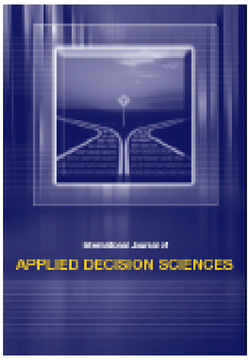

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An integrated fuzzy multi-criteria decision-making approach for prioritising strategies to drive the sustainable roll-on/roll-off port development: a case study of Thailand

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An integrated fuzzy multi-criteria decision-making approach for prioritising strategies to drive the sustainable roll-on/roll-off port development: a case study of Thailand

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Abstract: This study proposes a framework for prioritising strategies to drive sustainable roll-on/roll-off (RO/RO) port development by combining a fuzzy multi-criteria decision-making approach. The application of the proposed framework uses one of the largest RO/RO ports in Thailand as a case study. First, the measuring perspectives/criteria and driving strategies for sustainable port are identified through the extensive literature review along with port development plan. The fuzzy Delphi method is applied to select the suitable criteria and driving strategies for sustainable development of RO/RO port. Next, the fuzzy decision-making trial and evaluation laboratory (fuzzy DEMATEL) is employed to analyse the interrelationship between perspective and criteria as well as their importance weights. Finally, the fuzzy technique for order preference by similarity to ideal solution (fuzzy TOPSIS) is utilised to prioritise the driving strategies. The findings of this study indicate that digitalisation is the most important driving strategy followed by technology investment and implementation of the international standard program in developing the sustainable RO/RO port. Although, the proposed framework focuses on RO/RO ports in Thailand, it can be adapted to use with other types of ports as well.

Keywords: multi-criteria decision-making; MCDM; fuzzy Delphi; fuzzy DEMATEL; fuzzy TOPSIS; roll-on; roll-off; sustainability; Thailand.

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1 Introduction

Maritime transportation, especially the international seaports, plays a vital role in a global supply chain as a domestic distribution centre to the global market as well as the imported products from around the world to their home countries (Hiranandani, 2014). Over the past several decades, seaborne transportation has tremendously grown, which directly impacted port city with both positive and negative impacts. For example, ports generate occupations and incomes for the local community, but the prosperity of ports has destroyed the environment surrounding the port area and the quality of living of its local community as well (Lim et al., 2019; Oh et al., 2018). Environmental degradation has become a serious global issue nowadays due to global warming and climate change. Thus, there is a need to balance three dimensions of operational sustainability for seaports including economic growth, social responsibility, and environmental friendliness (Lim et al., 2019; Lu et al., 2016; United Nations, 2019). Since port operators are the main actors in the port industry, their understanding of sustainability can provide useful information for government to determine criteria to improve sustainable development (Lu et al., 2016; Oh et al., 2018). Phan et al. (2021) state that the sustainable port has been an increasingly interesting topic among port authorities and researchers in recent years. Despite a growing number of previous studies attempt to study ports sustainability development in various geographies (Lu et al., 2016; Oh et al., 2018; Roh et al., 2016). All of them are limited to container terminal operations. Other types of port operations such as roll-on/roll-off (RO/RO) seaports remain neglected. RO/RO seaport is a type of commercial deep seaport used to transport vehicle cargo, i.e., passenger cars, commercial trucks, buses, and trailers from the departure ports to the designated ports. RO/RO ports mainly provide services to automotive or car manufacturers, importing, exporting, and transporting vehicles to the targeted markets and ports in other countries.

An increase in regulations and competition in maritime transportation has been imposed to measure and continuously improve port sustainability across the world. Therefore, how to gain a sustainable competitive advantage and develop sustainability in a high and dynamic competitive environment poses a huge challenge for RO/RO port operators. This is because a port sustainability development has a significant effect on the success or failure of the port business. This issue can therefore be classified as a strategic task. Indeed, paving the way toward sustainable port development can be driven through suitable strategies initiated by port operators and regulated by port authorities. Due to limited resources and time, port operators are unable to employ all driving strategies at once. Thus, port operators must prioritise the driving strategies in a stepwise manner. Basically, the development of driving strategies should be consistent with the measuring perspective/criteria of port sustainability. Most studies determine the perspective/criteria based on triple bottom line (TBL) perspectives: economic, environmental, and social. The economic perspective is measured by port capacity, port financial and non-financial performance, market positioning, etc. Next, the environmental perspective focuses on consumption of energy, water treatment, pollution control, etc. Finally, the social perspective is assessed by employees' satisfaction, health and safety management, community development, etc. Apart from TBL perspectives, Phan et al. (2021) suggested that other port specific perspectives should be included in the sustainability assessment process such as organisational management, and port development policies. The strategic prioritisation of driving sustainable RO/RO port development is a complex issue because there are various criteria, and such criteria may interact and conflict with each other. Additionally, decision-making processes are often embedded with uncertain and ambiguous information from decision makers. The Fuzzy set theory introduced by Zadeh in 1965 is widely utilised to deal with imprecise information. Therefore, the prioritisation of sustainable RO/RO port development driving strategies can be addressed as a fuzzy multi-criteria decision-making (FMCDM) problem. In this study, a FMCDM framework integrating fuzzy Delphi, fuzzy decision-making trial and evaluation laboratory (DEMATEL), and fuzzy technique for order preference by similarity to ideal solution (TOPSIS) is proposed to solve this problem. An application of the proposed framework uses one of the largest international RO/RO ports in Thailand as a case study. The management of the RO/RO port can use the proposed framework as a guideline for assessing the driving strategies. Although the present study focuses on RO/RO port, the proposed framework can be adapted to other port types as well. Further, this study contributes to the existing literature in several aspects:

- First, as of today, there are no studies on the sustainability of the RO/RO port. Also, the existing literature relevant to this context provides less insight into how to properly implement driving strategies. For the best of our knowledge, the present work is the first to propose a framework for prioritising strategies to drive sustainable RO/RO port development.
- Second, most of the research studies port sustainability through the lens of TBL. In this study, the perspective namely 'port development policies' is also taken into account and combined with TBL in the proposed framework.
- Third, previous studies assume the port sustainability perspective/criteria to be independent of each other. But in reality, these perspectives/criteria may interact with each other. In this study, the analysis of interaction perspective/criteria is conducted by employing fuzzy DEMATEL.
- Finally, port sustainability has become a significantly interesting research topic by scholars and practitioners. But very few researches have been done on port sustainability in developing countries. Since many ports in developing countries such as Thailand are still lagging behind the sustainable development. This study attempts to make some progress towards understanding port sustainability context in a case of developing country.

There are eight sections in this paper. Section 1 presents an introduction. Section 2 provides the relevant literature review on sustainable ports and sustainable seaport driving strategies. The methods used in this study are displayed in Section 3. The proposed research framework is described in Section 4. The problem description is explained in Section 5. The analytic results are shown in Section 6. Section 7 provides the discussion. Finally, the conclusions and future research are drawn in Section 8.

2 Literature reviews

2.1 Sustainability in seaports

International seaports play a significant duty in the global marine logistics operation. Maritime transport is recognised as having the most negligible impact on the environment, but the popularity of maritime transport has led port operators desire to expand their port infrastructure to accommodate economic growth (Lim et al., 2019). Although the growth of port and port operations brings various businesses related to marine transport to erect the prosperity to the port cities and nearby cities which leads to a positive impact on social-economic development. Meantime, it also has negative impacts on port cities such as pollution, traffic congestion as well as an increasing crime rate, which has resulted in the reduction of competitiveness and ability to attract investors (Kong and Lui, 2021). Hence, the adoption of a sustainable concept is significantly essential for port authorities nowadays.

The sustainability concept in maritime transportation has been intensely explored according to the United Nations Conference on Environment and Development (UNCED) since 1992, which encouraged the maritime sectors to increase awareness of the environmental impact and assess the organisation's sustainability. Many international organisations confirmed that sustainable management should cover all three dimensions such as economic dimension, environmental dimension, and social dimension (Oh et al., 2018). Besides, the Brundtland Commission, the subsidiary of the United Nations, announced the latest Agenda 2030 for sustainable development in 2015 consisting of 17 sustainable development goals (SDGs) by addressing key areas of sustainable development particularly sustainable cities and communities (D'Amico et al., 2021; Katuwawala and Bandara, 2022; Liu et al., 2021).

Thus, the maritime sector is controlled by global and domestic legislations. For instance, MARPOL, Kyoto Protocol, Environmental Protection Act 1986 (Western Australian), Resource Management Regulations (New Zealand), Diesel Emission Reduction Act; DERA (USA), Environmental Protection and Management Act (Singapore) (Lim et al., 2019; Roh et al., 2016), which challenges port authorities to improve their operation to meet an international standard. Zhao et al. (2021a) supported that growing pressures from global legislations and domestic agreements are pushing ports to adopt sustainable development concepts faster as well as increasing the competitiveness in a sustainable way is the best practice to disseminate sustainability concepts. Additionally, the global COVID-19 pandemic has clearly changed port administration, port authorities are facing pressure to develop their ports into smart ports even faster, due to the restriction of human movement (Zhao et al., 2021b).

Seaports are an important intersection node of multi-stakeholders in the supply chain (Giudice et al., 2021), and also a major intermediary to motivate its stakeholders to implement their policies by collaborating with the regulators to formulate measures to promote sustainable development (Bjerkan et al., 2021). Moreover, as ports play a major role in driving national and global economies, they are recognised as the most important node in the supply chain to contribute the sustainable development (Katuwawala and Bandara, 2022). Several maritime ports in ASEAN have been developing sustainable strategies in order to reduce environmental degradation which is affected its stakeholders such as greenhouse gas emissions, energy saving, comply with the labour law (Gupta and Prakash, 2022).

