

Article

# Application of Fuzzy Delphi-AHP-TOPSIS for Selecting an International Crew Change Center in Taiwan

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**Abstract:** The COVID-19 crisis has brought disruption to the global economy and to international passenger and cargo transportation, and the unprecedented crew change crisis remains an issue for governments around the world to address. The selection of a port for international crew changes is a major decision for a country, and this port selection can be considered as a multi-criteria decision-making (MCDM) issue. As with other facility-siting issues, the issue of selecting a port for international crew changes requires consideration of several criteria relative to cargo transshipment, and since this process involves uncertainty, fuzzy logic must be incorporated into the process to obtain more accurate results. This study proceeds from the standpoint of shipping companies and ship management companies, conducting a survey questionnaire on carriers calling at Taiwan ports using cargo structure, transit costs, transit time, environmental factors, geographic location, infrastructure, and crew safety certification facilities. Fuzzy Delphi and FAHP are used to obtain the subjective opinions of carriers and FTOPSIS is used to explore and prioritize the objective opinions of carriers on international crew change ports. This is then used to construct an evaluation model of the key factors influencing the selection of an international crew change location for the development of Taiwanese ports. The results of the study showed that the hinterland industry economy was the main key factor and Kaohsiung container terminal 5 was the most suitable place for crew replacement.

**Keywords:** coronavirus; crew change; fuzzy multi-criteria decision-making; crew safe accredited facility



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## 1. Introduction

COVID-19 has an unprecedented rate of infection, mortality, and mutation [1]. The double lockdown of closed borders and domestic pandemic-prevention quarantine policies has become the biggest obstacle to ship supply and maintenance operations, international seafarer isolation operations, vaccination, shore leave, crew change, and repatriation operations. With the rise of the pandemic, international crew change has become increasingly strict. The double lockdown set up by each country's epidemic prevention policy has indirectly prevented seafarers from disembarking for crew changes, which in turn has caused seafarers to serve at sea for longer than their established contractual limits. The inability to replace or repatriate seafarers who have been executing their duties for such a long time not only seriously affects the safety and well-being of the crew, but also poses potential concerns for the security of maritime navigation and trade.

With 80% of global trade dependent on maritime transport and nearly 2 million seafarers worldwide needed to operate maritime transport and supply chain systems, Doumbia-Henry [2] in 2020 compiled responses to surveys from governments and the World Health Organization, the International Maritime Organization, the International Labor Organization, and the International Civil Aviation Organization on issues related to ship and airline crew members such as quarantine requirements, border closure restrictions,

crew change and repatriation, crew abandonment, certificate and license renewal, and ship supply and inspection. For crew change and repatriation, countries have only pledged to provide necessary assistance, but still with no comprehensive, standardized response.

Approximately 200,000 crew members have been affected by the crew change crisis so far in 2021, although this is down from 400,000 at the height of the pandemic in 2020 [3]. However, with many voyages suspended because of the sharp drop in international trade, the number of cases of crew members not being paid and being forced to stay on board for months without shore leave or being unable to return to their homelands is at a record high. Crews are concerned that, if they are unable to cooperate with the extended working hours and contracts, they may be blacklisted by shipping companies or ship management companies, resulting in unemployment after leaving, which has then, in reality, evolved into forced labor at sea [4].

In a 2020 study on the psychological stress on crew members during the pandemic conducted by Pesel et al. [5], 60% of the crew members cited onboard preventive measures and fear of infection as the main stressors, followed by severe insomnia and a recent sense of unhappiness and frustration in their jobs, indicating that the pandemic has had a significant impact on the crew's state of mind. A study to further understand the depth and breadth of the impact of the pandemic on crew health by Okeleke and Aponjolosun [6] suggests that, over the long term, the lack of a well-designed crew change program will lead to depression, anxiety, and insomnia, which could seriously affect their physical and mental health, as well as navigational safety. To avoid the loss of current crew and problems in recruiting future crew, the assistance of international organizations, national health and pandemic prevention centers, foreign offices, flag states, port state authorities, workers' unions, national medical institutions, and international shipping companies is still needed to provide for and solve the problem of crew change and repatriation. This will effectively reduce the physical and mental health issues and financial problems of the current crew members, as well as ensure the future long-term manpower needs of shipping.

Before the pandemic, the transshipment-research literature was focused on cargo issues, with none related to crew change. After the outbreak of the pandemic, there was clearly a problem with large numbers of international crew members needing to be replaced, and yet few papers began discussing the issues of crew stress and psychological health and none have been conducted concerning the choice of a crew replacement-port location. With the coronavirus constantly evolving, crew vaccination and the crew change crisis remain among the major issues faced by governments worldwide during the pandemic. This study attempts to fill this gap by combining the past standards for cargo transshipment and a Singaporean crew change as the evaluation criteria to try to construct a study on the development of an international crew change port in Taiwan. Taiwan is located where the route between Northeast Asia and Southeast Asia must meet and is also an important cargo transit port for routes from Asia to North America. Combining the strength of Taiwan's epidemic prevention and the establishment of safe and convenient crew transfer centers in seaports and airports, we can increase our international maritime reputation from a humanitarian standpoint and attract more shipping companies to call on our ports, increasing port revenues.

In terms of research methodology, multi-criteria decision-making can be a complete solution to multi-attribute, multi-objective, multi-level, and complex problems for decision makers through a combination of methods. Multi-criteria decision-making refers to making decisions under conflicting standards, since different evaluation criteria may exist under different standards, different characteristics, and different measurement units and relative weights. When the assessment issue involves high investment and high risk, it is very important to frame the problem correctly and clearly evaluate multiple criteria. Among the most commonly used multi-criteria decision-making methods, Delphi, AHP, and TOPSIS are the easiest to understand and implement [7]. However, in real life, human judgment and preferences cannot be accurately given a numerical value, and fuzzy set theory can compensate for this ambiguity and uncertainty. Therefore, this study combines Delphi, AHP,

and TOPSIS with fuzzy theory to construct an analysis of the suitability, importance, and key factors influencing port selection for the development of Taiwan's ports as international crew change ports. In terms of chapter configuration, the second section of this study reviews the relevant literature on the factors influencing the selection of ports by shipping companies, intermodal transport and hospital location, and also Singapore's crew change regulations. Section 3 describes the research methodology and evaluation components. Section 4 conducts an empirical analysis of the key factors influencing the development of international crew change and the best location among Taiwan's ports. Finally, conclusions and recommendations are presented.

## 2. Literature Review

This section reviews the selection of cargo transshipment ports, outbound transport, and the literature related to the research components, as well as Singapore's international crew change regulations, to facilitate understanding of the research components and the methodology used to obtain the evaluation criteria.

