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Strategic enhancement infrastructure connectivity: a fuzzy exploratory factors analysis in Thailand's regional ports within the RCEP framework

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Abstract

Purpose – Advancements in enhancing regional port connectivity are crucial to fostering global maritime transport. The objective of this paper is to explore the complex relationship between infrastructure connectivity and the regional port of Thailand, specifically within the Regional Comprehensive Economic Partnership (RCEP).

Design/methodology/approach – This paper utilised fuzzy logic in exploratory factor analysis and introduced a new factor based on shipping networks, port operations, trade and emerging innovations. This can enhance the regional port and facilitate infrastructure connectivity in the RCEP. The results of this study have been successfully applied in specific contexts involving port authorities and private shipping companies.

Findings – The study's findings indicate key factors for enhancing regional ports in Thailand. These factors include integrating connectivity, creating spare hubs, addressing service issues, optimising logistics and supply chains, considering market components and leveraging the digital market. These factors are also crucial for promoting infrastructure connectivity within the RCEP framework.

Originality/value – This research presents a strategic framework for enhancing regional ports in Thailand and improving international infrastructure. This is the first attempt to examine the influence of infrastructure connectivity on regional ports by applying fuzzy exploratory factor analysis to modernise infrastructure, which is key to unlocking the region's maritime potential.

Keywords Exploratory factor analysis, Regional port, RCEP, Infrastructure connectivity, Fuzzy logic
Paper type Research paper

1. Introduction

The Regional Comprehensive Economic Partnership (RCEP) was established in 2015 to reduce tariffs, facilitate investment, improve transport and services, and promote economic cooperation. These goals could be achieved by expanding capacity, strengthening multimodal transport linkages, and enhancing technology, which are essential for efficient trade among member countries (Chang *et al.*, 2020). Thailand holds a significant role in the RCEP framework, covering around 60% of the region's total trade. This integration is expected to boost demand for goods and services increasing Thailand's GDP. The country also benefits from tariff reductions under the RCEP framework, which is anticipated to improve Thailand's economic performance. As a result, exporters and importers in Thailand are likely to become more competitive in the global market. Approximately 52.3% of Thailand's exports are destined for the RCEP market, highlighting the country's reliance on this trade agreement for economic growth (Khao-uppatum and Chaisrisawatsuk, 2024).

Additionally, Thailand is geographically positioned as a central hub in Southeast Asia, making its ports crucial gateways for trade within the RCEP zone. These ports play a vital

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role in facilitating maritime trade and development, directly impacting Thailand's ability to benefit from the RCEP agreement. However, it is determined that the regional ports are based on small and medium-sized ports (SMPs), which are excluded from the global shipping network. They primarily serve the local economy and support transhipment activities. Hence, it would be beneficial to collaborate with these regional ports to expand alternative routes and attract more transportation, which will positively impact the maritime and shipping business beyond their local markets (Karimah and Yudhistira, 2020). Netirith and Ji (2022) emphasised the importance of Thailand in improving connectivity efficiency to promote trade within the RCEP framework. This underscores the significance of addressing the issue of regional port development in Thailand as a means to improve transportation logistics in the RCEP region. Thailand aims to improve trade facilitation by optimising cost efficiencies and strengthening connectivity. This can be accomplished through the establishment of an economic corridor that interconnects regional ports and transportation networks (Banomyong *et al.*, 2011).

The Port Authority of Thailand (PAT) classified regional ports in Thailand as Phuket Port, Songkhla Port, Ranong Port, Pakbara Port, and Sattahip Port (Suthiwartnarueput *et al.*, 2002). The regional ports currently face challenges such as geographic constraints, navigation difficulties, limited equipment handling capacity, shallow water depth, and inefficient facilities, making them unattractive to shippers and carriers (Kuznetsov *et al.*, 2015; Meyer, 2021; Merz *et al.*, 2023; Monios, 2017). Despite these challenges, the Port Authority of Trade (PAT) is strategically positioned to promote trade and economic growth by fostering innovation, enhancing competitive performance, and increasing port capacity. These challenges restrict the ports' access to shipping networks, trade opportunities, innovation, and maritime borders, which are critical factors influencing the development of infrastructure connectivity within the RCEP framework. Addressing these challenges through improved connectivity is essential to making Thailand's ports more competitive and strategically significant in the RCEP's maritime transport network.

Therefore, this paper aims to bridge this gap by addressing the research question, *"How can regional ports in Thailand facilitate the port system to promote infrastructure connectivity within the RCEP?"* The findings of this study highlight the future direction and innovations necessary to support and enhance infrastructure connectivity in the RCEP, with a specific focus on the regional ports of Thailand.

This paper aims to (1) develop a comprehensive set of variables by integrating maritime principles with innovation trends into regional port infrastructure connectivity. (2) formulate a robust regional connectivity model tailored to the unique needs of Thai regional ports. This model will serve as a strategic blueprint for enhancing infrastructure connectivity within the RCEP framework. (3) Employ the Fuzzy Exploratory Factor Analysis (FEFA) method to explore new factors influencing regional ports' infrastructure connectivity within the RCEP. This innovative approach provides a better understanding of the complex relationships between variables and facilitates a more informed decision-making amidst uncertain and dynamic data. The findings of this study will contribute to academic discourse and provide actionable insights for policymakers by modernising infrastructure connectivity in regional ports. This study aims to unlock the region's maritime potential, foster economic growth, and position Thailand as a key player in the global maritime arena within the RCEP framework. Ultimately, this exploration aims to catalyse positive change and drive sustainable development across the region.

This paper is structured as follows: Section 2 defines infrastructure connectivity and conducts a comprehensive review from the perspectives of trade, shipping networks, port operations, and emerging innovations by narrowing the development between them. Section 3 explains the data source and methods, while Section 4 outlines the data analysis procedures and results. Sections 5 and 6 discuss and propose implementation strategies for enhancing the connectivity of regional ports in Thailand to the RCEP. The last section presents the conclusion.

2. Literature reviews and developing points

The literature reviews examine the factors influencing the integration of regional ports, thereby providing a comprehensive understanding of the concept of infrastructure connectivity. These reviews build on previous studies to provide an in-depth understanding of the strategies, challenges and opportunities associated with improving regional port connectivity within global marine networks.

2.1 Connectivity and implementation models in networks

The concept of infrastructure connectivity has been introduced previously. It encompasses several proposed aspects such as distribution networks, freight flow, network analysis, and interconnection with other infrastructure systems for the enhancement of international trade, economics, service, and transportation (Bhattacharyay, 2012; Ducruet and Notteboom, 2012; Ducruet *et al.*, 2010). The systematic study conducted by Calatayud *et al.* (2016) presented definitions of connectivity based on the level of the network, which is influenced by the number of connections in the node and transport links. Additionally, enhanced connectivity can support economic growth and improve transportation services. Studies by Netirith and Ji (2022) also explored the concept of infrastructure connectivity's impact on trade by examining the relationship between modes of transport and the number of cross-borders. This study investigates how transportation infrastructure efficiency and connectivity influence trade dynamics, particularly the volume of imports and exports.

