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A Multi-centrality Model based on Borda Count Method for Identification of Important Ports in Maritime Networks

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***Abstract*—This paper aims to build a new multi-centrality model based on Borda count method for identification of important ports in maritime networks. Main contributions of this paper can be concluded as follows. First, it is found that the Asia-Europe routes of the Maersk shipping line is not homogeneous, indicating that a few hubs occupy major shipping lines. Secondly, the multi-centrality model based on Borda count method is conducted to identify vulnerable ports of maritime networks. The proposed analysis framework could contribute to generating valuable managerial implications for the stakeholders such as shipping lines, ports, and port states to ensure the robustness of the investigated maritime supply chains.**

Keywords*—*Maritime transport; Complex networks; Network topology; Resilience; Maritime risk

I. INTRODUCTION

With the fast development of container transportation, maritime network become one of the largest complex networks in the world. Random failures and deliberate attacks on a single element (node or edge) in the network may cause a cascading breakdown of the whole system. Foci of investigating the most important nodes of the network are moving from classical cause-consequence analysis at a local component level to a network vulnerability study from a global system perspective. Complex network theories and methods, including Social Network Analysis (SNA) and system simulation, are therefore playing increasingly important roles in analyzing the vulnerabilities of maritime supply chains [1-3].

People would make little consensus on the concept of “node importance” since it is a vague concept. Scholars in the field of Social Network Theory such as Freeman [4] deem that in social network, the importance of some node is related to “centrality” of the node. Freeman [4] reviewed the concept and measure of “centrality” and suggested three measure indexes for point centrality. “Degree” which can be used to measure the communication activity in a network is a proper measure. “Betweenness” reflects the frequency that a node is just between pairs of other nodes on the shortest paths. “Closeness” can be used to reflect the efficiency or independence of communication of the network. These three measure indexes are referenced to three different structural attributes.

Few works have addressed the node importance of the maritime network in the view of network aspect. Reference [5] is a pioneer. They model ports and scheduled liner containership services between Western Europe and North America as the nodes and links of a global network. They deem that the most important nodes are not necessarily the busiest ones, and that some nodes may be more heavily affected than others.

Single centrality provides partial information about nodes and cannot reflect the whole profile. In order to aggregate the information from different centrality measures and rank the nodes with respect to their overall role in the network, parametric approaches such as analytical hierarchy process [6], technique for order performance by similarity to ideal solution [7], fuzzy logic [8], and non-parametric ones like ordered weighted averaging [9] are used to assign a different weight to each measure. However, these methods require to subjectively evaluate the relative importance of the selected attributes. It sometimes makes decision makers to assign more importance to some attributes over the others, which often causes subjective bias. More importantly, it constrains the presentation of each combined measure to be uniformed. To avoid the subjective bias caused by decision maker preferences, a non-parametric method based on partial order set [10] was introduced to aggregate different topological measures to rank the nodes in a network. Furthermore, voting aggregation methods like the Borda Count method [11] and Copeland’s Score method [12], cutting down individual influence on the final result by electing a candidate with the broadest acceptance from all the voters, are often considered as a consensus-based approach rather than a majoritarian one. The principles of two methods are similar, while the calculation process of the Borda Count is simpler than that of Copeland’s Score. The Borda Count method is used in this paper, and it is a voting method in which voters rank candidates in order of preference. In this method, each candidate will be ranked by each voter by means of giving a certain number of points corresponding to the position of this candidate. The winner is the candidate who has the most points. It presents a rational solution in combining different measures from multi-centrality analysis as evidenced

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from its applications and the associated implications in recent studies.

The remaining part of this paper is organized as follows. In Section 2, maritime network modeling and data source are illustrated, and its basic topology features are analyzed in Section 3. In Section 4, identifications of important ports by individual centrality—degree, betweenness and closeness centrality are analyzed. In Section 5, the multi-centrality models based on the Borda Count method is developed. Finally, Section 8 concludes the paper by highlight its contributions and limits.

II. METHODOLOGY

A. *Maritime network modeling*

The typical definition of a maritime transport network is a graph where nodes are ports and links are inter-port connections realized by the circulation of vessels. In other words, the network is built based on ports of call, vessel characteristics and vessel movements. The links could be directed or non-directed links, weighted or non-weighted links, depending on the demands of research.

