Performance Evaluation of Major World Container Ports in the post-pandemic era: The 6th Generation Ports Model with Smart Ports

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ABSTRACT:
The port sector is facing challenges and opportunities in digital transformation and decarbonisation in the post-pandemic period. To address these focal issues, the Sixth Generation Port (6GP) model with smart ports has been proposed and iteratively refined, which comprises of six aspects and 14 criteria. However, this updated 6GP model lacks empirical assessment at a global scale. In addressing this research gap, this study aims to evaluate the 6GP model and port performance globally, taking cases of major container ports in both Asia and Europe, i.e., Singapore, Shanghai, Busan, Hong Kong, and Rotterdam ports. An innovative hybrid methodology integrating CFPR, MOORA, and VIKOR has been employed to explore
the business needs and development priorities of port stakeholders and to evaluate each port’s performance with reference to the 6GP model. The test results show that Singapore, Rotterdam, and Shanghai ports have notable performance, while Asian container ports achieved better performance in "service" and "smart port governance system and policy". In particular, Rotterdam achieved remarkable performance in digitalisation and decarbonisation in building a symbiosis system by smart port/city interface, while Shanghai focused on automation optimization for seamless flow of cargo and ship in the port. The contribution of this study lies in both theoretical and empirical aspects. From an empirical perspective, it validates the applicability of the 6GP model, enriching the existing literature on port evolution and devolution. It also enhances the weaknesses in the existing multi-objective optimization method. From an empirical perspective, it draws managerial and policy insights for the reference of policy-makers and port managers, and advocates collaborative action among different stakeholders.

KEYWORDS:
Sixth Generation Ports (6GP); port digitalisation; maritime industry decarbonisation; COVID-19; container port.

1. INTRODUCTION

The COVID-19 pandemic has caused unprecedented disruption throughout the global supply chains, exerting significant impacts on the port sectors which serve as pivotal nodes of the global trade network. Despite the pandemic having since stopped, ports are still in the post-pandemic recovery phase, necessitating concerted efforts to address the challenges and utilise the opportunities stemming from the acceleration of the pandemic, particularly in terms of digital transformation and decarbonisation.

Digitalisation has emerged as a pivotal measure to address these challenges, driving the adoption of cutting-edge technologies such as artificial intelligence, blockchain and the Internet of Things into port operations. The integration of digital technologies not only drives operational efficiency but also enhances supply chain resilience, enabling ports to swiftly adapt to dynamic market conditions and unforeseen disruptions (Wang and Pettit, 2022). From real-
time cargo tracking and optimization of terminal operations to predictive maintenance and automated logistics, digitalization has revolutionized traditional port management paradigms, launching an era of flexibility and innovation. Furthermore, digitalization has facilitated the seamless integration of disparate stakeholders within the port ecosystem, fostering collaboration and information sharing across the entire supply chain spectrum. Through digital platforms and collaborative tools, stakeholders can streamline communication, optimize resource allocation, and mitigate operational bottlenecks, thereby enhancing overall system efficiency and customer satisfaction.

Simultaneously, there exists a global imperative to mitigate the environmental footprint of port activities and transition toward sustainable operational practices. Port sectors alongside stakeholders are progressively deepening their engagement in decarbonisation efforts in line with the resolutions of the 26th and 27th sessions of the Conference of the Parties (COP26 and COP27), in tandem with a series of agreements and policies developed by the governments and international organisations (Song et al., 2023). Notably, initiatives such as the International Maritime Organization’s (IMO) Sulphur Emissions Regulation 2020, the Greenhouse Gas Emissions Reduction Strategy, and the Paris Agreement have made efforts to hold the increase in the global average temperature to well below 2°C above pre-industrial benchmarks. There is an increasing demand for decarbonisation measures to mitigate the impacts of climate change.

