Container Terminal Efficiency Measurement Using Data Envelopment Analysis: Pre-Pandemic Comparison of Colombo and Busan

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요 약 : *Increasing port competition driven by the containerisation has motivated ports and terminals to focus on their performance to efficiently utilise the available resources and to make strategic decisions in port development and expansion. With both inter-port and intra-port competition increasing in the port of Colombo, this study aims to measure the efficiency of the container terminals in Colombo comparing to terminals in the port of Busan using the DEA window analysis to determine their operational efficiency and to provide suggestions for future port development activities. Multiple window analyses were conducted using CCR and BCC models with different orientations and window lengths to compare the efficiencies of 11 DMUs in both ports during the period from 2015-2019 to measure the efficiencies prior to the COVID-19 pandemic. Results revealed the largest terminal operator, PNC in Busan, to be the most efficient overall, while the second highest efficiency was recorded by one of the smallest terminal operators, SAGT in Colombo, among the sample. Although use of DEA in port performance measurement has been popular for many years, efficiency measurements in the port of Colombo, the main hub port in the South Asian region, has not been comprehensively studied so far.*

핵심용어 : *Container terminal efficiency, DEA-Window, Pre-COVID19*

Container Terminal Efficiency Measurement Using DEA: Pre-COVID19 Comparison of Sri Lanka and South Korea

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Literature

- Different methods used to measure port performance (Cullinane, 2010)
  - Evaluating the cargo handling productivity at berths
  - Assessing a single factor productivity
  - Making comparisons to the optimum performance in a base period
  - Estimating a port cost function
  - Estimating a total factor productivity index
  - Using multiple regression model to evaluate port performance and efficiency
  - Utilising the economic concept of an efficient frontier
- DEA has been used widely in efficiency measurement with many practical applications (Thanassoulis, 2001)
- The ability to accommodate multiple inputs and outputs promoted the extensive use of DEA to analyse port production (Cullinane & Wang, 2007)
- DEA in Port Efficiency Measurement
  - Many studies since the first application by Roll and Hayuth (1993)
  - Using both cross-sectional and time series/panel data and both orientations.
  - Most considered CCR and BCC models. Extended DEA models were also applied
  - Window analysis was used by most studies considering panel data
  - Most common output variable: container throughput
  - Most common input variables: land, labour and equipment factors of port production
  - Due to the unavailability of accurate data most studies did not consider labour as an input

Introduction

Background

Growth of containerisation led to efficient transport systems
Shipping lines invest on dedicated container ships
Ports have developed dedicated terminals
Geographical monopolistic nature of ports diminished
Intense competition among ports for the cargo
Ports and terminals focus on improving efficiency

Objectives

- Measure the efficiency of container terminal operators in Colombo and Busan
- Identify the inefficient components in terminal operations
- Propose strategies to improve the efficiency of terminal operators
- Provide recommendations for future port development

Purpose and significance

- Fill the research gap in port efficiency measurement in Sri Lanka
- First study to comprehensively measure the efficiency of Colombo port

Literature

- Time series or panel data is more appropriate for container terminals to measure the efficiency over time (Panayides, et al., 2009)
- In most instances the choice of orientation will have only minor influence upon the scores obtained (Coelli, 1996)
- Input-oriented models are related to operational and managerial issues while the output-oriented models are considered in port planning and strategical contexts (Cullinane, et al., 2004)
- Window analysis is useful for detecting efficiency trends over time, which calculates the average efficiency of CCR and BCC models (Al-Eraqi, et al., 2008)
- Window analysis increases the number of units (DMUs) under evaluation, therefore increasing the discriminatory power of the DEA model (Pjevčević et al., 2012)

Methodology

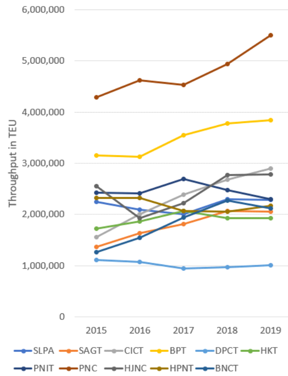
Extensive Literature	Determine DEA model structure	Data Collection	Data Envelopment Analysis (DEA)	Results
- Identify the measures of performances - Port performance measurement - Data Envelopment Analysis - Use of DEA in port performance measurement	- Variables: input/output - Orientation - Model: CCR, BCC, window -Window length	- Sample: 11 terminals - Panel data from 2015 to 2019 - Four inputs: Quay length, Terminal area, Number of quay cranes, Number of transfer cranes - One output: Container throughput	- Two models: DEA-CCR and DEA-BCC - Both orientations: Input-oriented and Output-oriented - Two window lengths: 3-year and 4-year - Total of eight analyses	- Compare the results of the eight analyses - Technical and Scale efficiency of terminals - Efficiency trends from 2015-2019 - Efficiency benchmarking - Inefficient components in terminals - Suggestions for improvement