### 2.1. Transit Ports

In terms of transit port risk-related studies, Kengpol et al. [8] conducted an evaluation framework for multimodal route planning from Bangkok to Da Nang looking at freight-damage risks, infrastructure and equipment risks, political and legislative risks, operational risks, macro risks, and environmental risks to reduce intermodal system costs, transport risks, and CO<sub>2</sub> emissions. In terms of selection of the location of transit ports, Chen et al. [9] used eight evaluation components, including location, cost of route, facilities, connectivity, port services, cargo information, customs regulations and government policies, and finance, as well as multiple evaluation criteria such as total cost, facility efficiency, multimodal transport interface, cargo security, safety and reliability, frequency of calling vessels and flights, cargo information availability, stability of government policies, simplicity and transparency of customs procedures, and banking and insurance services, to evaluate the key factors for carriers in selecting transit ports in China.

In an evaluation study of port selection under China's one belt, one road policy, Gao et al. [10] starts with port size, port location, port costs, hinterland economy, operational management, and growth potential as their evaluation framework, based on 18 criteria including container throughput, port infrastructure, industry size, number of working days, inbound and outbound costs, traffic connectivity, customs clearance and government policy, investment trends, and risks for evaluation of the one belt, one road transport as a reference basis for shipping companies in choosing ports of call. Bhatti and Hanjra [11] used port costs, port location, port efficiency, cargo volume, and intermodal connectivity as components and 15 factors including container handling costs, container dwell time, and road, railway line, airport infrastructure, and connectivity to construct the selection criteria for choosing ports of call for the one belt, one road transport mode.

Sumner and Rudan [12] identified the choice of port of call as one of the key factors in the supply-chain system, and therefore compiled eight evaluation components through the literature collection, namely transit port, proximity to industry and customs zones, meteo-oceanological factors, proximity to main navigational routes and feeder services, administrative and managerial efficiency, transit port cost structure, and transit port operational efficiency. Among the nearly 50 evaluation criteria, 6 factors, namely backup space at the terminal, transit time, labor problems, state aid and its influence on cost, free time, and port operation and working hours, were not mentioned in the above-cited port-selection literature.

Wang and Yeo [13] argue that total cost, feeder frequency, port staying time, climate, port congestion, availability of the hub port's space allocation, compatibility of cargo information EDI system service, and personal ties with hub port authorities are the main factors for evaluating the key influencing factors in transit from Nanjing to Shanghai and Ningbo via the Yangtze River delta. Kavirathna et al. [14], on the other hand, categorized in

a more systematic way the 33 evaluation criteria from the research of Kavirathna et al. [15] into five evaluation criteria, namely monetary, time, location, operation, and liner-related criteria to develop the Bay of Bengal transit port evaluation framework.

## 2.2. Outbound Transport

According to Agrawal [16], in addition to the huge losses incurred by the airline industry at this stage because of the suspension of passenger transportation, increased travel restrictions, weak tourism, reduced revenues, cancellation of nonessential business activities, and public fear is expected to cause the passenger transportation demand to fall even further from the current 30% to 60%, which will seriously jeopardize airline operations. Most airlines are unable to withstand the impact of fluctuating oil prices, fluctuating demand, currency devaluation, and the pandemic. If the empty flights of airlines can be chartered to assist international crews to return home, this may help reduce the expected losses from countries closing their borders because of the pandemic.

Since air–sea transportation is not door-to-door, it is necessary to rely on road transport to complete the air–sea transfer, so land transportation between the port and the airport must be considered to assist in crew replacement and repatriation by air–sea transportation. Taiwan’s land area is not large but since railroads do not connect with any international airports, they are not able to provide door-to-door service. Therefore, the use of charter buses is recommended to complete the connection between seaport and airport. Alkharabshah and Duleba [17], in view of the fact that the pandemic has had a serious impact on global transportation, conducted a study on the service quality of road transportation, in which distance between stops, need for transfers, suitable connections, frequency of routes, journey time, and waiting time were used as the criteria.

In view of Vietnam’s increasing volume of import and export shipments, logistics centers have become an important logistics infrastructure in the supply chain, and the issue of the siting of logistics centers plays a crucial role in the design and practice of logistics and supply-chain management. Pham et al. [18] combined FDM and TOPSIS to construct a site assessment framework for logistics centers in Vietnam from the standpoint of logistics operators and identified the northeast provinces of Ho Chi Minh, North Hanoi, and Da Nang for the installation of logistics centers in Vietnam in sequential order, according to priority.

## 2.3. Research Structure and Evaluation Criteria

This section reviews the selection of cargo transshipment ports, outbound transport, and the literature related to the research components, as well as Singapore’s international crew change regulations, to facilitate understanding of the research components and the methodology used to obtain the evaluation criteria.

The issue of siting medical facilities is as much about the health and well-being of people as the choice of transit ports is about the planning and profitability of shipping lines, both of which involve significant investment and risk in terms of people’s health and benefit to shipping lines. Due to the rapidly changing nature of the pandemic, the Maritime and Port Authority of Singapore has been facilitating international crew change services, so as to strengthen the crew change system to ensure the well-being of the crew as much as possible and enable the crew to safely perform their duties in good physical and mental health. In 2022, the Maritime and Port Authority of Singapore (MPA) [19] will again amend the relevant safety regulations in the 2021 Singapore International Crew Change Guidelines developed by the Singapore Shipping Association (SSA), and among the main topics for crew safety certification are the number of days for crew replacement applications, equipment for the station’s epidemic prevention personnel, medical testing capabilities, and quarantine isolation facilities.

As the global pandemic continues, the closed working environment of ships increases the epidemic risk since the crew is in such close contact for such a prolonged period. In the past, before the pandemic, cargo-related factors were the main considerations in vessel

transshipment without taking crew change into consideration. Thus, at this point, there is still no literature available for reference on the selection of international crew-change ports. In light of a number of confirmed cases of disrupted international crew-change operations during the pandemic, to benefit international crew members under the supervision of the epidemic-prevention and port management authorities and ensure the stability of international shipping operations, this study considers the issue of medical-facility siting along with the selection of crew change ports and attempts to construct evaluation components that combine the evaluation criteria of medical-related site selection, port selection, and Singapore's international crew safety regulations to develop future prevention and quarantine measures both on board and on shore to supervise the management and monitoring mechanisms both at sea and when entering port for international crew change operations and develop a research framework for shipping companies and ship management companies in choosing a crew change port and to analyze the best alternatives for the development of international crew change transit centers in Taiwanese ports. The results of the study will be used as a reference for future medical-related shipping studies.

