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Application of Delphi-AHP Method in Establishing Emission Control Area in Vietnam Seaport Group No. 4

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Abstract

Emission control areas (ECA), are sea areas where ships operate within must use low sulfur below 0.10% mass/mass. Concept of ECA is introduced by International Maritime Organization (IMO) and applied in the Baltic sea from 2005 with the target reduce air pollution and enhance quality of life. Although ECA criteria has been instructed in International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI but member state should follow but not limit the propose criteria. By using a combined Delphi and Analytical Hierarchy Process (AHP) method, a set of criteria for establishing ECA suitable for the conditions of Vietnam seaport group no. 4 (Southeast Vietnam seaport) has been developed through expert opinion survey. In order of priority from high to low weight, the criteria include: (i) Human population; (ii) Human health; (iii) Vessel traffic density; (iv) Environmental sensitivity; (v) Seaport development. The set of criteria for establishing ECA is necessary to ensure the quality of life and human health while maintaining seaports operation for socio-economic development. The result of study is not only valuable reference information for considering establishment of ECA at Vietnam seaport group no. 4 but also for others seaport group shared similar characteristic.

Keywords: Emission control area; Sea port criteria; Vietnam seaport; Air pollution

1. Introduction

Owing to the advantages of marine transport, seagoing vessels facilitate approximately 90% of global trade. Going along with the benefits of transportability is air pollution concerns. International Maritime Organization (IMO) has come up with IMO 2020 to enforce vessels comply with the sulphur limit in Emission control areas (ECA) at 0.10% mass by mass (m/m) and outside ECA at 0.50% m/m from 01/01/2020 (International Maritime Organization, 2019). This requirement is expected to bring positive benefit on human health (reduce 570.000 premature deaths in period 2020 - 2050) (International Maritime Organization, 2019).

According to IMO, there are 5 ECA in the world (International Maritime Organization, 2023). Member States of International Convention for the Prevention of Pollution from Ships (MARPOL) shall establish ECA as stipulated in Article 14 of Annex VI of MARPOL (International Maritime Organization, 2023). The basic criteria including the following contents:

(i) a description of the human populations and environmental areas at risk from the impacts of ship emissions; (ii) the nature of the ship traffic in the proposed ECA, including the patterns and density of such traffic (International Maritime Organization, 2022). Beside of recognized ECA such as Baltic sea, North Sea, United States Caribbean Sea, Mediterranean Sea, there are more new ECA has been studied and proposed to meet the need of member states in different criteria.

In term of ECA scale, Qin *et al.* (2019) analyzed the geographic scope of the four ECA and compared them to the actual situation of China's coastal regions. The research showed that within 12 nautical miles, 24 nautical miles, 50 nautical miles, and 100 nautical miles, emissions from shipping activities reduce 67%, 75%, 82%, and 88%, respectively. Zhou *et al.* (2023) examined the impact of the implementation of the ECA policy on air quality at the Waigaoqiao wharf, The research used a regression discontinuity model to analyze the effect of the policy, which involved a switch from high to low sulfur fuel, on SO_2 concentrations at both the local and regional levels from 2018 to 2021. The results showed that the ECA policy was effective in improving air quality at both the local and regional scales.

In term of health impact, Mwase *et al.* (2020) implemented the regulation limiting sulfur from 1.0% to 0.1% m/m in ECA from 2015 would reduce premature deaths in Sweden by 16% to 55%. The research investigated the effects on population exposure to particles ($PM_{2.5}$) from shipping and estimated related morbidity and mortality in Sweden's 21 counties at different spatial resolutions by using three exposure models.

In term of vessel traffic density, Lee *et al.* (2020) used automatic identification system data to estimate non-greenhouse gas emissions from ships in the Port of Incheon. The research discussed the need for long-term policies, such as the designation of a local ECA and the establishment of an emission management platform to reduce ship-source emissions.

Being one of the busiest group of seaport in Vietnam, seaport group no. 4 accounts for 43% - 61% total cargo through Vietnam seaport (Vietnam Maritime Administration, 2022). In order to manage air quality, Prime Minister has promulgated Decision no. 1973/QD-TTg date 23/11/2021 and strongly emphasized on responsibility for emission reduction in transport activities (Prime Minister, 2021). Among many proposed solutions to manage air quality, establishing ECA can be the most effective management tool, as it has been applied in many countries due to its feasibility for all relevant stakeholders (including competent authorities, shipping agencies, seaport operators, and public and private service sectors) to reduce emissions (especially SO_x) and improve air quality in the short term (Chang *et al.,* 2017). Therefore, this study aims to establish ECA in Vietnam seaport group no. 4 by using a combined Delphi and Analytical Hierarchy Process (AHP) method in establish ECA through survey.