Results & Discussion

- Characteristics of the DMUs

	Quay Length (m)	Terminal area (km²)	Quay Cranes (nos.)	Transfer Cranes (nos.)
Mean	1399.55	0.71	15.00	46.45
Std. Dev.	455.85	0.37	5.93	17.26
Min	826	0.2	7	19
Max	2232	1.454	26	73
Count	11	11	11	11

- However, the throughputs, facilities and equipment of the individual terminals are relatively similar in both ports



Methodology

- Model definitions

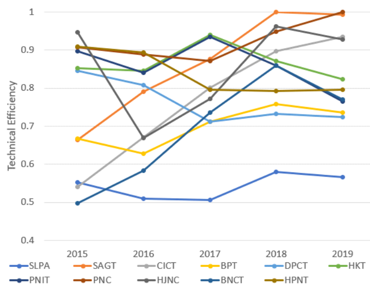
	Input orientation	Output orientation
CCR	$\theta^* = \min_{\lambda,\theta} \theta$ Subject to: $\sum_{r=1}^{k} \lambda_r x_{ir} \leq \theta x_{i0}$; $i = 1, \dots, m$ $\sum_{r=1}^{k} \lambda_r y_{jr} \geq y_{j0}$; $j = 1, \dots, n$ $\lambda_r \geq 0$; $r = 1, \dots, k$	$\phi^* = \max_{\lambda,\phi} \phi$ Subject to: $\sum_{r=1}^{k} \lambda_r x_{ir} \leq x_{i0}$; $i = 1, \dots, m$ $\sum_{r=1}^{k} \lambda_r y_{jr} \geq \phi y_{j0}$; $j = 1, \dots, n$ $\lambda_r \geq 0$; $r = 1, \dots, k$
BCC	adding the convexity constraint, $\sum_{r=1}^{k} \lambda_r = 1$	adding the convexity constraint, $\sum_{r=1}^{k} \lambda_r = 1$
Scale Efficiency	$SE_0 = \frac{\theta^*_{CCR}}{\theta^*_{BCC}}$ or $\frac{\phi^*_{CCR}}{\phi^*_{BCC}}$	

Results & Discussion

Overall;

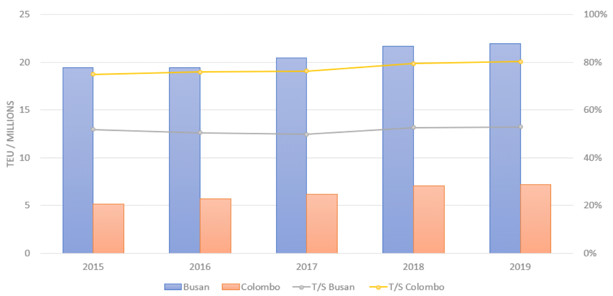
- All DMUs were technically inefficient
- Busan (0.810) was technically efficient than Colombo (0.730)
- Container terminal efficiency vary over time
- SAGT and PNC were efficient in 2018 and 2019
- 2019: Colombo (0.831) was technically efficient than Busan (0.818)
- CICT recorded the highest efficiency growth (72.8%)

Rank	DMU	Technical Efficiency
1	PNC	0.916
2	SAGT	0.874
3	HKT	0.873
4	PNIT	0.866
5	HJNC	0.835
6	HPNT	0.834
7	CICT	0.777
8	DPCT	0.759
9	BNCT	0.703
10	BPT	0.699
11	SLPA	0.539



Results & Discussion

- Characteristics of the DMUs

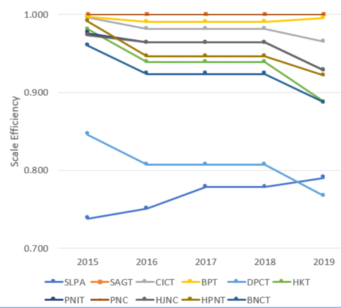


- In terms of the scale of production, Busan port is significantly larger than Colombo (328%)
- Mostly handle Transhipment cargo (52% and 77%)
- Throughput volumes increased (by 13% and 39%)

