 5, \omega_{cd} = 25, \omega_{dg} = 40, \omega_{ef} = 10, \omega_{eg} = 5, \omega_{fg} = 35$. The following illustrations represent induced subgraphs, in which the least central element(s) are eliminated, at each step of the method.



Vertex	Deg
a	30
b	115
c	65
d	65
e	30
f	70
g	85

Vertex	Deg
-	-
b	85
c	65
d	65
e	30
f	70
g	85

Vertex	Deg
-	-
b	70
c	65
d	65
-	-
f	60
g	80

Vertex	Deg
-	-
b	45
c	65
d	65
-	-
-	-
g	45

Vertex	Deg
-	-
-	
c	25
d	25
-	
-	
-	

Figure 1 – Example to illustrate the layer centrality methodology.

In the original set, the vertex with the smallest degree $d_0(i)$, i.e., vertex a, with degree $d_0(a) = 30$, is removed at the first iteration. Then, vertex e presents the smallest degree $d_1(e) = 30$, thus being removed at the second iteration. Then, vertex f presents the smallest degree $d_2(f) = 60$, thus being removed at the third iteration. At this point, vertices b and g present the smallest degree $d_3(b, g) = 45$, and are therefore removed at the final iteration. Table 1 shows the final order for this example.

Table 1 – Final order for the illustrative example in the layer methodology.

FINAL ORDER
c,d
b,g
f
e
a

Layer centrality may be, in certain cases, intermediary between degree and eigenvector centralities, because it takes into account the vertices' degrees, but it considers, to some extent, neighbours' centralities (Brandão *et al.*, 2015). On the other hand, layer centrality disregards all elements that have already been ranked, thus analysing the network created only between the most impactful elements. This characteristic may be desirable in some situations, for instance, if only ports that operate with significant amount of cargo should be considered for the transport of certain merchandise types, and if the methodology itself should defines this *significant amount of cargo*, instead of experts.

4 SCOPES AND METHODOLOGY FOR THE CASE STUDY

In this paper, we study Brazilian ports that traded non-containerized cargo with other national ports, as well as with foreign ports, because they represent a significant amount. In fact, maritime transport plays a much more important role to international trade than to national transport, according to the Special Secretary of Ports in Brazil. Therefore, the analysis would be incomplete without such trades.

We do not consider containerized cargo because it is measured in Twenty-Foot Equivalent Unit (TEU), whereas non-containerized cargoes, i.e., liquid bulk, granular bulk and loose cargo, are measured in tons. Taking both into account would require methods to combine them, and results would vary accordingly. Alternatively, two separate analyses would be necessary, as in Freire-Seoane *et al.* (2012) and Pais-Montes *et al.* (2012), for instance. To avoid such problems, we limit the scope of our study to non-containerized cargo.

We obtained the necessary data to evaluate the importance of each port in Brazil, from the Public Access Information System (SIG – *Sistema de Informações Gerenciais de Acesso Público*), by ANTAQ. We found 173 Brazilian ports (32 public ports and 141 private terminals) that transported non-containerized cargo with other domestic or foreign ports, from January to December 2014.

In terms of methodology, the first step is to build an adjacency matrix for each approach. For that, we transform the table extracted from ANTAQ, which presents the cargo transported from each origin to each destination, into the adjacency matrix, which indicates the cargo transported, between the port in the row and the port in the column, regardless of which is the origin and which is the destination. Thus, ports correspond to nodes and the amount of cargo transported between each pair of ports corresponds to the weight of the edge. With regard to foreign ports, we group them all into a single node, because our focus is on the Brazilian system. Thus, we do not analyse trades between foreign ports, and neither the importance of each port to the international system.

To calculate eigenvector and flow betweenness centralities, we used the UCINET program (Borgatti *et al.*, 2002), whereas the other measures described in section 3, did not require any particular software.

5 RESULTS AND DISCUSSIONS

In Table 2, we present the rankings for some Brazilian ports, considering the degree, eigenvector, flow betweeness, and layer centralities, ordered by the first one. Later in this section, we show a map representing all public ports (Figure 2).

Table 2 – Centrality Rankings for Brazilian ports and private terminals.

