The efficiency of national maritime logistics for 29 ocean countries: using super-efficiency DEA

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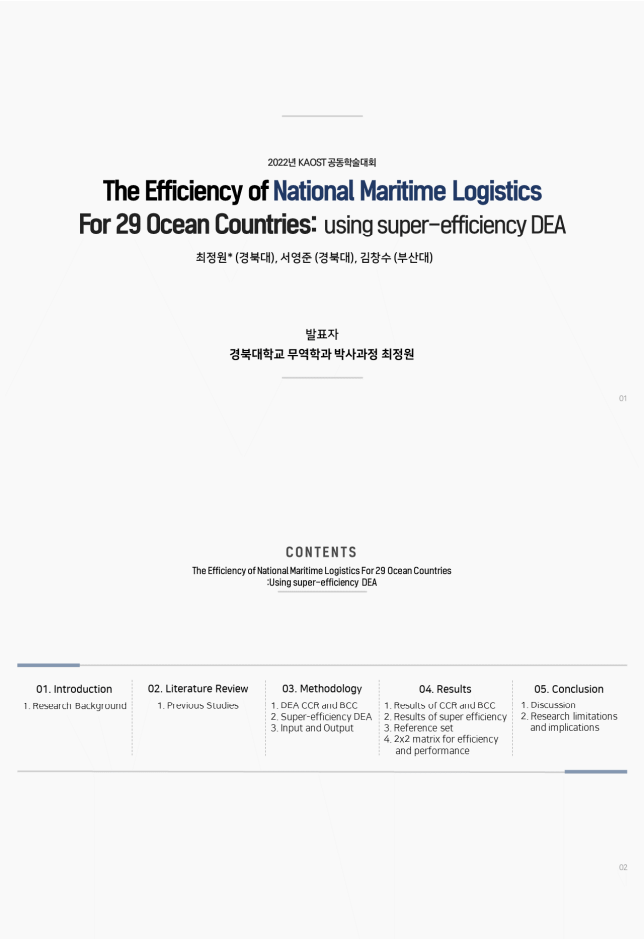
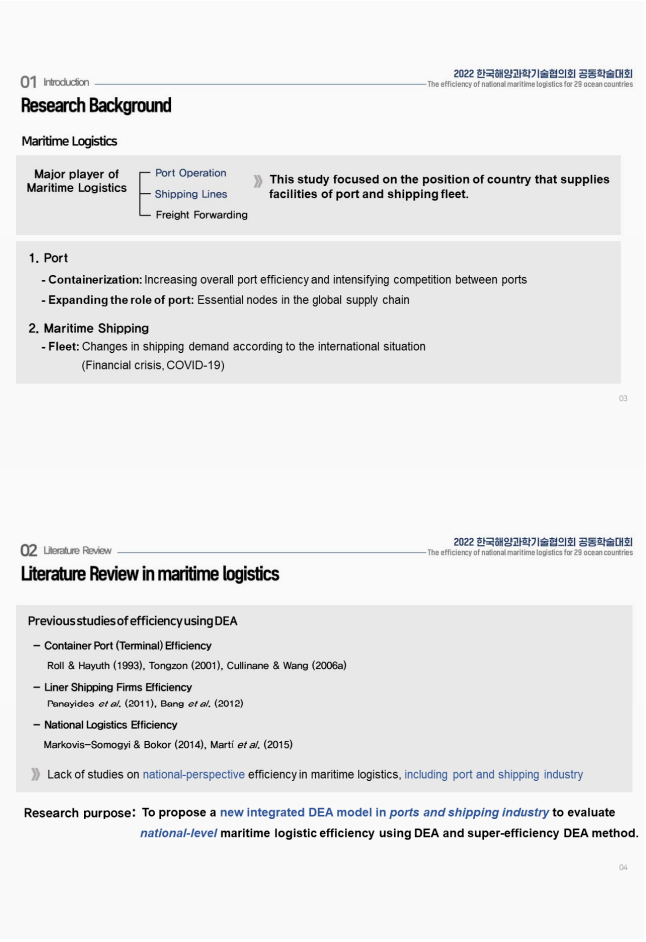
요 약 : With the expansion of the global supply chain, the efficiency of maritime logistics is considered a crucial factor for countries' trade and competitiveness. Nevertheless, prior research has not thoroughly evaluated the efficiency of maritime logistics, including countries' ports and shipping capacities. Accordingly, this study examines integrated maritime logistics efficiency at the national level using DEA-CCR, BCC, and super-efficiency DEA. Furthermore, this study identifies a difference between the selected countries' maritime logistics efficiency and LPI (Logistics Performance Index) through Spearman's correlation test as an ad-hoc analysis. From this, Asian countries showed higher efficiency and European countries showed higher LPI scores. These results might be derived from this difference in port-city development patterns. Additionally, the main cause of inefficiency in Europe and Japan might be attributed to high fleet capacity of control. Consequently, this study can provide valuable implications for coastal countries to set more efficient directions for maritime logistics investment and policy.