2. Methodology

2.1 Study area

The study area is Vietnam seaport group no. 4 include 3 main seaports in Southeast Vietnam (Ho Chi Minh City seaport, Dong Nai seaport and Ba Ria - Vung Tau seaport) as figure 1.

Vietnam seaport group no. 4 has the natural advantage of a dense river system capable of connecting waterway transport to seaports and industrial clusters. According to a study by Ho Quoc Bang, which conducted an emissions inventory in Ho Chi Minh City in 2019, emissions from seaport contributed 16% of SO_2 emissions, 8% of NO_x emissions, and 4% of total suspended particulate (TSP) emissions, making seaport one of the city's major emission sources (Ho *et al.,* 2019).

2.1.1 Similar characteristic

Function:

Seaport group no. 4 plays an important role in serving the socio-economic development of the Southern region, inter-regional, and the whole country, transiting goods for the Kingdom of Cambodia and also has a deep sea port, international transit as well as satellite ports, cargo collection hubs for seaports in the region (Prime Minister, 2021).

Location:

The location of seaport group no. 4 is in the Southeast region of Vietnam, an area influenced by the characteristic monsoon equatorial climate. In addition, seaport group no. 4 also shares maritime navigation channels (Sai Gon - Vung Tau channel, Dong Nai channel cross Dong Nai seaport and Ho Chi Minh City seaport while Vung Tau - Thi Vai channel cross Dong Nai seaport and Vung Tau seaport) (OneOcean, 2025).

2.1.2 Comparison

Despite of sharing similar function, each of seaport in group no. 4 is different in term of human population distribution, environmental sensitivity, seaport development, vessel traffic density.

Vessel traffic density:

According to Vietnam Maritime Administration, total number of ships go through Ho Chi Minh City seaport is highest (Vietnam Maritime Administration, 2022). Vessel traffic density in Vietnam seaport group no.4 in 2022 is described in figure 2.

Environmental sensitivity:

Van Phuoc Nguyen identified Environmental sensitivity of seaport group no. 4 by using Environmental sensitivity index (ESI) (Van Phuoc Nguyen & Thi Thu Hien Nguyen, 2019). The research showed that ESI in Can Gio mangrove forest - Ho Chi Minh City occupies the largest area at a high threshold, the second is Ba Ria - Vung Tau due to long coastline. In order from high to low, ESI at the Southeast seaports can be arranged from high to low as follows: (i) Ho Chi Minh City, (ii) Ba Ria - Vung Tau, (iii) Dong Nai.

Human population distribution:

According to General Statistics office of Vietnam, human population in Ho Chi Minh City is highest (General statistics office of Vietnam, 2022). Human population in Vietnam seaport group no. 4 in 2022 is described in table 1.

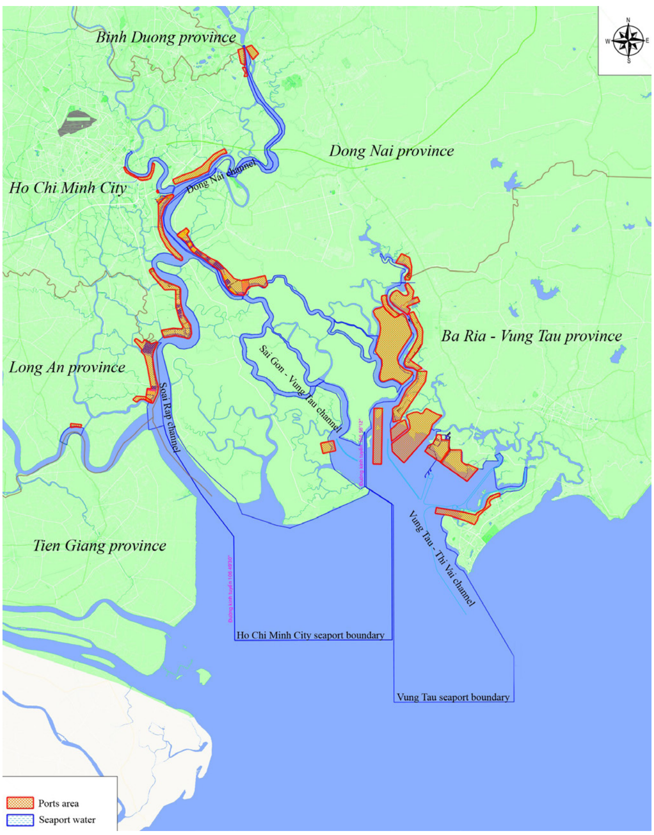

Figure 1. Study area

Seaport development:

Based on scale and function, seaport development is classified from high to low: (i) Ba Ria - Vung Tau seaport is classified as special seaport; (ii) Ho Chi Minh City seaport is planned to have the potential to become a special seaport; (iii) Dong Nai seaport is classified as class 1 seaport (Prime Minister, 2021).

In general, Vietnam seaport group no.4 can be ranked from 1 - 3 (high to low) in term of above criteria as table 2.

2.2 Methods

This study considers to pilot ECA within Vietnam seaport group no. 4 by apply Delphi - AHP method. The Delphi technique is typically employed in the initial phase to narrow down and identify the key variables, while the AHP is used in the next phase to assign weights to the selected variables and build the necessary decision-making model. There are many research areas had been used this combination technique such as maritime transport (Arof, 2015), TQM 4.0 model (Nguyen *et al.,* 2022). Order of research steps to build a set of criteria and score of priority options to establish ECA suitable for Southeast Vietnam conditions described in figure 3.

2.2.1 Develop a set of criteria

Throughout literature review, these criteria were collected in accordance with international convention. In order to comply with research area conditions, these criteria should be calibrating by using Delphi method.

2.2.2 Delphi method

The Delphi technique, introduced by Dalkey and Helmer in 1963, was designed to evaluate intangible variables or those shrouded in uncertainty by drawing on the knowledge and expertise of a diverse group

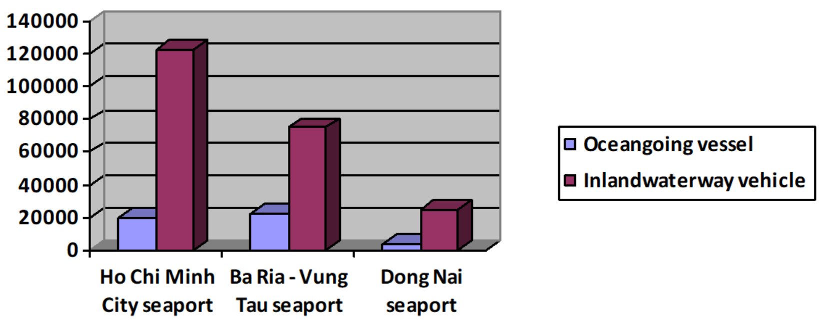

Figure 2. Vessel traffic density in seaport group no. 4

Table 1. Human population in Vietnam seaport group no. 4

Seaport	Human population (thousand)	Population density (people/km^2)	Land area (km^2)
Ba Ria - Vung Tau	1178.7	595	1982.6
Ho Chi Minh City	9389.7	4481	2095.4
Dong Nai	3255.8	555	5863.6

Table 2. Ranking of seaport

Seaport	Human population	Environmental sensitivity	Seaport development	Vessel traffic density
Ho Chi Minh City	1	1	2	1
Ba Ria - Vung Tau	3	2	1	2
Dong Nai	2	3	3	3

of experts through a process of anonymous and iterative consultation (Dalkey & Helmer, 1963). It is useful in a situation where individual judgments need to be combined in order to address a lack of agreement or in a situation with an incomplete state of knowledge on the research area. Four key features that need to be adhered in the Delphi procedure are: (i) the anonymity of Delphi panels; (ii) iteration that allows panelists to refine their views; (iii) controlled feedback; (iv) statistical aggregation of group response that allows for quantitative analysis and interpretation of data (Gene Rowe & George Wright, 1999). In fact, the identities of the expert respondents are typically kept confidential, even after the final report is completed. This anonymity helps prevent any respondent from overpowering the others, enabling all experts to freely share their opinions and encouraging them to acknowledge any mistakes by reassessing their previous judgments (Sekaran & Bougie, 2010).