Previous studies on infrastructure connectivity in maritime transport focused on ports, shipping networks, and feeder transit (Alstadt *et al.*, 2012). Research by Li *et al.* (2023) and Tang *et al.* (2011) conclusively demonstrated that hub-and-spoke networks, frequency of service, and distribution structures are integral parts of maritime connections. Reviews by Tsantis *et al.* (2023) indicate that trade factors and microeconomics are closely linked to connectivity, influenced by geographical factors, trade routes and levels of connectivity. Conversely, Li *et al.* (2023) emphasise port expansion into shipping networks to promote connectivity. Additionally, several studies have highlighted the issue of enhancing maritime connectivity by shaping the shipping capacity, investment, management frequency of port calls, vessel speed, number of vessels, and maritime services (Calatayud *et al.*, 2016; Wilmsmeier *et al.*, 2006; Ducruet and Notteboom, 2012; Bhattacharyay, 2012; Karimah and Yudhistira, 2020). The existing literature discusses how general ports are fully equipped with physical infrastructure. This paper expands upon the concept of connectivity by examining how it is implemented to enhance the connections between regional ports in Thailand. The goal is to improve infrastructure connectivity within the framework of the RCEP.

2.2 The role of regional ports in maritime networks

The literature reviews relating to regional ports, which means small and medium-sized ports, have been carried out in various ways. Monios (2017) discussed that the challenging issue in regional ports arises from the geographical dispersion of stakeholders and the government, which hinders connection and efficiency. In addition, several studies have contributed to sustainability management and smart specialisation policies to integrate them into the environment system of regional ports and hinterland areas (Kuznetsov *et al.*, 2015; Mortensen *et al.*, 2020; Meyer, 2021). Another study by Merz *et al.* (2023) investigated autonomous ships, which discharge at small ports to support port operations in the handling system. The research of Pérez *et al.* (2020) examines the competitive efficiency of small-sized ports through the integration and development of infrastructure. They assert that both specialisation and the size of ports significantly influence their overall efficiency. Polat (2017) presented a review chapter on feeder service and transhipment for small port sizes. The aim was to increase service frequency and ensure successful port coverage for shipping liners. Another study conducted by Lu *et al.* in 2018 applied a social network analysis to enhance marine container transportation in small and medium-sized ports in Korea, focussing on sea routes and network connections. Studies by Feng and Notteboom (2013) successfully established a multi-port gateway and inland logistics in the small and medium-sized ports of the Bohai Sea by using the multi-variable methodology in short sea shipping networks. Additionally, Medina *et al.* (2021) investigated a small port located in the Gulf of Atlantic to examine the increase in volume and benefits after the expansion of the Panama Canal. The literature reviews above have highlighted various regional port problems, including investments, sustainability management, hinterland expansion, feeder service, and transhipment compliance using different methods. There is a significant gap in understanding the systemic integration of regional ports into infrastructure connectivity based on supply chain networks, trade economics, and transportation connections.

2.3 Development of shipping networks to regional ports

The shipping network encompasses routing and connectivity between ports and countries, considering factors such as linkage, trade volume, service schedules, level of port competition, ship size, number of transhipments and service networks which impact the seamless flow of cargo (Tang *et al.*, 2011; Fugazza and Hoffmann, 2017; Ducruet, 2022; Ducruet and Notteboom, 2012; Ducruet, 2020; Saeed *et al.*, 2021). Furthermore, Wilmsmeier and Notteboom (2011) and Tsantis *et al.* (2023) contributed to the development of shipping networks by emphasising direct service, hub-and-spoke network models, and connections serving regional ports and shipping links. The volume of the port is also influenced by efforts to attract shipping liners for direct linkages and aims to reduce transport costs, as discussed by Boontaveeyuwat and Hanaoka (2010). Ducruet *et al.* (2010) demonstrated the relevance of inter-port flows by using optimisation of geographical specialisation, frequency, and connectivity of ship visits in each country under network planning. However, the linkage of regional ports to the maritime networks faces limited access to intermodal connection to other modes of transport in the hinterlands and port connection (Suthiwartnarueput, 2002).

Moreover, research by Karimah and Yudhistira (2020) and Alstadt *et al.* (2012) advocated for the expansion of shipping networks by increasing the number of port services, launching multi-year small feeder-port projects, enhancing the frequency of port calls and deploying fleets to meet the growing demands of global trade and expanding market opportunities. Meyer (2021) proposed optimising port priorities to enhance decision-making and connectivity in maritime networks, which is crucial for improving trade efficiency. The existing literature above has provided insights into the complexities of shipping liners and ports. However, additional research is needed to determine how the logical optimisation of shipping networks can enhance services, maximise profits, and improve connectivity.

2.4 Development of port operation for regional port connectivity

In infrastructure connectivity, effective port operations are crucial for ensuring smooth connectivity. Tiwari *et al.* (2003) stated that factors such as port characteristics, terminal layout and design, equipment facilities, and hinterland area significantly impact the efficiency of handling processes and connectivity activities. In a study by Yap and Notteboom (2011), it was found that the use of automation in ship and cargo handling, as well as advancements in technology, communication, and data sharing, can contribute to the facilitation of seamless connectivity within port operations. Furthermore, investing in cargo handling capabilities and improving service quality significantly enhances connection with major shipping lines visiting the ports. However, there is a gap in the literature review that applies operational concepts to ports. These concepts include collaborative port calls, optimisation techniques, and just-in-time processes, which still need to be implemented in regional ports. Additionally, incorporating new ideas such as production centres and logistics concepts, which are still novel in regional ports, could further support the process of supply chain and enhance connectivity (Mudunkotuwa *et al.*, 2024).

2.5 Development of trade to regional port

The development of trade to regional ports is crucial to enhancing economic connectivity. A systematic review conducted by Fugazza and Hoffmann (2017) stated that factors such as freight rates, cargo volume, transhipment, geographical location, market dynamics and distance are relevant for trade and maritime transportation. Ducruet and Notteboom (2012) suggested that the number of intra-regional shipping connections influences the growth of trade. Wilmsmeier *et al.* (2006) argued that the characteristics of port infrastructure impact port connectivity and influence maritime trade flows. Additionally, Bhattacharyay (2012) and Schellinck and Brooks (2014) determined that investment in infrastructure can enhance trade and economic development in each country, promoting seamless transport connectivity. Moreover, access to hinterland areas can determine port operation efficiency to handle varying cargo volumes. It is crucial to prioritise port connectivity and efficiency to promote trade (Sankla and Muangpan, 2022; Li *et al.*, 2023).

Additionally, Caliskan and Esmer (2020) used port marketing to improve port quality and customer satisfaction. One such strategy is boosting the container throughput in regional ports to attract more shipping liners and customers to select this port for alternative imports and exports (Tiwari *et al.*, 2003). These factors impact the efficiency of trade routes and the transportation of cargo between ports and their hinterlands. This study focuses on improving internal network trade connectivity, while the gap in this study can be addressed using digital port marketing strategies to promote regional port competitiveness. Furthermore, this gap can be bridged by utilising algorithms to conduct thorough demand analysis.

2.6 Development of emerging innovations to regional port

The maritime industry is increasingly adopting innovative technologies to enhance operational efficiency. These innovations can foster greater integration into the broader maritime network. The primary innovation trends are collaborative platforms and information sharing, which will be used in the future for real-time information tracking, digitalisation (AI, big data, blockchain), and automation for unitisation and optimisation to increase the efficiency of operations, economies, and supply chains (Muangpan and Suthiwartnarueput, 2019).