Table 1 Perspectives/criteria for sustainable port development

Perspectives	*Criteria*	*Description*
Economic	Foreign Direct Investment (FDI)	Government policy is a factor to attract foreign enterprises to invest in the host country. FDI impacts a country's economy by increasing export volumes, taxes, and the social aspect as job opportunities.
		Foreign enterprises need to maximise their profits by invest in aboard and move their knowledge to their host countries. In contrast, government costs are greater to spend more on marketing policies and fees on FDI (Wenfen et al., 2013). Nevertheless, FDI not only develops economic growth but also disrupts the continental environment (Bokpin, 2017).
	Value generated productivity	The value-added productivity of ports relates to efficiency management and productivity. To reduce the transportation cost and meet the customers' needs, the customer's perspective is the most relevant for port operators (De Martino et al., 2020).
	Port operational efficiency	Efficient port management affects the port economy as good port management can enhance cargo volume through the port and the number of port calls, and reduce processing time (Iannone et al., 2016; López-Bermúdez et al., 2019). Investing in port infrastructure and port facilities can increase port efficiencies by accommodating larger vessels. This will increase the numbers of cargo through the port (Lim et al., 2019; López-Bermúdez et al., 2019).
	High quality business service	The mistakes and unreliability of port operators cause customer dissatisfaction and further affect the value chain of logistics. Thus, well-service quality would retain loyal customers and attract potential customers such as shipping organisations, product owners or other supply chain related organisations (Yeo et al., 2015).
	Benefit from external stakeholders	The port system consists of multiple partners in the supply chain. Therefore, most studies have identified green cooperation with external stakeholders or social participation as one of the key factors in achieving sustainable development goals. For example, government participation in legislation to promote an environmental industry, which enables control the quality of air and water around the port. Therefore, ports should consider local communities and stakeholders to achieve sustainable development goals (Lim et al., 2019).
	Port development funding	Several ports aim to enhance their capacities by investing billions of dollars in infrastructure such as deeper vessel channels, large cranes, increased port facilities and properties to accommodate growing trade volumes, increase cargo size, and service requirements (Lu et al., 2016).
	Port infrastructure construction	The port industry's growth rate is increasing year by year; thus, port authorities are incentivised to expand terminals and dredge waterways to accommodate increased cargo volumes and larger ship sizes to reduce shipping costs (Diaz-Hernandez et al., 2017).
	Port throughput	Refers to the quantity of cargo that is processed through a time-limited terminal. Most studies used port throughput to evaluate port efficiency (Cong et al., 2020).
	GDP	Port industry creates jobs and contributes to local taxes and national incomes, which affect a nation's gross domestic product. Nevertheless, government policies are the main factor for the port throughput (Cong et al., 2020).
	Operating cost	Good berthing planning and allocation can reduce costs for the berth operators including the ability to accommodate the unexpected vessel arrival and minimise cargo relocation. The waiting time at the port as well as port planning will affect processing times and costs. These are port costs and affect operating costs (labour costs) and environmental costs (ship emissions and handling equipment) (Iannone et al., 2016).
	Cost-efficiency	The environmental enhancement may affect economic efficiency (Lim et al., 2019). Higher product volumes and labour skills result in higher cost efficiency (Zheng and Yin, 2015).

Table 1 Perspectives/criteria for sustainable port development (continued)

Perspectives	*Criteria*	*Description*
Environment	Water pollution management	The quality of water near the port depends on the location, size, type of activity, traffic of port, etc. The water risk assessment is essential for port operators to prevent unexpected circumstances (Gómez et al., 2015).
	Air pollution management	The vessel engine uses heavy fuel, which has a huge impact on the atmosphere, especially the bottom layers where people live. The vessels and port activities cause three main pollutants, i.e., sulphur oxide (SOx), nitrogen oxide (NOx), and particulate matter (PM). For the best practices, port operators and governments should consider monitoring air quality in the port areas, trains as well as enhance competitiveness of port and municipal authorities.
		Notwithstanding, the additional costs may be incurred (Bachvarova et al., 2018).
	Energy and resource usage	The energy efficiency of a port is to use less energy while providing the same potential port activities and services. Good management of port operation leads to energy efficiency because the operating time means energy consumption (Iris and Lam, 2019).
	Noise pollution	Logistics activity causes noise pollution which affects local communities such as health, well-being, and mentality issues. Therefore, the port must allocate suitable activities and define truck regulations to reduce noise pollution (Paschalidou et al., 2019).
	Green port management	The International Maritime Organization (IMO) and the Marine Environment Protection Committee (MEPC) have established rules and regulations for the prevention of pollution and greenhouse gas from marine logistics. In marine operation, port authorities are the centre of the port community to promote environmental practices. The implementation of green port solutions is to reduce the environmental impact of economic growth and monitor green port performances (Castellano et al., 2020).
	Ecosystem and habitats	The expansion of port industries and marine transportation creates ecological degradation, community infrastructures change, and the number of species and biodiversity reduction (Vörösmarty et al., 2018). Dredging is the main factor of port activity that destroys the port ecosystem and has a negative impact on port industry (Vörösmarty et al., 2018; Xiao and Lam, 2017).
	Soil pollution management	Economic prosperity directly affects the environment around the port as well as the quality of the soil (Oh et al., 2018). Dust diffusion from handling and storage of cargoes as well as fuel and chemical spills causing soil pollution in the port area. In addition, the soil quality can be measured by the concentration of chemicals in the soil layer (Trozzi and Vaccaro, 2000).
	Waste pollution management	Waste management including solids and liquids is defined as the main pollution factor of coastal and marine problems due to the degradation of air and water quality. Port activities such as oil discharge, litter and garbage, vessel sewage, and ballast discharge may cause seawater pollution and biomass. These are harm or cause of death of marine habitats and species diversities (Xiao and Lam, 2017).
	Green construction and facilities	Port pollution prevention and control are essential for sustainable port development. The low-carbon and green port projects were established to protect the port environment. The environment is destroyed, and resources are consumed by the previous port development to maximise benefits. Categorising and analysing the energy consumption and emissions of vehicles and port equipment allows emission reduction measures to be formulated (Wang et al., 2018).
Social	Health and safety	Older port workers suffer from noise and chemicals. And it tends to increase every year due to the growth of marine transport. Best practices in risk assessment such as improving the workplace, materials, technology, and working processes in occupational health and safety (OHS) are mostly found in large organisations. This is a big problem, especially in low-income countries (Walters et al., 2020).
	Job generation	Improving the efficiency of port operations requires a study of corporate innovation and technology. Innovations and technologies affect port economic growth and increase productivity and result in port workers losing their jobs. Also, information and communication technology (ICT) and port automation cause old workers to lose their jobs. Whereas there is an opportunity for the new generation with ICT knowledge (Esser et al., 2020).

Table 1 Perspectives/criteria for sustainable port development (continued)

Perspectives	*Criteria*	*Description*
Social	Job training	To increase personal responsibility and continued education, a training program helps port operators understand their job responsibilities and appropriateness within the organisational structure. The working conditions and safety of employees must be continually improved to meet the requirements of international standards (Roh et al., 2016).
	Public relations	Supporting social activities resulted in good public relations, which can be value-added to port services. The ports with a reputation for public relations gain the reliability and trustworthiness of their customers and attract loyal customers (Roh et al., 2016).
	Gender equality	The number of female workers in the port is relatively minimal. It is because work is so hard, low compensation, and strict working time (Esser et al., 2020). However, the gender gap depends on tasks and other restrictions such as countries with poor economic management may have limited resources to promote gender equity. Countries with low unemployment rates are easier to bridge the gender gaps than high unemployment countries (Lucia, 2019). Thus, improving the working environment, promoting work-life balance, and establishing new gender norms in organisations lead to gender equality success (Barreiro-Gen, 2021).
	Social image	Employee safety practices, improving the working environment, promoting social activities as well as the achievement in environmental management are essential. This may result in increased organisation social image performance and good reputation (Roh et al., 2016).
	Quality of living environment	Port activities and port expansion may affect the quality of living of local communities. Moreover, waste discharge from port operations is threatened coastal areas and the loss of rest areas. Such would affect the decision of living nearby the port area (Xiao and Lam, 2017). Greater environment management improves the quality of life for both employees and the local community. Increasing the reputation and social performance of an organisation can be achieved by enhancing employee safety and working conditions, as well as by supporting the local community (Roh et al., 2016).
	Social participation	Ports with high responsibility for sustainable development have the opportunity to get support from the government, community, public, and investors (Giudice et al., 2021; Lim et al., 2019). Meanwhile, ports must provide costly funding to meet the regulations and promote corporate social responsibility operations. This results in low economic performance (Lim et al., 2019).
Port development policy	Port development in next phase	To enhance the potential of maritime transportation and competitiveness, the Port Authority of Thailand plans to develop Laem Chabang Port (LCP) – Phase 3 to support economic expansion (PAT, 2019).
	Fundamental utility systems improvement	To reduce the risk of accidents and traffic congestion, LCP plans to improve road surfaces in the LCP areas to be able to support more truck weights (PAT, 2019).
	Dredging waterway	Maintaining the water's depth allows vessels to reach the port easier and safer. This is to increase economic viability and reduce logistic costs (PAT, 2019).
	Increase the volume of transit and transshipment cargoes via LCP	To increase the competitiveness to become the centre of intermodal transport of the country, LCP collaborates with the Port Authority of Thailand (PAT) to operate ports, shipping-lines, and customs to support the transportation and cargo transshipment through LCP (PAT, 2019).
	Green port project collaboration	To achieve the sustainable development goals, LCP established several green port projects to reduce carbon dioxide emissions by 10% within 2023, such as fuel reduction projects, reducing electric power, and promote renewable energy, etc. (PAT, 2019).
	PSHEMS	Maintaining international standards will provide confidence to port operators and create sustainable development. This is to meet international standards of service quality, safety and health of employees, and port environment (PAT, 2019).

The sustainability concept is popularly used as a business strategy and operational practice by port authorities to respond to their present and future businesses as well as stakeholders' responsiveness without destroying the quality of living and natural resources (Oh et al., 2018; Muangpan and Suthiwartnarueput, 2019). Besides, the sustainability concept is defined as one factor to leverage competitiveness (Lim et al., 2019). Regular communication of sustainable practices with external stakeholders such as governments, environmental organisations, and communities contributes to the success of the organisation's sustainability performance (Tsai and Lu, 2021).

Table 2 Driving strategies for sustainable port development

Driving strategies	*Description*
Technology investment	The usage of suitable technology such as electric equipment, start-stop engine equipment, onshore power supply (cold ironing), and automated mooring systems, gives port operators to reduce air pollution, and economic costs (Casazza et al., 2019; Seddiek, 2020; Iris and Lam, 2019; Roh et al., 2016). Moreover, Lucia (2019) indicated that the automatic port system resulted in gender gap reduction.
Alternative energy	Using alternative energy (liquefied natural gas, hydrogen, biofuels) instead of diesel fuel can significantly reduce greenhouse gas emissions in ports (Iris and Lam, 2019). Most equipment and vehicles in port consume diesel fuel, which produces high carbon emissions. The use of biodiesel blends in diesel engines is widely accepted as well as a low changing cost. Since most engines can be switched to biodiesel in a mixture of no more than 20% (B20) without modification or slightly modification (Misra et al., 2017).
Digitalisation	ICT plays an increasingly important role in the port industry. Implementation of IT systems in port data management is to enhance the competitiveness, safety, and the sustainability of port. Such systems are data collection and exchange as well as real-time analysing marine data between maritime supply chain and port industry. Port Community Systems is a standardised digital platform that is widely used in many ports worldwide (Di Vaio and Varriale, 2020). Additionally, digitisation can help port operators increase workflow flexibility and increase the efficiency of working in the long-term which leads to economic and sustainability growth (Giudice et al., 2021).
International standard program	Implementing an international standard program promotes port operators to increase operational efficiencies and create stakeholder engagement such as energy management system (ISO5001) (Iris and Lam, 2019), environment management system (ISO14000) (Teerawattana and Yang, 2019), and occupational health and safety management systems (ISO45001) (Salguero-Caparrós et al., 2020), etc.