Delphi method includes the following steps:

Step 1. Overview of issues to be surveyed and interviewed by experts;

Step 2. List suggestions in the form of a questionnaire using a Likert scale with scores of 1-5 (corresponding from least important to very important);

Step 3. Consider the appropriate observation variables in the scale according to the content validity ratio (CVR) with following equation:

$$CVR = (n_e - N/2)/(N/2)$$

Where; ne is the number of experts who rate from important and above (from 4 - 5 points). Based on the number of experts participating in the survey, there will be a suitable minimum CVR value (if lower, it will be removed from the set of criteria) according to table 3.

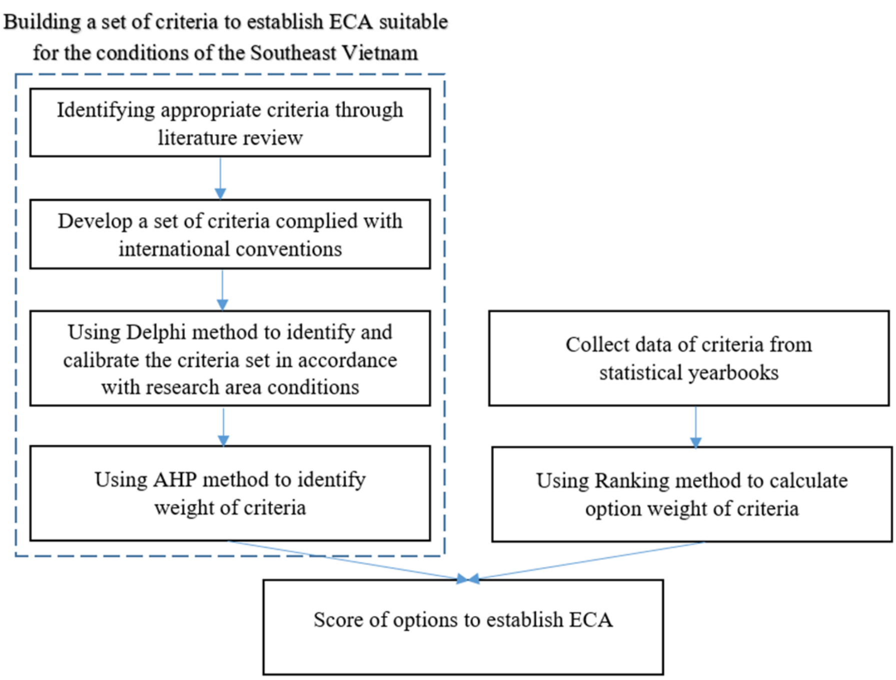

Figure 3. Research steps to establish ECA suitable for Southeast Vietnam conditions

Table 3. Content validity ratio based on the number of experts participating

Number of experts (n_e)	30	35	40
Minimum content validity ratio (CVR_{min})	0.33	0.31	0.29

2.2.3 Analytical Hierarchy Process method

The AHP is a type of Multi-Criteria Analysis that has been widely used in research for its effectiveness in tackling complex and unstructured problems. Developed by Saaty in 1980, this method utilizes a hierarchical model that includes levels for goals, criteria, sub-criteria, and alternatives (Saaty, 1980). The main objective of AHP is to choose the alternative that most effectively meets a specified set of criteria from a range of options, or to determine the weight of the criteria in any application by leveraging knowledge or experience from experts through a pair-wise comparison matrix of attributes (Saaty, 2008).

The advantage of this method is that it can be used for both qualitative and quantitative criteria. It can verify consistency when evaluating. It is easy to use as a decision-making tool, does not require overly complex techniques, and takes advantage of available statistical information. The difficulty in applying this method is that it requires processing a large amount of information. The AHP method is applied in the thesis to determine the weights for the criteria for establishing the ECA area. To be objective in comparing the rankings, the study consulted experts on the order of importance of the criteria, then compared and checked for consistency. When the test meets the requirements, the weights are calculated. The weighting process using AHP presented in figure 4.

The collected data will be checked the consistency and reliability by compare the consistency ratio:

$$CR = CI/RI$$

Where; CR is consistency ratio, $CI = (\lambda_{max}-n)/(n-1)$ is consistency index, RI is random index in accordance with number of criteria as table 4.

2.2.4 Ranking method

Finding the weights of criteria using the ranking method is a simple and easy-to-understand method for determining the relative importance of criteria in a multi-criteria decision making problem. This method is often used when it is necessary to determine the weights of criteria without specific data on the values or relationships between them.