PORTS	UF	CENTRALITY RANKINGS			
		Degree	Eigenvector	Flow Betweenness	Layer
Ponta da Madeira	MA	1	1	74	1
Tubarão	ES	2	2	51	2
Santos	SP	3	4	1	4
Itaguaí	RJ	4	3	45	3
Bacia Sedimentar de Campos		5	26	28	8
Almirante Barroso	SP	6	10	17	7
Ilha Guaíba	RJ	7	5	101	5
Almirante Maximiano Fonseca	RJ	8	8	27	9
Paranaguá	PR	9	6	12	6
Trombetas	PA	10	15	101	12
Marítimo Ponta Ubu	ES	11	7	101	10
Madre de Deus	BA	12	30	4	23
Itaqui	MA	13	9	6	13
Alumar	MA	14	21	34	14
Vila do Conde	PA	15	14	10	11
Rio Grande	RS	16	12	2	17
Suape	PE	17	20	3	22
Almirante Tamandaré	RJ	18	44	13	19
São Francisco do Sul	SC	19	12	42	15
Vitória	ES	20	24	5	16
Pecém	CE	36	18	30	31
Salvador	BA	37	52	16	36
Terbian	RS	38	23	43	38
Praia Mole	ES	39	25	101	37
Manaus	AM	40	75	26	43
Belém	PA	42	59	22	50
Maceió	AL	43	37	11	40
Santana	AP	44	30	29	49
São Sebastião	SP	45	56	14	42
Gregório Curvo	MS	46	26	85	46
J. F. de Oliveira Manaus	AM	86	75	93	87
Braskem Alagoas	AL	87	75	64	85
Cargill Agrícola	RO	88	75	101	86
Chibatão 2	AM	89	75	93	90
ATR Logística	AM	90	75	93	91
Barcaças Oceânicas	ES	91	75	101	89
TUP Belmont	RO	92	75	91	92
Vila Velha	ES	93	75	99	93
Barra do Riacho	ES	94	75	25	97
Ilhéus	BA	95	59	69	94
Copelmi	RS	96	75	101	95
Fernando de Noronha	PE	153	75	101	153
Estaleiro Brasa	RJ	154	75	81	154
Estaleiro Mauá	RJ	155	75	86	155
UTC Engenharia	RJ	156	75	101	156
Unidade de Offshore Techint	PR	157	75	101	157
Barra do Rio	SC	158	75	101	158
Bacia Sedimentar Espírito Santo		159	75	101	159
Estrela	RS	160	75	101	160
Intermoor	RJ	161	75	101	161
Navship	SC	161	75	101	161
Dow Itajaí	SC	163	75	101	163
Navecunha	AM	164	75	101	164
Cruzeiro Do Sul	AC	165	75	101	165
Monte Alegre	PA	166	75	101	166
Ipiranga Manaus	AM	167	75	101	167
Portonave	SC	168	75	97	168
Mac Laren	RJ	169	75	101	169
Complexo Portuário do Açu	RJ	170	75	101	170
Icoaraci	PA	171	75	101	171
Prainha	PA	172	75	101	172
Juruti	PA	173	75	101	173

From Table 2, we could observe that *Santos*, the greatest Brazilian container port (Containerisation International, 2014), only occupied the first place in the flow betweenness ranking. In other words, it is the most central port in terms of intermediating the flow of merchandise between other ports, but not according to the other centralities.

In fact, most public ports play a very important role nationally. For instance, *Santos, Rio Grande, Suape, Madre de Deus, Vitória, Itaqui, Rio de Janeiro, Fortaleza, Aratu, Vila do Conde, Maceió, and Paranaguá* are the first twelve ports according to the flow betweenness ranking – *Madre de Deus* (third) and *Vila do Conde* (tenth) are the only private terminals in this list. As for private terminals, 14 ports only traded internationally, all of which present null flow betweenness centrality, such as *Ilha Guaíba*. On the other hand, 81 private terminals did not trade with foreign ports, such as *Bacia Sedimentar de Campos.* In other words, private terminals do not have a fixed characteristic in terms of national or foreign trading.

With regard to the other three centralities, *Ponta da Madeira* and *Tubarão* occupied the first and second place, respectively. In fact, these private terminals traded the greatest amounts of cargo with foreign ports and present a very poor performance nationally, which resulted in low positions in the flow betweenness ranking.