2.2 Sustainable seaport perspectives/criteria

A popular way to study sustainable development is to identify the sustainable development perspectives/criteria. This is because the comprehensive perspectives/ criteria help organisations to understand the current situations and forecasts for the future to formulate the appropriate policies and management (Xiao and Lam, 2017). Lim et al. (2019) noted that the port sustainability measurements are achieved by identifying precise perspectives/criteria as the measurement basis; and by considering multidimensional approaches to establish the sustainability objectives. Most of the research assesses port sustainability based on TBL perspectives (Lu et al., 2016; Oh et al., 2018; Roh et al., 2016; Xiao and Lam, 2017; Lim et al., 2019). Apart from TBL perspectives, Roh et al. (2021) state that external cooperation is crucially significant to sustainable development, but only a few studies considered covering external stakeholders' management. Hence, this study also includes 'port development policy' perspective from a case study (Laem Chabang Port – LCP Phase 3). The perspectives/criteria of port sustainability measurement are shown in Table 1.

2.3 Sustainable seaport driving strategies

After identifying the perspectives/criteria for sustainable port development, the driving strategies for achieving port sustainability are drawn through an analysis of the literature review as shown in Table 2.

3 Method

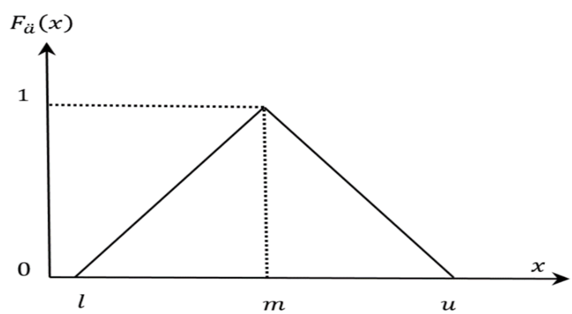
In this study, the integration of FMCDM approaches is presented as follows.

3.1 Fuzzy set theory

In 1965, the fuzzy set theory was designed by Zadeh to manage the indistinctness and inconsistency of human decisions (Khompatraporn and Somboonwiwat, 2017; Ebrahimi and Bridgelall, 2021). Furthermore, the use of linguistic variables gives more realistic than numeric values (Bouzon et al., 2016; Ocampo et al., 2020). Fuzzy set theory is a mathematical tool that converts the linguistic scale such as no influence, very low influence, low influence, high influence, and very high influence into fuzzy set numbers. The scale of the fuzzy set number is determined by establishing the triangular fuzzy numbers (TFNs) (Khompatraporn and Somboonwiwat, 2017; Ebrahimi and Bridgelall, 2021).

In order to present the membership function $F_{\ddot{a}}(x)$, TFNs often use a set of (l, m, u) values to define the lowest value, the most engaging value, and the highest value, respectively. The TFNs are shown in Figure 1.

Figure 1 TFNs of $F_{\ddot{a}}$



The methodology of fuzzy number can be formulated as follows (Khompatraporn and Somboonwiwat, 2017):

Definition 1: The membership function of fuzzy number is:

$$F_{\ddot{a}}(x)=\begin{cases} x-l/m-l, & l\le x\le m \\ u-x/u-m, & m\le x\le u \\ 0, & x<l, x>u \end{cases} \quad (1)$$

Definition 2: The mathematic operational between two TFNs of $\ddot{a}_1$ and $\ddot{a}_2$ can be defined as:

$\ddot{a}_1=(l_1, m_1, u_1)$ and $\ddot{a}_2=(l_2, m_2, u_2)$

$$\ddot{a}_1\oplus\ddot{a}_2=(l_1, m_1, u_1)+(l_2, m_2, u_2)=(l_2+l_2, m_1+m_2, u_1+u_2) \quad (2)$$

$$\ddot{a}_1\ominus\ddot{a}_2=(l_1, m_1, u_1)-(l_2, m_2, u_2)=(l_1-l_2, m_1-m_2, u_1-u_2) \quad (3)$$

$$\ddot{a}_1\otimes\ddot{a}_2=(l_1, m_1, u_1)\times(l_2, m_2, u_2)=(l_1\times l_2, m_1\times m_2, u_1\times u_2) \quad (4)$$

$$\ddot{a}_1\oslash\ddot{a}_2=(l_1, m_1, u_1)\div(l_2, m_2, u_2)=(l_1\div l_2, m_1\div m_2, u_1\div u_2) \quad (5)$$

$\mu\ddot{a}_1=(\mu\times l_1, \mu\times m_1, \mu\times u_1)$, μ is a constant value (6)

Definition 3: Aggregate the decision maker's $h(h = 1, 2, \ldots, H)$ by:

$$l=\min_{1\le h\le H}(l_h), m=\frac{1}{H}\sum\nolimits_{h=1}^{H} m_h, u=\max_{1\le h\le H}(u_h) \quad (7)$$

3.2 Linguistic variable

The linguistic variable is a type of variable to specify the criterion of linguistic values to fuzzy numbers (Sumrit, 2020). Ebrahimi and Bridgelall (2021) pointed out that five-point TFNs are the best approach to gain an expert's opinion. In this study adapts fuzzy linguistic values from Kazancoglu and Ozkan-Ozen (2018) as shown in Table 3.

Table 3 The fuzzy linguistic value for importance weights of perspectives/criteria and the driving strategies

Linguistic description for fuzzy DEMATEL	*Triangular fuzzy numbers*	*Linguistic description for fuzzy TOPSIS*
No influence (NI)	(0.00, 0.00, 0.25)	Very low (VL)
Very low influence (VLI)	(0.00, 0.25, 0.50)	Low (L)
Low influence (LI)	(0.25, 0.50, 0.75)	Medium (M)
High influence (HI)	(0.50, 0.75, 1.00)	High (H)
Very high influence (VHI)	(0.75, 1.00, 1.00)	Very high (VH)

Source: Adapted from Kazancoglu and Ozkan-Ozen (2018)

3.3 Fuzzy Delphi method

The fuzzy Delphi method was proposed by Ishikawa. Integrating the fuzzy set theory and Delphi technique (Hsu et al., 2010; Bouzon et al., 2016; Ebrahimi and Bridgelall, 2021) is to reduce Delphi method weaknesses such as questionnaire duration and cost (Hsu et al., 2010; Bui et al., 2020) as well as the indistinctness of the human judgment (Bouzon et al., 2016; Ebrahimi and Bridgelall, 2021; Ocampo et al., 2020) by providing a more complete demonstration of expert knowledge. This study applied the fuzzy Delphi method to select the appropriate criteria and driving strategies, which can be divided into six steps as follows:

Step 1 Collect criteria from literatures.

Step 2 Design a questionnaire based on the fuzzy Delphi principle by experts rating an important score for each criterion (i^n) for both the most conservative (minimum) and most positive (maximum) scores with a rating scale ranging from 1 to 10. Then, gather the expert's opinion from the survey questionnaire.

Step 3 Eliminate outlier data from each criterion (i^n). By using data obtained from step 2 to find out the values that the score outer of two standard deviations in both conservative and positive clusters. For each criterion (i^n) of conservative cluster, minimum (C_l^i), geometric mean (C_m^i), and maximum (C_u^i) are considered. Corresponding to each criterion (i^n) of the positive cluster, minimum (P_l^i), geometric mean (P_m^i), and maximum (P_u^i) are accounted.

Step 4 Setup TFNs of:

- Conservative value: $C^i = C_l^i, C_m^i, C_u^i$.
- Positive value: $P^i = P_l^i, P_m^i, P_u^i$ for each criterion (i^n).

The 'grey zone' is an overlapping area of C^i and P^i as shown in Figure 2. This is used to confirm the expert's opinion for each criterion (i^n), consented by comparing with the value of consensus significance (G^i). It means that the criterion (i^n) is determined importance.

Step 5 Examine the consistency of expert's opinion and determine the value of consensus significance (G^i) for each criterion (i^n) by following conditions:

- Condition 1: The criterion (i^n) is defined as a consensus when the value of conservative (C^i) and positive (P^i) of the TFNs are not overlapped $(C_u^i \le P_l^i)$. Therefore, the consensus significance value (G^i) is calculated as follows:

$$G^i = \frac{C_m^i + P_m^i}{2} \tag{8}$$

- Condition 2: When the value of conservative (C^i) and positive (P^i) of TFNs are overlapped $(C_u^i > P_l^i)$ and the range of grey zone value $(Z^i = C_u^i = P_l^i)$ is less than grey zone range C^i and $P^i (R^i = P_u^i - C_m^i)$. Hence, the value of consensus significance (G^i) of each criterion (i^n) is calculated by:

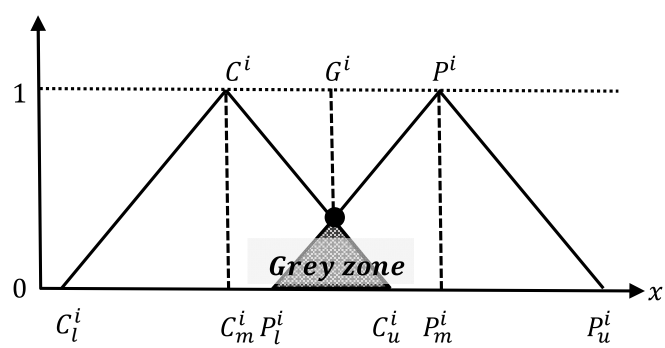
$$G^i = \frac{\left[\left(C_u^i \times P_m^i\right) - \left(P_l^i \times C_m^i\right)\right]}{\left[\left(C_u^i - C_m^i\right) - \left(P_m^i - P_l^i\right)\right]} \tag{9}$$

- Condition 3: When the value of (C^i) and (P^i) of TFNs are overlapped $(C_u^i > P_l^i)$ and the range of grey zone value $(Z^i = C_u^i - P_l^i)$ is greater than the grey zone range of C^i and $P^i(R^i = P_u^i - C_m^i)$, there is defined as non-consensus among expert's opinion. Therefore, repeat steps 2 to 5 until the values of each criterion (i^n) reach a consensus.

Step 6 Establish the threshold value (α) to pick the suitable criteria by comparing the values of consensus significance (G^i) to the threshold value (α). The criterion will be eliminated if the value of consensus significance is less than the threshold value ($G^i < \alpha$). For the threshold value (α), the Pareto principle (80/20 rule) is adopted to identify the appropriate criteria that must be considered in order to get a significant result. According to the 80/20 rule, "20% of factors account for an 80% degree of importance of all criteria" (Kuo and Chen, 2008). In this study, the threshold value (α) is set to 8, which means that if the consensus significant value (G^i) of each criterion greater than 8 is accepted to be considered, otherwise it will be rejected. The selection of suitable criteria is as follows:

- If $G^i \geq \alpha = 8$, this criterion is accepted.
- If $G^i < \alpha = 8$, this criterion is rejected.