핵심용어 : Maritime Logistics, Efficiency, DEA, Port, Coastal Country





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Methodology

Data Envelopment Analysis (DEA) DEA is a popular methodology for measuring the relative efficiency of a decision-making unit (DMU) based on multiple inputs and outputs. If $\phi = 1$, the DMU is efficient.

DEA CCR (Charnes, Cooper, and Rhodes, 1978)

- Constant returns to scale-based model
- CCR efficiency score = technical efficiency
- Output-oriented CCR model:

$$Max\ \phi + \left(\varepsilon \sum_{i=1}^{m} s_i^- + \varepsilon \sum_{r=1}^{s} s_r^+\right)$$

$$subject\ to$$

$$x_{i0} = \sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- \ (i = 1,2,\dots,m)$$

$$\phi y_{r0} = \sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ \ (r = 1,2,\dots s)$$

$$\lambda_j \geq 0\ (j = 1,2,\dots,n),\ s_r^+ \geq 0,\ s_i^- \geq 0$$

DEA BCC (Banker, Charnes, and Cooper, 1984)

- Variable returns to scale-based model
- BCC efficiency score = pure technical efficiency
- Output-oriented BCC model:

$$Max\ \phi + \left(\varepsilon \sum_{i=1}^{m} s_i^- + \varepsilon \sum_{r=1}^{s} s_r^+\right)$$

$$subject\ to$$

$$x_{i0} = \sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- \ (i = 1,2,\dots,m)$$

$$\phi y_{r0} = \sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ \ (r = 1,2,\dots s)$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \geq 0\ (j = 1,2,\dots,n),\ s_r^+ \geq 0,\ s_i^- \geq 0$$

Results of DEA analysis

1. Results of DEA CCR and BCC

No	DMUs	CCR eff. score	Difference from projection (%)				BCC eff. score	Difference from projection (%)				
			LSS	CP	FC	CON	LSCI		LSS	CP	FC	CON	LSCI
1	ARE	0.8075	0	0	0	23.833	23.833	0.8483	0	0	0	17.884	17.884
2	BEL	1	0	0	0	0	0	1	0	0	0	0	0
3	BRA	0.7812	0	-60.484	0	28.003	41.399	1	0	-0.001	0	0.001	0.001
4	CAN	0.4224	0	0	-1.452	831.917	136.766	0.4522	0	0	-16.446	339.887	131.388
5	CHN	1	0	0	0	0	0	1	0	0	0	0	0
6	DEU	0.7194	0	0	-68.016	274.3	38.995	0.7210	0	0	-68.389	270.909	38.696
7	DNK	0.4070	0	0	-70.805	4556.867	145.721	0.4258	0	0	-61.398	4071.253	134.834
8	FRA	0.6603	0	0	-12.378	948.002	51.442	0.6692	0	0	-19.389	881.924	49.443
9	GBR	0.7717	0	-42.817	0	669.211	29.578	0.7839	0	0	-32.959	0	370.435	27.24
10	GRC	0.6921	0	0	-75.995	305.255	44.482	0.8480	0	0	-87.467	181.815	5.483
11	HKG	1	0	0	0	0	0	1	0	0	0	0	0
12	IDN	0.5729	0	-36.539	0	106.539	74.539	0.5759	0	0	-22.142	0	83.427	73.644
13	IND	1	0	0	0	0	0	1	0	0	0	0	0	0
14	IRN	0.3093	0	0	0	867.186	223.334	0.9999	0	0	0	-0.002	0.055	0.01
15	ISR	0.5734	0	0	0	454.103	74.383	1	0	0	0	0	0.017	0.003
16	ITA	0.6535	0	0	-12.915	692.312	53.08	0.6894	0	0	-16.423	545.255	45.053	
17	JPN	0.5048	0	-10.912	0	586.794	98.106	0.5871	-16.333	-31.106	0	448.732	70.321	
18	KOR	1	0	0	0	0	0	1	0	0	0	0	0	
19	MYS	1	0	0	0	0	0	1	0	0	0	0	0	
20	NLD	0.8174	0	0	0	47.441	22.347	0.9493	-16.702	0	0	60.965	5.359	
21	NOR	0.1068	0	-50.139	0	5467.865	856.606	0.1068	0	-59.69	0	5422.964	851.91	
22	PHL	0.5208	0	-25.546	0	92.007	92.007	1	0	0	0	0.004	0.005	
23	RUS	0.4682	0	-28.829	0	337.331	113.605	0.4738	0	-15.791	0	303.794	111.052	
24	SGP	1	0	0	0	0	0	1	0	0	0	0	0	
25	TSA	0.7625	0	0	0	57.311	31.148	1	0	0	0	0.001	0.001	
26	TUR	0.6414	0	-6.766	0	198.272	55.915	0.6448	0	0	0	173.226	55.094	
27	TWN	0.811	0	0	-40.984	91.207	23.305	0.8942	0	0	-50.005	73.545	11.827	
28	USA	1	0	0	0	0	0	1	0	0	0	0	0	
29	VNM	0.9896	0	-34.316	0	37.674	1.048	1	0	-0.001	0	0.001	0	