In a recent study on the siting of healthcare facilities, Baran [20] argues that selection of an optimal site is an essential process in the construction of healthcare facilities, that there are multiple stages of hospital construction, and that planning management must consider numerous criteria to effectively evaluate the alternatives of relevant scenarios and criteria when making decisions. Miç and Antmen [21], on the other hand, use demographic structures, investment costs, travel time and costs, environmental factors, infrastructure, and location assessment scenarios to frame the issue of hospital site selection. Tripathi et al. [22] state that hospital site selection and construction are important to the planning and development of national health infrastructure and proposes a hospital site assessment framework based on 11 evaluation criteria including socio-economic, geographic, and environmental structural issues, as well as air pollution, land costs, and proximity to roads and railways.

The relevant research in the components of hospital site selection is similar, and the research of Miç and Antmen [21] has defined and explained those components in detail. Because the components and definitions of their research are more complete, this study has adopted the components and refined their definition, while additionally considering the impact that the entry of international crew into the country may have on public health and safety, as well as other related issues such as the needs arising from crew changes and social medical resources [23], all with reference to Singapore's crew change regulations to make the research framework more applicable to the study of shipping companies and ship management companies' selection of international crew change ports. The definitions of the research components are shown in Table 1.

As can be seen from Table 1, based on a review of the literature, this study constructs a framework of the best possible influencing factors in the development of an international crew change transit center in Taiwanese ports, dividing the study components into seven items, namely "cargo structure", "transit costs", "transit time", "environmental factors", "geographical location", "infrastructure", and "crew safety certification facilities". The evaluation criteria are shown in Table 2.



**Table 1.** Definition and evaluation criteria of the best alternatives for developing international crew-change transit centers in Taiwanese ports.

Shipping Research Component	Defining Transit Port Site Selection
Cargo Structure	Opinions or preferences of shippers and forwarders, including imports, exports and re-exports of containers, bulk, and other cargo volumes, industrial scale, import and export scale, industrial structure, opinions or preferences of shippers and forwarders
Transit Costs	Including cargo handling costs, warehousing and transport costs, inbound and outbound charges, port transit charges, port exchange costs, insurance charges, port taxes, free periods for containers stuck in port, space allocation and loading capacity of feeder vessels, connections between feeder vessels and hub ports, crew transfer and inland transportation charges
Transit Time	Port's proximity and connectivity to railways, highways, and airports; convenient and unobstructed inland transport; land transport connections and airline flight frequency; inland transport and transit demand; inland transport transit speed; customs clearance speed, convenience, and consistency; flexibility of port operations; frequency of connecting vessel schedules; on-time arrivals and departures; availability of dedicated or priority wharves, ability of carriers to have exclusive wharves; other contractual privileges; number of working days per week; waiting time for ships to enter port; port congestion; labor problems; number of days spent in port; operational coordination; labor productivity; security efficiency; document standardization; flexible machine operation and transfer process; operational management standardization
Environmental Factors	National subsidy policies; customs policies; port policies; epidemic prevention policies; coordination and harmonization of environmental protection policies; conflict resolution procedures; goods damaged in shipment; transit of cargo and transit of personnel; shipping operations; environmental, political, policy, and legislative risks; port organizational structure
Infrastructure	Port throughput; water depth; number and availability of vessel berths; adequate transit and logistics facilities; infrastructure modernization and availability; rail, highway, and airport infrastructure; electronic data interchange; container dwell time; trade facilitation agreements; cargo arrival and departure information; advanced navigation services; time required for loading and unloading; intermodal information sharing and management; cargo safety and service quality; and port financial status
Geographic Location	Geographic location, size of the port and hinterland, available space in the port, future port expansion, distance between the port and the hinterland, convenience of cargo collection, and actual number of days from adverse weather conditions to resumption of operations
Crew Safety Certification Facilities	Including the dispatch of the port shuttle boats and their operation staff; protective clothing, gloves, and other epidemic prevention equipment for shuttle bus drivers, airport staff, medical personnel in quarantine and vaccination facilities; number of fast screening tests, PCR tests, and medical testing personnel; the number of quarantine hotels, and their proximity to ports and airports; procedures for crew change; on-site protective equipment; vaccination and medical testing capacity; and quarantine holding facilities

**Table 2.** Evaluation criteria of the best alternatives for the development of international crew change transit centers in Taiwanese ports.

Evaluation Component	Evaluation Criteria	Sources (Methodology)
Cargo Structure	Maritime Cargo Volume	[11] (AHP); [12] (BWM)
	Hinterland Industrial Economy	[10] (AHP, ELECTRE III); [12] (BWM)
	Shipper's Opinions	[15] (Multinomial Logit); [14] (Grounded Theory)
Transit Costs	Inland Transport Costs	[12] (BWM)
	Port Operation Expenses	[18] (FDM, FTOPSIS); [11] (AHP); [13] (AHP, CFPR); [10] (AHP, ELECTRE III); [15] (Multinomial Logit); [14] (Grounded Theory); [12] (BWM)

Table 2. Cont.

Evaluation Component	Evaluation Criteria	Sources (Methodology)
Transit Time	Voyage Frequency	[13] (AHP, CFPR); [15] (Multinomial Logit); [14] (Grounded Theory); [12] (BWM); [9] (AHP)
	Professional Management Staff	[18] (FDM, FTOPSIS)
	Priority Berthing System	[13] (AHP, CFPR); [15] (Multinomial Logit); [14] (Grounded Theory); [12] (BWM)
	Accurate Shipping Schedules	[18] (FDM, FTOPSIS)
	Efficiency of Customs Clearance	[18] (FDM, FTOPSIS); [13] (AHP, CFPR); [10] (AHP, ELECTRE III); [12] (BWM)
	Port Operation Efficiency	[13] (AHP, CFPR); [10] (AHP, ELECTRE III); [15] (Multinomial Logit); [14] (Grounded Theory); [12] (BWM)
	Convenient Outbound Transportation	[17] (FAHP); [11] (AHP); [10]; [9] (AHP)
	Single Fee Window	[18] (FDM, FTOPSIS)
	Transportation Risk Management	[10] (AHP, ELECTRE III); [8] (AHP, DEA)
Environmental Factors	Transportation Policy and Regulations	[18] (FDM, FTOPSIS); [10] (AHP, ELECTRE III); [15] (Multinomial Logit); [14] (Grounded Theory); [12] (BWM)
	Port Organizational Structure	[12] (BWM)
Geographical Location	Port Location	[11] (AHP); [13] (AHP, CFPR); [10] (AHP, ELECTRE III); [15] (Multinomial Logit); [14] (Grounded Theory); [12] (BWM); [9] (AHP)
	Climate-Related Factors	[13] (AHP, CFPR); [12] (BWM)
Infrastructure	Transportation Security	[17]; [18] (FDM, FTOPSIS); [12] (BWM); [9] (AHP)
	Transport Hardware Facilities	[18] (FDM, FTOPSIS); [10] (AHP, ELECTRE III); [15] (Multinomial Logit); [14] (Grounded Theory); [12] (BWM); [9] (AHP)
	Information Technology Application	[18] (FDM, FTOPSIS); [11] (AHP); [13] (AHP, CFPR); [15] (Multinomial Logit); [14] (Grounded Theory); [12] (BWM); [9] (AHP)
	Port Financial Status	[15] (Multinomial Logit); [14] (Grounded Theory)
	Crew Change Procedures	[19]
Crew Safety Certification Facilities	On-Site Protective Equipment	[19]
	Medical Testing Capability	[19]
	Quarantine Isolation Facilities	[19]

