Evaluating the characteristics of container shipping networks in the Maritime Silk Road area

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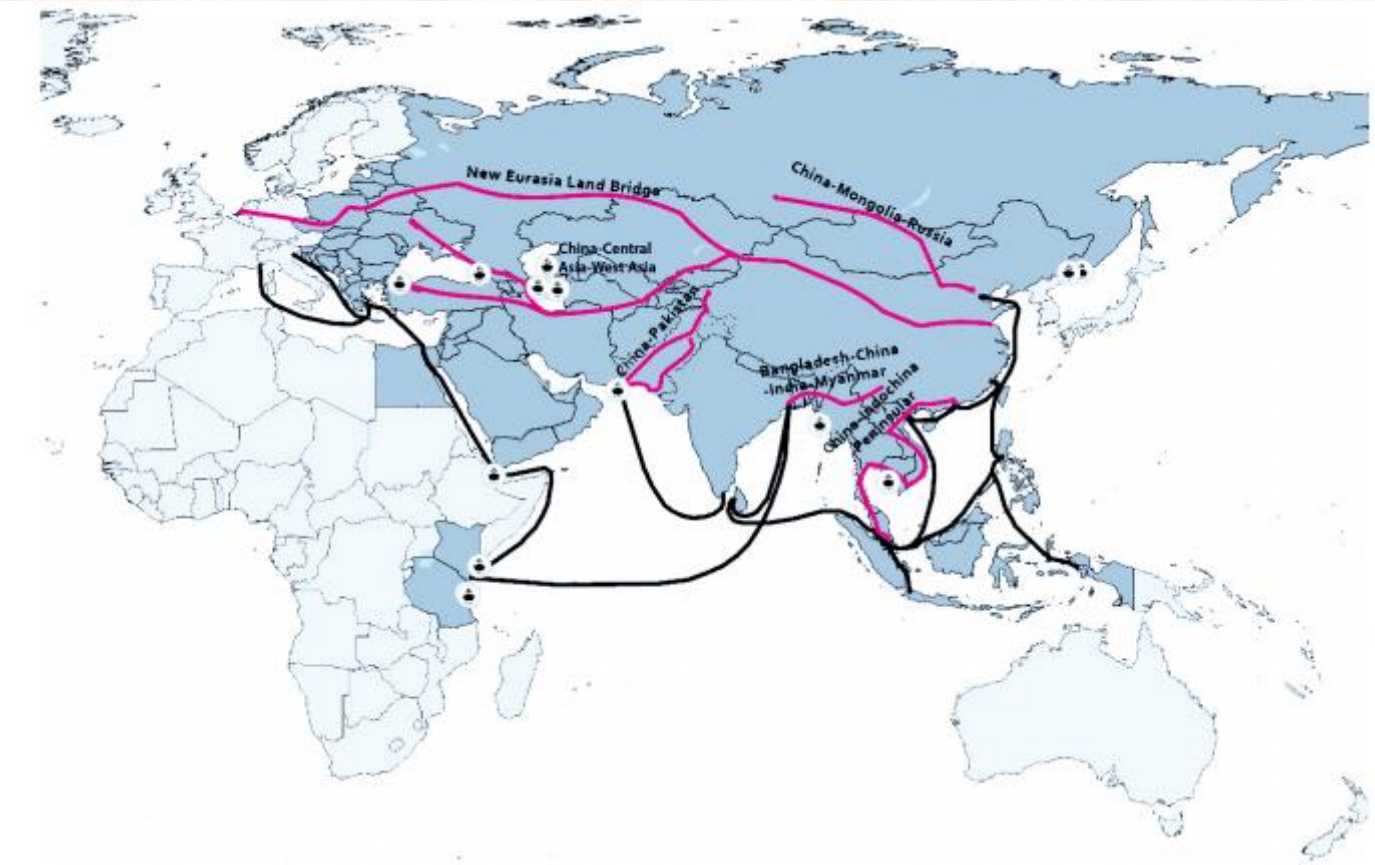
Contents

Introduction

1. In 2013, China proposed the "One Belt One Road" initiative, which is divided into two strategies, the "Silk Road Economic Belt" and the "21st Century Maritime Silk Road".

- The Chinese government also plans to strengthen the construction of 15 coastal port cities



World Bank. 2019. *Belt and Road Economics: Opportunities and Risks of Transport Corridors.* Washington, DC: World Bank.
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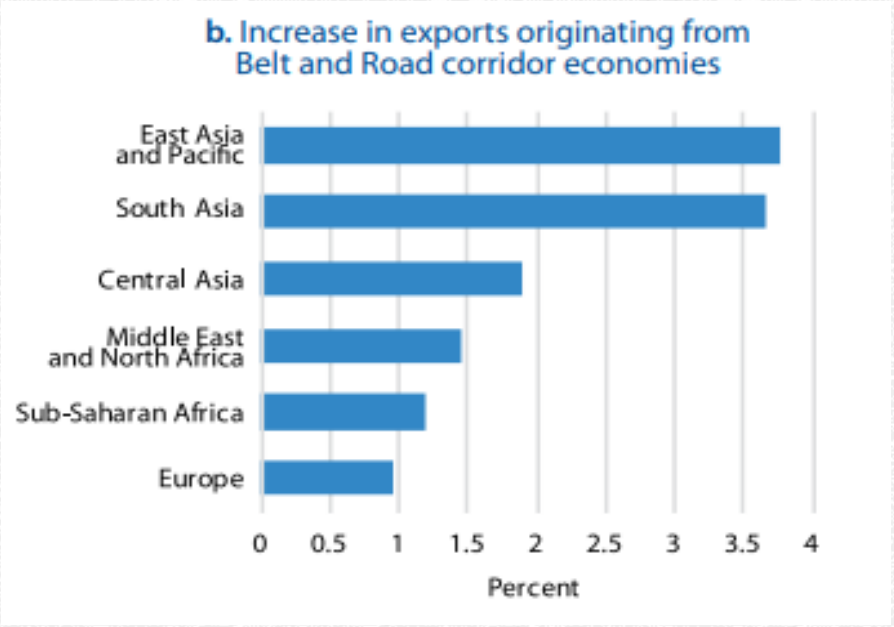
Introduction

2. In the past ten years, China's dry bulk and container trade accounted for half of the global seaborne trade.

- In 2018, China's ocean imports accounted for a quarter of the world's ocean trade. (UNCTED,2019)

3. China has become a transfer country for the fourth industrial transfer.

- The direction of transfer is mainly Southeast Asia, South Asia, and Africa, which is also the main direction of the Maritime Silk Road.