Projection: the DMU's efficient target with all inefficiency removed

$$\widehat{x_{i0}} = x_{i0} - s_i^{-*} \ (i = 1,2,\dots,m)$$

$$\widehat{y_{i0}} = \phi y_{i0} + s_r^{+*} \ (r = 1,2,\dots,s)$$

Methodology

Super-efficiency DEA (CCR,BCC) (Andersen and Petersen, 1993) Super-efficiency DEA can distinguish the ranking of efficient DMUs.
The difference of basic DEA is that when evaluating DMU_0, the efficiency is calculated by excluding DMU_0

Super-efficiency CCR DEA

- Constant returns to scale-based model
- Output-oriented super-efficiency CCR model:

$$Max\ \phi^{super}$$

$$subject\ to$$

$$x_{i0} \geq \sum_{j=1,\neq 0}^{n} x_{ij}\lambda_j \ (i = 1,2,\dots,m)$$

$$\phi^{super} y_{r0} \leq \sum_{j=1,\neq 0}^{n} y_{rj}\lambda_j \ (r = 1,2,\dots s)$$

$$\lambda_j \geq 0\ (j = 1,2,\dots,n)$$

Super-efficiency BCC DEA

- Variable returns to scale-based model
- Output-oriented super-efficiency BCC model:

$$Max\ \phi^{super}$$

$$subject\ to$$

$$x_{i0} \geq \sum_{j=1,\neq 0}^{n} x_{ij}\lambda_j \ (i = 1,2,\dots,m)$$

$$\phi^{super} y_{r0} \leq \sum_{j=1,\neq 0}^{n} y_{rj}\lambda_j \ (r = 1,2,\dots s)$$

$$\sum_{j=1,\neq 0}^{n} \lambda_j = 1$$

$$\lambda_j \geq 0\ (j = 1,2,\dots,n)$$

Results of DEA analysis

2. Summary of DEA-CCR and BCC results CCR score = Technical Efficiency; BCC score = Pure Technical Efficiency; Scale Efficiency = CCR score/BCC score