In light of the above considerations, this study aims to evaluate the performance of major container ports globally in the context of the sixth-generation port (6GP) model with smart ports in the post-pandemic era. By examining the intersection of port performance with focal issues in the port industry, such as digitalization and decarbonization, this study seeks to investigate the key drivers, challenges, and impacts of the ongoing transformation within the global port industry, as well as development priorities from different stakeholders’ perspectives, providing insights for port stakeholders including port operators, policy-makers, etc.

2. THEORETICAL BACKGROUND WITH CONCEPTUAL DEVELOPMENT
In reflecting on the multifaceted challenges and opportunities facing the port industry in recent years, especially the fusion technology, the concept of the 6GP model with smart ports has been proposed (Lee et al., 2020; Song et al., 2022). This conceptual model builds upon earlier iterations, including the initial first-generation port (1GP) model to the fourth-generation port (4GP) model proposed by UNCTAD (1999). Beresford et al. (2004) and Pettit and Beresford (2009) contributed to the port devolution literature by criticising and adding missing port functions to 4GP. Subsequently, discussions on port generation evolved with the introduction of the fifth generation port (5GP) model, characterized as a "customer-centric community port". This 5GP was further refined by Flynn et al. (2011) and Lee and Lam (2016), and empirically tested by Lee et al. (2018). Lee et al. (2018) tested the 5GP, focusing on the performance evaluation of major container ports in Asia (e.g., Busan, Hong Kong, Singapore, and Shanghai ports), revealing that the Singapore and Hong Kong ports are closely aligned with the criteria of 5GP, whereas Busan and Shanghai ports are lagging in meeting most of the criteria of the 5GP. With the introduction of the 6GP, an initial empirical study of 6GP was conducted by Song et al. (2024), which confirmed its feasibility by evaluating the performance of the top six container ports in mainland China under the 6GP criteria, offering insights into contemporary challenges in the port industry.

Nevertheless, considering the emerging issues facing the port industry such as the post-COVID-19 period, digitalisation, and decarbonisation (CDD), the 6GP model has undergone iterative refinement, revising aspects, features and criteria building upon these foundational concepts and empirical findings in Lee et al. (2024). The newly updated 6GP model consists of six aspects, "Service", "Smart technology", "Sustainability", "Cluster", "Hub", and "Smart port governance system and policy". Under these aspects, there are 10 features and 14 criteria (see Table 1). Through iterative refinement, the updated 6GP model aims to provide a comprehensive framework of contemporary ports in the post-pandemic era and beyond. However, this updated 6GP model has not yet been empirically validated and previous empirical cases for generation port models were limited to China or Asia, with no demonstration cases from major container ports worldwide.

Taking into account the aforementioned research background and gaps, this paper attempts to test the revised 6GP model, taking major container ports in the world beyond mainland China, such as Singapore, Shanghai, Busan, Hong Kong, and Rotterdam ports. Recognizing the
criteria differences in port management and development policies between Asia under the Asian Port Doctrine (Lee and Flynn, 2011) and Europe under the European Continental Doctrine (Alan and Walters, 1979), this paper assumes that there may remain differences and peculiarities in evaluating performance of the updated 6GP model with smart ports between Asia and Europe. This paper aims to evaluate the performance of six aspects, ten features and 14 criteria of the 6GP model, encompassing five major container ports in the world (refer to Table 1).

3. METHODOLOGY AND DATA COLLECTION

This study employs a hybrid methodology consisting of three methods: the Consistent Fuzzy Preference Relation (CFPR) method, the Multi-Objective Optimization based on Ratio Analysis (MOORA) technique, and the VIskriterijumska Optimizacija i KOmpromisno Resenje (VIKOR), to evaluate the performance of major container ports in the world.