Next, we have *Itaguaí*, which is also poorly ranked by the flow betweenness centrality, though very well ranked according to the other centralities. This public port presents a poor performance when we only analyse the national flow, although it is, by far, the most relevant public port for international trade. In fact, according to the layer and eigenvector centralities, it is more central than *Santos*, because of its connections with international ports, despite having traded less cargo, as shown in the degree centrality ranking.

Similarly, *Paranaguá*, another public port, is better ranked in the layer and eigenvector centralities than in the degree centrality, because of its connections with international ports. On the other hand, the centrality rankings show that *Madre de Deus* has a greater importance in terms of national trade, than in terms of international trade. In other words, by comparing all four centrality rankings, we obtain relevant information, regarding the type of trade and its comparative amount.

In Table 3, we present the correlation indexes between the degree, eigenvector, layer and flow betweenness centrality rankings. We may observe that the flow betweenness centrality ranking is the least related to the other three rankings, particularly to the eigenvector ranking. The flow betweenness ranking prizes ports that present considerable flow with other national ports. On the other hand, the eigenvector ranking values connections with foreign ports, because they form the most central group – in fact, the ports' eigenvector centralities and the total amount of cargo they exchanged with foreign ports has a correlation index of 99.97%. This is why the eigenvector and flow betweenness rankings present such low correlation.

The degree centrality represents, by definition, the amount of trade, whether it is with national or international ports. This ranking and the layer centrality ranking are highly correlated, as shown in Table 3. However, Table 2 shows that they are more similar towards the end of the rankings. In

Table 3 – Correlation Indexes between Rankings.

Correlation	Degree	Eigenvector	Layer	F. Betweenness
Degree	-	77.39%	99.77%	64.55%
Eigenvector	77.39%	-	77.78%	48.61%
Layer	99.77%	77.78%	-	63.47%
F. Betweenness	64.55%	48.61%	63.47%	-

the beginning, the layer centrality has many similarities with the eigenvector ranking. In fact, the first seven positions of both rankings are exactly the same, and different from the degree ranking.

Thus, in this sense, the layer centrality behaved as an intermediary between the degree ranking, representing the amount of trade, and the eigenvector ranking, representing connection to international ports, in this case study. More specifically, the layer centrality provides an intermediate measure between both traditional centralities for certain ports, such as *Bacia Sedimentar de Campos*, *Almirante Barroso, Trombetas, Madre de Deus, São Francisco do Sul, Praia Mole, Terminal Manaus*, and others.

On the other hand, there are cases in which such logic does not apply (hereinafter referred to as divergent results), such as *Vitória, Bacia Sedimentar de Santos* and *Portocel. Vitória* is ranked in 20^{th} place in the degree ranking, in 24^{th} place in the eigenvector ranking, though in 16^{th} place in the layer ranking. Analysing the adjacency matrix, we observe that *Vitória* is very connected to *Almirante Barroso* (39% of *Vitória*'s total connections), which is very well ranked. A similar situation happens with *Bacia Sedimentar de Santos*, which is tightly connected (37%) to *Madre de Deus*, well ranked in the layer ranking. Contrarily, *Portocel* is ranked 22^{nd} in the degree ranking, 17^{th} in the eigenvector ranking, and 32^{nd} in the layer ranking. This port has many connections with *Fibria* (29%) and *Belmonte* (17%), which are poorly ranked.

Therefore, ports connected to many low or medium-ranked ports, tend to occupy lower positions in the layer ranking, when compared to the eigenvector ranking. On the other hand, ports connected to few highly ranked ports tend to occupy higher positions in the layer ranking, when compared to the eigenvector ranking. However, such divergent results are rare in this case study.

Comparing the present study with efficiency evaluations of Brazilian ports, based on non-containerized cargo, such as Bertoloto *et al.* (2011), we may verify certain similarities. For instance, many well-ranked units were also considered efficient therein, namely *Ponta da Madeira, Tubarão, Santos* and *Ilha Guaíba,* ranked from 1^{st} to 5^{th} place in the layer centrality ranking, as well as *Trombetas*, *Alumar*, and *Almirante Soares Dutra*, ranked from 12^{th} to 18^{th} place in the layer centrality ranking. However, certain efficient ports from Bertoloto *et al.* (2011) were not well ranked in the present study, namely *Maceió, São Sebastião* and *Braskarne*, ranked respectively in the 40^{th}, 42^{nd} and 116^{th} positions, in the layer ranking.