Source: World Bank. 2019. *Belt and Road Economics: Opportunities and Risks of Transport Corridors.*

Introduction

Research objectives

1. First, use Social Network Analysis to reveal the structural characteristics of the Maritime Silk Road network.

- Find out the key ports of the Maritime Silk Road and their role in the network.

- Evaluate the network status of the Maritime Silk Road and find out the problems in the network.

2. Second, according to the content of the China's investment development strategy, new ports and routes will be added to the Maritime Silk Road network, and the changes in the network centrality index will be measured.

- Reveal the relationship between the construction of the Maritime Silk Road and the maritime logistics network and provide a theoretical basis for advancing the construction of the Maritime Silk Road.

Literature Review

When constructing a shipping network, ports or port cities are usually used as nodes, and routes between ports are used as links to construct the network.

1. Research on Network Characteristics of Maritime Silk Road Using Social Network Analysis

- Zeng et al.(2015) and Liu et al.(2017)found that the Maritime Silk Road shipping network has the characteristics of "small-world" and "scale-free".

- Zou et al.(2016) use the import and export trade data of various countries in 2001, 2007, and 2013, found that the trade network density of countries along with the “Belt and Road Initiative” has increased.

- Wang et al. (2017) using international shipping data from China's container ports for 1995, 2005, and 2015, found that Singapore, Kelang, Colombo, and Suez ports, built closer relations with Chinese ports.

Research on Maritime Silk Road Shipping Network

Author	Data	Main measure
Zeng et al. (2015)	● 78 ports in global	● Network characteristics
Chen et al. (2016)	● 50 ports in Southeast Asia	● Network characteristics ● Node centrality ● Hierarchical clustering
Yang et al. (2016)	● 123 ports in global	● Network characteristics ● Node centrality ● Connectivity
Liu et al. (2017)	● 164 ports in global	● Network characteristics ● Node centrality
Wang et al. (2017)	● 62 port cities in the world	● Network characteristics ● Node centrality
Jiang et al. (2018)	● 453 ports in global ● 3444 links	● Network characteristics ● Community structure
Wu et al. (2018)	● 169 ports in global	● Network characteristics ● Node centrality ● Vulnerability

Literature Review

2. Research on the Centrality of Nodes on the Maritime Silk Road

- Three commonly used centrality indicators: Degree centrality, Closeness centrality and Betweenness centrality
  (Chen et al. 2016; Pan et al. 2015; Liu et al 2017)

3. Research on Shipping Network Using Weighted Network Index

Author	Nodes	Link weights	Unweighted measures	Weighted measures
Gonzalez et al. 2012	Ports	TEUs	-Degree centrality -Betweenness centrality	-Node strength
Tovar et al. 2015	Ports	TEUs	-Degree centrality -Betweenness centrality	-Port accessibility index
Li et al. 2016	China ports	Number of flights	-Node degree	-Node strength -Average shortest paths -Clustering coefficient -Matching coefficient -Network structure entropy
Wang et al. 2017	Port cities	Number of flights	-Degree centrality -Closeness centrality -Betweenness centrality -Hub and spoke structure	-Link Strength

Methodology

1. Network degree and its distribution

- The degree of a node describes the influence of a node in the network and the degree value represents the number of sides connected to the node. Node degree value is

$$C_d(i) = k(i)$$

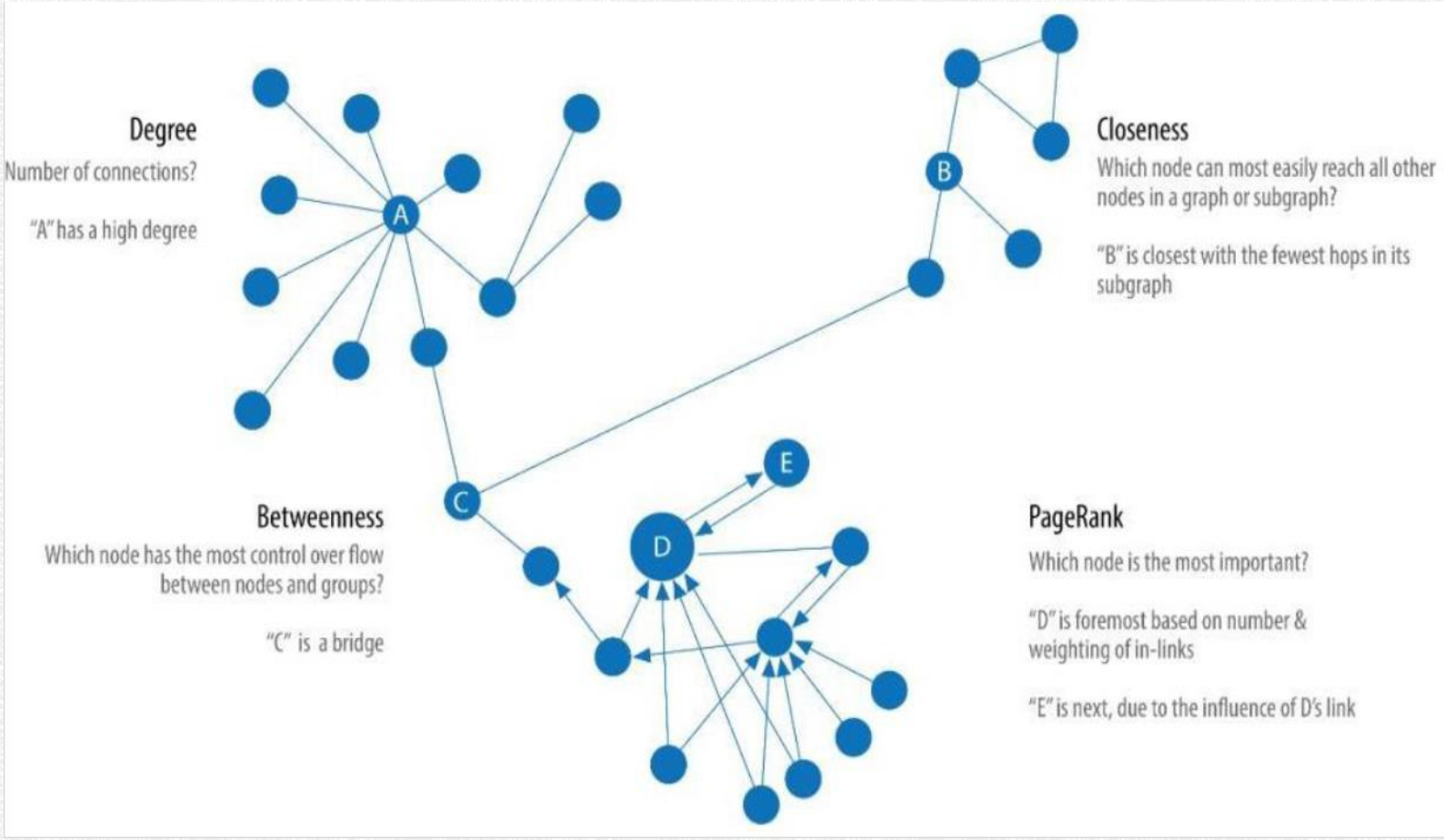
- The average degree of network is expressed as < k >

$$< k > = \frac{1}{N}\sum_{i=1}^{N} k_i$$

- The nodes in the network usually meet a certain probability distribution, the degree of scale-free network obeys power exponential distribution.