As can be seen from Table 2, based on a review of the literature, this plan constructs a framework of factors influencing shipping companies and ship management companies' choice of international crew change ports. Regarding the evaluation criteria, cargo structure includes three items: maritime cargo volume, hinterland industrial economy, and shippers' opinions. Transit costs includes two items: inland transport costs and port operation expenses. Transit time includes eight items: voyage frequency, professional management staff, priority berthing system, accurate shipping schedules, efficiency of customs clearance, port operation efficiency, convenient outbound transportation, and a single fee window. Environmental factors include three items: transportation risk management, transportation policies and regulations, and port organizational structure. Geographic location includes two items: port location and climate-related factors. Infrastructure includes four items: transportation security, transport hardware facilities, information technology application, and port financial status. Crew safety certification facilities include four evaluation criteria: crew change procedures, on-site protection equipment, medical testing capability, and quarantine isolation facilities.

## 2.4. Discussion

The main purpose of the decision analysis is to understand the current situation of the problem and to find a solution to the problem in a scientific way. The issue of crew change of ports involves an enormous capital expenditure from shipping companies, transportation route planning, public health and safety, medical capacity and equipment, and adequate space, problems that cannot be solved by a single research method. To obtain structure, stability, and credibility in the research process and results, this study collected relevant evaluation factors through a review of relevant literature and conducted assessment criteria suitability analysis through a collection of experts' opinions to obtain the most relevant evaluation criteria for the issue, while reducing the time required for repeated testing of conventional DM and the feedback time of FDM. In addition, FAHP can simplify the hierarchy of complex issues to obtain a relative comparison of the order of importance of the assessment components and criteria on the issue. Finally, using FTOPSIS, the alternatives are sorted according to the closest to the positive ideal solution and the farthest from the negative ideal solution to rank the alternative solutions. Therefore, this study uses the above characteristics of FDM, FAHP, and FTOPSIS to conduct research and analysis on shipping companies and ship management companies' the selection of crew change port locations, in the hope that the research results can provide future reference for the shipping industry, port operators, and national public health units.

## 3. Research Methodology

### 3.1. Fuzzy Delphi Method

Delphi was introduced by Dalkey and Helmer in 1960. The method is based on the anonymous expression of opinions or judgments by experts on specific topics. After the experts' opinions are obtained, they are collated, summarized, and counted, and then anonymously fed back to the experts to solicit their opinions again, and then concentrated and fed back again until the experts' opinions are consistent. Anonymity and feedback are its main features. The questionnaire sent to the experts through the questioner is open-ended, asking only questions related to the topic and inviting the experts to provide their opinions on the issues to be addressed. The survey is repeated several times in the hope of obtaining consistent expert opinions. If there is no consistency after several iterations, then the median can be used or alternate methods undertaken to obtain more expert opinions. This method makes full use of experts' knowledge and experience and allows experts to express their opinions on issues independently, resulting in a high degree of objectivity. However, the multiple iterations of the survey are often time-consuming, so other, more convenient methods are gradually being developed.

Murray et al. [24] first applied fuzzy theory to the Delphi method. Ishikawa et al. [25] further used the concepts of cumulative number assignment and the concept of fuzzy points to integrate expert opinions into fuzzy numbers. In other words, using the concept of fuzzy number to process the expert opinions retrieved by the Delphi method not only has the advantage of handling semantic ambiguity and retaining more expert information, but also has a better degree of consensus than the traditional Delphi method. In view of the fact that the traditional Delphi method requires several repetitions to achieve a professional standard of consensus, a satisfactory consistency of expert opinions is not easy to achieve [26]. If FST is applied to the Delphi method, it can not only provide similar results as the traditional Delphi method, but also reduce the time and cost of the survey, making it suitable for selecting key evaluation criteria [27]. Therefore, this study uses FDM with triangular fuzzy numbers to analyze the suitability of key factors influencing shipping companies and ship management companies in selecting crew change centers, with FDM solving the shortcomings of the traditional Delphi method. The procedural steps are as follows:

#### Step 1: Gather Expert Opinions

Use the semantic values from the questionnaires to determine each expert's importance rating of each factor.



### Step 2: Design the Questionnaire

Based on a review of the literature, the key factors in shippers' choices of crew change ports are compiled with 5 standing for "very suitable", 4 for "suitable", 3 for "normal", 2 for "unsuitable", and 1 for "very unsuitable".

### Step 3: Establish Triangular Fuzzy Numbers

Calculate the triangular fuzzy number valuation of each influencing factor for the expert group. This formula is shown in Equation (1). Suppose that the importance rating of the  $k_{th}$  influencing factor ( $k = 1, 2, 3, \dots, n$ ) by the  $i_{th}$  expert ( $i = 1, 2, 3, \dots, m$ ) is  $\tilde{w}_{ik} = (L_{ik}, M_{ik}, U_{ik})$ , then the fuzzy weight  $\tilde{w}_k$  of the  $k_{th}$  influencing factor is:

$$\tilde{w}_k = (L_k, M_k, U_k), k = 1, 2, \dots, n \quad (1)$$

where  $L_k = \min_i \{L_{ik}\}$ ,  $M_k = \frac{1}{n} \sum_{i=1}^n M_{ik}$ ,  $U_k = \max_i \{U_{ik}\}$ .