Furthermore, autonomy is applied to a vessel that comes to a port with advanced navigation systems. This can lead to increased cargo transhipment and improved connectivity within the port system (Merz *et al.*, 2023; Kurt and Aymelek, 2024). On the other hand, integrating “smartness” into regional ports is an interesting approach to improve connectivity by increasing communication and data sharing with 5G networks (Sankla and Muangpan, 2022). Wang *et al.* (2023) explored the integration of drones into the maritime industry to monitor port activities and provide real-time data to improve decision-making processes in maritime logistics. The integration of smart technologies has the potential to bring ports into the global supply chain and ensure that they remain competitive and interconnected in maritime transportation.

This study addresses several deficiencies in existing research by introducing a novel conceptual and theoretical framework that provides a comprehensive understanding of the pivotal role of regional ports in Thailand, emphasising their significance in maritime connectivity. Additionally, this study identified new factors that support the enhancement of regional ports, introducing a novel dimension and offering fresh perspectives for consideration in the development and management of these ports. This study aims to significantly influence the discourse on regional port connectivity and its implications for regional economic partnerships like RCEP.

3. Methodology

3.1 Questionnaire and survey participants

This research employed a purposive sampling approach, targeting respondents with expertise in transportation and infrastructure related to maritime affairs. This study selected participants consisting of senior professionals, employees, and officers at ports in Thailand, as well as other managers and staff associated with shipping liner services, port operation, and port authority. Respondents from the academic sector who are experts in maritime transportation were included. It was directly relevant to the objectives of the study as strategic functions within maritime transportation and port management. The authors used the information on the online platform of the Port Authority in Thailand (PAT) to gather details about management and officer-level personnel. Additionally, the shipping liner company and port provided contact information via email and telephone.

The survey was conducted using a questionnaire administered through email, interviews and telephone interactions between October and December 2023 to the respondents. To ensure that the respondents were qualified to participate, the authors explained the aim of the research and provided instructions on how to complete the questionnaire. Furthermore, the privacy of the respondents' information was guaranteed to prevent potential conflicts of interest. The questionnaires were sent to 130 respondents, to ensure diverse representation and reliable data capturing perspectives across various sectors of the maritime industry. The findings were assured to be unbiased and not influenced by any single group. The surveys were mainly sent out through online systems, and the final dataset consisted of 60 responses, ensuring comprehensive coverage of the scale's effectiveness for development.

The survey measurements in this paper were derived from previous literature and organised into three sections. The first section included questions about the respondents' management positions, years of working experience, and work departments. The second section focused on innovation trends based on shipping networks, maritime trade, port operations, and future innovation to facilitate maritime connectivity. Out of 41 items, 11 items were selected for the shipping network, 7 for port operation, 12 for maritime trade, and 11 for innovation trends. The assessment to increase the potential of regional ports in Thailand was conducted based on various parameters outlined in Table 1. Finally, respondents were instructed to evaluate the importance of innovations using a Likert scale to assess performance.

3.2 Conceptual modelling and factor identification

Exploratory Factor Analysis, a method used to reduce large numbers of variables into essential factors, was employed to assess regional ports in Thailand. Four main steps were generated to meet the requirements of this research objective. The first step involves a literature review and content analysis technique to identify critical factors, specifically in maritime connectivity. Several tests were then conducted to verify the acceptability of

Variables and measuring items	Labels	
Shipping Network		
1. Collaborative port call optimisation	SN1	Meyer (2021), Calatayud *et al.* (2016)
2. Smart dynamic route optimisation between main and regional port	SN2	Monios (2017)
3. Utilise regional port into multi-port gateway	SN3	Wilmsmeier and Monios (2016), Banomyong *et al.* (2011), Tran and Haasis (2014), Karimah and Yudhistira (2020)
4. Direct and indirect linkage to regional port	SN4	Tang *et al.* (2011)
5. Promote regional ports as second-tire hubs	SN5	Banomyong *et al.* (2011)
6. Optimisation based on priorities into regional port	SN6	Meyer (2021)
7. Inland port connection between other modes of transport	SN7	Feng and Notteboom (2013)
8. Utilise regional port for transhipment	SN8	Ducruet and Notteboom (2012), Ducruet (2022), Saeed *et al.* (2021)
9. Integrating regional ports to extend transportation network for distribution	SN9	Ducruet (2020)
10. Diversification of Shipping Routes and feeders to regional ports	SN10	Alstadt *et al.* (2012), Polat (2017), Boontaveeyuwat and Hanaoka (2010)
Port Operation		
1. Optimise loading and unloading cargo in regional port	PO1	Sankla and Muangpan (2022), Jia *et al.* (2017)
2. Smart supply chain process between regional port and other	PO2	Li *et al.* (2023), Muangpan and Suthiwartnarueput (2019), Jia *et al.* (2017)
3. Just in time to portal in regional port	PO3	Li *et al.* (2023), Vidya and Taghizadeh-Hesary (2021)
4. Production centre in regional port	PO4	
5. Customs automation and integration	PO5	Sankla and Muangpan (2022)
6. Robotic and automated for cargo handling in regional port	PO6	Nguyen and Woo (2022)
7. Utilising technologies in port terminals	PO7	Sankla and Muangpan (2022), Li *et al.* (2023), Min (2022), Merz *et al.* (2023)
Trade		
1. Digital marketing of regional port	TT1	Caliskan and Esmer (2020), Sankla and Muangpan (2022)
2. Increasing market share in regional port	TT2	Chang *et al.* (2020), Caliskan and Esmer (2020)
3. Machine learning algorithms predict future demand for port services	TT3	Tiwari *et al.* (2003), Tang *et al.* (2011)
4. Increasing shipping volumes to visit regional port	TT4	Ducruet (2020), Wilmsmeier *et al.* (2006)
5. Dynamic pricing of freight rate suite attractive to visit regional port	TT5	Caliskan and Esmer (2020), Banomyong *et al.* (2011), Wilmsmeier and Monios (2016)
6. Capacity expansion into regional port and hinterland area	TT6	Medina *et al.* (2021), Pérez *et al.* (2020), Monios (2017)
7. Frequency of liner service to visit regional port	TT7	Ducruet *et al.* (2010), Karimah and Yudhistira (2020), Tran and Haasis (2014)
8. Frequency of regional port charter service to visit	TT8	
9. Frequency of bareboat service to visit regional port	TT9	

(*continued*)

Table 1.
Constructs and associated items

Variables and measuring items	Labels	
10. Enhance the local market to promote regional port	TT10	Chang *et al.* (2020)
11. Increasing container throughput through regional port	TT11	Chang *et al.* (2020), Mortensen *et al.* (2020)
12. Collaborative fleet management systems	TT12	Monios (2017)
Emerging Innovations		
1. Implement blockchain for transactions and information exchange	IT1	Sankla and Muangpan (2022), Merz *et al.* (2023)
2. Create a centralised data platform for data sharing	IT2	Li *et al.* (2023), Sankla and Muangpan (2022)
3. Smart real-time container tracking and monitoring	IT3	Meyer (2021)
4. An autonomous ship with auto-handling equipment in regional port	IT4	Sankla and Muangpan (2022), Kurt and Aymelek (2024)
5. Shipping collaboration and alliance between regional port	IT5	Caliskan and Esmer (2020)
6. Investment of infrastructures into regional port	IT6	Bhattacharyay (2012), Schellinck and Brooks (2014)
7. Interaction for interconnected regional port communities	IT7	Ducruet (2022)
8. Governmental collaboration into regional port	IT8	Monios (2017)
9. Smart multimodal and intermodal transport corridors to regional port	IT9	Suthiwartnarueput *et al.* (2002)
10. Interconnected system of regional port within a region	IT10	Schellinck and Brooks (2014)
11. Usage of drones in regional port	IT11	Wang *et al.* (2023)