Methodology

2. Centrality Analysis



Methodology

DC

"연결중심성"

Degree Centrality

$$DC(i) = \sum_{j \in V}^{N} \frac{x_{ij}}{N-1}$$

Connections

"평균연관성"

Mean Associations

$$MA(i) = \sum_{j \epsilon V}^{N} \frac{w_{ij}}{N-1}$$

MA

Intermediating role
control overflow

NBC

"매개중심성"

Node Betweenness Centrality

$$NBC(i) = \frac{2}{(N-1)(N-2)} \sum_{j \in V}^{N} \sum_{k \in V}^{N} \frac{g_{jk}(i)}{g_{jk}}$$

"삼각 매개중심성"

Triangle Betweenness Centrality

$$TBC(i) = \frac{2}{(N-1)(N-2)} \sum_{j \in V}^{N} \sum_{k \in V}^{N} f(i),$$

$$f(i) = \begin{cases} 1, if\ w_{jk} < \min(w_{ij}, w_{ik}) \\ 0, else \end{cases}$$

TBC

Methodology

HC

"조화중심성"

Harmonic Centrality

$$HC(i) = \frac{1}{\mathrm{n}-1}\sum_{i \neq j}\frac{1}{d_{ij}}$$

- A variant of closeness centrality to solve the unconnected graphs problems.
- Proposed by Marchiori and Latora in 'Harmony in the Small World'.

- d_{ij}: The shortest distance between node i and node j.
- Sums the inverse of those distances. This enables it to deal with infinite values.

- Here Harmonic centrality is used to evaluate the spatial advantage of a port in the network and the efficiency of connecting with other ports.

Relative accessibility

WHC

"가중 조화중심성"

Weighted Harmonic Centrality

$$HC(i) = \frac{1}{\mathrm{n}-1}\sum_{i \neq j}\frac{1}{w_{ij}}$$

- w is the weighted adjacency matrix
- w_{ij}: weighted sum of links between node i and j

- For the Maritime Silk Road shipping network, the higher the weighted harmonic centrality value, the closer and more convenient it is to transport goods to other ports.

Methodology

PR

"페이지랭크"
PageRank

$$PR(i) = \frac{1-d}{N} + d\left(\sum_{j \epsilon U(i)}^{N} \frac{PR(j)}{l_j}\right)$$

Importance(inflow)

"가중페이지랭크"
Weighted PageRank

$$WPR(i) = \frac{1-d}{N} + d\left(\sum_{j \in U(i)}^{N} \frac{WPR(j) \cdot w_{ji}}{l_j}\right)$$

WPR

RPR

"역 페이지랭크"
Reverse PageRank

$$PR(i) = \frac{1-d}{N} + d\left(\sum_{j \epsilon U(i)}^{N} \frac{PR(j)}{l_j}\right)$$

Importance(outflow)

"가중 역 페이지랭크"
Weighted Reverse PageRank

$$WPR(i) = \frac{1-d}{N} + d\left(\sum_{j \in U(i)}^{N} \frac{WPR(j) \cdot w_{ji}}{l_j}\right)$$

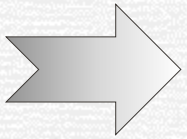
WRPR

Data

- As of the end of January 2020, 138 countries and regions around the world have signed the "Belt and Road Initiative" with China.
- Schedule data for the entire month of October 2019
- Including 81 carriers and 2,137 routes worldwide

Sort out:
One city, one port principle
One Belt One Road Initiative partner country
Countries along the Maritime Silk Road

Global Shipping Network
Node: 517
Link:1873



Maritime Silk Road Network
Node:294
Link:1038

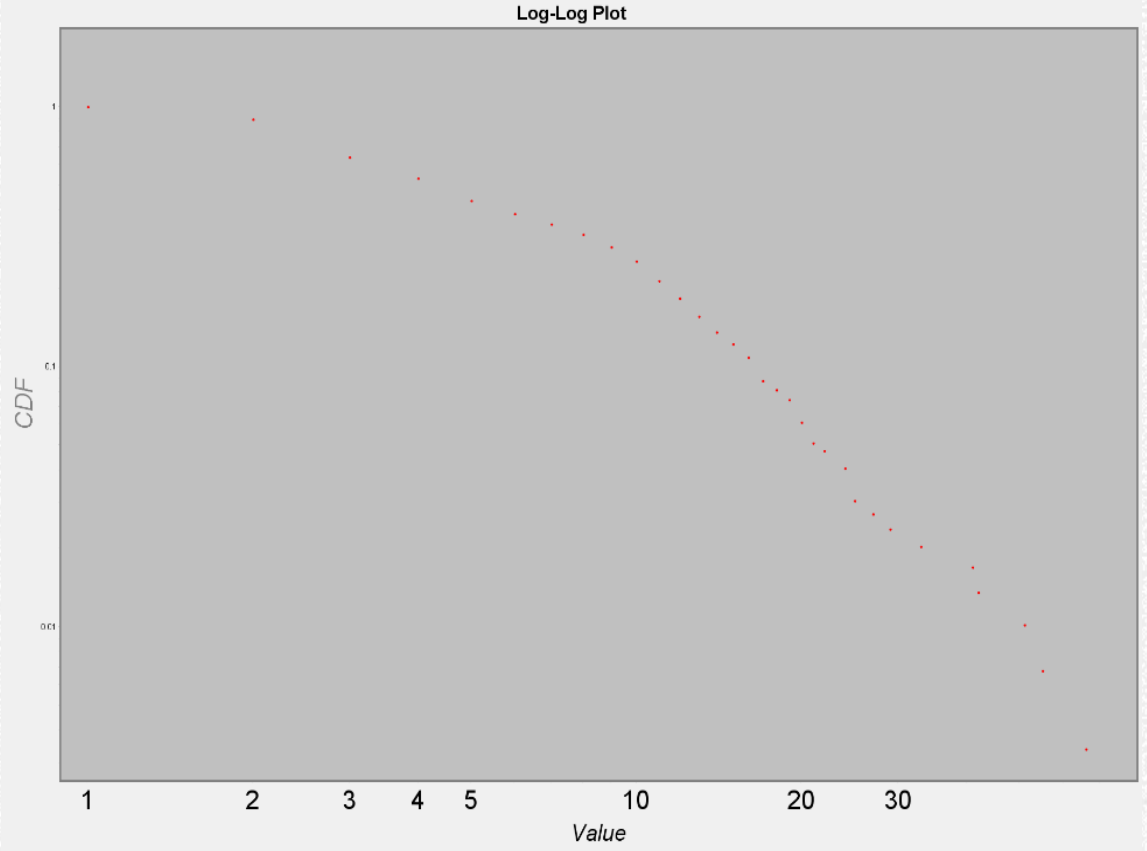
Number and proportion of ports in various regions