First, the CFPR method is utilized to identify weights, which is superior to other weighting methods in that it effectively reduces information demand while ensuring the validity of the survey, thus enhancing investigative efficacy (Herrera-Viedma et al., 2004). The CFPR method ensures consistency in decision-making by examining the transferability property in fuzzy preference relations. Specifically, it characterizes consistency through the additive transitivity property of fuzzy preference relations, thereby constructing consistent fuzzy preference relations from a set of preference data. This approach enhances the reliability of preference relations provided by decision-makers, thus avoiding inconsistent solutions in the decision-making processes.

Second, the MOORA and VIKOR serve as a rank identification mechanism for the target ports, facilitating an efficient performance assessment. The rationale behind utilizing both methods simultaneously lies in their complementary nature. MOORA offers a straightforward ranking mechanism that identifies the relative positions of ports based on the 6GP criteria. VIKOR, on the other hand, provides a detailed scoring system that provides decision-makers with the opportunity to make a comprehensive assessment of port performance from multiple perspectives. The MOORA method was first introduced by Brauers and Zavadska (2006), which integrates ratio analysis and reference point methods, offering distinct advantages
including low calculation complexity, robust results, and expedited processing time. Moreover, Chakraborty’s (2011) study demonstrated that MOORA, compared to traditional multi-criteria decision-making methods like AHP, TOPSIS, ELECTRE, and PROMETHEE, is characterised by short computation time and good stability. It has been applied in various studies to efficiently solve complex decision-making problems, including material selection, and examining factors affecting the operational and financial performance of the third-party logistics service providers (Karande and Chakraborty, 2012; Pal Singh et al., 2022).

The VIKOR, on the other hand, serves as another ranking method, which is based on the principle of compromise between the criteria. It seeks to find a solution that achieves the best possible compromise among conflicting criteria, introducing an aggregating function representing the distance from the ideal solution. This ranking index amalgamates all criteria while considering their relative importance, achieving a balance between overall satisfaction and individual satisfaction. The VIKOR determines a compromise solution, that results in maximum "group utility" for the "majority" while minimum individual regret for the "opponent" (Opricovic and Tzeng, 2004). In addition, it provides two indices of evaluation, i.e. acceptable strengths and acceptable stability, which allow for more in-depth discussion and analysis by decision-makers when examining. This approach ensures a comprehensive assessment of port performance, taking into account the collective welfare and individual preferences of stakeholders involved in the decision-making process. Its application offers decision-makers the opportunity to discuss and compare the evaluation results provided by MOORA, thereby helping ensure the reliability and validity of the assessments and facilitating more informed decision-making.

This holistic approach comprising CFPR-MOORA-VIKOR provides a comprehensive assessment framework for the 6GP model, incorporating both quantitative and qualitative dimensions, and offering insights into the dynamics of smart port development and governance. In other words, this hybrid method can distinguish which ports conform to the 6GP smart port, or identify the aspects in which ports deviate from meeting the criteria to become 6GP smart ports.

Regarding the data collection, a validated questionnaire was designed and distributed to four key groups of experts and stakeholders in the port industry, i.e., shipping companies, port
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authorities, freight forwarders, and port experts. The questionnaire was structured into three components, i.e., the relative importance of 6GP criteria, the interrelationships of 6GP criteria, and the performance of the selected ports within the context of these criteria. Both a pilot survey along with interviews, and the main survey were conducted. The pilot survey was conducted between the end of August to the beginning of September and the beginning of December to mid-December 2023, to assess the appropriateness of the questionnaire design and to identify possible problems in the main survey. The main survey commenced in early December 2023, with 25 valid questionnaires collected by mid-January 2024, with an average of over 20 years of working experience of the respondents.