Rank	DMUs	CCR score	Rank	DMUs	BCC score	RTS	Rank	DMUs	Scale eff.
1	BEL	1.0000	1	BEL	1.0000	Constant	1	BEL	1.0000
1	CHN	1.0000	1	BRA	1.0000	Increasing	1	CHN	1.0000
1	HKG	1.0000	1	CHN	1.0000	Constant	1	HKG	1.0000
1	IND	1.0000	1	HKG	1.0000	Constant	1	IND	1.0000
1	KOR	1.0000	1	IND	1.0000	Constant	1	KOR	1.0000
1	MYS	1.0000	1	ISR	1.0000	Increasing	1	MYS	1.0000
1	SGP	1.0000	1	KOR	1.0000	Constant	1	NOR	1.0000
1	USA	1.0000	1	MYS	1.0000	Constant	1	SGP	1.0000
9	VNM	0.9896	1	PHL	1.0000	Increasing	1	USA	1.0000
10	NLD	0.8174	1	SGP	1.0000	Constant	10	DEU	0.9979
11	TWN	0.811	1	THA	1.0000	Increasing	11	IDN	0.9948
12	ARE	0.8075	1	USA	1.0000	Constant	12	TUR	0.9947
13	BRA	0.7812	1	VNM	1.0000	Increasing	13	VNM	0.9896
14	GBR	0.7717	14	IRN	0.9999	Increasing	14	RUS	0.9883
15	THA	0.7625	15	NLD	0.9493	Constant	15	FRA	0.9867

Rank	DMUs	CCR score	Rank	DMUs	BCC score	RTS	Rank	DMUs	Scale eff.
16	DEU	0.7194	16	GRC	0.9480	Increasing	16	GBR	0.9819
17	GRC	0.6921	17	TWN	0.8942	Increasing	17	CAN	0.9773
18	FRA	0.6603	18	ARE	0.8483	Increasing	18	DNK	0.9558
19	ITA	0.6535	19	GBR	0.7839	Constant	19	ARE	0.9519
20	TUR	0.6414	20	DEU	0.7210	Increasing	20	ITA	0.9476
21	ISR	0.5734	21	ITA	0.6894	Increasing	21	TWN	0.9070
22	IDN	0.5729	22	FRA	0.6692	Increasing	22	NLD	0.8611
23	PHL	0.5208	23	TUR	0.6448	Increasing	23	JPN	0.8598
24	JPN	0.5048	24	JPN	0.5871	Constant	24	BRA	0.7812
25	RUS	0.4682	25	IDN	0.5759	Increasing	25	THA	0.7625
26	CAN	0.4224	26	RUS	0.4738	Increasing	26	GRC	0.7301
27	DNK	0.4070	27	CAN	0.4322	Increasing	27	ISR	0.5734
28	IRN	0.3093	28	DNK	0.4258	Constant	28	PHL	0.5208
29	NOR	0.1068	29	NOR	0.1068	Constant	29	IRN	0.3093

Input and Output variables

- DMU: 29 countries that handled 80.4% of world container port throughput in 2019

Northern and South America (3)	Asia (16)			Europe (10)
	Eastern Asia (5)	South-eastern Asia (6)	Southern and western Asia (5)	
Brazil	China	Indonesia	India	Belgium
Canada	Hong Kong	Malaysia	Iran	Denmark
United States	Japan	Philippines	Israel	France
	South Korea	Singapore	Turkey	Germany
	Taiwan	Thailand	United Arab Emirates	Greece
		Viet Nam		Italy
				Netherlands
				Norway
				Russian Federation
				United Kingdom

- Input and output variables (2019)

Input (year)	References	Output (year)	References
The number of container ports (2020)	Tongzon (2001), Valentine and Gray (2001), Lin and Tseng (2005)	**Container port throughput (2019)** (TEU)	Tongzon (2001), Wang et al. (2003), Cullinane et al. (2006)
Container fleet of control (2020.1.1) (1000 TEU)	Chao *et al.* (2018), Gutiérrez *et al.*(2014), Zhu (2011)	**Liner Shipping Connectivity Index (2019)** (maximum value in 2006 Q1=100)	Pham *et al.* (2020)
Level of seaport service* **(2019)** (1-100 score)	Marti *et al.* (2015), Lee (2016)		

* Efficiency of seaport service: frequency, punctuality, speed, price

Results of super-efficiency DEA analysis

1. Result of super-efficiency CCR

Rank	DMUs	DEA-CCR	SE-DEA-CCR
1	CHN	1.0000	5.6464
2	HKG	1.0000	3.3181
3	SGP	1.0000	2.0688
4	MYS	1.0000	1.4249
5	USA	1.0000	1.3286
6	KOR	1.0000	1.1151
7	IND	1.0000	1.0222
8	BEL	1.0000	1.0085