In 2007, reference [13] introduced the idea of space *L* and space *P* into maritime networks, and extended the idea to the case of directed networks. The space *L* consists of nodes and links. A link exists between a pair of nodes if they are consecutive stops on a ship route (Figure 1). In this kind of topology, the node degree *k* is the sum of different ship routes one can take from a given port. However, in the space *P*, only if there is a ship schedule traveling between two nodes, the link between the two nodes exists. Therefore, the node degree *k* in this topology is the sum of nodes reachable using a single ship route and the distance can be interpreted as a number of transfers (plus one) one has to take to get from one port to another.

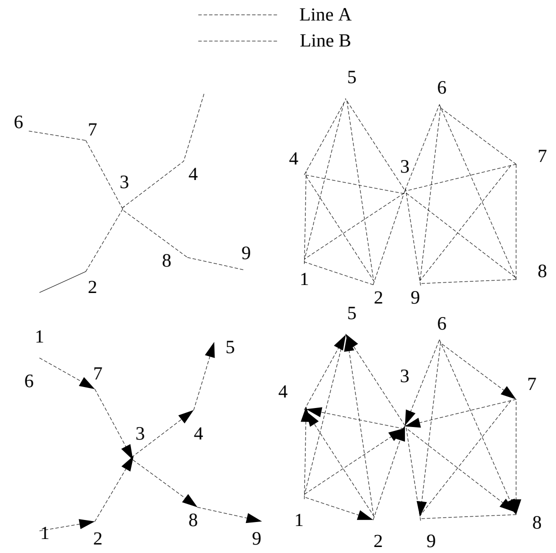

Fig. 1 The case of directed network (From reference[13])

Reference. [12] also used the above two different network representations to construct the worldwide maritime transportation network. Reference [10] provided two concepts GDL (Graph of Direct Links) and GAL (Graph of All Links) instead of space *L* and *P*. On the one hand, the GDL only includes direct successive calls between ports (namely from port A to port B and from port B to port C). On the other hand, the GAL includes direct and indirect calls. It can be argued that if two ports belong to the same liner service or loop, although they are not adjacent calls (that is from port A to port C), they are also connected. In this research, the network type space *L* (GDL) is considered, which consists of nodes (*i.e.*, ports), and a link between two nodes exists if they are consecutive stops on the same ship route.

TABLE I. PORT INDEX AND ITS NAME

Index	Port name	Index	Port name
1	Aarhus	28	Le havre
2	Algeciras	29	Marsaxlokk
3	Ambarli	30	Nagoya
4	Antwerp	31	Nansha
5	Barcelona	32	Nansha new port
6	Beirut	33	Ningbo
7	Bremerhaven	34	Odessa
8	Busan	35	Port Klang
9	Chiwan	36	Port Said
10	Colombo	37	Port tangiers
11	Constantza	38	Qingdao
12	Dalian	39	Rijeka
13	Felixstowe	40	Rotterdam
14	Fossurmer	41	Salalah
15	Gdansk	42	Shanghai
16	Genoa	43	Singapore
17	Gothenburg	44	Suez canal container terminal (SCCT)
18	Hamburg	45	Tanjungpelepas
19	Hong Kong	46	Trieste
20	Ilyichevsk	47	Valencia
21	Izmitkorfezi	48	Vungtao
22	Jebel all	49	Wilhelmshaven
23	Jeddah	50	Xiamen
24	Kobe	51	Xingang
25	Koper	52	Yantian
26	Kwangyang	53	Yokohama
27	La spezia	54	Zeebrugge

B. Data source and visualization

The data source in our research is from Maersk shipping line with a focus on its Asia-Europe routes in July 2016 from Maersk website (http://www.maerskline.com), including 19 shipping lines and 54 call ports. Table 1 shows the index number of each port.