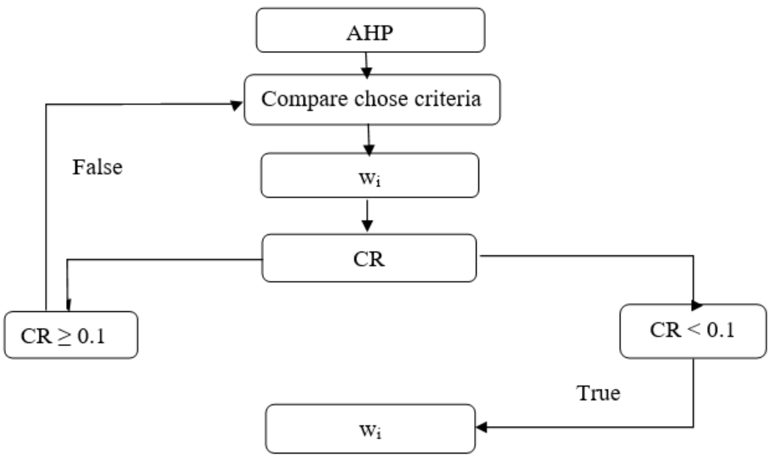

Figure 4. Weighting process using AHP

Table 4. Random index

Number of criteria (n)	1	2	3	4	5
Random index (RI)	0.00	0.00	0.52	0.89	1.11

If the CR value is less than 0.10, the survey result is considered to be consistent.

Steps to apply the ranking method: Step 1. Identify the criteria to be ranked; Step 2. Evaluate the importance of each criterion: Rank the criteria based on their importance, from the most important to the least important; Step 3. Calculate the weights of the criteria.

The ranking method is not the ideal method in all situations (especially when there is complexity in the relationship between criteria) but it is a simple and effective way to determine the weights of criteria when making multi-criteria decisions. In this study, the ranking method is preferred because most of the criteria in quantitative form are available in statistical the available data collected from statistical yearbooks.

2.3 Field survey

In order to gather information from relevant stakeholders, a survey was conducted (by combined multiple forms such as interviews, emails, and phone calls) from April to July, 2024 and divided into 4 group of experts as table 5.

3. Results and Discussion

3.1 Results

3.1.1 Identify set of criteria

According to literature review and case study of proposal to Designate an ECA for the Commonwealth of Puerto Rico and the United States Virgin Islands (United States, 2010), there are 4 popular criteria was found including:

- Human population;
- Environmental sensitivity;
- Seaport development;
- Vessel traffic density.

These criteria will be examined for correction in the next step. There are no specific sub-criteria for each representative criterion because the purpose of establishing ECA in this study is to assess the area of priority application.

3.1.2 First Delphi survey

A survey was sent to 40 experts to evaluate criteria collected. The result of first Delphi survey is shown in table 6.

Table 5. List of participated experts

Group	Target group of experts	Number of experts (people)	Experience (year)	Education level
1	Educational/research institution	10	5	Master and above
2	Seaport operator	10	10	
3	Relevant agency (maritime service company, shipowner, registration agency, shipyard…)	10	10	Bachelor and above
4	State management agency	10	10	

Table 6. First Delphi survey

No.	Proposed criteria	Mean	n_e	CVR	Compared with $CVR_{min} = 0.29$
	Criteria collected from literature review				
1	Human population	4.69	39	0.95	Accepted
2	Environmental sensitivity	4.49	38	0.90	Accepted
3	Seaport development	4.56	38	0.90	Accepted
4	Vessel traffic density	4.61	37	0.85	Accepted
	Additional proposed criteria				
5	Human health	-	-	-	-

Through the synthesis of the survey results, it was noted that all proposed criteria were met (CVR > 0.29) and the additional criterion "Human health" was collected. The reason is that the benefits of effectively controlling air quality in the area will contribute to improving the quality of life, health, and life expectancy of the population.

3.1.3 Second Delphi survey

Repeat survey of the same experts (this time only 35 experts participated in the survey) to evaluate the 5 criteria collected from round 1. The result of second Delphi survey is shown in table 7.