Figure 2 TFNs of fuzzy Delphi method



3.4 *Fuzzy DEMATEL method*

The DEMATEL, presented in Geneva by the Battelle Memorial Institute between 1972–1976 is used to define a causal factor relationship among variables in a complex system (Kazancoglu and Ozkan-Ozen, 2018; Khompatraporn and Somboonwiwat, 2017; Ocampo et al., 2020). Suitable decision-making in a complex system requires an understanding of the interrelationship between variables (Khompatraporn and Somboonwiwat, 2017). However, the ambiguity of human decision-making is difficult for numerical-based values decision. Thus, the fuzzy DEMATEL is an integration of the DEMATEL method and fuzzy set theory, which is used to deal with human ambiguity.

The fuzzy DEMATEL approach is widely used for several objectives, especially in the subjective of human decisions (Khompatraporn and Somboonwiwat, 2017; Ocampo et al., 2020). There are five steps of fuzzy DEMATEL are shown below:

Step 1 Once the criteria and driving strategies are selected by the fuzzy Delphi method. Then, the questionnaires are designed based on the fuzzy DEMATEL method to determine the cause-effect relationship among perspectives/criteria.

Step 2 Collect the questionnaires and convert the linguistic scale into TFNs. TFNs is shown in Table 3.

Step 3 Defuzzification by converting the fuzzy number into crisp value according to Kazancoglu and Ozkan-Ozen, (2018) method as follows:

- Establish direct-relation matrix $\tilde{Z}$.

  Let $\tilde{Z}_{ij}^{h} = (l_{ij}^{h}, m_{ij}^{h}, u_{ij}^{h})$ obtained pairwise comparison of factor *i* affects the factor *j*, given by the experts $h(h = 1, 2, \ldots, H)$.

- Normalise the matrix $\tilde{\tilde{Z}}$ by:

$$xl_{ij}^{h} = \left(l_{ij}^{h} - \min l_{ij}^{h}\right) / \Delta_{\min}^{\max}, \tag{10}$$

$$xm_{ij}^{h} = \left(m_{ij}^{h} - \min l_{ij}^{h}\right) / \Delta_{\min}^{\max}, \tag{11}$$

$$xu_{ij}^{h} = \left(u_{ij}^{h} - \min l_{ij}^{h}\right) / \Delta_{\min}^{\max} \tag{12}$$

  where $\Delta_{\min}^{\max} = \max u_{ij}^{h} - \min l_{ij}^{h}$.

- Calculate left (*xls*) and right (*xrs*) normalised value by:

$$xls_{ij}^{h} = xm_{ij}^{h} \big/ \left(1 + xm_{ij}^{h} - xl_{ij}^{h}\right), \tag{13}$$

$$xrs_{ij}^{h} = xu_{ij}^{h} \big/ \left(1 + xu_{ij}^{h} - xm_{ij}^{h}\right) \tag{14}$$

- Compute crisp value by:

$$x_{ij}^{h} = \left[xls_{ij}^{h}\left(1 - xls_{ij}^{h}\right) + xrs_{ij}^{h} xrs_{ij}^{h}\right] \big/ \left(1 - xls_{ij}^{h} + xrs_{ij}^{h}\right) \tag{15}$$

- Normalise crisp value by:

$$q_{ij}^{h} = \min l_{ij}^{h} + x_{ij}^{h} \Delta_{\min}^{\max} \tag{16}$$

- Aggregate crisp value from all experts (*H*) from:

$$\tilde{Q} = \frac{1}{H}\left(q_{ij}^{h1} + q_{ij}^{h2} + \ldots + q_{ij}^{H}\right) \tag{17}$$

Step 4 Applied DEMATEL method from Khompatraporn and Somboonwiwa (2017), as follows:

- Normalised the direct-relation matrix $(\tilde{D})$ by:

$$\gamma = \max\left(\max_{1\le i\le n}\sum_{j=1}^{n} q_{ij}, \max_{1\le j\le n}\sum_{j=1}^{n} q_{ij}\right) \tag{18}$$

where $\max_{1\le i\le n}\sum_{j=1}^{n} q_{ij}$, indicates the highest overall direct influence from all factors. Correspondingly, $\max_{1\le i\le n}\sum_{j=1}^{n} q_{ij}$, represents the highest overall direct influence obtained by all factors.

Then, compute the normalised direct-relation matrix $(\tilde{D})$ as:

$$\tilde{D} = \tilde{Q}/\gamma \tag{19}$$

- Setup total-relation matrix $(\tilde{T})$ by:

$$\tilde{T} = \tilde{D}\left(\tilde{I} - \tilde{D}\right)^{-1} \tag{20}$$

where $(\tilde{I})$ is defined as identity-matrix $\tilde{I}_{n\times n}$.

- Let t_{ij} be compositions of total-relation matrix $(\tilde{T})$

$$r_i = \sum_{j=1}^{n} t_{ij}, \begin{pmatrix} r_{i1}, \\ r_{i2}, \\ \vdots, \\ r_{in} \end{pmatrix} \tag{21}$$

$$c_j = \sum_{i=1}^{n} t_{ij}, \left(c_{j1}, c_{j2}, \ldots, c_{jn}\right) \tag{22}$$

where r_i denotes the sum of rows in total-relation matrix $(\tilde{T})$ and c_j denotes the sum of columns in total-relation matrix $(\tilde{T})$.

Horizontal axis $(r_i + c_j)$ describes the degree of importance among factors, while vertical axis $(r_i - c_j)$ indicates the causal relationship among factors. A positive result of $(r_i - c_j)$ shows factors classified as 'cause variable' and a negative result of $(r_i - c_j)$ shows factors classified as 'effect variable' (Kazancoglu and Ozkan-Ozen, 2018).

Step 5 Determine the threshold values of perspectives/criteria by

$$\boldsymbol{\delta} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} V_{ij}}{m \times n} \tag{23}$$

The element values in the total influence matrix are greater than threshold values $(\boldsymbol{\delta})$, indicating that there are significant interrelationships between perspective/criteria. Conversely, the values less than the threshold value are not significantly interrelationships.

Step 6 Determine the important weights of criteria adopted from Pourjavad and Shahin (2020) as follows:

$$W_i = \left[(r_i + c_j)^2 + (r_i + c_j)^2 \right]^{1/2} \tag{24}$$

Next, normalise the important weight (W_i) by:

$$W_i = w_i \Big/ \sum_{i=1}^{n} w_i \tag{25}$$

3.5 *Fuzzy TOPSIS method*

The fuzzy TOPSIS technique is applied to decide the alternatives which are the best suitable match with the criteria. In 1981, Hwang and Yoon proposed the TOPSIS method to select the best suitable alternatives by selecting the best alternative that nearest distance to the positive ideal solution and the longest distance from the negative ideal solution. The ideal solution identifies from the best and the worst rating score for each variable in the group. Whereas the positive ideal solution is from the highest value of each benefit column and the lowest value of each cost column. For the negative ideal solution, it is from the highest value of each cost column and the lowest value of each benefit column. This method is popularly used for ranking the solutions. In order to overcome the indistinctness and inaccuracy of the human decision, the integrated of fuzzy set theory with TOPSIS is able to solve the problems above mention (Ocampo et al., 2020; Sirisawat and Kiatcharoenpol, 2018). The steps in fuzzy TOPSIS adopted by Emovon and Aibuedefe (2020) can be demonstrated as follows:

Step 1 Design a fuzzy TOPSIS-based questionnaire to rank scores for each driving strategy based on criteria.

Step 2 Gather data from questionnaire, then transform to corresponding TFNs.

Step 3 Aggregate the all-expert's opinion (H) by establishing matrix ($\tilde{X}$).

$$\tilde{X}_{ij}^{h} = \left(l_{il}^{h}, m_{il}^{h}, u_{il}^{h} \right), \tag{26}$$

where

$$l_{ij}^{h} = \min_{h} l_{ij}^{h},\ m_{ij}^{h} = 1 \Big/ H \left(\sum_{h=1,}^{H} m_{ij}^{h} \right),\ u_{ij}^{h} = \max_{h} u_{ij}^{h}.$$

Step 4 Calculate the normalised fuzzy decision matrix ($\tilde{R}$). In this step, the benefit and cost criteria have been specified.

$$\tilde{R} = \left(\frac{l_{ij}^{h}}{u_j^{*}}, \frac{m_{ij}^{h}}{u_j^{*}}, \frac{u_{ij}^{h}}{u_j^{*}} \right), \text{ where } u_j^{*} = \max_{i} u_{ij}^{h}, \text{ (beneficial criteria)} \tag{27}$$

$$\tilde{R} = \left(\frac{l_j^{-}}{l_{ij}^{h}}, \frac{l_j^{-}}{m_{ij}^{h}}, \frac{l_j^{-}}{u_{ij}^{h}} \right), \text{ where } l_j^{-} = \min_{i} l_{ij}^{h}, \text{ (cost criteria)} \tag{28}$$

Step 5 Compute the weighted normalised fuzzy decision matrix ($\tilde{V}$)

$$\tilde{V} = \tilde{r}_{ij} \times W_i \tag{29}$$

For this study, obtained the weights (W_i) from the fuzzy DEMATEL method.

Step 6 Determine fuzzy positive ideal solution: FPIS, (A^*) and fuzzy positive ideal solution: FNIS (A^-) by:

$$A^* = \left(\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^*\right), \text{ where } \tilde{v}_j^* = \max_i \left(\tilde{v}_{ij}\right) \tag{30}$$

$$A^- = \left(\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-\right), \text{ where } \tilde{v}_j^- = \min_i \left(\tilde{v}_{ij}\right) \tag{31}$$

Step 7 Compute the distance from fuzzy positive ideal solution: FPIS, (A^*) and fuzzy positive ideal solution: FNIS (A^-), where $i = 1, 2, \ldots, m$ $j = 1, 2, \ldots, n$ then the distance from FPIS and ENIS can be expressed by:

- The distance from fuzzy positive ideal solution (D_i^*):

$$D_i^* = \sum\nolimits_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^*\right); \tag{32}$$

where

$$d_{\left(\tilde{v}_{ij}, \tilde{v}_j^*\right)} = \sqrt{\frac{1}{3}\left[\left(\tilde{v}_{ijl} - \tilde{v}_{jl}^*\right)^2 + \left(\tilde{v}_{ijm} - \tilde{v}_{jm}^*\right)^2 + \left(\tilde{v}_{iju} - \tilde{v}_{ju}^*\right)^2\right]}.$$

- The distance from fuzzy positive ideal solution (D_i^-):

$$D_i^- = \sum\nolimits_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^-\right); \tag{33}$$

where

$$d_{\left(\tilde{v}_{ij}, \tilde{v}_j^-\right)} = \sqrt{\frac{1}{3}\left[\left(\tilde{v}_{ijl} - \tilde{v}_{jl}^*\right)^2 + \left(\tilde{v}_{ijm} - \tilde{v}_{jm}^*\right)^2 + \left(\tilde{v}_{iju} - \tilde{v}_{ju}^*\right)^2\right]}.$$

Step 8 Define the closeness coefficient (CC_i)

$$CC_i = D_i^- \Big/ D_i^- + D_i^*. \tag{34}$$

The highest closeness coefficient (CC_i) is selected as the best alternative solution.