### Step 4: Defuzzification

In this study, the graded multiple integrals representation method (GMIR) proposed by Chen and Hsieh [28] is used to transform a fuzzy set into an explicit set to facilitate decision-making. This method defuzzifies the fuzzy weight  $\tilde{w}_k$  of each influencing factor into an explicit value,  $S_k$ , as shown in Equation (2).

$$S_k = \frac{L_k + 4M_k + U_k}{6}, k = 1, 2, \dots, n \quad (2)$$

### 3.2. Fuzzy Analytic Hierarchy Process

AHP is a multi-criteria decision-making method that combines qualitative and quantitative approaches. It is mainly applied to unstable situations and decision-making problems with multiple attributes. By systematizing the hierarchy, a complex evaluation system is converted into a clear hierarchical structure, and an evaluation scale from 1 to 9 is used to compare the weights of each evaluation criterion to establish pairwise comparisons and a pairwise comparison matrix, as well as to calculate its eigenvalue and eigenvector. Finally, a consistency check is performed to ensure the consistency of the decision-maker's evaluations. The computational steps are as follows:

#### Step 1: Construct a Pairwise Comparison Matrix for Each Expert

Construct a pairwise comparison matrix of the relative importance of the evaluation factors, as in Equation (3).

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} \quad (3)$$

where  $a_{ij} = 1/a_{ji}$ ,  $a_{ij} > 0$ ,  $\forall i, j$ ,  $i, j = 1, 2, \dots, n$  represents the relative importance of factor  $i$  with respect to factor  $j$ . This pairwise comparison matrix  $A$  is called the positive reciprocal matrix. If all the relative measures fit the transitivity law, i.e.,  $a_{ik} = a_{ij} \times a_{jk}$ , which holds for all  $i, j, k$ , then  $A$  is said to be a consistent matrix, and an obvious case where matrix  $A$  is consistent is  $a_{ij} = w_i/w_j$ ,  $i = 1, 2, \dots, n$ ;  $j = 1, 2, \dots, n$ . In the equation,  $w_1, w_2, \dots, w_n$  represent the weights of  $n$  evaluation factors under a factor belonging to hierarchy  $i - 1$  in hierarchy  $i$ .

#### Step 2: Construct a Fuzzy Pairwise Comparison Matrix

The pairwise comparison matrix is integrated into a fuzzy pairwise comparison using Equation (1).

#### Step 3: Defuzzification of the Fuzzy Pairwise Comparison Matrix

Use Equation (2) to convert the fuzzy pairwise comparison to a pairwise comparison with explicit values.

#### Step 4: Calculation of Eigenvalues and Eigenvectors

Due to the complexity involved in using the traditional eigenvalues and eigenvectors to compute the weights of factors, this study uses the average of normalized columns (ANC) method proposed by Saaty to replace the complex calculations to compute the decision factors' weights, namely the weight  $w_i$  of the decision factor  $C_i$  as in Equation (4).

$$w_i = \frac{\sum_{j=1}^n a_{ij}}{\sum_{i=1}^n \sum_{j=1}^n a_{ij}}, i = 1, 2, \dots, n \quad (4)$$

#### Step 5: Consistency Check

The measure of consistency is called consistency ratio (C.R.), which is the ratio of the consistency index (C.I.) to the random index (R.I.), i.e.,  $C.R. = C.I./R.I.$  Whether it is a measure of the decision-maker's judgment or a measure of the entire hierarchy, Saaty suggests that the consistency ratio should be less than or equal to 0.1 for consistency to be guaranteed.

### 3.3. Fuzzy Technique for Order Preference by Similarity to Ideal Solution

TOPSIS was proposed by Hwang and Yoon in 1981 [29] to solve multi-attribute decision-making problems. This method considers that the most suitable option should not only be the closest to the positive ideal solution (PIS), but also the farthest from the negative ideal solution (NIS). The PIS set maximizes the benefit-producing attributes or minimizes cost-increasing attributes while the NIS set minimizes benefit-producing attributes or maximizes cost-increasing attributes. Benefit-producing attributes refer to criteria where the larger the value of the characteristic, the greater the overall performance evaluation. Therefore, according to the concept of "the closest to PIS and the farthest from NIS", the distance between each option and the positive and negative ideal solutions is calculated and the relative distances are compared to find the most suitable option. The calculation steps of the TOPSIS method are as follows.

Step 1: Construct a Decision Matrix for Each Expert  $D = [x_{ij}]_{m \times n}$

$$D = \begin{matrix} & \begin{matrix} C_1 & \dots & C_n \end{matrix} \\ \begin{matrix} A_1 \\ \vdots \\ A_m \end{matrix} & \begin{bmatrix} x_{11} & \dots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \dots & x_{mn} \end{bmatrix} \end{matrix} \quad (5)$$

This decision matrix  $D$  has  $m$  feasible options, considering  $n$  evaluation criteria, and  $x_{ij}$  represents the performance evaluation value of the  $i_{th}$  option under the  $j_{th}$  evaluation criterion.

#### Step 2: Construct a Fuzzy Decision Matrix

The decision matrix is integrated into a fuzzy decision matrix using Equation (1).

#### Step 3: Defuzzification of the Fuzzy Decision Matrix

Use Equation (2) to convert the fuzzy decision matrix to a decision matrix with explicit values.

Step 4: Normalize the Decision Matrix to Get Normalized  $R = [r_{ij}]_{m \times n}$

The different units between the evaluation criteria are not conducive to comparison and computation, so the decision matrix is converted to a unitless normalized matrix. The normalization method is shown in Equation (6).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}}, i = 1, \dots, m; j = 1, \dots, n \quad (6)$$

where  $r_{ij}$  represents the performance value of the  $i_{th}$  feasible solution after the  $j_{th}$  evaluation criterion is normalized.

Step 5: Establish a Weighted Regularization Decision Matrix  $V = [v_{ij}]_{m \times n}$

Each criterion has its relative importance, expressed by the matrix  $W = [w_1, w_2, \dots, w_n]$ , where  $w_j$  is the weight of the  $j_{th}$  evaluation criterion and  $\sum_{j=1}^n w_j = 1$ . Calculate the normalized decision matrix  $V$  as shown in Equation (7).

$$V = [v_{ij}]_{m \times n}, \text{ where } v_{ij} = w_j r_{ij} \quad (7)$$

Step 6: Determine the Positive Ideal Solution  $A^+$  and the Negative Ideal Solution  $A^-$

The positive and negative ideal solutions are shown in Equations (8) and (9).

$$A^+ = \{v_1^+, v_2^+, v_3^+, \dots, v_n^+\} = \left\{ \left( \max_i v_{ij} \mid j \in J_1 \right), \left( \min_i v_{ij} \mid j \in J_2 \right) \mid i = 1, \dots, m; J_1 + J_2 = n \right\} \quad (8)$$

$$A^- = \{v_1^-, v_2^-, v_3^-, \dots, v_n^-\} = \left\{ \left( \min_i v_{ij} \mid j \in J_1 \right), \left( \max_i v_{ij} \mid j \in J_2 \right) \mid i = 1, \dots, m; J_1 + J_2 = n \right\} \quad (9)$$

where  $J_1$  and  $J_2$  represent the number of benefit attributes and cost attributes, respectively.