Area	Sub-Region	Number of ports	Ports of partner countries	Proportion %
Asia	East Asia	33	33	100%
	Southeast Asia	41	41	100%
	South Asia	28	28	100%
	Middle East	46	46	100%
Africa	The rest of Africa	37	36	97%
Europe	Mediterranean	39	28	72%
	The rest of Europe	26	18	69%
America	Latin America	29	29	100%
Oceania	South Pacific	15	15	100%
	Total	294	274	93%

Analysis Results

1. The degree distribution is similar to the power-law distribution, and the Maritime Silk Road network proved to be a scale-free network.

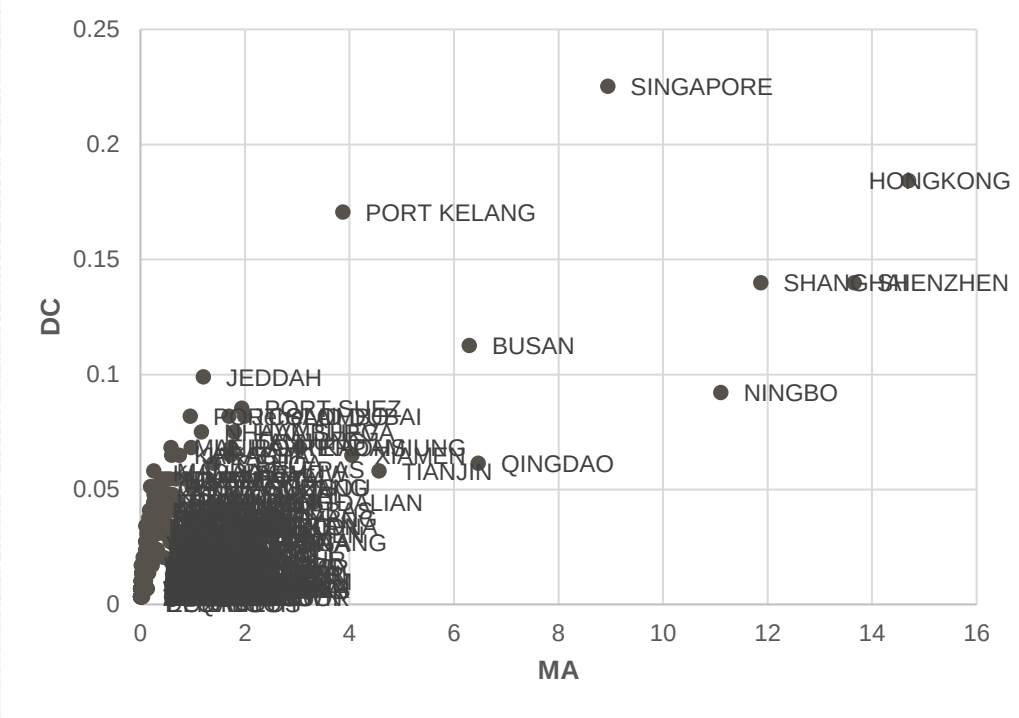
- The value of the exponent γ is 3.44. In a scale-free network, the index γ is usually between 2 and 3. γ >3 means that the Maritime Silk Road network is not ‘Hub and spoke’ structure