4. PRELIMINARY TEST RESULTS

The first part of the main findings concerns the relative importance of the 14 criteria of 6GP evaluated by four groups of stakeholders in the port industry (e.g., shipping companies, port authorities, freight forwarders, and port experts), which reflect the differences in their perceptions of the different criteria during the assessment process. Table 1 is organized into "Aspects", "Features", and specific "Criteria" of the 6GP, with corresponding weight values provided by the stakeholders. The results assist port operators, users, and academics in understanding the different priorities of each other when engaging in port-related business. Overall, among the 14 criteria, the top three weighted criteria are "(E2) Shipping service connectivity", "(F2) Consistency of smart port policy", and "(F1) Transparency of smart port governance". Instead, the bottom three ranked criteria are "(C1) Coordination/collaboration of port-city interface development", "(A2) Efficiency", and "(C3) Decarbonization management and policy".

Notably, stakeholders from shipping companies, port authorities, and freight forwarders, representing the industry's perspectives of the port, generally share similar views. However, there are significant differences in perspectives between these industry stakeholders and port experts (i.e. academics). A common view is that all four stakeholder groups consider the criteria "(E2) Shipping service connectivity" to be highly important. The most argued criteria is "(B1) Establishment of smart technology platform with digitalization", which was perceived as less
critical by port operators and users and ranked between 12th and 13th out of the 14 criteria, whereas academics consider it as highly important ranked it as the third most important criteria.

It is also interesting to note that, the port authority group is more interested in the smart port governance system and policy and developing green ports along with decarbonisation policies. On the other hand, the shipping company group prefers ports that provide reliable port services. The group also places the highest relative weight on reliable information network monitoring to secure quick responses to service problems at the port. These differences in weight shed light on the importance and priorities accorded to different criteria by different stakeholders involved in the assessment process.

Table 1 – Relative weights of 6GP criteria evaluated by four groups of port stakeholders

<table>
<thead>
<tr>
<th>Aspects</th>
<th>Features</th>
<th>Criteria</th>
<th>Shipping co.</th>
<th>Port authority</th>
<th>Freight forwarder</th>
<th>Port expert</th>
<th>Max</th>
<th>Min</th>
<th>Range</th>
<th>Avg.</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>(A) Service</em></td>
<td>Customer-centric Service</td>
<td>(A1) Reliability</td>
<td>0.070</td>
<td>0.074</td>
<td>0.063</td>
<td>0.069</td>
<td>0.074</td>
<td>0.063</td>
<td>0.11</td>
<td>0.069</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(A2) Efficiency</td>
<td>0.070</td>
<td>0.059</td>
<td>0.055</td>
<td>0.062</td>