4 Proposed research frameworks

This study provides a framework for prioritising strategies to drive sustainable RO/RO port development. The proposed framework is divided into seven phases as:

1 identifying the perspectives/criteria and driving strategies

2 selecting the criteria and driving strategies

3 developing a decision model

4 analysing the interrelationship between perspectives/criteria

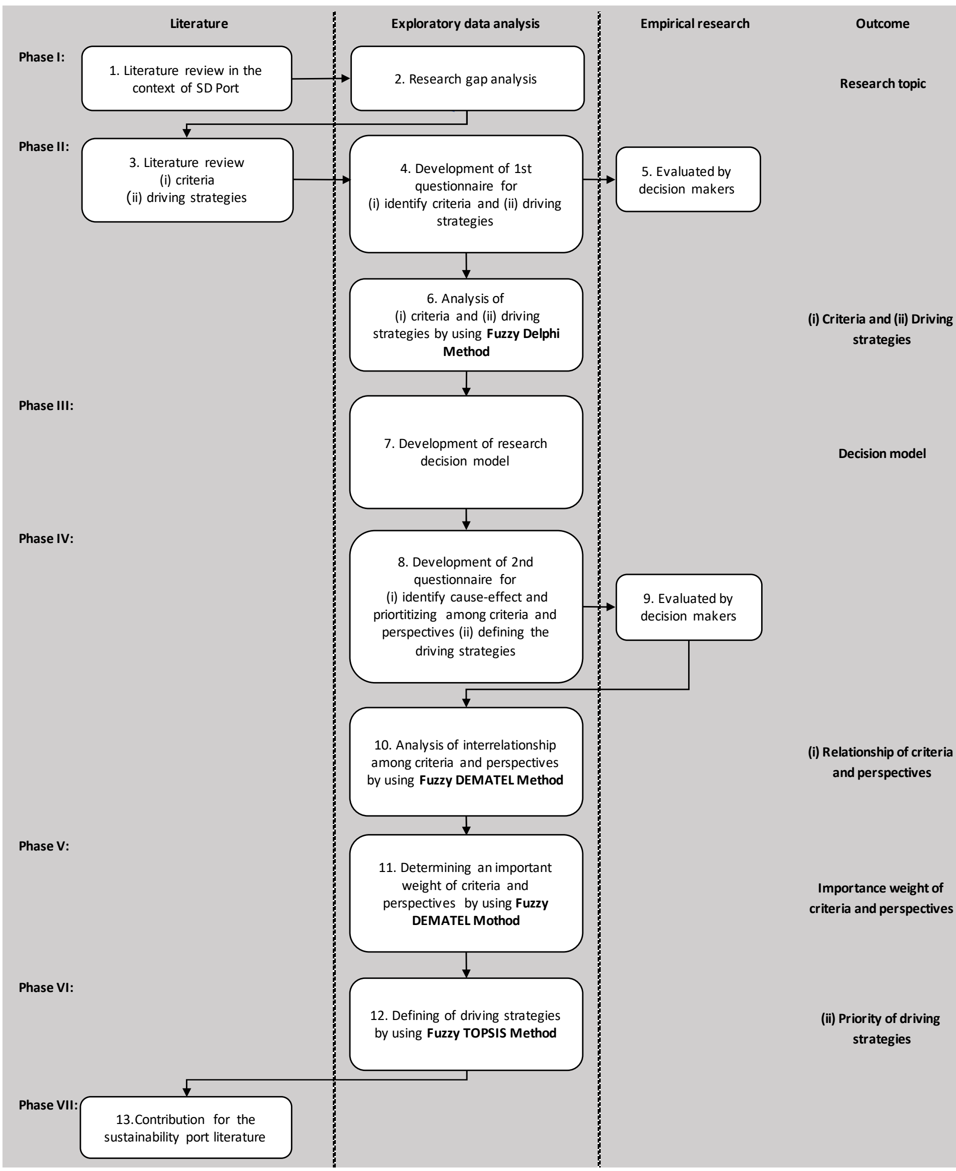
5 obtaining the importance weights of perspectives/criteria

6 prioritising strategies to drive sustainable RO/RO port development

7 providing contributions for the sustainability port literature.

The proposed framework is depicted in Figure 3.

Figure 3 The proposed framework for driving the sustainable RO/RO port development



5 Problem description

The empirical case for this study is one of the largest RO/RO ports in Thailand, located at LCP authority in the eastern part of Thailand. This RO/RO port is managed by a private organisation. The service capacity of the port provides 1.2 million vehicles per year and up to 80,000 deadweight tonnage vessels. Since Thai government promotes the automotive industry as a major production based in central of Asia. This port is therefore important in driving an export of completely built-up vehicles for the country's automotive sector. The concept of sustainable development has become a global agenda for entrepreneurs around the world, which challenges port authorities to manage their ports sustainably to take benefit for the sustainable competitive advantages.

In addition, the sustainable development is a policy from RO/RO port's top management. However, the managerial staffs of the case study have no clear picture of how to properly prioritise driving strategies. In this regard, this proposed framework can assist them to implement such strategies step by step. To do this, a group of decision makers with more than ten years of professional experience, knowledge and expertise in port management or related fields is formed. The decision makers comprised of nine managerial staffs: including four from Port Authority of Thailand (PAT), one from Marine Department, three from RO/RO port operation, and one academician from a university. Since few scholars have done research on RO/RO port operations, only one academician is selected as an expert in this study. Details of the qualifications of nine decision makers are shown in Table A1.

6 Results

6.1 Phase I: identifying the perspectives/criteria and driving strategies

Through a comprehensive literature review and port development policy, 34 criteria under four perspectives and four driving strategies for port sustainability are identified, as shown in Table 1 and Table 2, respectively.

6.2 Phase II: selecting the criteria and driving strategies

Due to the lack of RO/RO port sustainability from the literature, the selection of criteria and driving strategies is done through expert opinion. The experts (defined in Table A1) are invited to review criteria and driving strategies in Table 1 and Table 2, respectively. FDM (described in Section 3.1.3) is employed to screen the criteria and driving strategies to assess a sustainable RO/RO port development. Firstly, the experts provide a rating score for evaluating the suitability of each criterion and driving strategies based on the questionnaires. Secondly, data gathered from experts are calculated for the conservative and optimistic values of each criterion and driving strategies. Any data are outside two standard deviations, which were removed from consideration. For each criterion and driving strategies, it is computed for three values of conservative cluster, i.e., minimum (C_l^i), geometric mean (C_m^i), and maximum (C_u^i), as well as three values of positive cluster, i.e., minimum (P_l^i), geometric mean (P_m^i), and maximum (P_u^i). Subsequently, the consensus significant value (G^i) for each criterion and driving strategies is calculated to check the consistent of experts' opinion using either equation (8) or equation (9), depending on FDM conditions. In this study, the threshold value (α) is set as 8. Therefore, the criteria and driving strategies with G^i values less than 8 is a reject. As it can be seen from the results in Table 4 and Table 5, 14 criteria and three driving strategies are accepted to use in this study.

6.3 Phase III: Developing a decision model

Based on the results from FDM in Phase II, a decision model for prioritising sustainable RO/RO port development driving strategies is developed as depicted in Figure 4.

Figure 4 A decision model for prioritising sustainable RO/RO port development driving strategies

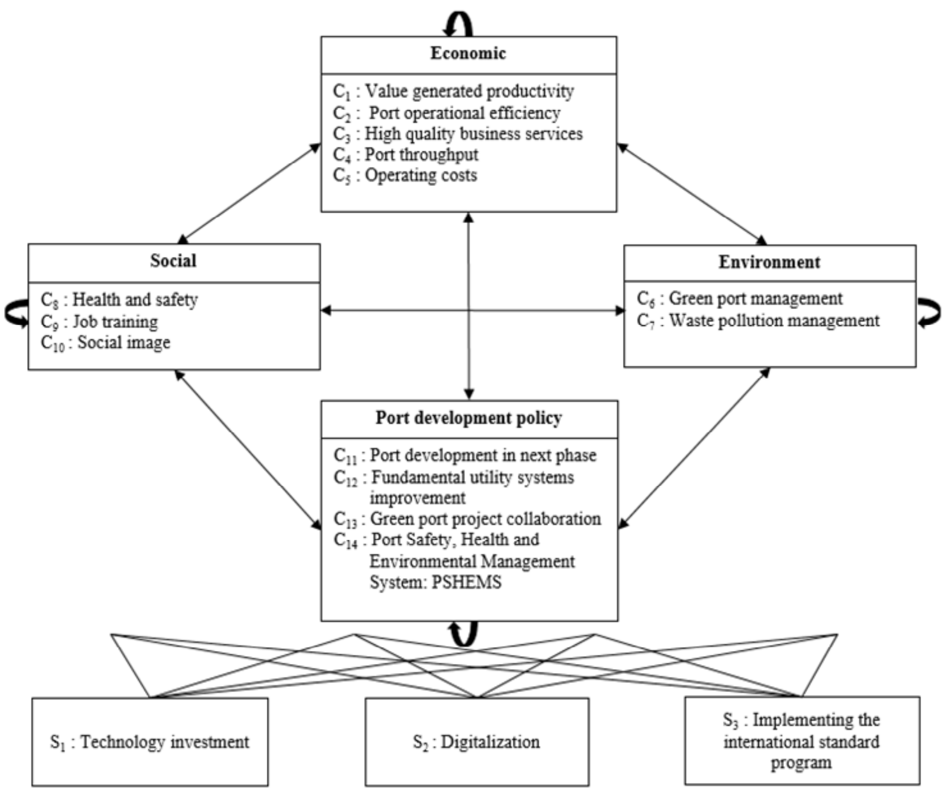


Table 4 The results of criteria selection

Criteria	*Conservative value*		*Positive value*		*Geometric mean*		*Consensus significance value*	*Decision*
	C_l	C_u	P_l	P_u	G_l	G_u		
Foreign direct investment	2	4	6	8	3.07	7.23	6.69	Rejected
Value generated productivity	3	5	6	9	4.36	7.37	8.05	*Accepted*
Port operational efficiency	3	7	8	10	4.61	9.40	9.31	*Accepted*
High quality business services	3	7	8	10	4.95	8.95	9.43	*Accepted*
Benefits from external stakeholders	2	3	5	9	2.45	7.15	6.03	Rejected
Port development funding	2	4	7	9	2.70	7.78	6.59	Rejected
Port infrastructure construction	2	5	8	9	3.33	8.16	7.41	Rejected
Port throughput	2	5	9	10	3.42	9.56	8.20	*Accepted*
GDP	2	3	5	8	2.35	6.65	5.68	Rejected
Operating costs	3	6	7	9	4.19	7.80	8.09	*Accepted*
Cost-efficiency	3	6	7	9	3.89	7.63	7.71	Rejected
Water pollution management	3	6	6	8	3.71	7.59	7.50	Rejected
Air pollution management	2	4	6	8	3.09	7.53	6.85	Rejected
Energy and resource usage	3	4	6	8	3.26	7.53	7.02	Rejected
Noise pollution	3	4	6	8	3.63	7.46	7.37	Rejected
Green port management	3	6	7	8	4.16	7.70	8.01	*Accepted*
Ecosystem and habitats	3	4	6	8	3.37	7.46	7.10	Rejected
Soil pollution management	2	4	7	8	2.93	7.70	6.78	Rejected
Waste pollution management	4	6	7	9	5.18	7.96	9.16	*Accepted*