Step 7: Calculate the Distance between Each Option and the Positive Ideal Solution and the Negative Ideal Solution

The Euclidean distance formula is used to calculate the distance  $d_i^+$  between each option and the positive ideal solution and the distance  $d_i^-$  between each option and the negative ideal solution, as shown in Equations (10) and (11).

$$d_i^+ = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^+)^2}, i = 1, \dots, m \quad (10)$$

$$d_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2}, i = 1, \dots, m \quad (11)$$

Step 8: Calculate the Closeness Coefficients between Each Alternative and the Ideal Solution

When evaluating the most suitable option, one cannot just be closer to the positive ideal solution and assert that it is a better option. The distance between the solution and the positive and negative ideal solutions must be considered at the same time; that is, the closeness coefficient (CC) must be considered as well. The closeness coefficient  $CC_i$  of the feasible option  $A_i$  is calculated as shown in Equation (12).

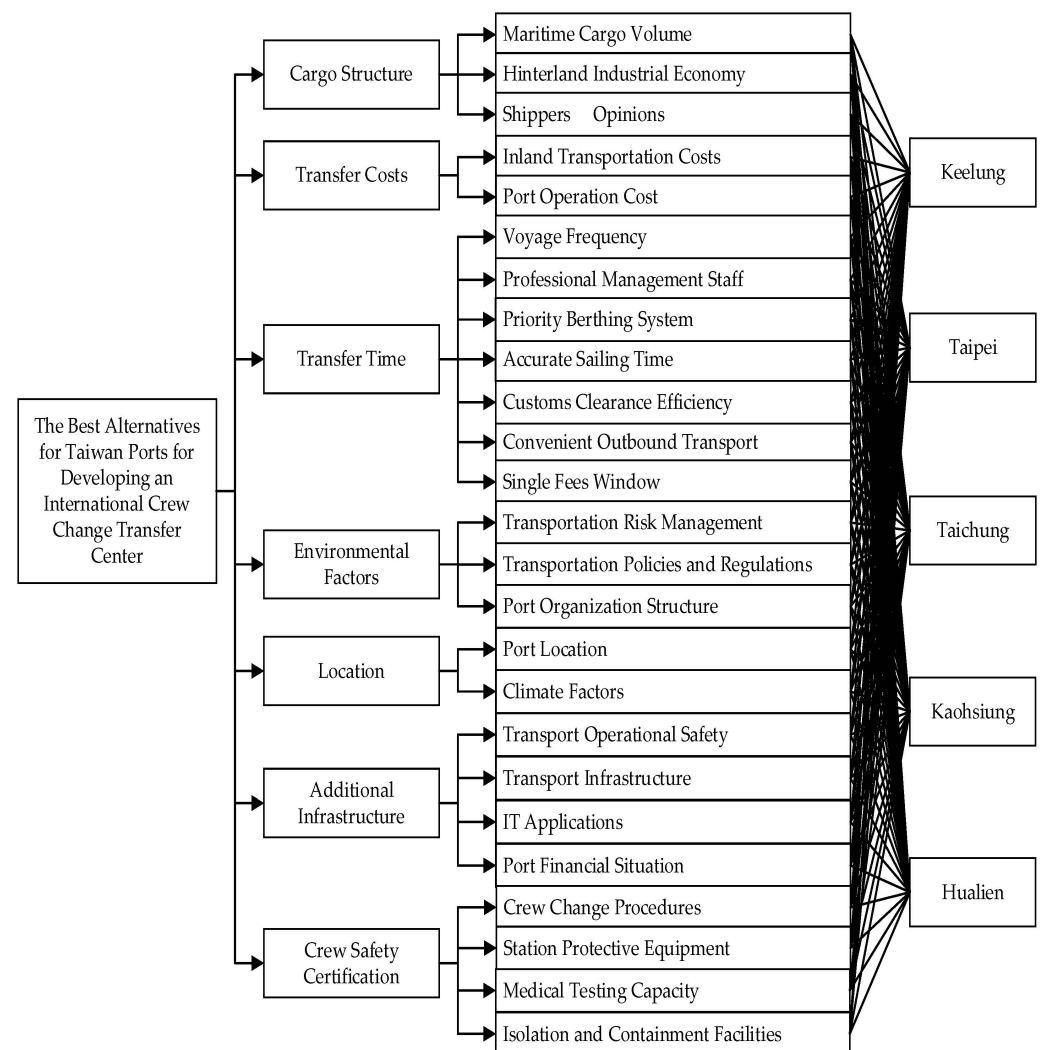
$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-}, \text{ where } 0 \leq CC_i \leq 1, i = 1, \dots, m \quad (12)$$

Step 9: Sort the Options according to the Closeness Coefficient

When  $CC_i = 1$ ,  $A_i = A^+$  and when  $CC_i = 0$ ,  $A_i = A^-$ ; we then can know that when  $CC_i$  approaches 1, option  $A_i$  will be the closest to the positive ideal solution and the farthest from the negative ideal solution at the same time. Therefore, the  $CC_i$  of the feasible solutions are ranked from largest to smallest, and the solution with the largest closeness coefficient value is the most suitable option.

### 3.4. Influencing Factors Evaluation Framework

Because of the completeness of the framework and definitions, this study adopts the framework proposed by Miç and Antmen [21] and integrates it with Singapore's existing crew change regulations to make it more applicable to the study of shipping companies' selection of international crew change ports. In addition, through the compilation of the literature related to the evaluation objectives, components, criteria, and alternative options of the factors affecting the selection of ports of call and intermodal transit ports and crew change regulations, we constructed an analytical evaluation framework for Taiwan's development of international crew change centers and its best alternative options, as shown in Figure 1.



**Figure 1.** Key influencing factors and best alternatives for developing international crew transit centers in Taiwanese ports.