<td>0.070</td>
<td>0.055</td>
<td>0.015</td>
<td>0.062</td>
<td>13</td>
</tr>
<tr>
<td><em>(B) Smart technology</em></td>
<td>Smart technology platform with digitalization</td>
<td>(B1) Establishment of smart technology platform with digitalization</td>
<td>0.064</td>
<td>0.062</td>
<td>0.059</td>
<td>0.080</td>
<td>0.080</td>
<td>0.059</td>
<td>0.021</td>
<td>0.066</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(B2) Information network security and stability</td>
<td>0.071</td>
<td>0.073</td>
<td>0.075</td>
<td>0.073</td>
<td>0.073</td>
<td>0.071</td>
<td>0.004</td>
<td>0.073</td>
<td>5</td>
</tr>
<tr>
<td><em>(C) Sustainability</em></td>
<td>Symbiosis of port and city</td>
<td>(C1) Coordination/collaboration of port-city interface development</td>
<td>0.073</td>
<td>0.049</td>
<td>0.072</td>
<td>0.047</td>
<td>0.073</td>
<td>0.047</td>
<td>0.026</td>
<td>0.061</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Resilient system</td>
<td>(C2) Intelligent monitoring and fault response system</td>
<td>0.069</td>
<td>0.070</td>
<td>0.076</td>
<td>0.072</td>
<td>0.076</td>
<td>0.069</td>
<td>0.007</td>
<td>0.072</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Decarbonization</td>
<td>(C3) Decarbonization management and policy</td>
<td>0.057</td>
<td>0.064</td>
<td>0.071</td>
<td>0.066</td>
<td>0.071</td>
<td>0.057</td>
<td>0.014</td>
<td>0.065</td>
<td>12</td>
</tr>
<tr>
<td><em>(D) Cluster</em></td>
<td>Clustering</td>
<td>(D1) Port industry clustering</td>
<td>0.065</td>
<td>0.071</td>
<td>0.064</td>
<td>0.069</td>
<td>0.071</td>
<td>0.064</td>
<td>0.008</td>
<td>0.067</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(D2) Maritime and technology industry clustering</td>
<td>0.067</td>
<td>0.071</td>
<td>0.068</td>
<td>0.073</td>
<td>0.073</td>
<td>0.067</td>
<td>0.006</td>
<td>0.070</td>
<td>7</td>
</tr>
<tr>
<td><em>(E) Hub</em></td>
<td>Infrastructure</td>
<td>(E1) Software and hardware infrastructure</td>
<td>0.078</td>
<td>0.069</td>
<td>0.084</td>
<td>0.082</td>
<td>0.084</td>
<td>0.069</td>
<td>0.015</td>
<td>0.078</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Foreland link</td>
<td>(E2) Shipping service connectivity</td>
<td>0.082</td>
<td>0.080</td>
<td>0.084</td>
<td>0.091</td>
<td>0.091</td>
<td>0.080</td>
<td>0.010</td>
<td>0.084</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Hinterland link</td>
<td>(E3) Hinterland connectivity</td>
<td>0.073</td>
<td>0.066</td>
<td>0.072</td>
<td>0.065</td>
<td>0.073</td>
<td>0.065</td>
<td>0.008</td>
<td>0.069</td>
<td>9</td>
</tr>
<tr>
<td><em>(F) Smart port governance system and policy</em></td>
<td>Transparency of smart port governance with consistency of smart policy</td>
<td>(F1) Transparency of smart port governance</td>
<td>0.079</td>
<td>0.089</td>
<td>0.076</td>
<td>0.078</td>
<td>0.089</td>
<td>0.076</td>
<td>0.013</td>
<td>0.081</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(F2) Consistency of smart port policy</td>
<td>0.080</td>
<td>0.102</td>
<td>0.081</td>
<td>0.073</td>
<td>0.102</td>
<td>0.073</td>
<td>0.029</td>
<td>0.084</td>
<td>2</td>
</tr>
</tbody>
</table>