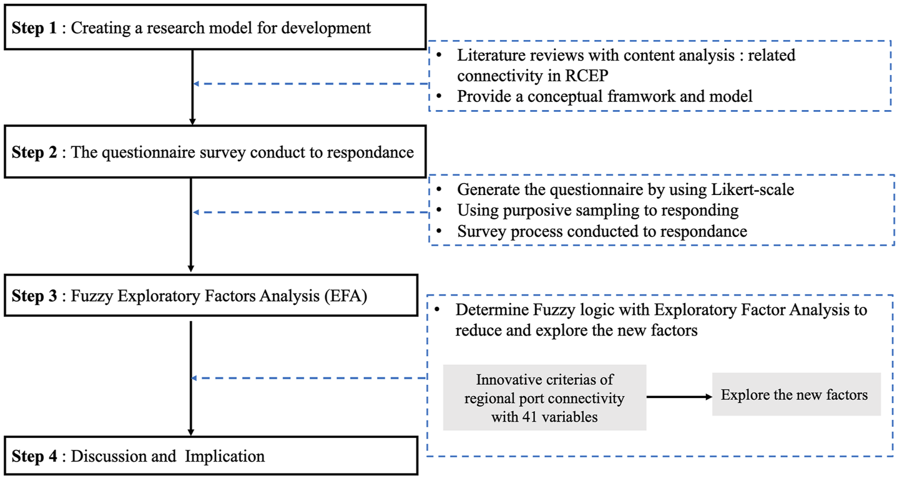
Note(s): Survey respondents rated their agreement on a scale of 1–5, with 1 indicating "strongly agree" and 5 indicating "strongly disagree". Participants were asked to rate their agreement with various performance indicators
Source(s): Authors' review

Table 1.

various types of errors. The second stage assessed the potential of connectivity, which included a pilot test conducted with expertise to improve connectivity in RCEP. At this stage, the respondents were required to rank each issue by expressing their level of agreement using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The next step applied a quantitative approach by Fuzzy EFA, where several criteria were summarised into a smaller number to highlight an element of that dimension. The final step involved implementing a strategy to enhance the regional port connectivity in Thailand and promote trade in the RCEP, as illustrated in Figure 1.

3.3 Fuzzy exploratory factor analysis (FEFA)

Exploratory Factor Analysis (EFA), a statistical technique, was utilised to identify and explore the factors within a set of correlated variables. This technique involves analysing the linear combination and covariance matrix of observed variables (Lu *et al.*, 2016; Hair *et al.*, 2010). It can be explained that variables ($A_1, A_2, \ldots\ldots, A_p$) can be categorised into two or more predominant factors that explain (F_2). Therefore, each variable A_q can be represented as a linear combination of factors where $A_q = , k_{1q}F_1 + k_{2q}F_2$, and k_{iq}



Source(s): Authors

Figure 1.
The methodological framework employed in this study

represents the loading impact factor for i. It is crucial to adhere to the standard EFA procedure to identify latent factors and determine their loadings on variables.

In addition, the fuzzy exploratory factor analysis (EFA) technique is employed to categorise uncertain variables accurately. This study was an extension of the work by Baradaran and Ghorbani (2020), who innovatively applied Fuzzy EFA to assess e-learning service quality. This research adapts their methodology to explore key factors in regional port connectivity. Fuzzy EFA enables effective analysis of complexities and uncertainties. Fuzzy logic was utilised to classify the variables based on Table 1 to develop regional port connectivity. Subsequently, a questionnaire was created to examine the level of each evaluation criterion, as shown in Table 2. This measurement of fuzzy numbers aims to evaluate the connectivity of regional ports.

Step 1: Generating a matrix of random data with fuzzy values.

The fuzzy data matrix $(\widetilde{k}_{m\times r})$ is defined for assessment variables $(\widetilde{K}_i \,|\, i = 1, 2, \ldots.., r)$ and n assessments $(\widetilde{k}_{ij} \,|\, i = 1 \ldots .r; j = 1, \ldots .., m)$, where all components are fuzzy $\widetilde{k}_{ij} = (k_{ij}, k_{ij}^{a}, k_{ij}^{b})$. Following this, a fuzzy value was inserted to be applied with a triangular fuzzy number as $\widetilde{D} = (o, \alpha, \beta)$, where o indicates the minimum expected value, α, β are higher values of fuzziness based on Eq. (1) (Lin *et al.*, 2011). Additionally, the triangular fuzzy numbers are presented in Figure 2.

Verbal expression	Corresponding fuzzy number
Strongly disagree	1,1,3
Disagree	1,3,5
No opinion	3,5,7
Agree	5,7,9
Strongly agree	7,9,9

Source(s): Adapted from Baradaran and Ghorbani (2020)

Table 2.
Measurement of fuzzy number

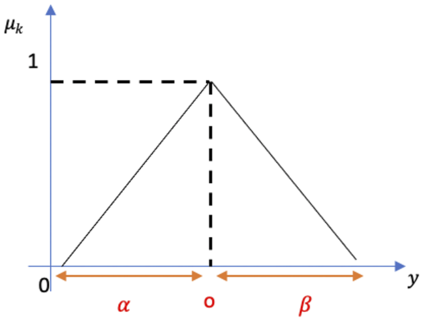


Figure 2. Triangular fuzzy numbers

Source(s): Adapted from Baradaran and Ghorbani (2020)

$$\mu_k \sim (y) = \begin{cases} 1 - \dfrac{o - y}{\alpha} & o - \alpha < y \leq o \\ 1 - \dfrac{o - y}{\beta} & o \leq y < o + \beta \\ 0 & \textit{Otherwise} \end{cases} \tag{1}$$

Step 2: Calculate the matrix of random data with fuzzy values.

The correlation efficiency matrix outlines the connections between each pair of variables to quantify the linear dependence and compute them using Eq. (2) (Baradaran and Ghorbani, 2020) based on the observed data matrix.

$$\overline{\widetilde{K}}_j = \left(\overline{k}_j, k_j^{-a}, k_j^{-b}\right) = \left(\frac{\sum_{i=1}^{n} k_{ij}}{n}, \frac{\sum_{i=1}^{n} k_{ij}^{a}}{n}, \frac{\sum_{i=1}^{n} k_{ij}^{b}}{n}\right) \tag{2}$$

The fuzzy correlation coefficient between $\widetilde{K}_i$ and $\widetilde{K}_j$ can be calculated using Eq. (3) as a triangular fuzzy number $\widetilde{S}_{ij} = (s_{ij}, s_{ij}^{a}, s_{ij}^{b})$. The denominator and numerator of this equation represent the fuzzy covariance and fuzzy variance of the variables, respectively. Later, the correlation coefficients are inserted into the fuzzy correlation matrix $\widetilde{S}_{n \times n}$

$$\widetilde{S}_{ij} = \frac{\sum_{w=1}^{n} \left(\widetilde{S}_{iw} - \overline{\widetilde{K}}_i\right)\left(\widetilde{S}_{jw} - \overline{\widetilde{K}}_j\right)}{\sqrt{\sum_{w=1}^{n} \left(\widetilde{S}_{iw} - \overline{\widetilde{K}}_i\right)^2 \sum_{w=1}^{n} \left(\widetilde{k}_{jw} - \overline{\widetilde{K}}_j\right)^2}} \tag{3}$$