Average score America: 0.84
Asia: 1.34 (Eastern Asia: 2.28)
Europe: 0.63

2. Result of super-efficiency BCC

Rank	DMUs	DEA-BCC	SE-DEA-BCC	
1	CHN	1.0000	6.7869	
2	SGP	1.0000	2.0688	
3	MYS	1.0000	1.5264	
4	THA	1.0000	1.5078	
5	USA	1.0000	1.4076	
6	VNM	1.0000	1.2648	
7	KOR	1.0000	1.1403	
8	BEL	1.0000	1.0559	
9	BRA	1.0000	1.0000*	Infeasible DMUs
9	HKG	1.0000	1.0000*	
9	IND	1.0000	1.0000*	
9	PHL	1.0000	1.0000*	
9	IRN	1.0000	1.0000*	
9	ISR	1.0000	1.0000*	

Results of super-efficiency DEA analysis

3. Frequency in reference set in super-efficiency CCR and BCC

- Result of super-efficiency CCR model

Belgium	China	Hong Kong (SAR)	Korea, Rep. of	Malaysia	Singapore	United States
3	15	4	12	16	4	2

- Result of super-efficiency BCC model

Brazil	China	Hong Kong (SAR)	Korea, Rep. of	Malaysia	Singapore	Thailand	Viet Nam
2	12	5	13	9	3	4	8

Results of super-efficiency DEA analysis

4. 2x2 Matrix for Efficiency and Performance

- Logistics Performance Index (LPI): The LPI is developed by World Bank to evaluate national logistics performance based on six indicator
(1) Customs (2) Infrastructure (3) Service quality
(4) Timeliness (5) International Shipments (6) Tracking and tracing

- Spearman's rank correlation test with LPI ranking and SE-DEA ranking

			The LPI Ranking	The SE-DEA Ranking
Spearman's rho	The LPI Ranking	Correlation Coefficient	1.000	0.239
		Sig. (2-tailed)	.	0.212
		N	29	29
	The SE-DEA Ranking	Correlation Coefficient	0.239	1.000
		Sig. (2-tailed)	0.212	.
		N	29	29

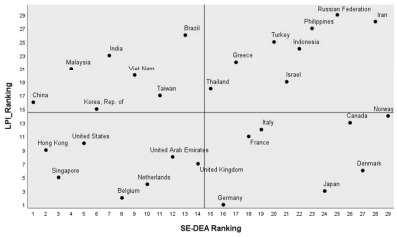
The correlation between two ranking is not statistically significant at 5% level

→ Countries could refer to separated information about performance or efficiency and maritime logistics or overall efficiency

Results of super-efficiency DEA analysis

4. 2x2 Matrix for Efficiency and Performance

Based on the high and low ranking of two indicators, the 29 countries are divided into four quarters



Discussion

1. The average efficiency score of Asian countries is the highest.
- There are global hub ports such as Port of Singapore and Port of Hong Kong in Asian region.
- Creating high container transport demand with strong growth of the economic system in Asia-Pacific region.
- Different patterns of development between ports in Asian countries and Europe and America countries might be reflected.

2. Fleet capacity is most of the cause of inefficiency in the Europe countries and Japan.
- Except for China, the cause of inefficiency of Germany, Denmark, Greece, and Japan is container fleet capacity.
- It is because although the growth rate of fleet slowed, the supply of container shipping exceeded demand until 2019.

3. Asian countries and European countries have common characteristics in 2x2 matrix.
- European countries tend to have high performance on overall logistics system except for Russia and Greece.
- Asian countries tend to show high efficiency in maritime logistics but relatively low performance in the overall logistics system. Hong Kong, Singapore and UAE are highly ranked in both, and Japan is similar to European countries.
- North and South American countries have no common characteristics.

Research limitations and implications

1. Limitations
- Due to the lack of national-level integrated data, the level of seaport service and the number of container ports are used as an alternative input variables
- Due to the lack of data in the actual shipping charter ratio, the actual utilization of container ships was not reflected

2. Implications
- Providing the information of efficiency on policy and investment of maritime logistics industry to stakeholders and policymakers
- Providing the results of ranking of efficient countries and reference countries using super-efficiency DEA