Results & Discussion

- PNC and SAGT were scale efficient throughout the study period
- SLPA indicated DRS throughout
- Majority of the DMUs (56.8%) indicated IRS
- In 2019, both PNC and SAGT indicated CRS while all others recorded IRS properties

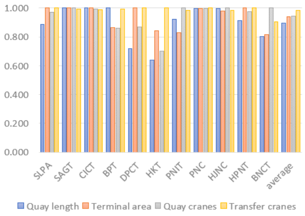
Rank	DMU	Scale Efficiency
1	SAGT	1.000
1	PNC	1.000
3	BPT	0.992
4	CICT	0.981
5	PNIT	0.959
6	HJNC	0.959
7	HPNT	0.951
8	HKT	0.937
9	BNCT	0.924
10	DPCT	0.807
11	SLPA	0.767



Results & Discussion

- Overall, the resource utilisation of the DMUs was high (0.941)
- Resource utilisation in Colombo (0.986) is higher than Busan (0.926)
- Transfer crane was the most efficient input (0.986)
- Quay length was the least efficient input (0.897)

Rank	DMU	Utilisation
1	SAGT	99.85%
2	PNC	99.63%
3	CICT	99.53%
4	HJNC	99.03%
5	HPNT	97.25%
6	SLPA	96.40%
7	PNIT	93.48%
8	BPT	92.85%
9	DPCT	89.75%
10	BNTC	88.05%
11	HKT	79.53%



DMU	Quay length	Quay cranes (QC)	Terminal area	Transfer cranes (TC)	Efficient operations
SLPA	Inefficient	Inefficient	Efficient	Efficient	Yard
SAGT	Efficient	Efficient	Efficient	Inefficient	Quay
CICT	Efficient	Inefficient	Efficient	Inefficient	Infrastructure
BPT	Efficient	Inefficient	Inefficient	Inefficient	Berth allocation
DPCT	Inefficient	Inefficient	Efficient	Efficient	Yard
HKT	Inefficient	Inefficient	Inefficient	Efficient	TC allocation
PNIT	Inefficient	Efficient	Inefficient	Inefficient	QC allocation
PNC	Inefficient	Inefficient	Inefficient	Efficient	TC allocation
HJNC	Inefficient	Efficient	Inefficient	Inefficient	QC allocation
HPNT	Inefficient	Inefficient	Efficient	Efficient	Yard
BNCT	Inefficient	Efficient	Inefficient	Inefficient	QC allocation

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Conclusion

- All window analyses conducted indicate the dynamic nature of the container terminal production, therefore, cross-sectional analyses might not accurately depict the true efficiency of the container terminal/port production
- PNC, the largest terminal operator in terms of the scale of port production, exhibited the highest technical efficiency, however, SAGT and HKT, 10th and 8th in terms of the scale of production, recorded the second and the third highest efficiencies. Therefore, the scale of production alone cannot determine the technical efficiency of container port production
- Rapid efficiency gains of CICT and BNCT can be attributed to the learning curve phenomenon proposed by Min and Park (2005)
- Observing the high resource utilisation of the terminal operators overall in Colombo, the inefficiencies can be associated to scale efficiency rather than the pure technical efficiency
- Despite being the least efficient among the sample, SLPA recorded high resource utilisation than most of the terminal operators in Busan, therefore, the limitations in quay infrastructure and the outdated equipment could be attributed to the poor performance
- Colombo indicated an increasing trend in overall efficiency with high resource utilisation levels. Also, CICT, the only deep-draft terminal in Colombo, recorded IRS properties in 2019 demonstrating the potential to develop terminals for mega container ships
- Overall input resource utilisation of Busan was relatively low which indicates a surplus of input resources available

Recommendations

SLPA	• Invest on deep-draft container terminals • Invest on state-of-the-art quay cranes • Relocate the outdated smaller cranes to serve feeder berths • Redevelop the surplus shallow draft quays as multipurpose terminals
SAGT	• Invest on a deep-draft container terminals to utilize the expertise
Colombo	• Port development related to deep-water container terminals
Busan	• Cooperation strategies to manage the input resources • Port marketing strategies to attract throughput volumes

Limitations
- Sample size
- Data availability
- Inherent Limitations of DEA

Future research
- Labour as an input variable
- More terminals to increase the discriminatory power
- More time periods to account the dynamic nature of the industry
- Inputs related to technological interventions