Eq. (3) shows a significant increase in the correlation coefficient related to the fuzzy number, suggesting that the fuzzy correlation coefficient appears illogical. The lower s_{ij}^{a} and upper-level s_{ij}^{b} need to be determined using Eq. (4).

$$s_{ij}^{A} = s_{ij} - \widehat{s}_{ij}^{A};\; s_{ij}^{B} = \begin{cases} s_{ij} + \widehat{s}_{ij}^{B}\; where\; s_{ij} + \widehat{s}_{ij}^{B} < 1 \\ 1\; where\; s_{ij} + \widehat{s}_{ij}^{B} \geq 1 \end{cases} \tag{4}$$

Step 3: Estimate the latent factors and compute factor loading

Assuming that the set of latent variables is $G_{n\times 1}$, and the variables of fuzzy vector are $(\widetilde{y}_{q\times 1})$, which are related to the fuzzy data matrix $(\widetilde{k}_{n\times q})$ shown in Eq. (5), the following is the relationship between the latent and observable variables:

$$(\widetilde{y}_{q\times 1}), = G_{n\times 1} \times \widetilde{v}_{n\times q} \tag{5}$$

The matrix $\widetilde{\mathrm{v}}_{\mathrm{n}\times\mathrm{q}}$ is a fuzzy coefficient matrix extracted from correlation coefficients. The primary step involves calculating the eigenvalues of $\widetilde{S}_{n\times n}$. The fuzzy matrix $\widetilde{\mathrm{S}}_{\mathrm{n}\times\mathrm{n}}$ will have the highest value n as a fuzzy eigenvalue, denoted as $\widetilde{\Lambda}_l = (\lambda_l, \lambda_l^a, \lambda_l^b,)$, where $\widetilde{\Lambda_1} \geq \widetilde{\Lambda_2} \geq \ldots \geq .\widetilde{\Lambda}_n$. The fuzzy eigenvalues λ_{l} are obtained by solving the sequence of equations $|\mathrm{S} - \lambda_j = 0|$, where the matrix S contains the essential aspects of the fuzzy correlation coefficients s_{ij}. Furthermore, the eigenvectors f_c are derived by solving the equation $S_{fl} = \lambda_l f_l$ to determine appropriate values for the left and right eigenvalues of the matrix $\widetilde{S}_{n\times n}$ shown in Eqs (6)–(7) proposed by Baradaran and Ghorbani (2020).

$$\begin{gathered} \mathrm{Max} \sum_{\mathrm{l}=1}^{\mathrm{n}} \lambda_{\mathrm{l}}^{\mathrm{A}}\; 0 \leq \lambda_{\mathrm{l}}^{\mathrm{A}} \leq \lambda_{\mathrm{l}}\; \forall \mathrm{k} = 1, 2, \ldots\ldots, \mathrm{n} \\ |\lambda_{\mathrm{l}}^{\mathrm{A}} \mathrm{S}_{\mathrm{fl}}| \leq \max\left\{\left|\sum_{\mathrm{j}=1}^{\mathrm{n}} \mathrm{s}_{\mathrm{ij}}^{\mathrm{A}} \mathrm{f}_{\mathrm{jc}}\right|, \left|\sum_{\mathrm{j}=1}^{\mathrm{n}} \mathrm{s}_{\mathrm{ij}}^{\mathrm{B}} \mathrm{f}_{\mathrm{jc}}\right|\right\} \forall \mathrm{k} = 1, 2, \ldots\ldots, \mathrm{n} \end{gathered} \tag{6}$$

$$\begin{gathered} \mathrm{Min} \sum_{\mathrm{l}=1}^{\mathrm{n}} \lambda_{\mathrm{l}}^{\mathrm{B}}, \lambda_{\mathrm{l}}^{\mathrm{A}} \geq \lambda_{\mathrm{l}}, \forall \mathrm{k} = 1, 2, \ldots\ldots, \mathrm{n} \\ |\lambda_{\mathrm{l}}^{\mathrm{B}} \mathrm{S}_{\mathrm{fl}}| \geq \min\left\{\left|\sum_{\mathrm{j}=1}^{\mathrm{n}} \mathrm{s}_{\mathrm{ij}}^{\mathrm{A}} \mathrm{f}_{\mathrm{jc}}\right|, \left|\sum_{\mathrm{j}=1}^{\mathrm{n}} \mathrm{s}_{\mathrm{ij}}^{\mathrm{B}} \mathrm{f}_{\mathrm{jc}}\right|\right\} \forall \mathrm{k} = 1, 2, \ldots\ldots, \mathrm{n} \end{gathered} \tag{7}$$

Mathematical methods are employed to generate appropriate values for the left and right boundaries of the triangle eigenvalue fuzzy numbers. Deviation from the previous formulae may result in a negative increase in fuzzy numbers in a situation where the left value exceeds the right value. Nonetheless, the method employed in this study makes it possible to obtain appropriate values for the left and right in eigenvalue fuzzy numbers. The correlation matrix eigenvalues determine the number of common factors in the data. The study uses triangular fuzzy numbers, with eigenvalues larger than 1 as a common factor. The loading factors can be computed using Eq. (8). If the eigenvalues are greater than 1, the corresponding factor will be determined.

$$\widetilde{\mathrm{v}} = \widetilde{\mathrm{v}}_{\mathrm{la}} = \left(\left[\mathrm{v}_{\mathrm{ig}}^{\mathrm{A}}, \mathrm{v}_{\mathrm{ig}}^{\mathrm{B}}\right]\right) = \begin{cases} \left[\sqrt{\lambda_{\mathrm{g}}^{\mathrm{A}} \mathrm{s}_{\mathrm{ig}}}, \sqrt{\lambda_{\mathrm{g}}^{\mathrm{B}} \mathrm{s}_{\mathrm{ig}}}\right], \mathrm{f}_{\mathrm{jc}} \geq 0 \\ \left[\sqrt{\lambda_{\mathrm{g}}^{\mathrm{B}} \mathrm{s}_{\mathrm{ig}}}, \sqrt{\lambda_{\mathrm{g}}^{\mathrm{A}} \mathrm{s}_{\mathrm{ig}}}\right], \mathrm{f}_{\mathrm{jc}} \leq 0 \end{cases} \tag{8}$$

Step 4: Analysing underlying variables and adjusting the coordinate system

Variable loadings are utilised to interpret factors. High variable loading on a factor indicates significant similarities between the factor and the corresponding variable.to interpret the factors.

4. Data analysis and results

A total of 130 questionnaires were distributed to respondents, with 41 assessment indicators. Only 60 responses were considered usable for this study, which accounts for approximately 46% of the distributed questionnaires. Data analysis was conducted using Jamovi software and Excel. The study involved a robust sample base, with over 40% of the respondents classified as senior staff members holding managerial positions. This demographic demonstrates outputs with a high level of knowledge and perspective in the field of maritime transport, attributed to their industry experience exceeding 5 years. Furthermore, over 75% of the respondents are involved in port operations, such as port authorities, shipping liners, and freight forwarders, as shown in Table 3.