The study in Sousa Junior *et al.* (2013) with regard to solid bulk cargo that ports from the Northeast handled in 2006, diverged even more. The single efficient terminal was not present in our study, i.e., did not handle non-containerized cargo in 2014. Moreover, the efficiency of the other ports therein had no relation with their rankings herein. For instance, *Itaqui* and *Suape*, well ranked in the present analysis, had efficiencies of 35% and 10%, respectively, whereas *Areia Branca*, ranked in 56th place in the layer centrality, presented efficiency of 77%.

Figure 2 shows a map representing the layer ranking for all public ports in the analysis, obtained with the ArcMap software. Since it wouldn't be possible to visualize all 173 ports, Figure 2 represents only public ports. We also show the name for certain states that will be referred to herein.

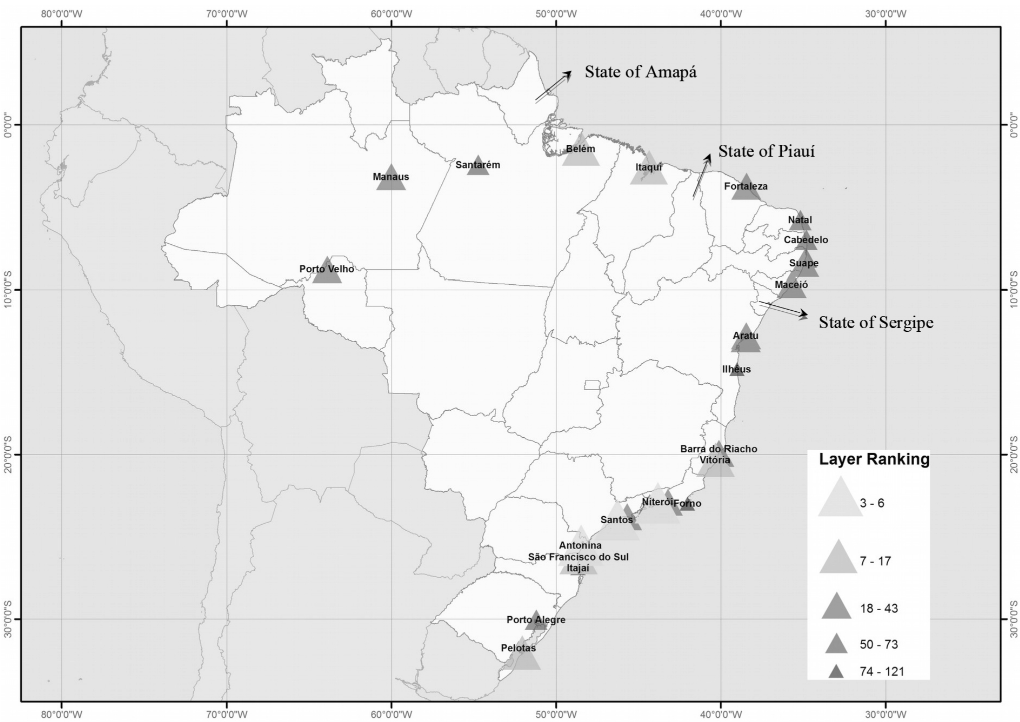


Figure 2 – Map representing public ports in the layer ranking.

We may observe that the greatest public ports are in the south-eastern region, although the north-eastern region presents many average-sized ports. We may also verify that most small ports are very close to other greater ports, so that the vast majority of the coastal states have at least one average-sized public port.

In fact, only three coastal states do not have a public port: *Amapá*, *Piauí*, and *Sergipe*, shown in the map. In the cases of *Amapá* and *Sergipe*, the private sector filled the public gap: there are three private terminals in *Amapá*, namely, *Santana*, *Estação de Santana* and *Texaco Amapá,* ranked, respectively, in 49th, 105th and 128th place in the layer ranking; and two private terminals in *Sergipe*, namely, *Carmópolis* and *Inácio Barbosa,* ranked, respectively, in 39th and in 84th place in the layer ranking.