Through the synthesis of the survey results, it was noted that all 5 criteria were met (CVR > 0.31). The survey process to serve the construction of a set of criteria for establishing ECA suitable for the conditions of the Vietnam seaport group no.4 ended in round 2 because all the criteria in the questionnaire reached the required CVR value and there were no additional criteria. It can be seen that the human population and human health factors are of the greatest concern to experts because they are directly affected by emissions from shipping activities.

3.1.4 AHP analysis

There were 5 criteria has been identified by using Delphi method. In order to identify the weights different of those criteria, AHP method was applied by sending questionnaire to 35 experts to get result as describe in table 8.

Table 7. Second Delphi survey

No.	Proposed criteria	Mean	n_e	CVR	Compared with CVR_{min} = 0.31
1	Human population	4.60	33	0.89	Accepted
2	Environmental sensitivity	4.46	33	0.89	Accepted
3	Seaport development	4.54	33	0.89	Accepted
4	Vessel traffic density	4.57	32	0.83	Accepted
5	Human health	4.60	34	0.94	Accepted

Table 8. AHP result

Exp	Criteria					CR
	Human population	Environmental sensitivity	Seaport development	Vessel traffic density	Human health	
	Group of experts: Educational/ Research institution					
1.	0.279	0.300	0.092	0.051	0.279	0.09 Accepted
2.	0.366	0.068	0.133	0.068	0.366	0.01 Accepted
3.	0.200	0.200	0.200	0.200	0.200	0.00 Accepted
4.	0.161	0.475	0.042	0.161	0.161	0.01 Accepted
5.	0.123	0.333	0.333	0.089	0.123	0.04 Accepted
6.	0.294	0.064	0.055	0.294	0.294	0.03 Accepted
7.	0.098	0.212	0.057	0.536	0.097	0.03 Accepted
8.	0.231	0.231	0.077	0.231	0.231	0.00 Accepted
9.	0.097	0.097	0.215	0.545	0.046	0.02 Accepted

Table 8. AHP result (Cont.)

			Group of experts: Seaport operator			
10.	0.200	0.200	0.200	0.200	0.200	0.00 Accepted
11.	0.546	0.085	0.061	0.066	0.242	0.07 Accepted
12.	0.392	0.071	0.071	0.075	0.392	0.08 Accepted
13.	0.358	0.059	0.084	0.140	0.358	0.05 Accepted
14.	0.412	0.058	0.058	0.058	0.412	0.00 Accepted
15.	0.346	0.121	0.075	0.337	0.121	0.03 Accepted
16.	0.111	0.111	0.333	0.333	0.111	0.00 Accepted
17.	0.281	0.103	0.060	0.275	0.281	0.05 Accepted
18.	0.091	0.273	0.273	0.273	0.091	0.00 Accepted
			Group of experts: Relevant agency			
19.	0.076	0.162	0.316	0.316	0.130	0.08 Accepted
20.	0.283	0.054	0.098	0.283	0.283	0.01 Accepted
21.	0.234	0.054	0.054	0.054	0.604	0.02 Accepted
22.	0.061	0.219	0.552	0.106	0.061	0.03 Accepted
23.	0.391	0.075	0.050	0.093	0.391	0.06 Accepted
24.	0.364	0.134	0.064	0.074	0.364	0.05 Accepted
25.	0.120	0.120	0.110	0.531	0.120	0.08 Accepted
26.	0.333	0.111	0.111	0.333	0.111	0.00 Accepted
27.	0.333	0.111	0.111	0.111	0.333	0.00 Accepted
			Group of experts: State management agency			
28.	0.123	0.360	0.033	0.360	0.123	0.03 Accepted
29.	0.202	0.061	0.104	0.104	0.530	0.05 Accepted
30.	0.429	0.048	0.048	0.048	0.429	0.00 Accepted
31.	0.283	0.098	0.283	0.283	0.054	0.01 Accepted
32.	0.052	0.162	0.162	0.162	0.462	0.06 Accepted
33.	0.161	0.161	0.161	0.469	0.048	0.02 Accepted
34.	0.200	0.200	0.200	0.200	0.200	0.00 Accepted
35.	0.349	0.121	0.061	0.349	0.121	0.01 Accepted

Ranking of criteria according to mean of each criterion weights described in table 9.

After compared mean of criteria weights, the highest weight is "Human population" and lowest weight is "Seaport development".

3.1.5 Identify priority seaport to establish ECA

By using ranking method to get the weight between 3 main seaports of Vietnam group no.4 from table 2, the option weights of each seaport are described in table 10.