Table 4 shows that 41 variables across four dimensions have been created by FEFA using an axis rotation matrix to reduce the number of variables. The observed variables in Table 1 have been classified into 7 latent factors, and each observed variable is assigned to a latent component, resulting in a reduction in the number of latent variables. Table 4 lists the eigenvalues and fuzzy variance of each component. The new common factors are named based on the variables assigned to them and classified according to infrastructure connectivity.

The first set of questions aims to address the development of Thailand's regional port to improve infrastructure connectivity in RCEP. The findings revealed that four main factors (shipping networks, port operation trade, and emerging innovation) have been explored, resulting in the identification of seven critical factors to enhance the connectivity of Thailand's regional ports, as shown in Figure 3 and Table 4. The analysis revealed that factor 1, "Integration of Connectivity," accounts for the largest portion of the variance (6.78, 6.74, 6.72) and has the highest eigenvalues (3.388, 3.258, 3.158), indicating its dominance in

Table 3. The profile of respondents

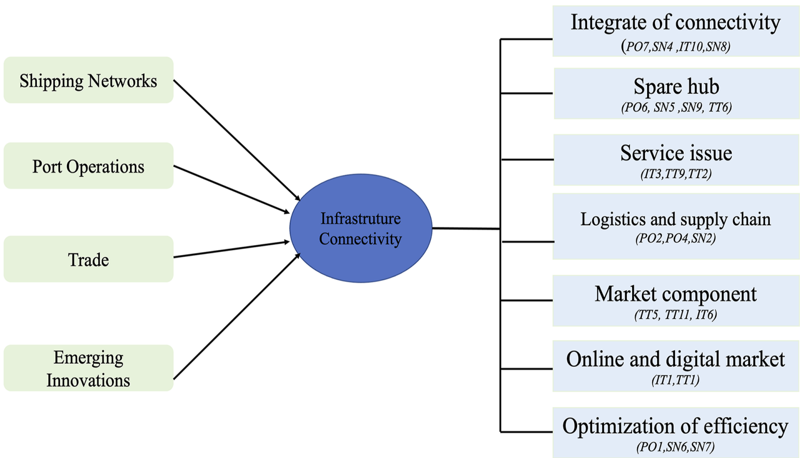
Characteristic	No. of respondents	Percentages
Job title		
Management level	8	13
Senior staff	18	30
Junior staff	13	21
Officer	12	20
Administrator	9	15
Years of working experience		
Less than 5 years	15	25
5–10 year	33	55
More than 10 years	12	20
Work department		
Port Authority	14	23
Port operation officer	15	25
Academic	11	18
Freight forwarder	8	13
Shipping liner	12	20

Source(s): Authors

No.	Variance	Eigenvalues	Loading factor	Corresponding indices	Factor title
1	(6.78,6.74,6.72)	(3.388,3.258,3.158)	(0.958,0.948,0.94)	PO7	Integrate of connectivity
			(0.327,0.325,0.325)	SN4	
			(0.958,0.948,0.94)	IT10	
			(−0.392,−0.391,−0.441)	SN8	
			(0.315,0.315,0.318)	TT7	
2	(6.04, 5.90,5.87)	(2.054,2.107,1.985)	(0.92,0.885,0.734)	PO6	Spare hub
			(0.91,0.871,0.747)	SN5	
			(0.308,0.343,0.323)	SN9	
			(0.359,0.405,0.412)	TT6	
3	(5.44,5.55,4.95)	(1.788,1.720,1.630)	(0.485,0.572,0.534)	IT3	Service issue
			(0.636,0.701,0.634)	TT9	
			(0.674,0.702,0.443)	TT2	
4	(4.78,4.59,4.35)	(1.388,1.439,1.487)	(−0.403,0.816,−0.341)	PO2	Logistics and supply chain
			(0.876,−0.347,0.771)	PO4	
			(0.462,0.313,−0.422)	SN2	
5	(4.55,4.25,4.33)	(1.292,1.291,1.276)	(0.541,0.358,0.379)	TT5	Market component
			(−0.379,−0.716,−0.765)	TT11	
			(0.437,0.413,0.441)	IT6	
6	(4.38,4.21,4.31)	(1.163,1.206,1.246)	(−0.352,0.359,0.554)	IT1	Online and digital markets
			(−0.364,−0.394,−0.354)	TT1	
7	(3.44,4.04,4.15)	(0.971,1.063,1.151)	(−0.509,−0.509,−0.466)	PO1	Optimisation of efficiency
			(−0.402,−0.402,−0.331)	SN6	
			(0.429,0.429,0.319)	SN7	

Source(s): Authors

Table 4. The results of fuzzy exploratory analysis



Source(s): Authors

Figure 3. Exploratory infrastructure connectivity models

the dataset. These factors show a strong association with loading factors on PO7 (0.958, 0.948, 0.94) and IT10 (0.315,0.315,0.318), representing variables strongly associated with the concept of infrastructure connectivity essential for both domestic and international connections. This connectivity is crucial for regional ports to effectively handle various inbound and outbound shipping lines related to RCEP. This integration involves direct and indirect links through feeder services and transhipment activities, which can support the distribution of goods across Southeast Asia and to the broader members of RCEP. The incorporation of technology and automation should collaborate with regional ports to improve port operation efficiency and overall connectivity from small regional areas to the main regional trade.

The implementation of the second factor, "Spare Hub", shows strong positive loading factors. It also accounts for a significant portion of variances (6.04, 5.90, 5.87), with eigenvalues ranging from 2.054 to 1.985. The value of loading factors on PO6 (0.92, 0.885, 0.734) and SN5 (0.91, 0.871, 0.747) demonstrate strong relationships within this theme. The findings suggest that there are opportunities to improve the efficiency of cargo handling in regional ports by integrating advanced robotic automation. This could help strengthen regional ports as secondary hubs, facilitating the smooth movement of goods within the RCEP (Banomyong *et al.*, 2011). Factor 3, "service issue", explains a moderate amount of variance (5.44, 5.55, 4.95) and has significant but not the highest eigenvalues (1.788, 1.720, 1.630) in the overall analysis. The focus is on using technology for smart tracking to resolve issues, minimise disruptions, and ensure the reliability of services in the small ports. Additionally, it aims to expand the frequency of bareboat services and effectively increase market share. This can provide new insights into service quality for maritime transportation in the RCEP. The variance values for factor 4, "Logistics and supply chain", factor 5, "Market component", and factor 6, "Online and digital markets", range from 4.35 to 4.78, with eigenvalues from 1.388 to 1.487, indicating moderate significance. The Market component has variance values ranging from 4.25 to 4.55 and eigenvalues from 1.276 to 1.292, with loading factors for TT5, TT11, and IT6 showing both positive and negative associations.

Intelligent cargo flow systems have been emphasised in regional ports in Thailand. However, the private terminal sector or the government needs to invest in advanced technologies that can significantly enhance connectivity efficiency. Additionally, establishing a production centre in a regional port is important for localised manufacturing, thus enhancing the maritime supply chain process in the regional port area. The data indicates that the processing of the supply chain, including cost management and production capabilities, is capable of supporting the interconnectedness of regional ports in RCEP (Medina *et al.*, 2021).