However, there are no ports – public or private – in the state of *Piauí*. Although this state is historically unproductive, and sustained by the public sector (Galeno, 2011), its economy has been growing considerably, particularly increasing its exports (Cury, 2014). In other words, *Piauí* seems to be an interesting location for a new port.

6 CONCLUSION

This study analysed the influence of each port in the Brazilian system nowadays, based on the flow of non-containerized cargo, between January and December 2014. We also considered trades with foreign ports, which were grouped into a single unit. We studied and applied layer centrality, preliminarily introduced in Bergiante *et al.* (2011), as well as three traditional measures, namely, degree, eigenvector and flow betweenness centralities, for comparison purposes.

As the eigenvector centrality, the layer centrality takes the centrality of neighbours into account, using, however, a much less complex method, and dispensing with computational aid. Such simplicity is particularly interesting for evaluations of public services, since regulatory agencies, non-governmental organizations, and the general public could easily confirm such evaluations.

In our case study, we compared all four centralities and observed that, in most cases, layer centrality behaves as intermediary between the degree and eigenvector centralities, although, in certain cases, it produces divergent results. Such results tend to occur with elements connected to many medium-ranked units, or to few highly ranked units.

We verified that the most impactful ports, according to the degree, eigenvector and layer rankings, were private terminals, namely *Ponta da Madeira* and *Tubarão*. These ports traded the greatest amount of non-containerized cargo with foreign ports, but had a very poor performance with other national ports. Thus, despite having the greatest performance according to such centralities, they presented low flow betweenness centrality.

The public ports of *Santos* and *Itaguaí* were ranked in third and fourth place, according to the degree, eigenvector and layer rankings. Almost 100% of *Itaguaí's* trades were with foreign ports, thus, this port also presented low flow betweenness centrality. On the other hand, *Santos* had a very important role in the national trade and was ranked in first place in the flow betweenness ranking. Many other public ports also presented a very important role nationally.

We also analysed the map for public ports and verified that the greatest public ports are in the southeastern region, although the vast majority of the coastal states have at least one average-sized public port. Furthermore, the private sector filled the public gap for two of the three coastal states without a public port. Only the state of *Piauí* has no ports, public or private. Although historically unproductive, *Piauí* has been growing economically, and particularly increasing exports. Thus, it seems to be an appropriate location for a new port.

Furthermore, impactful ports identified herein should receive special attention from government and port managers in maintenance planning, as well as in other infrastructure projects, because they cause the greatest impacts to the Brazilian port system. Future works may include containerized cargo in the analysis, using, for instance, a bi-criteria composition. Moreover, layer centrality studies should be further developed.

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References

[1] AGENCIA NACIONAL DE TRANSPORTES AQUAVIÁRIOS (ANTAQ) - National Waterway Transportation Agency. 2016. *Conheça a ANTAQ (Meet ANTAQ)* [online]. Brazil. http://www.antaq.gov.br/Portal/Institucional.asp (Accessed 29 May 2016).

[2] BARRAT A, BARTHÉLÉMY M, PASTOR-SATORRAS R & VESPIGNANI A. 2004. The architecture of complex weighted networks. *Proceedings of the National Academy of Sciences of the United States of America* **101**(11): 3747-3752. doi: 10.1073/pnas.0400087101

[3] BERGIANTE N C R, SOARES DE MELLO J C C B, NUNES, M V R & PASCHOALINO F F. 2011. Application of a centrality measure proposal to evaluate the network of a Brazilian airline. *Journal of Transport Literature* **5**(4): p. 119-135.

[4] BERTOLOTO R F & SOARES DE MELLO J C C B. 2011. Eficiência de portos e terminais privativos brasileiros com características distintas (Efficiency of Brazilian ports and private terminals with distinct characteristics). *Journal of Transport Literature* **5**(2): 4-21.

[5] BONACICH P & LLOYD P. 2001. Eigenvector-like measures of centrality for asymmetric relations. *Social Networks* **23**: 191-201.

[6] BONDY A & MURTY U S R. 2008. *Graph Theory*, Springer, 2008, XII, 651 p.

[7] BORGATTI S P, EVERETT M G & FREEMAN L C. 2002. *Ucinet 6 for Windows: Software for Social Network Analysis*, Harvard, MA: Analytic Technologies.