Source: IAME 2024
Subsequently, another main finding of the study lies in the assessment of the performance of the selected ports by four groups of respondents based on their experiences. The results revealed notable distinctions in the performance among the four ports, particularly between Asia and Europe, across the 14 criteria. The Port of Singapore emerged with the highest performance across ten criteria, excelling specifically in "Shipping service connectivity," "Reliability," and "Efficiency." As well, the Port of Rotterdam ranked best in five criteria, particularly in "Establishment of digital smart technology platforms" and "Decarbonization management and policies". The two ports ranked equal highest in "Consistency of Smart Port Policies". In contrast, the Port of Hong Kong had the lowest performance among the five ports in 11 criteria, and especially it had the largest gap with the other ports in terms of "Decarbonization management and policy". Overall, the Singapore, Rotterdam, and Shanghai ports ranked on the top three in order, followed by the Port of Busan and Hong Kong ports.

It is worth noticing that the Port of Rotterdam showed better performance than Asian ports in terms of digitalisation and decarbonisation, while Asian ports (Singapore and Shanghai ports) achieved better performance in the aspects of "Services", "Cluster", and "Transparency of smart port governance".

Table 2 – Performance evaluation of 6GP criteria for the five ports

<table>
<thead>
<tr>
<th>Aspects</th>
<th>Criteria</th>
<th>Weights</th>
<th>Singapore</th>
<th>Shanghai</th>
<th>Busan</th>
<th>Hong Kong</th>
<th>Rotterdam</th>
<th>Max</th>
<th>Min</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Service</td>
<td>(A1) Reliability</td>
<td>0.069</td>
<td>4.3</td>
<td>3.5</td>
<td>3.5</td>
<td>4.0</td>
<td>4.3</td>
<td>3.5</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(A2) Efficiency</td>
<td>0.062</td>
<td>4.3</td>
<td>4.1</td>
<td>3.6</td>
<td>3.5</td>
<td>4.0</td>
<td>3.5</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>(B) Smart technology</td>
<td>(B1) Establishment of smart technology platform with digitalization</td>
<td>0.066</td>
<td>3.9</td>
<td>3.9</td>
<td>3.3</td>
<td>3.2</td>
<td>4.2</td>
<td>4.2</td>
<td>3.2</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>(B2) Information network security and stability</td>
<td>0.073</td>
<td>4.1</td>
<td>3.7</td>
<td>3.5</td>
<td>3.5</td>
<td>4.2</td>
<td>4.2</td>
<td>3.5</td>
<td>0.7</td>
</tr>
<tr>
<td>(C) Sustainability</td>
<td>(C1) Coordination/collaboration of port-city interface development</td>
<td>0.061</td>
<td>4.0</td>
<td>3.6</td>
<td>3.4</td>
<td>3.0</td>
<td>3.8</td>
<td>4.0</td>
<td>3.0</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>(C2) Intelligent monitoring and fault response system</td>
<td>0.072</td>
<td>4.0</td>
<td>3.5</td>
<td>3.6</td>
<td>3.3</td>
<td>3.9</td>
<td>4.0</td>
<td>3.3</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>(C3) Decarbonization management and policy</td>
<td>0.065</td>
<td>3.7</td>
<td>3.2</td>
<td>3.2</td>
<td>2.9</td>
<td>4.2</td>
<td>4.2</td>
<td>2.9</td>
<td>1.3</td>
</tr>
<tr>
<td>(D) Cluster</td>
<td>(D1) Port industry clustering</td>
<td>0.067</td>
<td>4.3</td>
<td>3.7</td>
<td>3.4</td>
<td>3.4</td>
<td>3.9</td>
<td>4.3</td>
<td>3.4</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>(D2) Maritime and technology industry clustering</td>
<td>0.070</td>
<td>4.2</td>
<td>3.7</td>
<td>3.3</td>
<td>3.1</td>
<td>4.0</td>
<td>4.2</td>
<td>3.1</td>
<td>1.1</td>
</tr>
<tr>
<td>(E) Hub</td>
<td>(E1) Software and hardware infrastructure</td>
<td>0.078</td>
<td>4.2</td>
<td>4.0</td>
<td>3.7</td>
<td>3.5</td>
<td>4.1</td>
<td>4.2</td>
<td>3.5</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>(E2) Shipping service connectivity</td>
<td>0.084</td>
<td>4.6</td>
<td>4.0</td>
<td>3.7</td>
<td>3.7</td>
<td>4.1</td>
<td>4.6</td>
<td>3.5</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>(E3) Hinterland connectivity</td>
<td>0.069</td>
<td>3.5</td>
<td>3.5</td>
<td>3.2</td>
<td>3.4</td>
<td>3.9</td>
<td>3.9</td>
<td>3.2</td>
<td>0.7</td>
</tr>
</tbody>
</table>
5. DISCUSSION AND IMPLICATIONS

In the context of the 6GP model with smart ports, characterised mainly by CDD, and especially in the post-pandemic era, the findings of this study offer significant insights for major container ports with port stakeholders around the world. Discussions and implications derived from the test results are expected to shed light on the following key aspects:

5.1. Theoretical Insights

From a theoretical perspective, this study contributes to filling the research gap in port devolution literature by empirically evaluating the updated 6GP model and extending its applicability beyond to a global context, providing valuable insights into the global applicability of the 6GP model. Furthermore, this study has innovatively applied fusion methodologies i.e., CFPR-MOORA-VIKOR, an innovative approach that reduces data requirements and improves computational efficiency while ensuring the reliability of the results.