An adjacency matrix ***A*** represents the links connecting each pair of nodes. The element a_{ij} of the adjacent matrix ***A*** equals to 1 if there is a link from node *i* to *j* or 0 otherwise. A directed network means that links point in one direction from one node to another node. Then nodes have two different degrees, the in-degree $k_{in}(i)$, which is the number of incoming edges, and the out-degree $k_{out}(i)$, which is the number of outgoing edges [13].

$$k_{in}(i) = \sum_{j\neq i} a_{ji}, k_{out}(i) = \sum_{j\neq i} a_{ij}, k_{all}(i) = \sum_{j\neq i}(a_{ji} \text{ or } a_{ij}) \quad (1)$$

Because shipping routes are directed, links in the network should also be directed. From the asymmetric adjacent matrix ***A***, three kinds of degree can be calculated—in-degree, out-degree and all-degree which does not take into account the direction of links.

In addition, weighting should be addressed especially in transportation networks. Because some paths have more traffic flows than others, hence playing more important roles in the functioning of the whole network. Traffic on a transportation network is not equally distributed.

In this study, we assume that the more shipping routes from port *i* to port *j*, the greater the weight of link from *i* to *j*.

The element w_{ij} of the link weight matrix ***W*** is usually used to represent the strength or importance of relations from port *i* to port *j*. We define the element w_{ij} of the weight matrix ***W*** is the number of shipping lines traveling from port *i* to port *j* [14]. Then, another important metric is deduced, called node strength. Node strength is defined as the total weight of node connections. The strength distribution is a characteristic of node. It is also divided into in-strength, out-strength and all-strength in our network.

$$s_{in}(i) = \sum_{j\neq i} w_{ji}, s_{out}(i) = \sum_{j\neq i} w_{ij}, s_{all}(i) = \sum_{j\neq i}(w_{ij} + w_{ji}) \quad (2)$$

Finally, the network contains 54 nodes and132 directed and weighted edges.

The network visualization is shown in Figure 2. The size of the edges reflects the weights of the associated links.

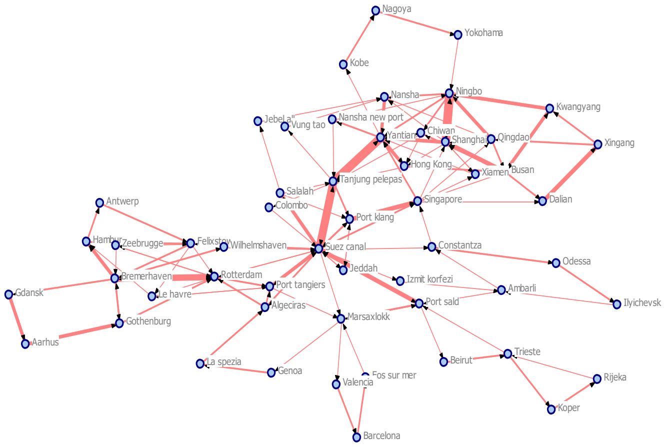

Fig. 2 Visualization of network

III. Analysis on Network Topology Features

A. Degree metrics and their distributions

The above Figure 1 only shows the network topology. It is necessary to use statistical methods to further investigate the network topology features. In statistics, the topology structure of networks can be analyzed by distribution functions. The spread in the number of edges of a node, *i.e.*, node degree, is characterized by a distribution function $P(k)$, which describes the probability that a randomly selected node I has exactly k_i edges. Emergence of a power-law in the degree distribution $P(k) \sim k^{-\gamma}$ in complex networks is an interesting self-organized phenomenon in complex systems. Such a network is called scale-free network. In this section, node degree distributions are analyzed.

The all-degree distribution is obtained and shown in Figure 3. The part of the distribution exhibits a power law-like degree distribution too.

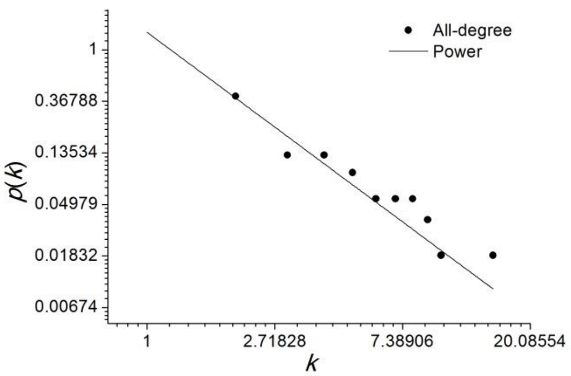

Fig. 3 Degree distribution of non-directed network in log-log coordinate

In Figure 2, the all-degree distribution's power-law fitting curve is $p(k)$= 1.404*$k^{-1.838}$ with R-square0.9586 and adjusted R-square 0.9552.