[8] BRANDAO L C, DEL-VECCHIO R R & SOARES DE MELLO J C C B. 2015. Graph Centrality Analysis for the Evaluation of the 2014 Guanabara Cup. *Proceedings of the 5th International Conference on Mathematics in Sport, Loughborough University, UK,* p. 11-18.

[9] CAILLAUX M A, SANT'ANNA A P, ANGULO-MEZA L & SOARES DE MELLO J C C B. 2011. Container logistics in Mercosur: Choice of a transhipment port using ordinal

Copeland method, Data Envelopment Analysis and Probabilistic Composition. *Maritime Economics & Logistics* **13**(4): 355-370.

[10] CASTILLO HIDALGO D & MOHAMED-CHÉRIF F. Z. 2017. La configuración de las redes de transporte marítimo en Africa noroccidental. 1880-1939. (The configuration of maritime transport networks in Northwest Africa). *Investigaciones de Historia Economica* **13**(2): 81-92. doi: 10.1016/j.ihe.2016.02.001

[11] CHANG V & TOVAR B. 2014. Drivers explaining the inefficiency of Peruvian and Chilean ports terminals. *Transportation Research Part E: Logistics and Transportation Review* **67**: 190-203.

[12] CONTAINERISATION INTERNATIONAL. 2014. *One Hundred Ports – the World's Biggest Container Terminals* [online]. http://europe.nxtbook.com/nxteu/informa/ci_top100ports2014/ (Accessed 8 March 2015).

[13] CURY J. 2014. Piauí é o 2° Estado com maior crescimento de exportações (Piauí is the second state with the greatest increase of exports). *Cidade-Verde.com* [online]. http://cidadeverde.com/economiaenegocios/64463/piaui-e-o-2-estado-com-maior-crescimento-de-exportacoes (Accessed 18 May 2016).

[14] DUCRUET C, ROZENBLAT C & ZAIDI F. 2010. Ports in multi-level maritime networks: evidence from the Atlantic. 1996–2006. *Journal of Transport Geography* **18**: 508-518. doi: 10.1016/j.jtrangeo.2010.03.005

[15] ERCSEY-RAVASZ M, LICHTENWALTER R, CHAWLA N V & TOROCZKAI Z. 2012. Range-limited Centrality Measures in Complex Networks. *Physical Review E* **85**(6): 066103.

[16] ERCSEY-RAVASZ M & TOROCZKAI Z. 2010. Centrality Scaling in Large Networks. *Physical Review Letters* **105**(3): 038701.

[17] EVERTON S F. 2012. *Disrupting Dark Networks (Structural Analysis in the Social Sciences)*, Cambridge University Press, New York, NY, USA.

[18] FREEMAN L C. 1979. Centrality in networks: I Conceptual clarification. *Social Networks* **1**: 215-239.

[19] FREEMAN L C, BORGATTI S P & WHITE D R. 1991. Centrality in valued graphs: A measure of betweeness based on network flow. *Social Networks*, Vol.13, p.141-154. doi: 10.1016/0378-8733(91)90017-N

[20] FREIRE-SEOANE M J, GONZALEZ-LAXE F & PAIS-MONTES C. 2013. Foreland determination for containership and general cargo ports in Europe. 2007–2011. *Journal of Transport Geography* **30**: 56-67. doi: 10.1016/j.jtrangeo.2013.03.003

[21] GALENO L. 2011. IBGE alerta: "economia do Piauí é dependente do setor Público" (The Brazilian Institute of Geography and Statistics alerts: Piauí's economy is dependent on the public sector). *CidadeVerde.com* [online]. http://cidadeverde.com/noticias/88497/ibge-alerta-economia-do-piaui-e-dependente-do-setor-publico (Accessed 18 May 2016).

[22] GRINDROD P & HIGHAM D. J. 2013. A matrix iteration for dynamic network summaries. *SIAM Review* **55**(1): 118-128. doi: 10.1137/110855715

[23] HEDETNIEMI S M, COCKAYNE E J & HEDETNIEMI S T. 1981. Linear algorithms for finding the Jordan center and path center of a Tree. *Transportation Science* **15**(2): 98-114.