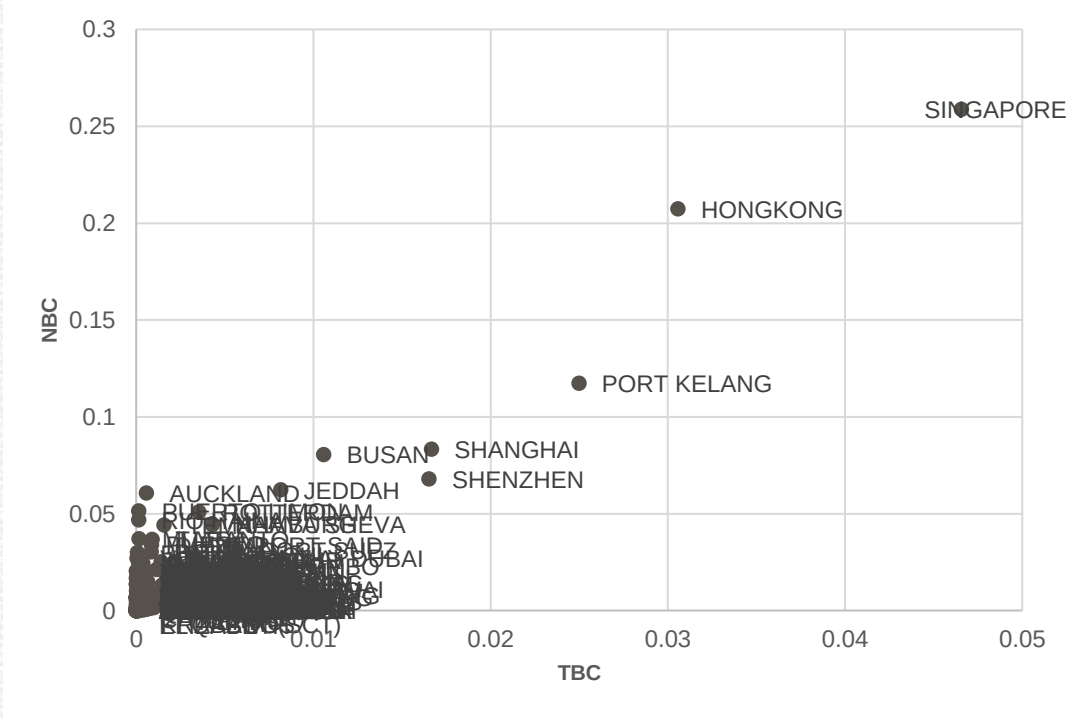


Analysis Results

Rank	DC	MA	NBC	TBC	HC	WHC	RPR	WRPR
1	SINGAPORE	HONGKONG	SINGAPORE	SINGAPORE	SINGAPORE	SHENZHEN	BUSAN	SINGAPORE
2	HONGKONG	SHENZHEN	HONGKONG	HONGKONG	HONGKONG	SHANGHAI	HONGKONG	HONGKONG
3	PORT KELANG	SHANGHAI	PORT KELANG	PORT KELANG	PORT KELANG	NINGBO	SHANGHAI	SHANGHAI
4	SHENZHEN	NINGBO	SHANGHAI	SHANGHAI	SHENZHEN	QINGDAO	NINGBO	BUSAN
5	SHANGHAI	SINGAPORE	BUSAN	SHENZHEN	SHANGHAI	DALIAN	SHENZHEN	PORT KELANG
6	BUSAN	QINGDAO	SHENZHEN	BUSAN	BUSAN	BUSAN	DALIAN	JEDDAH
7	JEDDAH	BUSAN	JEDDAH	JEDDAH	JEDDAH	TIANJIN	QINGDAO	PORT SUEZ
8	NINGBO	TIANJIN	AUCKLAND	NINGBO	PORT SUEZ	HONGKONG	SINGAPORE	SHENZHEN
9	PORT SUEZ	XIAMEN	PUERTO LIMON	PORT SUEZ	NINGBO	XIAMEN	TIANJIN	COLOMBO
10	COLOMBO	PORT KELANG	ROTTERDAM	COLOMBO	PORT SAID	LIANYUNGANG	XIAMEN	Jebel Ali DUBAI
11	Jebel Ali DUBAI	DALIAN	RIO HAINA	PORT SAID	Jebel Ali DUBAI	SINGAPORE	KAOHSIUNG	HAMBURG
12	PORT SAID	KAOHSIUNG	HAMBURG	Jebel Ali DUBAI	NHAVA SHEVA	KAOHSIUNG	PORT KELANG	LE HAVRE
13	HAMBURG	COLOMBO	NHAVA SHEVA	NHAVA SHEVA	TANJUNG PELEPAS	GUANGZHOU	YANTAI	NEW DELHI
14	NHAVA SHEVA	PORT SUEZ	TEMA	HAMBURG	COLOMBO	KWANGYANG	KWANGYANG	TANJUNG PELEPAS
15	KAOHSIUNG	HAMBURG	MUARA	LE HAVRE	ROTTERDAM	LAEM CHABANG	GUANGZHOU	KARACHI
16	ROTTERDAM	ROTTERDAM	TARANTO	ROTTERDAM	HAMBURG	BANGKOK	KEELUNG	TARANTO
17	LE HAVRE	TANJUNG PELEPAS	DURBAN	KAOHSIUNG	LE HAVRE	PORT KELANG	LIANYUNGANG	ROTTERDAM
18	MANILA	Jebel Ali DUBAI	PORT SAID	KARACHI	MANILA	COLOMBO	TANJUNG PELEPAS	PORT SAID
19	XIAMEN	GENOA	PORT SUEZ	TANJUNG PELEPAS	DUBAI	NHAVA SHEVA	INCHEON	DURBAN
20	TANJUNG PELEPAS	BARCELONA	DOHA	MANILA	MADRAS	TAICHUNG	JEDDAH	NINGBO
21	JAKARTA	JEDDAH	BINTULU	JAKARTA	XIAMEN	KEELUNG	COLOMBO	Constanta
22	KARACHI	NHAVA SHEVA	KARACHI	GENOA	KAOHSIUNG	TANJUNG PELEPAS	Jebel Ali DUBAI	KAOHSIUNG
23	QINGDAO	KWANGYANG	Jebel Ali DUBAI	XIAMEN	GUANGZHOU	HOCHIMINH	LAEM CHABANG	IQUIQUE
24	GENOA	LAEM CHABANG	PUERTO CABELLO	QINGDAO	JAKARTA	ULSAN	TAICHUNG	XIAMEN
25	TIANJIN	GUANGZHOU	VOSTOCHNY	DAMMAM	SUEZ CANAL	KHOR FAKKAN	JAKARTA	LYTTELTON
26	MADRAS	LE HAVRE	MADRAS	DAMIETTA	ISTANBUL	PASIR GUDANG	PORT SUEZ	DALIAN
27	NAPOLI	PORT SAID	NEW DELHI	MADRAS	NAPOLI	SHANTOU	PASIR GUDANG	NHAVA SHEVA
28	VALENCIA	LIANYUNGANG	KUCHING	NAPOLI	GENOA	Jebel Ali DUBAI	PENANG	ISTANBUL
29	DAMIETTA	VALENCIA	CALLAO	VALENCIA	QINGDAO	SUEZ CANAL	HOCHIMINH	MANILA
30	DAMMAM	JAKARTA	ISTANBUL	TIANJIN	LAEM CHABANG	FUQING	ULSAN	DAMMAM

Analysis Results





- DC&MA:
- DC: Singapore, Hongkong, and Kelang ports
- MA: Hongkong, Shenzhen, and Ningbo
- While ports with higher MA values are connected to many ports, the freight volume is also larger, and the ports are busy.

- NBC&TBC:
- Singapore, Hongkong, Port Kelang are important intermediary ports for the maritime silk road network.
- Goods from all over the world are concentrated or evacuated here.

Analysis Results

➢ HC&WHC

- HC: Shenzhen, Hongkong, and Port Kelang
- WHC: Top10--Shenzhen, Shanghai, Ningbo, Qingdao, Dalian, Busan, Tianjin, Hongkong, Xiamen, Lianyungang.
- They are almost located along the coast of China. They are closely connected to ports around the world and have the shortest connection path, the closest distance.

➢ RPR&WRPR

- The maritime silk road routes are mostly from Chinese ports to all parts of the world, so RPR &WRPR is a better indicator than PR & WPR.
- To measure the impact of a port’s outflow.
- RPR: Busan, Hongkong, and Shanghai.
- WRPR is Singapore, Hongkong, Shanghai. Busan's ranking fell, and Ningbo's ranking also fell.