The expansion of the study context to encompass container ports globally facilitates a comprehensive comparative analysis between Asia and Europe. This analysis reveals the strengths and weaknesses of each region in developing smart ports with the reference of the 6GP model, fostering cross-learning, and providing effective references for ports to formulate strategies for the realization of smart ports.

5.2. Empirical Insights with Managerial Implications

The findings of this study offer managerial insights into addressing contemporary challenges facing the port industry, particularly the impact of COVID-19, digitalization, and decarbonization. The performance evaluation results, detailed in Table 2, provide decision-makers with a holistic view of port development strategies.

The evaluation of port performance revealed notable distinctions among the selected ports, particularly between Asian and European ports. The Port of Singapore demonstrated superior
performance across various criteria, emphasizing its prominence in shipping service connectivity, reliability, and efficiency. Conversely, the Port of Hong Kong exhibited lower performance, especially concerning decarbonization management and policy, highlighting areas for improvement.

Notable distinctions in performance among selected ports, particularly between Asian and European ports, underscore the need for tailored strategies. While Asian ports (Singapore and Shanghai ports) excel in service-related aspects and transparency of smart port governance, European ports, notably Rotterdam, demonstrate better performance in digitalization and decarbonization initiatives. These insights highlight the importance of strategic decision-making to address specific challenges and capitalize on emerging opportunities.

The relative importance of the 14 criteria evaluated by different stakeholder groups (Table 1) emphasizes diverse perspectives within the port industry. While shipping companies, port authorities, and freight forwarders share common perspectives, the divergence in views with port experts (academics) underscores the need for a balanced approach and cross-industry dialogue with cooperation. Decision-makers could utilize the results of the evaluation to prioritise development strategies and allocate resources efficiently. By understanding the dynamic needs of port stakeholders, port operators and users could strategically focus on aspects aligned with their customers’ expectations, enhancing overall system efficiency and improving their competitiveness in the evolving global trade environment.

6. CONCLUSION

In summary, this study tested empirically the 6GP model that incorporates the focal issues of the port industry in the post-pandemic period, i.e., digitalisation, decarbonisation, smart port, taking the major container ports in both Asia and Europe. This study is expected to identify the key port performance of 14 criteria of 6GP from the perspectives of four stakeholder groups, utilizing an innovative hybrid approach CFPR-MOORA-VIKOR. The study contributes to the academic and field industry in both theoretical and empirical dimensions:

From a theory building perspective: i) This study fills the research gap in the existing literature on port devolution and evolution by empirically evaluating the updated 6GP model and
validating its applicability to container ports. ii) This study enhances the weaknesses in the existing multi-objective optimization method. iii) This study extends the port scope of the study from Chinese ports (Song et al., 2024) to the worldwide ports context and, consequently, contributes to further comparative study of the 6GP model with smart ports between Asia and Europe. Therefore such further comparative study may highlight differences, objectives and directions of developing sustainable future ports under the 6GP model.

From an empirical perspective: i) This paper offers managerial insights into addressing the current focal issue of the impact of COVID-19, Digitalisation and Decarbonisation on port industry, referring to the findings of performance of major container ports by port stakeholder groups. ii) This paper also provides decision-makers with a holistic view of port development strategies to improve the competitiveness of their ports in the post-pandemic era, based on the performance evaluation results (see Table 1). In other words, port authorities can prioritize to meet the different business needs of each port user with their limited resources.

Acknowledging limitations in the study, such as its focus on major container ports and limited geographic scope. Future research should expand to include a more diverse set of ports globally. In addition, due to the continual evolution of technology, industry practices and global events, there is a need for ongoing monitoring and updating of the 6GP model to ensure its relevance and applicability to the evolving port industry.

REFERENCES


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