## 4. Empirical Analysis and Discussion

### 4.1. Suitability Analysis of Influencing Factors

The first stage of this study is to seek professional opinions through the FDM and screen for appropriate evaluation criteria through the concept of a threshold value. The maximum value, minimum value, and geometric mean of the explicit value were adopted by the simple center-of-gravity method and the geometric mean of 0.488 was set as the threshold value, so that an explicit value greater than or equal to 0.488 was considered to be sufficiently adequate, and thus the said evaluation criterion was retained. After adopting the threshold values, the screening results of the evaluation criteria for key influencing

factors in the selection of international crew change transit ports by shipping companies and ship management companies are shown in Table 3.

**Table 3.** Sub-group suitability analysis of factors influencing the selection of crew change transit ports by carriers.

Evaluation Component	Evaluation Criteria	Explicit Value	Screening Result
Cargo Structure	Maritime Cargo Volume	0.543	Delete
	Hinterland Industrial Economy	0.488	
	Shippers' Opinions	0.457	
Transit Costs	Inland Transport Costs	0.483	Delete
	Port Operation Expenses	0.487	Delete
Transit Time	Flight Frequency	0.518	Delete
	Professional Management Staff	0.397	
	Priority Berthing System	0.518	
	Accurate Shipping Schedules	0.502	Delete
	Efficiency of Customs Clearance	0.500	
	Port Operation Efficiency	0.473	
	Convenient Outbound Transportation	0.528	
Environmental Factors	Single Fee Window	0.525	Delete
	Transportation Risk Management	0.530	
	Transportation Policy and Regulations	0.402	
Geographic Location	Port Organizational Structure	0.488	Delete
	Port Location	0.445	
Infrastructure	Climate-Related Factors	0.430	Delete
	Transportation Security	0.515	Delete
	Transport Hardware Facilities	0.485	
	Information Technology Application	0.517	Delete
Crew Safety Certification	Port Financial Status	0.438	
	Crew Change Procedures	0.607	Delete
	On-Site Protective Equipment	0.473	
	Medical Testing Capabilities	0.420	Delete
	Quarantine Isolation Facilities	0.580	

As shown in Table 3, this study uses 14 evaluation criteria as the basis for correlation analysis, namely maritime cargo volume, hinterland industrial economy, flight frequency, priority berthing system, accurate shipping schedules, efficiency of customs clearance, convenient outbound transportation, single fee window, transportation risk management, port organizational structure, transportation security, information technology application, crew change procedures, and quarantine isolation facilities.

#### 4.2. Importance Analysis of Key Influencing Factors

After compiling the section on the importance of the key influencing factors of the valid questionnaires, the C.I. value was 0.0344 and the C.R. value was 0.0382 for the 5 components and 14 evaluation criteria, showing that the valid questionnaires met the standard of consistency. The relative importance of the key factors influencing shipping companies' choices of crew change transit ports is shown in Table 4.



**Table 4.** Importance ranking of key factors influencing shipping companies and ship management companies' choices of ports for international crew changes.

Evaluation Component	Weight (Prioritized)	Evaluation Criteria	Weight (Prioritized)	Overall Weight (Prioritized)
Cargo Structure	0.2651(1)	Maritime Cargo Volume	0.3060(7)	0.0811(6)
		Hinterland Industrial Economy	0.6940(1)	0.1840(1)
Transit Time	0.2528(2)	Flight Frequency	0.3231(8)	0.0817(5)
		Priority Berthing System	0.1539(12)	0.0389(11)
		Accurate Shipping Schedules	0.1466(13)	0.0370(12)
		Efficiency of Customs Clearance	0.1232(14)	0.0311(13)
		Convenient Outbound Transportation	0.1603(11)	0.0405(10)
		Single Fee Window	0.0929(15)	0.0235(14)
Environmental Factors	0.2006(3)	Transportation Risk Management	0.4609(4)	0.0926(4)
		Port Organizational Structure	0.5391(3)	0.1081(2)
Infrastructure	0.1713(4)	Transportation Security	0.4191(10)	0.0718(7)
		Information Technology Application	0.5809(6)	0.0995(3)
Crew Safety Certification	0.1102(5)	Crew Change Procedures	0.5575(2)	0.0614(8)
		Quarantine Isolation Facilities	0.4425(5)	0.0488(9)

As shown in Table 4, cargo structure (26.51%) is the most important of the five evaluation components, followed by transit time (25.28%), environmental factors (20.06%), infrastructure (17.13%), and crew safety certification (11.02%). In terms of evaluation criteria, the top five key factors were hinterland industrial economy (18.40%), followed by port organizational structure (10.81%), information technology application (9.95%), transportation risk management (9.26%), and flight frequency (8.17%).

#### 4.3. Analysis of Alternatives

After establishing the weighting of the evaluation criteria, the questionnaire's selection scheme was compiled for shippers and ship management companies to select the transit port closest to the positive ideal solution and farthest from the negative ideal solution, with the most suitable ports in order of priority shown in Table 5.

**Table 5.** Ranking of the most suitable type of port for international crew change.

Port	$Si^+$	$Si^-$	Proximity Coefficient
Keelung	0.0350	0.0349	0.4996(2)
Taipei	0.0302	0.0297	0.4958(3)
Taichung	0.0376	0.0365	0.4922(4)
Kaohsiung	0.0399	0.0399	0.5000(1)
Hualien	0.0472	0.0429	0.4762(5)

Table 5 shows that, among the five alternatives, the best ports for international crew change are Kaohsiung, Keelung, Taipei, Taichung, and Hualien, with proximity coefficients of 0.5000, 0.4996, 0.4958, 0.4922, and 0.4762, respectively. Among them, Keelung Port is the best in terms of transportation risk management and information technology application. Taipei Port is the best in terms of a single fee window. The port organization structure is best at Taichung Port.

Kaohsiung Port is the best port for transit in terms of cargo volume, hinterland industry economy, flight frequency, priority berthing system, accurate shipping schedules, efficiency of customs clearance, convenient outbound transportation, transportation security, crew change procedures, and quarantine isolation facilities.

#### 4.4. Managerial Implications

The pandemic forced countries to suspend many nonessential activities, and while the pandemic will ease and the economy will revive, the humanitarian issue of crew change must still be given special attention [30]. In view of this, some countries have begun to focus on crew change. Panama, as an unavoidable crossroad situated between South and North America, has arranged ship changes for more than 11,000 crew members so far. The U.S. provides vaccinations for international crews calling at the Port of Los Angeles. Belgium was the first country in the European Union to provide vaccinations to the international crew of ships calling at Antwerp, Ghent, and Zeebrugge. The Netherlands is the first country to offer vaccination to crew members on Dutch-registered ships and will expand to all other nationalities on ships calling at Rotterdam in the future. Taiwan's neighboring Port of Singapore is a standard stopover port on the Asia–Europe route, and, in 2021, a floating vessel was used to assist 500–600 international crew members per day to change ships and quarantine. Hong Kong's industry and government are also investigating the use of speedboats to transport international crew to cruise ships to complete quarantine before changing ships or taking charter flights home [31]. According to the statistics of Inchcape Shipping Services [32], there are fewer than 20 countries in the world that prohibit international crew replacement. Taiwan, Brunei, and Palau are among the Asian countries in this group.