Furthermore, the "market components" have variance values ranging from 4.25 to 4.55 and eigenvalues from 1.276 to 1.292. These components are crucial for standardising and expanding regional ports to increase container throughput in Thailand. This development can enable the implementation of dynamic pricing in the maritime market, making it more appealing to shipping lines. This can enhance their competitiveness and contribute to the smooth flow of the RCEP and the overall economy. The "Online and digital markets" combined two components (Blockchain for transactions and information exchange) and TT1 (Digital marketing of regional ports). It leverages digital tools for better engagement and communication on one platform. It ensures that real-time data are accurate to support optimisation and management levels. It is one of the small parts that fulfil the efficiency of connectivity in RCEP. The "Optimisation of Efficiency" has a smaller portion of the variance value and loading factor for optimising loading and unloading cargo (PO1), prioritising operations within regional ports (SN6), and enhancing efficiency through inland port connections (SN7), which reveals significant challenges. The optimisation focuses on key aspects such as the efficient loading and unloading of cargo. It is critical to improving port operations, as delays in cargo handling can lead to congestion and reduced throughput, thus impacting the overall efficiency of the port. Lastly, the variance, eigenvalues, and loading factors together provide a detailed explanation of how these variables contribute to the underlying theme.

Figure 3 explains the model of exploratory infrastructure connectivity. This model supports the identification of the relationships of complexity variables by grouping related variables into a small set of latent factors. This makes the model more interpretable and manageable. The figure identifies key areas such as shipping networks, port operations, trade, and emerging innovations as primary influences on infrastructure connectivity. Using EFA can determine how these observed variables cluster into distinct factors. Consequently, EFA facilitates the development of robust theoretical frameworks, enhances strategic planning, and supports better decision-making by highlighting the critical dimensions of infrastructure connectivity. The proposed variables were analysed in Table 2, and the outcomes, including factor classification and loading, are detailed in Table 4.

5. Discussion

In alignment with our research objectives, the findings underscore the exploratory factors that significantly strengthen the efficiency of Thailand's regional ports and contribute to maritime connectivity in RCEP. Each port has unique characteristics, such as geographical location, scale, capacity, infrastructure, and development strategies. Therefore, as detailed in Table 5, it is necessary to ensure that each factor is implemented and utilised effectively to support regional connectivity to answer the research question.

Port of Bangkok: Strategic Asset in RCEP connectivity. As a small port in Thailand, Bangkok Port maintains the role of a primary hub or spare hub port to facilitate trade, enhancing connectivity across the region. By integrating strategies within the RCEP framework, Bangkok Port can enhance service quality by facilitating seamless trade flows through the port. This involves utilising smart container tracking and dynamic pricing. Implementing these measures not only enhances operational efficiency but also positions the port as a key contributor to RCEP, promoting regional economic integration and connectivity.

Ranong Port faces capacity limitations and cannot expand its hinterland due to geographical constraints, similar to Chiang Saen, Chiang Khong and Phuket Port. To overcome these challenges, it should focus on implementing digital marketing strategies and enhancing the local market in the area. By doing so, Ranong Port has the potential to position itself as a key distribution centre on the western side of the RCEP framework, serving as a spare hub port to support regional trade. The Songkhla Port is strategically located on the Kra Isthmus on the eastern side of southern Thailand. This advantageous location positions it as a key link in the coastal and regional port networks. The port has the potential to support infrastructure related to RCEP by expanding its hinterland, improving connectivity, and developing intermodal and multimodal infrastructures such as road and double-track rail. It is recommended that the port capitalise on its handling capacities and market services to attract more business, aligning with Thailand's long-term plan. As a result, Songkhla Port has the potential to serve as a hub port similar to Ranong Port, playing a crucial role on Thailand's eastern side and contributing to the connectivity of infrastructure within the RCEP.

The *Map Ta Phut Port, Rayong, and Sriracha ports* are strategically located on the Eastern side of Thailand, an area known for its major industrial and manufacturing zones. Expanding the hinterland and physical facilities in these ports, such as improving road connectivity, extending road lanes, and adding double rail tracks, would significantly ease access and connectivity between the ports and the hinterland, thus enhancing capacity and regional integration within the RCEP framework. Due to their proximity to major manufacturing areas, these ports can be designed to function as production centres, thus

Table 5. The implementation of fuzzy exploratory factor to Thailand's regional port

Port name/Factor	Description	Integration of Connectivity				Spare hub				Service issue			Logistics and supply chain			Market component			Online and digital market		Optimisation of efficiency		
		PO7	SN4	IT10	SN8	PO6	SN5	SN9	TT6	IT3	TT9	TT2	PO2	PO4	SN2	TT5	TT11	IT6	IT1	TT1	PO1	SN6	SN7
Bangkok Port (medium size)	Size / capacity = 12,000 Length (m) = 3100 Draft = 8.2 m Container Throughput = 1,500,000 TEU		✓		✓	✓	✓	✓		✓	✓		✓		✓		✓		✓	✓	✓		✓
Ranong port	Size / capacity = 12,000 Length (m) = 150 m Draft = 8.2 m Container storage = 11,000 Capacity = 3 berth	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓
Songkhla port	Length (m) = 510 Draft = 9 m Container storage = 11,000 Berth = 3 Shore Crane: Mobile type Handling capacity: 128,00 TEU	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓		✓
Map ta phut port	Length (m) = 330 Draft = 10 m Berths = 2 Capacity = Max 60,000 dwt Quayside gantry crane 2 units x 40 M	✓	✓			✓			✓			✓	✓			✓	✓	✓		✓	✓		
Rayong Port	Length (m) = 900 Draft = max18.5 m Capacity ranging from 800 to 150,000 DWT.	✓	✓	✓					✓	✓	✓		✓	✓		✓	✓	✓		✓	✓	✓	✓
Sriracha Port	Length (m) = 1210 Width (m) = 40 Draft = max 14 m Capacity ranging from 120,000 DWT.	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓
Phuket Port	Length (m) = 360 m Width (m) = 30 Draft = 10 m	✓	✓	✓				✓		✓		✓	✓		✓	✓	✓		✓		✓	✓	✓
Chiang Saen Port	Length (m) =108 Width (m) = 24 Draft = 2-2.5 m		✓	✓	✓			✓				✓	✓			✓			✓	✓			✓
Chiang Khong Port	Length (m) = 180 Width (m) = 24		✓	✓	✓			✓				✓	✓			✓			✓	✓			✓

Source(s): Authors

improving efficiency in maritime logistics and enhancing connectivity between ports. Additionally, as the private sector operates all three ports, there is considerable potential for investment in automation technology and the integration of blockchain. These advancements could optimise operations, improve process efficiency, and ensure faster connectivity within RCEPs.

In addition, Chaing Sean and Chaing Khong ports are small ports that serve river transportation. Their challenging geographical locations, limited capacity, and fluctuating river water levels make them unsuitable as spare hub ports. However, both ports can play a strategic role in enhancing regional connectivity by operating as gateway ports along the border, facilitating trade between Thailand, Laos, and China. To further strengthen their connectivity potential, these ports could invest in advanced technologies such as smart logistics chains, automation, computer systems, and digital marketing strategies to increase the dynamism of regional ports.