Analysis Results

➢ Comprehensive centrality ranking

- Based on the Borda count method(Baround H et al. 2014) the port is regarded as a candidate, and each centrality is regarded as a vote. The model of inclusion centrality, intermediary centrality, proximity centrality, WPR, and WRPR are established.
- $Rank_{MA}(i), Rank_{TBC}(i), Rank_{WHC}(i), Rank_{WPR}(i), Rank_{WRPR}(i)$ represent the ranking of each index in the whole network. $S_{MA}(i), S_{TBC}(i), S_{WHC}(i), S_{WPR}(i), S_{WRPR}(i)$. They represent the scores of each centrality

$$S_{MA}(i) = n - Rank_{MA}(i) + 1$$

$$S_{TBC}(i) = n - Rank_{TBC}(i) + 1$$

$$S_{WHC}(i) = n - Rank_{WHC}(i) + 1$$

$$S_{WPR}(i) = n - Rank_{WPR}(i) + 1$$

$$S_{WRPR}(i) = n - Rank_{WRPR}(i) + 1$$

Adding the scores of each centrality of a node is the comprehensive centrality score of the node

$$S_T = S_{MA}(i) + S_{TBC}(i) + S_{WHC}(i) + S_{WPR}(i) + S_{WRPR}(i)$$

Analysis Results

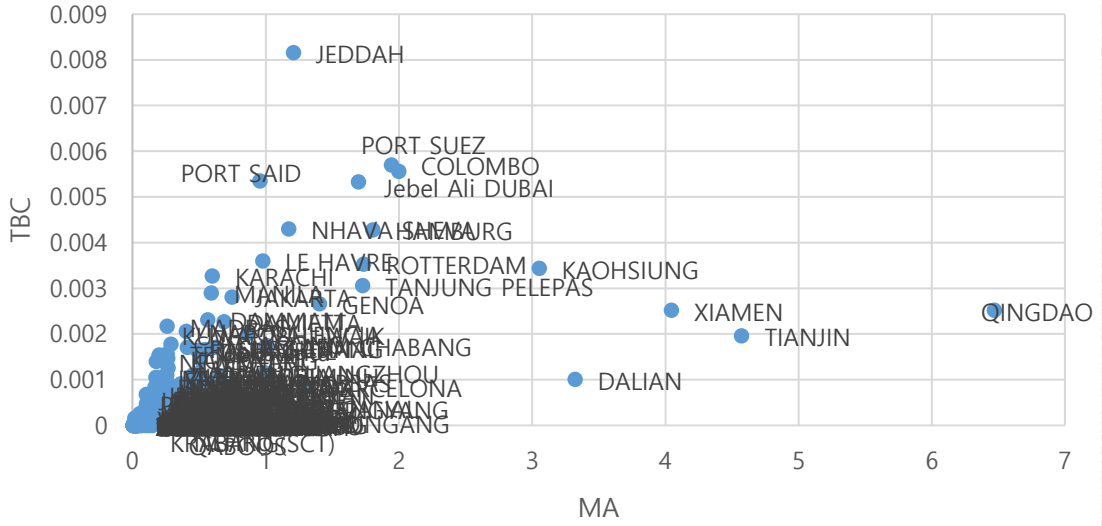
Rank	MA	TBC	WHC	WPR	WRPR
1	HONGKONG	SINGAPORE	SHENZHEN	HAMBURG	SINGAPORE
2	SHENZHEN	HONGKONG	SHANGHAI	HONGKONG	HONGKONG
3	SHANGHAI	PORT KELANG	NINGBO	GENOA	SHANGHAI
4	NINGBO	SHANGHAI	QINGDAO	ROTTERDAM	BUSAN
5	SINGAPORE	SHENZHEN	DALIAN	Constanta	PORT KELANG
6	QINGDAO	BUSAN	BUSAN	TEMA	JEDDAH
7	BUSAN	JEDDAH	TIANJIN	COLOMBO	PORT SUEZ
8	TIANJIN	NINGBO	HONGKONG	TIANJIN	SHENZHEN
9	XIAMEN	PORT SUEZ	XIAMEN	NEW DELHI	COLOMBO
10	PORT KELANG	COLOMBO	LIANYUNGANG	DOUALA	Jebel Ali DUBAI
11	DALIAN	PORT SAID	SINGAPORE	NHAVA SHEVA	HAMBURG
12	KAOHSIUNG	Jebel Ali DUBAI	KAOHSIUNG	MOMBASA	LE HAVRE
13	COLOMBO	NHAVA SHEVA	GUANGZHOU	SHENZHEN	NEW DELHI
14	PORT SUEZ	HAMBURG	KWANGYANG	IZMIR	TANJUNG PELEPAS
15	HAMBURG	LE HAVRE	LAEM CHABANG	BUSAN	KARACHI
16	ROTTERDAM	ROTTERDAM	BANGKOK	LOME	TARANTO
17	TANJUNG PELEPAS	KAOHSIUNG	PORT KELANG	HOCHIMINH	ROTTERDAM
18	Jebel Ali DUBAI	KARACHI	COLOMBO	DAMIETTA	PORT SAID
19	GENOA	TANJUNG PELEPAS	NHAVA SHEVA	JEDDAH	DURBAN
20	BARCELONA	MANILA	TAICHUNG	PIRAEUS	NINGBO
21	JEDDAH	JAKARTA	KEELUNG	KUCHING	Constanta
22	NHAVA SHEVA	GENOA	TANJUNG PELEPAS	AQABA	KAOHSIUNG
23	KWANGYANG	XIAMEN	HOCHIMINH	PORT SUEZ	IQUIQUE
24	LAEM CHABANG	QINGDAO	ULSAN	LE HAVRE	XIAMEN
25	GUANGZHOU	DAMMAM	KHOR FAKKAN	BREMERHAVEN	LYTTELTON
26	LE HAVRE	DAMIETTA	PASIR GUDANG	ST.PETERSBURG	DALIAN
27	PORT SAID	MADRAS	SHANTOU	PORT OF SPAIN	NHAVA SHEVA
28	LIANYUNGANG	NAPOLI	Jebel Ali DUBAI	PUERTO CABELLO	ISTANBUL
29	VALENCIA	VALENCIA	SUEZ CANAL	KLAIPEDA	MANILA
30	JAKARTA	TIANJIN	FUQING	VIGO	DAMMAM