To protect international seafarers' rights to life and health, the Ministry of Transportation, the Ministry of Foreign Affairs, the Immigration Bureau, the Customs Administration, and the Centers for Disease Control and Prevention should refine the management of COVID-19 prevention and control by jointly formulating pandemic prevention and control operational procedures for international crew exchanges. Each locality should implement the overall process of pandemic prevention and control through a point-to-point mode to ensure public health safety. In other words, after a ship has docked, special vehicles should be arranged for point-to-point transportation between the port, quarantine station, transport terminal, reception center, and airport, while tracking the physical condition of the crew to reduce the possibility of disease transmission caused by crew changes. At the same time, the international crew's whereabouts and health status are recorded through the international crew real-name system and other pandemic prevention QR codes to build a strong defense against the virus at the national border.

To cover the increased vaccination, inland transportation, transfer, and related pandemic prevention costs for crew changes, a small tax could be levied on the shipowners according to the New Zealand model. Alternatively, according to the Dutch model, the shipowners could pay the costs of crew quarantine, vaccination, sea and air transfer on arrival, so as to provide a safe and stable source of funds for crew replacement. As the domestic pandemic is easing and the vaccination rate is rising, vaccine, quarantine facilities, medical equipment and capabilities that would be needed for crew changes should be stockpiled as early as possible. If an international crew-change and -transfer center is established in Kaohsiung Port, it will be helpful, from a humanitarian standpoint, for solving the problem of crew change, as well as maritime trade and navigation safety, while also enhancing the reputation of the Port of Kaohsiung.

## 5. Conclusions and Recommendation

### 5.1. Conclusions

In this study, a combination of three MCDM methods—FDM, FAHP, and FTOPSIS—is proposed and applied to the influencing factors' suitability, importance, and alternative choices. The results of the empirical analysis of factors for choosing an optimal crew-change transit center showed that evaluation criteria such as maritime cargo volume, hinterland industrial economy, flight frequency, priority berthing system, accurate shipping schedules, efficiency of customs clearance, convenient outbound transportation, single fee window, transportation risk management, port organizational structure, transportation security,

information technology application, crew change procedures, and quarantine isolation facilities were the basis for the importance analysis of the key influencing factors.

In terms of the evaluation framework, cargo structure is the most important, while hinterland industrial economy is the most important evaluation criterion. From this, it can be seen that factors related to inbound, outbound, and transshipment volume are still the main considerations for shipping companies and ship management companies when choosing a crew transshipment center, while factors related to crew change such as crew-safe accredited facilities are less important.

Among the major international commercial ports in Taiwan, Kaohsiung Port is the best choice for the development of a crew change transit centers because of its superiority over other ports in terms of cargo volume, hinterland industry economy, flight frequency, priority berthing system, accurate shipping schedules, efficiency of customs clearance, convenient outbound transportation, transportation security, crew change procedures, and quarantine isolation facilities, as well as other factors. Within, Kaohsiung Container Terminal 5 has a large hinterland area and is close to medical clinics and urban areas, as well as the Kaohsiung International Airport, making it the best choice for adding a medical and isolation housing facility for conducting international crew transfers.

The COVID-19 crisis has brought disruption to the global economy and to international passenger and cargo transportation, and the unprecedented crew change crisis remains an issue for governments around the world to address. At present, only a very few countries have the ability to vaccinate international crews, allow them disembarkation leave, or provide assistance in repatriation. With the novel coronavirus continuing to mutate, the problem of international crew vaccination, providing disembarkation leave, and the wait for repatriation will become increasingly serious both in developed countries with advanced shipping structures and the developing countries that supply much of the crew. The main contribution of this study is to provide shipping companies and ship management companies help in selecting the most optimal crew change transit center. FDM, FAHP, and FTOPSIS are combined to understand the relevance and importance of the key influencing factors that affect shipping companies and ship management companies' selection of crew change transit centers, and to address the issue of ranking optimal crew-change transit centers. Through its ranking of the key influencing factors affecting the choice of crew change transit ports, this study may be effective in reducing the time in making crew change policy decisions and speed up crew change operations.

Furthermore, the combination of FDM, FAHP, and FTOPSIS can adequately reflect the opinions of experts while addressing the uncertainties and ambiguities in the decision-making process for selection of a crew transfer center, making this more appropriate and complete than using other research methods in the selection of research methods and research results. The combination of research methods offered in this study can also be applied to other multi-criteria decision problems. Finally, this study also addresses the practical issues of developing and integrating international crew exchange disease prevention and control procedures, as well as the levying of fees for costs associated with crew replacement.

## 5.2. Recommendation

Although FDM, FAHP, and FTOPSIS are simple combinations of research methods, their applicability to a wide range of fields and topics can be found from previous studies, thus demonstrating their stable and reliable theoretical foundations. However, this combination is not the only combination that provides a compilation of expert opinions, a comparative analysis of the components and criteria, and the selection of the best alternative. This study shows that cargo structure and hinterland industrial economy are respectively the most important factors and criteria considered by shipping companies and ship management companies when considering crew replacement. Future studies can be conducted using the fuzzy analytic network process (FANP) or the alternative queuing method (AQM), which are similar to FAHP, to compare the evaluation components and

criteria. Otherwise, grey relational analysis (GRA) or fuzzy VlseKriterijumska Optimizacija I Kompromisno Resenje (FVIKOR), which are similar in nature to FTOPSIS, can be used to analyze and compare the best land, sea, and air passenger and freight transshipment and crew change ports in specific regions or countries outside of Taiwan with better cargo structure and hinterland industrial economy.

Even with the worst effects of the pandemic beginning to ease, it would be short-sighted and even naïve to think that the problems that arose are no longer of concern. As the virus continues to mutate, there is no guarantee that it will not become even more virulent and that our vaccines will continue to be effective. In addition, this may have just been a precursor of what could become another new normal in the future. With increasing encroachment on animal habitats and climate change upsetting animals' and pathogens' natural rhythms and environments, it is likely that we will see new outbreaks of novel diseases, some of which may be even deadlier. With increasing globalization and travel, disease can spread ever faster. It is also hoped that this research be used to prepare us for an uncertain future.

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