Consequently, the in-degree, out-degree and all-degree, tending to follow a power law-like distribution, imply the existence of several hubs in the investigated network occupying a majority of links.

B. Node strength metrics and their distributions

The all-strength distribution is shown in Figure 4. The part of the distribution exhibits a power law-like degree distribution.

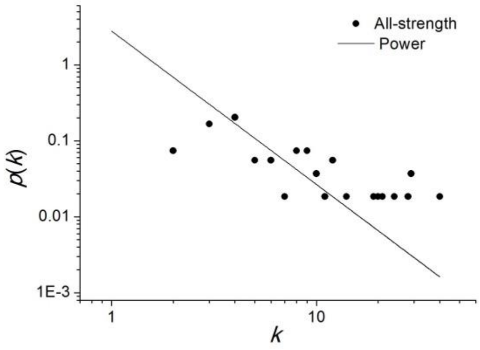

Fig. 4 Strength distribution of non-directed network in a log-log coordinate.

In Figure 8, the all-degree distribution's power-law fitting curve is$p(k)$= 2.79*$k^{-2.02}$ with R-square 0.7511 and Adjusted R-square 0.744.

If random attacks occur on a heterogeneous network of ports, it is less likely to happen on hubs and will not have much effect on the structure and function of the whole system. But once failures occur on hub ones, the impact would spread quickly throughout the network.

IV. Identification of Important Ports by Individual Centrality

A. Degree centrality

First, we identify important ports according to node degrees. From Table 2, we can see that except port NO.44, other high-degree ports have no significant differences from each other. However, port NO.44 is Suez Canal container terminal (SCCT), which presents the gate between Europe and Asia, and obviously the analysis result verifies its importance. Other high degree ports are NO.42 (Shanghai with a high out-degree), NO.43 (Singapore with a high out-degree), NO.52 (Yantian with a high in-degree), NO.45 (Tanjung pelepas with both high in-degree and out-degree), and NO.40 (Rotterdam with a high in-degree) with specific sequences according to different degrees.

Secondly, we investigate the strength of the ports. The top 5 ports are NO.44 (SCCT), NO.42 (Shanghai), NO.52 (Yantian), NO.33 (Ningbo), NO. 45 (Tanjung pelepas). Ningbo replaces Singapore, which means that more shipping lines connect with Ningbo.

TABLE II. TOP 5 HIGH DEGREE PORTS

Sorted by out-degree		Sorted by in-degree		Sorted by all-degree	
Port index(Name)	Out-degree	Port index(Name)	In-degree	Port index(Name)	All-degree
44(SCCT))	13	44(SCCT)	9	44(SCCT)	15
42(Shanghai)	6	52(Yantian)	8	52(Yantian)	10
43(Singapore)	6	40(Rotterdam)	7	43(Singapore)	9
52(Yantian)	5	45(Tanjung pelepas)	6	45(Tanjung pelepas)	9
45(Tanjung pelepas)	5	42(Shanghai)	5	42(Shanghai)	8

B. *Betweenness centrality*

We conduct the analysis on node betweenness. From Table 3 it can be seen that port NO.36 (Port Said) is an unexpected key node in the network, and other key nodes are kept in similar places to those obtained by the above methods.

TABLE III. TOP 4 PORTS BASED ON BETWEENNESS CENTRALITY

Index(Name)	**Node betweenness**
44(SCCT)	1860.15
45(Tanjung pelepas)	913.667
36(Port Said)	679
52(Yantian)	628.85

C. *Closeness centrality*

Top 4 ports are listed in Table 4.NO.13 (Felixstowe), NO.35 (Port Klang) are identified due to their high out-closeness.