The most interesting aspect of this study is discovering a new strategy for shaping a regional port to support maritime connectivity in RCEP. The combination of these factors can provide value to the regional port, contributing to the establishment of infrastructure connections. The government and shipping liner can adjust these factors based on the regional port's context to promote RCEP. The author claims that the new exploratory factors are a new finding in existing literature. The results suggest that establishing a regional port in Thailand can enhance infrastructure connectivity in RCEPs.

6. Policy implementation

This section outlines a new strategy and design policy aimed at improving the efficiency of connectivity to regional ports across Thailand. The implementation of these strategies involves two main perspectives: port authorities and shipping liners. To successfully achieve this, a multi-faceted approach should be adopted, integrating various aspects of regional port operations. The proposed policy includes the following elements:

(1) Development of Spare Hub ports

The strategy for developing spare hubs to enhance maritime efficiency within RCEP involves developing Songkhla and Ranong ports as spare hub ports in Thailand. These ports are strategically located on the eastern and western coasts of Thailand, making them well-positioned to extend the route network and distribution system to improve connectivity. However, due to the limitation of port size, the government needs to allocate funding and invest in upgrading facilities. Additionally, while technology investment requires substantial capital, there is a need to assess whether these ports have the capability to implement and sustain these technologies in the long term. This can be achieved by implementing robotics to enhance berth equipment, cargo handling capabilities, and technological advancements. These improvements are essential to facilitate quick turnaround times and ensure a steady reduction in the maritime supply chain to facilitate faster and more reliable routes into the connectivity (Banomyong *et al.*, 2011). This strategy can make this small port into a spare hub to support Thailand's connectivity to RCEP. Additionally, shipping liners can benefit from using spare hubs and optimising their routes, cargo volume, and frequency of port calls as feeder ports. This will support the short-sea shipping market, maintain service levels, avoid delays, and reduce operational costs. Consequently, shipping liners can foster strong partnerships with regional ports and contribute to a more integrated and efficient maritime network within the RCEP framework.

(2) Next-Gen Port Integration Policy

This policy aims to position Thailand's regional ports as competitive players in the next generation of global trade, particularly within the framework of RCEP. It focuses on improving the digital capabilities of regional ports by adopting advanced technologies, implementing smart port innovations, and enhancing market connectivity. Thailand will comprehensively assess the digital and infrastructural upgrades, especially in tracking technologies for real-time information sharing. The improvements will focus on tracking cargo movement within the port, between the ship and the port, and between ports to enhance communication and ensure long-term operational efficiency. Investing in this technology will enable the terminal to offer services such as cargo tracking, estimated time of arrival alerts, and efficient yard management, optimising the flow of goods and reducing turnaround time. The strategic will ensure that these factors can be fully utilised to enhance cargo flow through connectivity to regional ports. However, a significant challenge of this policy is the need to implement standardised technology systems across all regional port locations. It will take a high investment to upgrade existing infrastructure and equip personnel with the necessary skills to effectively use new technologies. The process also requires careful planning to ensure that all ports comply with the same technological standard.

To effectively implement these technologies, it is crucial to develop a next-generation workforce that is well-trained in operating new systems and equipment. This development should include training in cybersecurity and safety protocols to ensure secure and efficient handling of advanced technologies, minimising risks and promoting a safe working environment. By investing in both digital infrastructure and human capital, Thailand's ports can enhance their competitiveness to meet the future maritime transport system.

(3) Optimised Market Components and Value Services

The policy aims to improve the services offered by small ports by increasing their market share and the frequency of services. The shipping liner can manage the optimal volume for each regional port call to reach a saturation point, leading to a quicker turnaround time for ship including adding the number of port calls to visit Thailand. The new strategy seeks to attract shipping liner companies to operate and trade in the regional market and transportation in regional areas, benefiting the overall shipping ecosystem and providing more alternatives and services through alliances. The new findings of this study are based on the factors of "logistic and supply chain networks", which align with the concept of "regional load centre networking" proposed by Notteboom and Rodrigue (2005). It requires integration with modern supply chains combined with logistics distribution concepts to establish a production centre, distribution centre, or assembly part within a regional port to enhance the value of service support connectivity within the regional port. Expanding capacity to support the load centre is a challenging policy because of the limited available space. However, implementing automated stacking cranes (ASCs) or multi-level racking systems can optimise vertical space utilisation by effectively increasing storage capacity without expanding the port's capacity (Nguyen and Woo, 2022; Sankla and Muangpan, 2022). In addition, the technical expertise for training skill, financial investment, and initiating the supply chain processes within regional ports. There is a need for specialised training to develop the necessary skills among the workforce to achieve technological advancements and evolving industry standards. However, implementing this policy will offer long-term benefits by strengthening the entire transportation chain from its starting point to its final destination. Lastly, Thailand's maritime department can enhance responsiveness to strategic planning based on data optimisation for decision-making to control the structure of shipping network demand and port size. This optimisation also involves routing visits to the regional port to enhance collaboration with network actors such as shipping companies, terminal operators, and logistics and supply chain sections. This strategy has difficulties in ensuring the quality and availability of data, which may not always be reliable or up-to-date. To achieve optimal data for decision-making, it is essential to implement advanced data analytics tools and provide technical training to ensure data consistency and accuracy in a timely decision.

7. Conclusion

This study successfully establishes the connectivity of regional ports in Thailand and contributes to infrastructure development within the RCEP framework by employing an advanced Fuzzy Exploratory Factor Analysis approach. The findings identify the major factors that can be implemented into new tactics, regulations, and policies to enhance regional port connectivity in RCEP. This research presents an effective method for integrating the concept of connectivity with current maritime transport and future innovation trends across multiple variables. The advantage of this study lies in its ability to operate at a deeper level of engagement, providing a grounding in both theoretical understanding and practical application. In addition, these findings hold significant implications for informing port and maritime transport policies. By aligning with national-level strategies and prioritising improvement efforts, Thailand can achieve positive outcomes beyond the regional port. This can contribute to long-term trade development and economic integration within frameworks like RCEP, the Belt and Road Initiative, and the ASEAN Economic Community.

On the other hand, the outcome can highlight the potential of maritime actors (port authorities, terminal operators, and shipping liners) to enhance regional ports. This can be achieved not only by improving their operational capabilities but also by adding value through strengthened infrastructure connectivity among RCEPs. The model provides a roadmap for advancing toward the next generation of regional ports, which can generate value through improved maritime connectivity. It recommends that Thailand’s ports prioritise technological advancements and automation to enhance port performance and achieve connectivity development goals.

However, it is important to acknowledge the limitations of this study, which focused exclusively on regional ports in Thailand and specific regional contexts. This might only fully represent some potential viewpoints or experiences related to broader infrastructure connectivity. Although the findings of this study are sufficient for a detailed analysis, they are based on a limited number of experts, which may restrict the applicability of the results across all regional port contexts. This study employed fuzzy exploratory factor analysis (EFA) to address uncertainties in expert assessments. EFA effectively captures and quantifies uncertainties in expert opinions. However, due to fuzzy sets’ interpretative nature, EFA introduces subjectivity into the data analysis process, which could impact the objectivity typically aimed for in quantitative analyses.

Further focused investigations aimed at elucidating these uncertainties would not only contribute to studies in various countries but also yield significant findings that could serve as reference points for other economic integration initiatives like the Belt and Road Initiative and the ASEAN Economic Community. Finally, it is imperative to advance the understanding of these concepts, especially with the strategic alignment of transportation infrastructure development to achieve sustained economic growth.

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