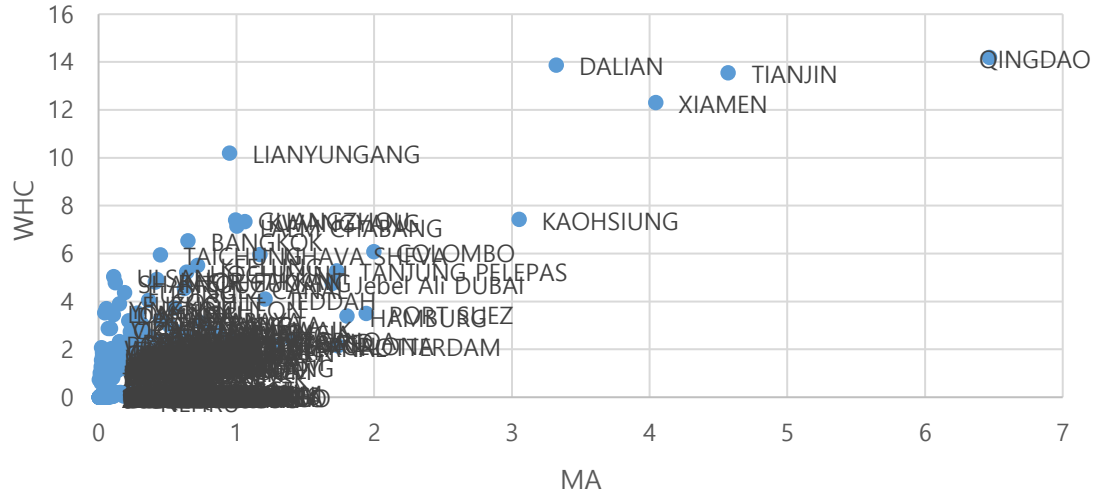
Rank	Port	S_T
1	HONGKONG	1461
2	SHENZHEN	1447
3	BUSAN	1438
4	SHANGHAI	1430
5	COLOMBO	1419
6	SINGAPORE	1411
7	PORT KELANG	1408
8	HAMBURG	1395
9	NINGBO	1392
9	JEDDAH	1392
11	PORT SUEZ	1385
12	NHAVA SHEVA	1384
13	TIANJIN	1381
14	QINGDAO	1372
15	ROTTERDAM	1353
16	XIAMEN	1348
17	Jebel Ali DUBAI	1341
18	LE HAVRE	1337
19	GENOA	1299
20	DALIAN	1295
21	JAKARTA	1294
22	DAMMAM	1287
23	KAOHSIUNG	1284
24	KARACHI	1278
25	Constanta	1276
26	VALENCIA	1274
26	DAMIETTA	1274
28	PORT SAID	1270
29	BARCELONA	1259
30	MANILA	1256

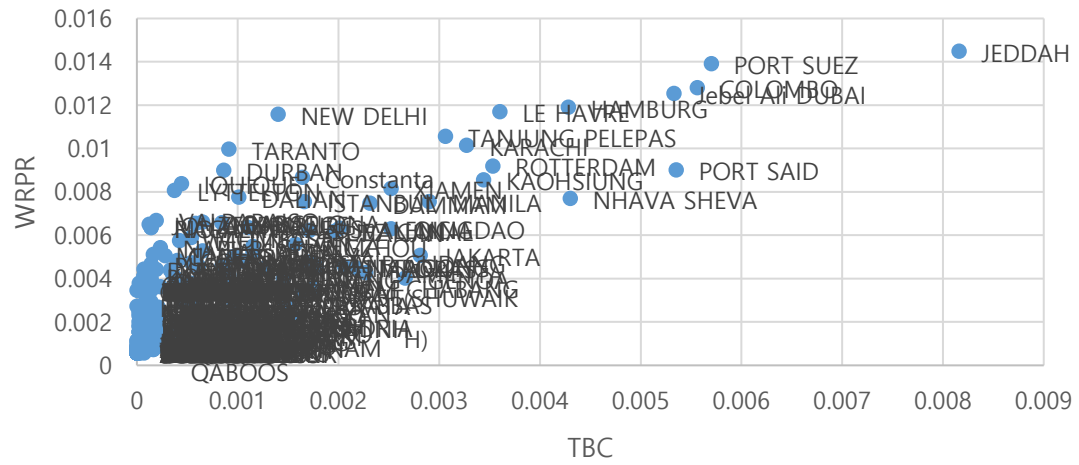
Analysis Results

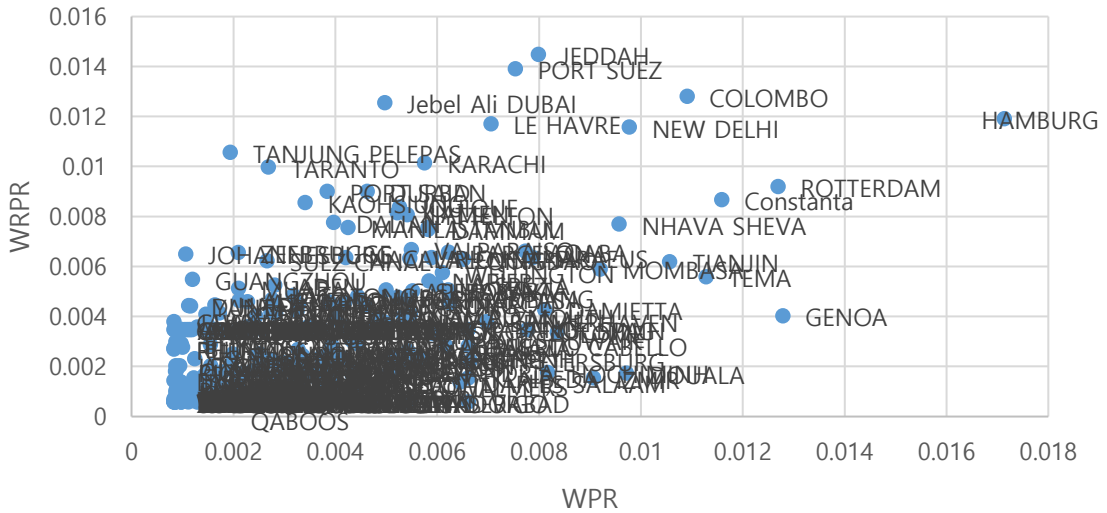
- Based on the combination of weighted and unweighted centrality index comparative analysis and comprehensive centrality ranking, we will remove the following seven core ports:
- Singapore, Hongkong, Port Kelang, Shenzhen, Shanghai, Busan, and Ningbo port
- Then, use weighted centrality value cross points to compare scatter plots

Analysis Results









Analysis Results

- The World Bank's "Belt and Road Economics" report released in 2019 mentioned 28 foreign investment projects in ports and shipping routes that China is currently or is planning to build.