Table 4 The results of criteria selection (continued)

Criteria	*Conservative value*		*Positive value*		*Geometric mean*		*Consensus significance value*	*Decision*
	C_l	C_u	P_l	P_u	G_l	G_u		
Green construction and facilities	3	4	7	8	3.46	7.56	7.24	Rejected
Health and safety	3	7	8	9	5.56	8.27	9.69	*Accepted*
Job generation	3	5	6	8	3.92	7.11	7.47	Rejected
Job training	3	6	7	8	5.00	7.58	8.79	*Accepted*
Public relations	3	4	6	8	3.57	7.11	7.12	Rejected
Gender equality	2	4	6	8	2.70	6.95	6.17	Rejected
Social image	3	6	7	9	4.45	7.54	8.22	*Accepted*
Quality of living environment	3	4	6	8	3.57	7.09	7.11	Rejected
Social participation	3	5	6	9	3.56	7.35	7.23	Rejected
Port development in next phase	4	6	8	10	4.44	9.12	9.00	*Accepted*
Fundamental utility systems improvement	3	7	8	9	5.01	8.49	9.25	*Accepted*
Dredging waterway	2	7	8	10	3.32	9.23	7.94	Rejected
Increase the volume of transit and transhipment cargoes via LCP	2	4	5	9	2.78	7.25	6.41	Rejected
Green port project collaboration	3	6	7	9	4.45	7.98	8.44	*Accepted*
Port Safety, Health and Environmental Management System (PSHEMS)	3	6	8	9	4.23	8.59	8.52	*Accepted*

Table 5 The result of driving strategies selection

Driving strategies	*Conservative value*		*Positive value*		*Geometric mean*		*Consensus significance value*	*Decision*
	Cl	*Cu*	*Pl*	*Pu*	*Gl*	*Gu*		
Technology investment	3	6	9	9	4.05	9.00	8.55	*Accepted*
Alternative energy	2	4	7	9	2.74	7.78	6.63	Rejected
Digitalisation	3	6	8	9	4.05	8.49	8.30	*Accepted*
Implementing the international standard program	3	6	8	9	4.48	8.39	8.67	*Accepted*

Table 6 The cause-and-effect group of perspectives/criteria and importance weights

Perspectives/criteria	*Type of criteria*	r_i	c_j	$r_i + c_j$	$r_i - c_j$	*Group*	*Weight*	*Rank*
Economic perspective (P_1)	-	*10.25*	*10.57*	*20.82*	*–0.32*	*Effect*	*0.246*	*3*
Value generated productivity (C_1)	Benefit	9.09	9.82	18.91	–0.73	Effect	0.072	5
Port operational efficiency (C_2)	Benefit	9.44	10.13	19.58	–0.69	Effect	0.074	3
High quality business services (C_3)	Benefit	9.30	10.11	19.41	–0.81	Effect	0.074	3
Port throughput (C_4)	Benefit	9.63	10.00	19.63	–0.38	Effect	0.075	2
Operating costs (C_5)	Cost	9.33	9.83	19.16	–0.50	Effect	0.073	4
Environment perspective (P_2)		*10.24*	*9.88*	*20.12*	*0.35*	*Cause*	*0.238*	*4*
Green port management (C_6)	Benefit	9.90	9.52	19.42	0.38	Cause	0.074	3
Waste pollution management (C_7)	Benefit	9.12	9.25	18.38	–0.13	Effect	0.070	7
Social perspective (P_3)		*10.53*	*10.85*	*21.38*	*–0.32*	*Effect*	*0.252*	*2*
Health and safety (C_8)	Benefit	9.88	8.85	18.72	1.03	Cause	0.071	6
Job training (C_9)	Benefit	8.89	7.79	16.68	1.11	Cause	0.063	10
Social image (C_{10})	Benefit	9.64	10.37	20.00	–0.73	Effect	0.076	1
Port development policy perspective (P_4)		*11.34*	*11.04*	*22.38*	*0.29*	*Cause*	*0.264*	*1*
Port development in next phase (C_{11})	Benefit	9.52	8.70	18.21	0.82	Cause	0.069	8
Fundamental utility systems improvement (C_{12})	Benefit	9.00	8.63	17.64	0.37	Cause	0.067	9
Green port project collaboration (C_{13})	Benefit	9.42	8.94	18.36	0.48	Cause	0.070	7
Port Safety, Health and Environmental Management System (PSHEMS) (C_{14})	Benefit	9.49	9.70	19.19	–0.21	Effect	0.073	4

6.4 Phase IV: Analysing the interrelationship between perspectives/criteria

The interrelationships between perspectives/criteria are analysed by deploying fuzzy DEMATEL approach. Using the linguistic terms in Table 3, experts are assigned to evaluate the influence between a pair of criteria/perspectives through questionnaires. The linguistic terms gathered from each questionnaire is transformed into corresponding TFNs and then a direct-relation matrix is constructed. Next, all elements in each direction-relation matrix are converted to crisp values using equations (10)–(16). Subsequently, all crisped direction-relation matrices are aggregated into a 14 × 14 single matrix using equation (17) and then normalised using equations (18)–(19). The normalised direct-relation matrix of criteria and perspectives are depicted in Table A2 and Table A3, respectively. The total-relation matrix can be obtained using equation (20). Also, the total-relation matrix of criteria and perspectives are depicted in Table A4 and Table A5, respectively. Thereafter, the sum of row values (r_i) and the sum of column values (c_j) in the total-relation matrix are calculated by using equation (21) and equation (22), respectively. The $r_i + c_j$ values are calculated to determine the important degrees of the criteria/perspectives (higher $r_i + c_j$ value be more important degree). The $r_i - c_j$ values are calculated to classify the criteria/perspectives to cause group ($r_i - c_j > 0$) or effect group ($r_i - c_j < 0$). The cause-and-effect group of criteria and perspectives are shown in Table 6, Figure 5 and Figure 6, respectively. Then, the threshold value (δ) is computed using equation (23). The results are $\gamma = 0.672$ for criteria and $\gamma = 2.647$ for perspectives. Based on equation (23), each value in the total-relation matrix is greater than δ, indicating that there is an interrelationship between the element in row and the element in column, otherwise there is no interaction. The direction of the arrow edges connecting a pair of elements indicates the interrelationship between the two elements. A visualisation of the interrelationship between the perspective/criteria is shown in Figure 7.

Figure 5 The cause-and-effect group of criteria (see online version for colours)

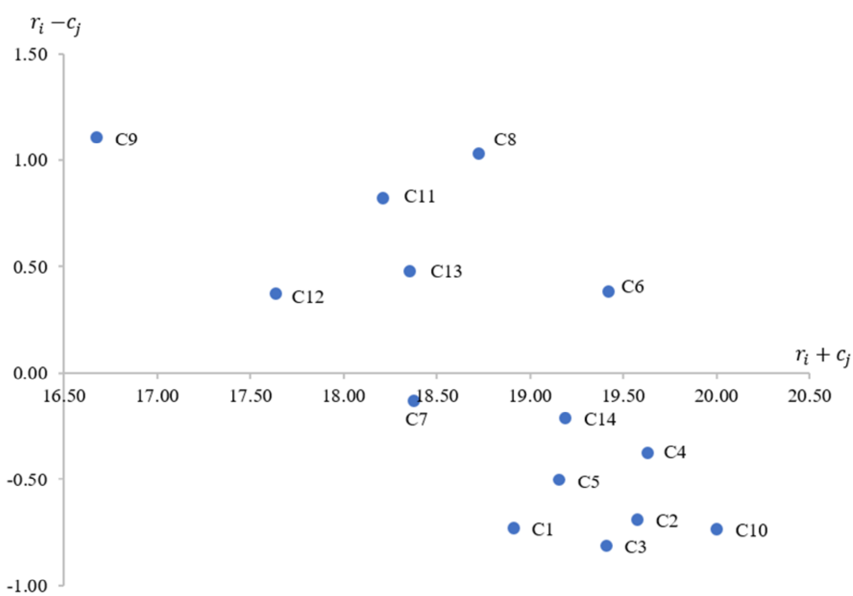


Figure 6 The cause-and-effect group of perspective (see online version for colours)

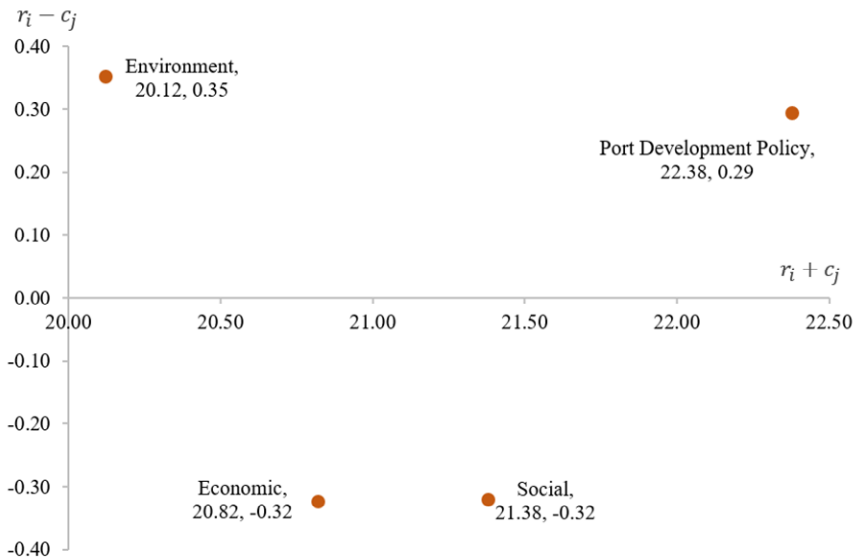
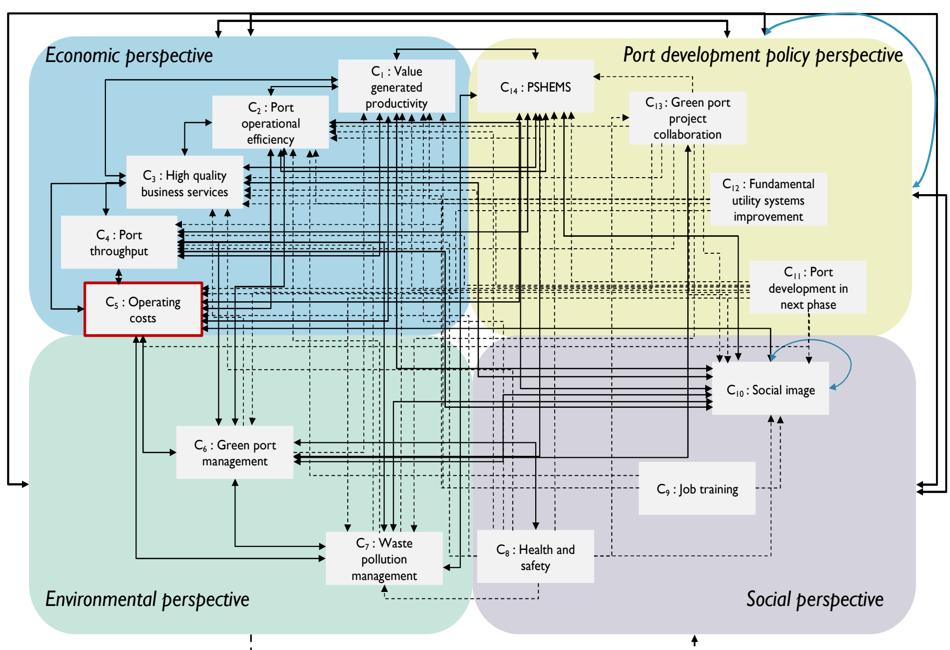