[24] HOLME P, PARK S M, KIM B J & EDLING C R. 2007. Korean university life in a network perspective: Dynamics of a large affiliation network. *Physica A* **373**: 821-830. doi: 10.1016/j.physa.2006.04.066

[25] JORDAN C. 1869. Sur les assemblages de lignes (On the assembly of lines). *Journal Für Die Reine und Angewandte Mathematik* **1869**(70): 185-190.

[26] JOYCE K E, LAURIENTI P J, BURDETTE J H & HAYASAKA S. 2010. A new measure of centrality for brain networks. *PLoS One*, Vol. 5(8, e12200. doi: 10.1371/journal.pone.0012200

[27] KALUZA P, KÖLZSCH A, GASTNER M T & BLASIUS B. 2010. The complex network of global cargo ship movements. *Journal of the Royal Society Interface* **7**: 1093-1103. doi: 10.1098/rsif.2009.0495

[28] KATZ L. 1953. A new index derived from sociometric data analysis. *Psychometrika* **18**: 39-43. doi: 10.1007/BF02289026

[29] LAGOUDIS I. N, THEOTOKAS I & BROUMAS D. 2017. A literature review port competition research. *International Journal of Shipping an Transport Logistics* **9**(6): 724-762. doi: 10.1504/IJSTL.2017.10007004

[30] MCCALLA R, SLACK B & COMTOIS C. 2005. The Caribbean basin: Adjusting to global trends in containerization. *Maritime Policy and Management* **32**(3): 245-261. doi: 10.1080/03088830500139729

[31] MENESCAL R. 2015. Informações do Setor de Transporte Aquaviário no Brasil (Information of the Brazilian Waterway Transport Sector). *ANTAQ* [online]. http://www.antaq.gov.br/Portal/pdf/Palestras/2015/20151111_Rogerio_Menescal_Workshop_Logistico_Transportes.pdf (Accessed 4 January 2016).

[32] NG A K Y, PADILHA F & PALLIS A A. 2013. Institutions, bureaucratic and logistical roles of dry ports: the Brazilian experiences. *Journal of Transport Georgaphy* **27**: 46-55. doi: 10.1016/j.jtrangeo.2012.05.003

[33] PADILHA F & NG A K Y. 2012. The spatial evolution of dry ports in developing economies: The Brazilian experience. *Maritime Economics & Logistics* **14**: 99-121. doi: 10.1057/mel.2011.18

[34] PAIS-MONTES C, FREIRE-SEOANE M J & GONZALEZ-LAXE F. 2012. General cargo and containership emergent routes: A complex networks description. *Transport Policy* **24**: 126-140. doi: 10.1016/j.tranpol.2012.06.022

[35] PORTOS DO BRASIL. 2015. Histórico (History). *Secretaria de Portos da Presidência da República* [online]. http://www.portosdobrasil.gov.br/sobre-1/institucional/base-juridica-da-estrutura-organizacional/historico (Accessed 29 May 2016).

[36] SANCHEZ R J, HOFFMAN J, MICCO A, PIZZOLITTO G V, SGUT M & WILMSMEIER G. 2003. Port Efficiency and International Trade: Port Efficiency as a Determinant of Maritime Transport Costs. *Maritime Economics and Logistics* **5**: 199-218.

[37] SARAMÄKI J, KIVELÄ M, ONNELA J.-P, KASKI K & KERTÉSZ J. 2007. Generalizations of the clustering coefficient to weighted complex networks. *Physical Review E*, Vol. 75, 027105. doi: 10.1103/PhysRevE.75.027105

[38] SOUSA JUNIOR J N C, NOBRE JUNIOR E F, PRATA B A & SOARES DE MELLO J C C B. 2013. Avaliação da eficiência dos portos utilizando análise envoltória de dados: estudo de caso dos portos da região nordeste do Brasil (Port efficiency evaluation using data envelopment analysis: a case study of ports from the Brazilian northeastern region). *Journal of Transport Literature* **7,**(4): 75-106.

[39] TOVAR B, HERNÁNDEZ R & RODRÍGUEZ-DÉNIZ H. 2015. Container port competitiveness and connectivity: The Canary Islands main ports case. *Transport Policy* **38**: 40-51. doi: 10.1016/j.tranpol.2014.11.001

[40] ZHANG B & HORVATH S. 2005. A general framework for weighted gene co-expression network analysis. *Statistical Applications in Genetics and Molecular Biology* **4**(1) article 17.

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