No.	Project	Country	Improvement type	Status	Status date
1	Lamu Port	Kenya	New seaport	Under construction	2018-11-06
2	Suez Canal	Egypt, Arab Rep.	New seaport	Under construction	2018-10-24
3	Sihanoukville Port	Cambodia	New seaport	Under construction	2018-09-12
4	Dar es Salaam Port	Tanzania	Seaport expansion	Under construction	2018-09-01
5	Colombo Port City	Sri Lanka	New seaport	Under construction	2018-08-02
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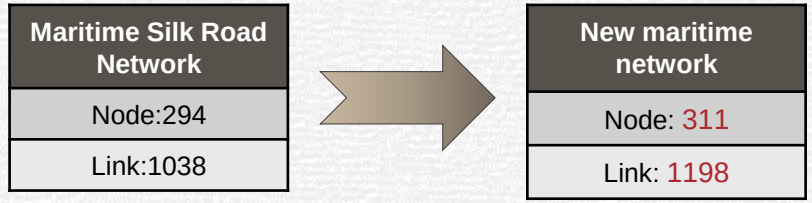
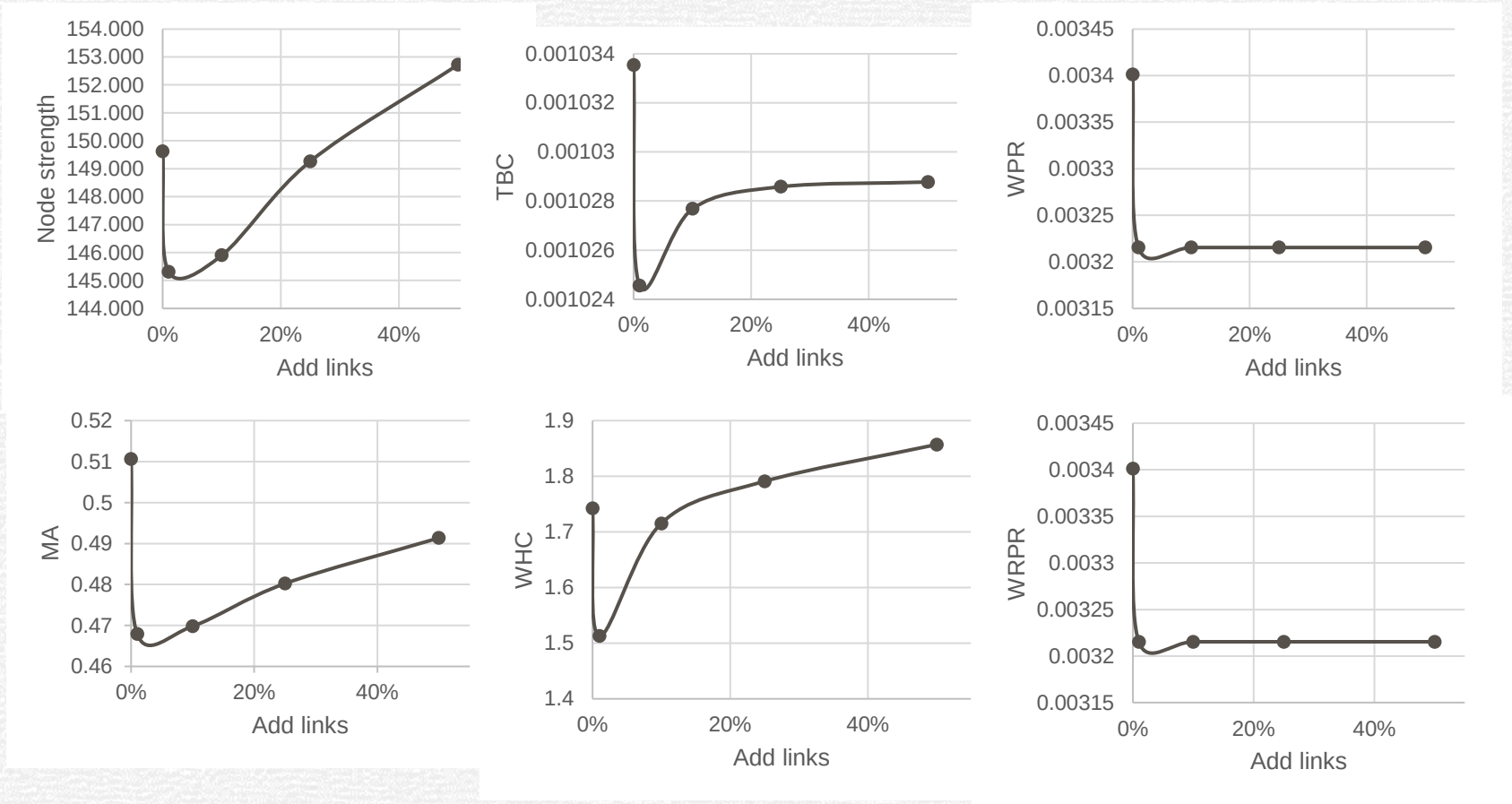
28	Cabinda Port	Angola	New seaport	Under construction	2017-01-25

1. Take the planned ports as new nodes
2. Take the content of the investment project, the cities around the new ports, and the ports connected to these cities as references to establish new links.
3. Increase the shipping frequency values indicated by these links by 10%, 25%, and 50%.
4. Then, compare the changes in the average of each weighted index.



Analysis Results

3. Efficiency analysis of the network



- It can be seen from the changes of WHC that the addition of ports and routes can improve the overall efficiency of the network and enhance the network accessibility. That is to improve the overall efficiency of the network.

Conclusion

- The maritime Silk Road shipping network is a scale-free network.
- Hongkong, Singapore, Port Kelang, Shenzhen, Shanghai, Busan, Colombo, and Ningbo are the hub ports of the maritime Silk Road shipping network, mainly distributed in the southeast coast of China and Southeast Asia.
- The coastal ports in northern China are not geographically dominant, and most of the ports are small in scale.
- The connection with overseas port cities follows the law of decreasing distance. The Maritime Silk Road Network has the most frequent cooperation with ports in Southeast Asia, followed by ports in Southwest Asia and the Middle East.

Conclusion

Suggestion:

- The connection between general ports and branch ports should be strengthened.
- Provide subsidies to carriers participating in the opening of maritime Silk Road routes.
- Promote port enterprises(freight forwarding; port; terminal; logistics center) to participate in the construction of route network, which can provide effective means for my country's port enterprises to extend the service chain and improve competitiveness

Limitations of the study and suggestions for further research

- The limitation of data acquisition is that only one month's flight frequency is collected. If longer period shipping data can be collected, the data will be more meaningful.
- The next step is to study the evolution of the Maritime Silk Road network in the past 10 years with throughput as the weight.

Thank You

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