Given the lack of data on human health impacts from hospitals in terms of residential information, and the fact that the survey year of respiratory diseases was affected by the COVID-19 pandemic, the study considered the option weights of the human population value as an alternative proxy for the human health criterion. By multiply option weights (table 10) with mean of criteria weights (table 9), the priority option is identified according to table 11.

3.2 Discussion

Throughout recent research from Zhou *et al.* (2023); Mwase *et al.* (2020); Lee *et al.* (2020); Qin *et al.* (2019), the study employed the Delphi-AHP method to identify and rank a set of criteria for establishing ECA in Vietnam seaport group no. 4. According to MARPOL Annex VI, the findings indicate that human population and human health are the most significant criteria, as they stand to benefit the most from the implementation of ECA.

Taking into account factors related to Human population, Human health, Vessel traffic density, Environmental sensitivity, Seaport development, all of which are key considerations in determining the optimal location for ECA within the scope of study. Ho Chi Minh City seaport emerges as the most representative option for ECA establishment up to 2050 (score of option: 0.492), the second option is Dong Nai seaport (score of option: 0.256), the last option is Ba Ria - Vung Tau seaport (score of option: 0.252). Thorough, multi-stakeholder approach used in this study, involving a large number of experts from diverse background, lend credibility to the results and underscores the objectivity of the decision-making process.

The key strength of this study lies in its application of the Delphi-AHP method, which leverages a large and diverse group of survey participants to achieve an objective

Table 9. Ranking of criteria

Criteria	Rank	Mean of criteria weights
Human population	1	0.245
Human health	2	0.239
Vessel traffic density	3	0.223
Environmental sensitivity	4	0.152
Seaport development	5	0.141

Table 10. Option weights of Vietnam seaport group no. 4

Seaport	Vessel traffic density	Human population	Environmental sensitivity	Seaport development	Human health
Ho Chi Minh City	0.523	0.523	0.523	0.303	0.523
Ba Ria - Vung Tau	0.303	0.174	0.174	0.523	0.174
Dong Nai	0.174	0.303	0.303	0.174	0.303

Table 11. Score of Option

Seaport	Weight	Rank
Ho Chi Minh City	0.492	1
Dong Nai	0.256	2
Ba Ria - Vung Tau	0.252	3

and comprehensive result. The Delphi-AHP approach, with its iterative rounds of expert feedback and structured decision-making framework, provides a rigorous means of identifying and prioritizing the relevant criteria for establishing ECA in the Vietnam seaport group no.4. The ranking method employed in this study allows for the flexible incorporation of quantitative data at various scales, enabling a thorough assessment of the different criteria. The limitation is lack of specific information regarding the “Human health” criterion, which may impact the accuracy of the identified priority option. In addition, it is also difficult to locate ECA on local scale because air pollution affects residential areas, which are influenced by meteorological conditions. To address this, the decision-makers should consider supplementing the Delphi-AHP analysis with additional tools, such as conducting an in-depth emission inventory and air pollution simulation modeling, while also accounting for relevant meteorological conditions. By adopting a more comprehensive approach that combines the insights from the Delphi-AHP process with a detailed assessment of emissions and air quality impacts, the decision-making process can be further strengthened. This holistic evaluation would provide a more robust and reliable basis for establishing an effective ECA in the Vietnam seaport group no.4, ensuring that the chosen location maximizes the benefits to both the environment and the health of the surrounding population.

4. Conclusion

In order to strengthen air quality management through controlling emissions from shipping activities, improve air quality and ensure public health, there is a need to establish ECA as instructed by IMO. A set of criteria to establish ECA in Vietnam seaport group no.4 was identified and ranked (from less important to more important): Seaport development, Environmental sensitivity, Vessel traffic density, Human health, Human population.

Among of Vietnam seaport group no. 4, Ho Chi Minh City seaport should be priority to establish ECA in order to improve air quality as well as quality of life. This is a seaport area that is statistically known to have a large population, a high density of vessel and significant environmentally sensitive areas.

The results of this study provide a basic set of criteria to consider establishing ECA for other groups of Vietnam seaports or a typical seaport that is planned with similar characteristics in seaport function and location. The study also serves as a foundation for future studies aimed at assessing the effectiveness of establishing ECA through a simulation model of air pollution dispersion under specific meteorological conditions.

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