TABLE IV. TOP 4 PORTS IN TERMS OF CLOSENESS

Sorted by incloseness		**Sorted by outcloseness**	
Port index(Name)	***Incloseness***	***Port index(Name)***	***Outcloseness***
44(SCCT)	35.57	44(SCCT)	42.4
45(Tanjung pelepas)	33.333	45(Tanjung pelepas)	34.194
52(Yantian)	30.636	13(Felixstowe)	33.544
36(Said)	30.114	35(Klang)	33.333

V. A MULTI-CENTRALITY MODEL BASED ON BORDA COUNT

The Borda count is a single-winner election method in which voter ranks options or candidates in order of preference. The Borda count determines the outcome of a debate or the winner of an election by giving each candidate, for each ballot, a number of points corresponding to the number of candidates ranked lower. Once all votes have been counted the option or candidate with the most points is the winner. Because it sometimes elects broadly acceptable options or candidates, rather than those preferred by a majority, the Borda count is often described as a consensus-based voting system rather than a majoritarian one.

In this paper, a model containing degree centrality, node strength centrality, betweenness centrality and closeness centrality is developed based on the Borda Count method. For example, there are 54 ports totally in this case, the all-degree of node No.44 ranks the first, so it gets 54 points, and the strength of this node also ranks the first, and it gets 54 points again. The total score of No.44 is 270. All ports are calculated and ranked and the result is shown in Table 5.

TABLE V. RANKING OF ALL INDEXED PORTS IN TERMS OF THEIR AGGREGATED CENTRALITY MEASURES

Ranking	Index	Name	Ranking	Index	Name
1	44	SCCT	28	54	Zeebrugge
2	45	Tanjungpelepas	29	23	Jeddah
3	52	Yantian	30	26	Kwangyang
4	40	Rotterdam	31	51	Xingang
5	36	Said	32	32	Nansha new port
6	42	Shanghai	33	12	Dalian
7	43	Singapore	34	49	Wilhelmshaven
8	37	Tangiers	35	53	Yokohama
9	33	Ningbo	36	47	Valencia
10	13	Felixstowe	37	48	Vung tao
11	35	Port Klang	38	34	Odessa
12	29	Marsaxlokk	39	27	La spezia
13	8	Busan	40	30	Nagoya
14	7	Bremerhaven	41	10	Colombo
15	38	Qingdao	42	20	Ilyichevsk
16	31	Nansha	43	21	Izmit korfezi
17	9	Chiwan	44	39	Rijeka
18	19	Hong Kong	45	6	Beirut
19	46	Trieste	46	24	Kobe
20	41	Salalah	47	14	Fos sur mer
21	11	Constantza	48	16	Genoa
22	2	Algeciras	49	5	Barcelona
23	17	Gothenburg	50	25	Koper
24	50	Xiamen	51	15	Gdansk
25	3	Ambarli	52	4	Antwerp
26	28	Le havre	53	22	Jebel all
27	18	Hamburg	54	1	Aarhus

VI. DISCUSSIONS AND CONCLUSION

There are scanty studies on identification of important ports of maritime network. Our work is a study of multi-disciplinary nature incorporating science relating to complex network, vulnerability analysis and maritime transportation operations. The findings reveal that the proposed methodology is capable of providing insights on the identification of important ports in maritime networks.

Main contributions of this paper can be concluded as follows. First, from the data source, basic network topology features are analyzed. All degree and strength based exhibit a power law-like distribution. As a result, it is found that the Asia-Europe routes of the Maersk shipping line is not homogeneous, indicating that a few hubs occupy major shipping lines. Secondly, given that single centrality cannot provide sufficient information about vulnerability analysis of nodes for reasonable decision making, the multi-centrality model based on Borda count method is conducted to identify vulnerable ports of maritime network. It should be well noted that by using the models, this study can provide more insightful analysis, including: First, managerial implications for stakeholders. The proposed analysis framework could contribute to generating valuable managerial implications for the stakeholder such as shipping lines, ports, and port states to ensure the robustness of the investigated maritime supply chains. For example, the result of our empirical study based on the data of the Maersk Line is helpful to identify key ports with respect to the vulnerability of its EU-Asia maritime network. The empirical can easily be expanded to other shipping lines.

In future research, the traffic volume of cargo throughput should be taken into account properly. In addition, the prerequisite for the research of this kind is a stable topology of the network in a fixed time window, and the dimensions of time can be investigated to reveal their impacts to the vulnerability of maritime supply chains in a dynamic manner in future work.

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