Figure 7 The interrelationship between the perspective/criteria (see online version for colours)



6.5 Phase V: Obtaining the importance weights of criteria

The importance weights of criteria can be obtained by equations (24)–(25), as shown in Table 6, showing that C_{10} (0.076) > C_4 (0.075) > C_2 = C_3 = C_6 (0.074) > C_5 = C_{14} (0.073) > C_1 (0.072) > C_8 (0.071) > C_7 = C_{13} (0.070) > C_{11} (0.069) > C_{12} (0.067) > C_9 (0.063).

6.6 Phase VI: Prioritising strategies to drive sustainable RO/RO port development

The fuzzy TOPSIS method described in Section 3.1.5 is exploited to prioritise the strategies to drive sustainable RO/RO port development. By using linguistic terms in Table 3, experts provide the rating scores for driving strategies namely 'technology investment' (S1), 'digitalisation' (S2), and 'implementing the international standard program' (S3) based on criteria through questionnaires. Linguistic terms from questionnaires are converted to TFNs and aggregated into a fuzzy decision matrix using equation (26). The fuzzy decision matrix is normalised using either equation (27) or equation (28) depending on type of criterion, the result is presented in Table 7. In this study, all criteria are categorised as benefit criteria, excepted operating costs (C_5) are defined as cost criteria. Equation (29) is used to calculate the weighted normalised fuzzy decision matrix, which these weights are obtained from fuzzy DEMATEL method in Table 6, as resulted in Table 8. Subsequently, FPIS (A^*) and FNIS (A^-) are determined by equations (30)–(31), as shown in Table 9. Next, the distance from each element in the weighted normalised fuzzy decision matrix to FPIS (D_i^*) and FNIS (D_i^-) are calculated using equations (32)–(33), respectively, as demonstrated in Tables 10–11. Finally, the closeness coefficient (CC_i) is defined by equation (34) to prioritise sustainable RO/RO port development driving strategies, as displayed in Table 12. Based on the result shown in Figure 8, 'digitalisation' is identified as the most important driving strategy for the sustainable development of RO/RO port, followed by 'technology investment' and 'implementing the international standard program', with the closeness coefficient (CC_i) value as 1.0809, 1.0556, and 1.0259, respectively.

Table 7 The normalised fuzzy decision matrix $(\tilde{R})$

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
S_1	(0.50, 0.81, 1.00)	(0.50, 0.89, 1.00)	(0.50, 0.89, 1.00)	(0.25, 0.81, 1.00)	(0.50, 0.29, 0.25)	(0.00, 0.58, 1.00)	(0.00, 0.56, 1.00)
S_2	(0.50, 0.78, 1.00)	(0.50, 0.89, 1.00)	(0.50, 0.86, 1.00)	(0.25, 0.78, 1.00)	(0.50, 0.29, 0.25)	(0.00, 0.53, 1.00)	(0.00, 0.47, 1.00)
S_3	(0.50, 0.83, 1.00)	(0.50, 0.86, 1.00)	(0.50, 0.86, 1.00)	(0.25, 0.75, 1.00)	(1.00, 0.33, 0.25)	(0.00, 0.78, 1.00)	(0.00, 0.75, 1.00)

	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}
S_1	(0.00, 0.58, 1.00)	(0.00, 0.61, 1.00)	(0.50, 0.81, 1.00)	(0.25, 0.81, 1.00)	(0.00, 0.67, 1.00)	(0.00, 0.50, 1.00)	(0.00, 0.53, 1.00)
S_2	(0.00, 0.53, 1.00)	(0.00, 0.58, 1.00)	(0.25, 0.78, 1.00)	(0.25, 0.78, 1.00)	(0.00, 0.61, 1.00)	(0.00, 0.47, 1.00)	(0.00, 0.53, 1.00)
S_3	(0.00, 0.72, 1.00)	(0.00, 0.61, 1.00)	(0.50, 0.89, 1.00)	(0.25, 0.83, 1.00)	(0.00, 0.78, 1.00)	(0.00, 0.69, 1.00)	(0.25, 0.81, 1.00)

Table 8 The weighted normalised fuzzy decision matrix $(\tilde{V})$

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
S_1	(0.04, 0.06, 0.07)	(0.04, 0.07, 0.07)	(0.04, 0.07, 0.07)	(0.02, 0.06, 0.07)	(0.04, 0.02, 0.02)	(0.00, 0.04, 0.07)	(0.00, 0.04, 0.07)
S_2	(0.04, 0.06, 0.07)	(0.04, 0.07, 0.07)	(0.04, 0.06, 0.07)	(0.02, 0.06, 0.07)	(0.04, 0.02, 0.02)	(0.00, 0.04, 0.07)	(0.00, 0.03, 0.07)
S_3	(0.04, 0.06, 0.07)	(0.04, 0.06, 0.07)	(0.04, 0.06, 0.07)	(0.02, 0.06, 0.07)	(0.07, 0.02, 0.02)	(0.00, 0.06, 0.07)	(0.00, 0.05, 0.07)
	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}
S_1	(0.00, 0.04, 0.07)	(0.00, 0.04, 0.06)	(0.04, 0.06, 0.08)	(0.02, 0.06, 0.07)	(0.00, 0.04, 0.07)	(0.00, 0.03, 0.07)	(0.00, 0.04, 0.07)
S_2	(0.00, 0.04, 0.07)	(0.00, 0.04, 0.06)	(0.02, 0.06, 0.08)	(0.02, 0.05, 0.07)	(0.00, 0.04, 0.07)	(0.00, 0.03, 0.07)	(0.00, 0.04, 0.07)
S_3	(0.00, 0.05, 0.07)	(0.00, 0.04, 0.06)	(0.04, 0.07, 0.08)	(0.02, 0.06, 0.07)	(0.00, 0.05, 0.07)	(0.00, 0.05, 0.07)	(0.02, 0.06, 0.07)

Table 9 The fuzzy positive ideal solution: FPIS, (A^*) and fuzzy negative ideal solution: FNIS, (A^-)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
(A^*)	(0.04, 0.06, 0.07)	(0.04, 0.07, 0.07)	(0.04, 0.07, 0.07)	(0.02, 0.06, 0.07)	(0.04, 0.02, 0.02)	(0.00, 0.06 0.07)	(0.00, 0.05, 0.07)
(A^-)	(0.04, 0.06, 0.07)	(0.04, 0.06, 0.07)	(0.04, 0.06, 0.07)	(0.02, 0.06, 0.07)	(0.07, 0.02, 0.02)	(0.00, 0.04, 0.07)	(0.00, 0.03, 0.07)
	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}
(A^*)	(0.00, 0.05, 0.07)	(0.00, 0.04, 0.06)	(0.04, 0.07, 0.08)	(0.02, 0.06, 0.07)	(0.00, 0.05, 0.07)	(0.00, 0.05, 0.07)	(0.02, 0.06, 0.07)
(A^-)	(0.00, 0.04, 0.07)	(0.00, 0.04, 0.06)	(0.02, 0.06, 0.08)	(0.02, 0.05, 0.07)	(0.00, 0.04, 0.07)	(0.00, 0.03, 0.07)	(0.00, 0.04, 0.07)

Figure 8 Prioritisation of driving strategies by closeness coefficient (CC_i) (see online version for colours)

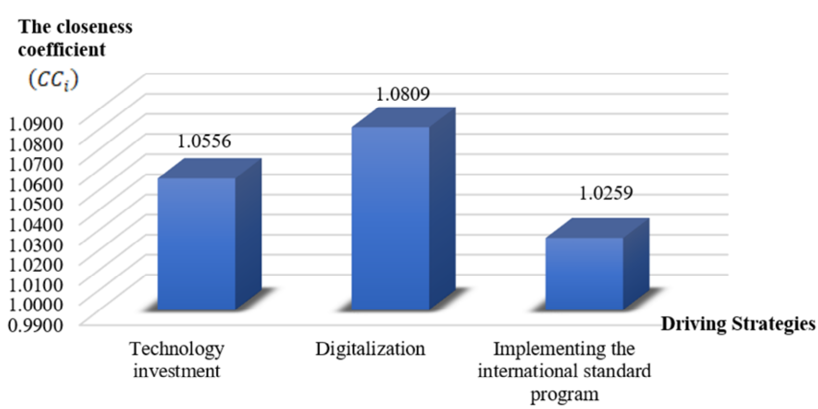


Table 10 The distance from fuzzy positive ideal solution (D_i^*)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
S_1	0.0011	0.0000	0.0000	0.0000	0.0000	0.0083	0.0078
S_2	0.0023	0.0000	0.0012	0.0012	0.0000	0.0106	0.0112
S_3	0.0000	0.0012	0.0012	0.0024	0.0211	0.0000	0.0000
	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}
S_1	0.0057	0.0000	0.0037	0.0011	0.0043	0.0078	0.0157
S_2	0.0080	0.0010	0.0120	0.0022	0.0064	0.0089	0.0157
S_3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 11 The distance from fuzzy negative ideal solution (D_i^-)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
S_1	0.0011	0.0012	0.0012	0.0024	0.0211	0.0024	0.0034
S_2	0.0000	0.0012	0.0000	0.0012	0.0211	0.0000	0.0000
S_3	0.0023	0.0000	0.0000	0.0000	0.0000	0.0106	0.0112
	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}
S_1	0.0023	0.0010	0.0110	0.0011	0.0021	0.0011	0.0000
S_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S_3	0.0080	0.0010	0.0120	0.0022	0.0064	0.0089	0.0157

Table 12 Prioritisation of driving strategies by closeness coefficient (CC_i)

Driving strategies	(D_i^*)	(D_i^-)	CC_i	*Rank*
S_1	0.0556	0.0514	1.0556	2
S_2	0.0809	0.0235	1.0809	1
S_3	0.0258	0.0785	1.0258	3

7 Discussion

In this study, a decision model for prioritising driving strategies for RO/RO port sustainability development is developed, composing of 14 criteria under four perspectives and three driving strategies, as shown in Figure 4. By applying fuzzy DEMATEL approach, criteria are divided into cause-and-effect group. Six criteria namely ‘green port management’, ‘health and safety’, ‘job training’, ‘port development in next phase’, ‘fundamental utility systems improvement’, ‘green port project collaboration’ are classified to cause group. Meanwhile eight criteria, i.e., ‘value generated productivity’, ‘port operational efficiency’, ‘high quality business services’, ‘port throughput’, ‘operating costs’, ‘waste pollution management’, ‘social image’ and ‘PSHEMS’ are classified to effect group. Considering the $r_i + c_j$ values of perspectives, ‘port development policy’ has the highest $r_i + c_j$ score of 22.38, which is classified in the cause group. Therefore, it is the most important perspective of sustainable RO/RO port development. This finding is contrast with Lu et al. (2016) and Oh et al. (2018), that identified economic perspective is the most crucial for container ports in developing countries. It may arise from 'port development policies' perspective is taken into account and combined with TBL in the proposed framework. For the RO/RO port in this case study, the sustainable development is under the port development plan. Therefore, the success of sustainable development highly will rely on the effectiveness of the port development plan implementation.

In view of the relative importance weight, the finding for sustainable development of RO/RO port indicates that 'social image' is the most important criteria, followed by 'port throughput', 'port operational efficiency', 'high quality business service' and 'green port management'. Compared to Oh et al. (2018), it is stated that 'job generation', 'waste pollution management', and 'water pollution management' are the most significant for container port operation. In consideration of social image, Xiao and Lam (2017) remarked that 'social image' regarding to environmental friendliness and quality of the living environment are major drivers that will lead a city port to economic benefits. It also hints that RO/RO port operators should provide a higher level of social image to attract the quality customers and maintain loyal customers, resulting in increasing port throughput. From port throughput viewpoint, most port operators use port throughput as the fundamental of port efficiency assessment that contributes to port economic (Cong et al., 2020). In terms of port operational efficiency, this finding may support a study of Iannone et al. (2016) pointing out that operational efficiency is crucial to the TBL interrelation of sustainable port development. This is because port congestion related to operational efficiency means the amount of machinery emissions, employee safety as well as logistics costs. Thus, the sustainability in RO/RO port operators should be inevitably considered at the port operational efficiency.

In terms of driving strategies, the finding of this research indicates that digitalisation is the most effective strategy for enhancing sustainable development in RO/RO port. The adoption of digital platforms in operational processes can push ports closer to the SDGs. According to a study by Di Vaio and Varriale (2020), the use of digital platforms can reduce paperwork and optimise the entire supply chain of port operations. Since most RO/RO ports in Thailand use fragmented digital platforms and many operation processes still use paper in their transactions. Thus, it hinders the real-time exchange of information between partners in the supply chain. In order to achieve sustainable RO/RO port development, this research recommends that Thai Port Authority should give the first priority for digital port transformation.

8 Conclusions and future research

The move towards sustainability has become compulsory for all industries and the port sector is no exception. Sustainable development of port not only enhances the competitiveness and competitive advantages, but it also improves operational processes. Basically, the success of sustainable port development requires the implementation of the right driving strategies from port operators. However, it is difficult to implement all driving strategies at the same time due to limited resources and time. Thus, it requires to prioritise the driving strategies in the appropriate manner. Although much existed research has been devoted to port development of sustainable containers. But it is rather less attention on RO/RO port. Additionally, there is also scarce research that is examined in the context of strategy-driven implementation priorities. To bridge the gap, this study proposes a framework to prioritise driving strategies for sustainable RO/RO port development. In this study, the integrated MCDM methods based on the fuzzy sets are applied to address this issue. The proposed FMCDM framework consists of fuzzy Delphi, fuzzy DEMATEL, and fuzzy TOPSIS. The proposed framework employs one of the largest RO/RO ports in Thailand as a case study. The findings in this study could guide the PAT in paving the way to implement the driving strategies in a stepwise manner under time and resource constraints. The study also contributes to the existing literature on sustainable port development in MCDM domain as:

1 considering the perspective of port development policy in conjunction with the TBLs (economic, environmental, and social)

2 considering the interrelation between assessment factors (critical success factors: CSFs)

3 adapting the proposed framework to other types of ports by aiming to bring strategies towards sustainable port development.

According to future research recommendations, comparative studies should be conducted using a combination of other MCDM methods. Additionally, this problem can be solved under different fuzzy environments such as type 2 fuzzy sets, and hesitant fuzzy sets.

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Appendix

Table A1 The demographic information of decision makers

Demographic information	*Numbers of decision makers*
Place of work	
Port Authority of Thailand	4
Marine department	1
Private port operation	3
University	1
Position	
Administrator	2
Manager	5
Assistant manager	1
Academician	1
Experience	
10–15 years	3
16–21 years	4
Above 22 years	2
Education	
Bachelor's degree	2
Master's degree	7
Gender	
Male	7
Female	2

Table A2 The normalised direct-relation matrix $(\tilde{D})$ of criteria

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_1	0.000	0.079	0.082	0.079	0.076	0.060	0.057
C_2	0.082	0.000	0.090	0.090	0.087	0.057	0.057
C_3	0.085	0.090	0.000	0.087	0.082	0.056	0.060
C_4	0.079	0.093	0.090	0.000	0.082	0.065	0.062
C_5	0.076	0.082	0.071	0.085	0.000	0.065	0.057
C_6	0.073	0.065	0.065	0.071	0.071	0.000	0.076
C_7	0.062	0.051	0.054	0.062	0.065	0.082	0.000
C_8	0.062	0.073	0.079	0.065	0.071	0.079	0.079
C_9	0.068	0.076	0.079	0.060	0.065	0.068	0.071
C_{10}	0.071	0.071	0.079	0.082	0.073	0.079	0.076
C_{11}	0.082	0.076	0.076	0.090	0.079	0.073	0.068
C_{12}	0.068	0.085	0.076	0.076	0.068	0.062	0.062
C_{13}	0.071	0.065	0.062	0.060	0.062	0.093	0.082
C_{14}	0.065	0.071	0.071	0.054	0.062	0.079	0.085

Table A2 The normalised direct-relation matrix $(\tilde{D})$ of criteria (continued)

Criteria	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}
C_1	0.056	0.051	0.079	0.065	0.060	0.060	0.068
C_2	0.065	0.054	0.090	0.068	0.057	0.046	0.065
C_3	0.062	0.059	0.085	0.065	0.054	0.046	0.062
C_4	0.062	0.048	0.076	0.082	0.071	0.048	0.068
C_5	0.062	0.057	0.065	0.071	0.076	0.062	0.068
C_6	0.073	0.065	0.087	0.068	0.068	0.090	0.082
C_7	0.067	0.059	0.082	0.057	0.059	0.087	0.085
C_8	0.000	0.068	0.087	0.054	0.071	0.079	0.085
C_9	0.065	0.000	0.076	0.048	0.045	0.062	0.068
C_{10}	0.070	0.062	0.000	0.068	0.051	0.073	0.071
C_{11}	0.059	0.040	0.051	0.000	0.079	0.071	0.071
C_{12}	0.065	0.045	0.057	0.071	0.000	0.057	0.071
C_{13}	0.067	0.062	0.082	0.054	0.068	0.000	0.076
C_{14}	0.073	0.068	0.082	0.057	0.068	0.079	0.000

Table A3 The normalised direct-relation matrix $(\tilde{D})$ of perspectives

Perspective	*Economic*	*Environment*	*Social*	*Port development policy*
Economic	0.000	0.215	0.322	0.334
Environment	0.251	0.000	0.298	0.322
Social	0.298	0.298	0.000	0.310
Port development policy	0.357	0.321	0.322	0.000

Table A4 The total-relation matrix $(\tilde{T})$ of criteria

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_1	0.618	0.711	0.712	0.703	0.689	0.654	0.635
C_2	0.718	0.663	0.744	0.738	0.723	0.674	0.657
C_3	0.710	0.735	0.651	0.725	0.709	0.665	0.650
C_4	0.728	0.761	0.757	0.668	0.731	0.694	0.674
C_5	0.705	0.730	0.719	0.724	0.634	0.674	0.650
C_6	0.740	0.754	0.753	0.750	0.738	0.652	0.705
C_7	0.678	0.687	0.688	0.689	0.680	0.677	0.585
C_8	0.729	0.760	0.763	0.744	0.737	0.724	0.706
C_9	0.667	0.694	0.695	0.671	0.666	0.649	0.635
C_{10}	0.720	0.741	0.747	0.742	0.724	0.708	0.687
C_{11}	0.722	0.738	0.736	0.742	0.721	0.694	0.672
C_{12}	0.675	0.710	0.701	0.694	0.676	0.651	0.634
C_{13}	0.705	0.720	0.716	0.707	0.698	0.706	0.679
C_{14}	0.705	0.730	0.729	0.707	0.703	0.698	0.686

Table A4 The total-relation matrix $(\tilde{T})$ of criteria (continued)

Criteria	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}
C_1	0.609	0.538	0.725	0.608	0.599	0.617	0.673
C_2	0.638	0.559	0.760	0.632	0.617	0.626	0.694
C_3	0.627	0.556	0.745	0.621	0.606	0.618	0.682
C_4	0.647	0.564	0.761	0.655	0.641	0.640	0.708
C_5	0.628	0.555	0.729	0.627	0.628	0.634	0.689
C_6	0.674	0.594	0.790	0.659	0.654	0.695	0.740
C_7	0.622	0.548	0.730	0.602	0.601	0.646	0.690
C_8	0.604	0.596	0.789	0.645	0.655	0.684	0.741
C_9	0.605	0.479	0.709	0.581	0.574	0.608	0.660
C_{10}	0.655	0.577	0.691	0.643	0.624	0.664	0.712
C_{11}	0.638	0.550	0.731	0.573	0.642	0.653	0.704
C_{12}	0.611	0.528	0.699	0.608	0.538	0.609	0.669
C_{13}	0.640	0.566	0.751	0.617	0.625	0.583	0.703
C_{14}	0.649	0.575	0.757	0.624	0.630	0.661	0.637

Table A5 The total-relation matrix $(\tilde{T})$ of perspectives

Perspective	*Economic*	*Environment*	*Social*	*Port development policy*
Economic	2.392	2.414	2.696	2.746
Environment	2.589	2.233	2.679	2.736
Social	2.685	2.525	2.519	2.801
Port development policy	2.907	2.712	2.956	2.760