Dry port location selection for integration with inland waterway transport in developing countries: A case study in Northern Vietnam

by

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Delft University of Technology

PREFACE

This research marks the end of my two-year journey pursuing the Master programme in Transport, Infrastructure and Logistics at Delft University of Technology. This is an unforgettable chapter of my life which is full of gratitude and growth, both academically and personally.

First, I am deeply grateful to my chair and first supervisor, Jafar Rezaei. If it had not been for your guidance, I could not have accomplished this research. I remember during the first days that we discussed potential topics, your expertise in logistics and supply chain decision-making supported me to have a clearer orientation. Knowledge and understanding that I accumulated after these seven months of research have inspired my confidence and passion for multi-criteria decision analysis in this field in general and Best-Worst Method in particular. Your encouragement during the process significantly boosted my research spirits and helped me overcome challenges. Second, I would like to sincerely thank my second supervisor, Arjan van Binsbergen. All your detailed feedback contributed to improvements in my research. I really appreciate your great patience in giving explanations and raising critical questions for a more well-rounded approach to my Thesis. Third, without the support of twenty-seven experts in Vietnam, this research could not have been done. Your precious time and insights shared during many interviews greatly contributed to the case study findings.

Importantly, the Justus and Louise van Effen Excellence Scholarship gave me this once-in-a-lifetime opportunity to study abroad, stepping out of my comfort zone, becoming an independent young scholar raising her voice in Europe, publishing scientific papers and growing to address all her problems. No words can fully describe my joy, gratitude and confidence in a bright future after this journey. Thank you, TU Delft, for your financial aid. I have found a better version of myself and have fulfilled my promise stated in the application: being an active ambassador to grow the popularity of TU Delft among Vietnamese students.

Above all, from the bottom of my heart, my family in Vietnam is my strongest inspiration, motivation and pillar of support throughout this joyful but challenging period. Your unconditional love, encouragement and constant companionship always boost my positive energy. *Con cảm ơn bố mẹ!* The warmest thank you is sent to my boyfriend, Cuong Thinh. Thank you for turning the time zone difference to a trivial matter and bringing the happiness of developing together. To my friends, I am truly grateful for having you by my side.

Finally, to the readers of this research, I hope you enjoy it and find useful information. It is a proof of my passion for the development of transport, infrastructure and logistics, for the contribution to more optimized decision-making of dry port location selection in developing countries, including my home country - Vietnam.

Nguyen Thi Minh Hoa
Delft, August 2024

SUMMARY

Dry port has emerged as a critical element of transport infrastructure, eliciting substantial research and investment for its development. The strategic selection of dry port locations not only enhances the effectiveness of connections between seaports and hinterlands but also supports the sustainable advancement of the logistics industry, given that dry port operations can integrate with more environmentally friendly transportation modes, particularly inland waterway transport. Extensive research has been conducted to identify optimal dry port locations within the framework of inland waterway container terminals. Nevertheless, these studies primarily focus on developed economies, leaving a notable research void in developing countries. Therefore, the primary goal of this research is to propose a methodology framework to select the best dry port location focusing on the integration with inland waterway transport in developing countries. A relevant main research question is formulated as below:

How to determine the best dry port location for integration with inland waterway transport in developing countries?

This study contributes to literature a new hybrid MCDA approach in the field of dry port location selection, implementing a combination of the BWM and ELECTRE III in this domain. An analytical case study of Northern Vietnam, considering five alternative dry ports, is conducted to demonstrate the efficacy of the proposed framework. Twenty-seven Vietnamese experts, categorized into three groups - policymakers and consultants, dry port investors and operators, and dry port users - participate in the decision-making process, contributing insights to this case study. An aggregated group decision-making approach is employed.

Four main criteria are considered in this case study: economic, accessibility, location, and environmental criteria. Economic criteria are evaluated by three sub-criteria: decrease in transport cost, increase in transport time, and cargo throughput capacity. Accessibility is divided into accessibility to inland waterway infrastructure, road infrastructure, railway infrastructure, and seaport infrastructure. Location criteria include proximity to other logistics platforms, proximity to production bases, proximity to consumption markets, and room for expansion. Environmental criteria encompass a decrease in air pollution, a decrease in transport congestion, and an impact on urban areas.

Despite differences in the preferences of the three expert groups, the final aggregated results indicate that the most important criterion is economic, followed by location and accessibility. The environment is the least important criterion in the selection of a dry port location for integration with inland waterway transport in Northern Vietnam. Among the sub-criteria, the decrease in transport cost is assigned the highest weight, which is twelve times higher than the weight of accessibility to railway infrastructure, the least important sub-criterion. Phu Dong dry port, located in Hanoi, surpasses the other four alternatives and is chosen as the best location for the Vietnamese government to invest in developing integration with inland waterway transport.

This research contributes to the literature by addressing the gap in dry port location selection for integration with inland waterway transport in developing countries. The case study in Northern Vietnam, along with the combination of BWM and ELECTRE III, is scrutinized for the first time in this field. This methodology framework can be generalized for application in other developing countries concerned with dry port location selection for integration with inland waterway transport and possessing similar characteristics to Northern Vietnam.

This paper has several limitations. First, it assigns equal weights to all three stakeholder groups. Future research could explore stakeholder analysis in greater depth to determine the different decision-making powers of each group. Second, stakeholders' inconsistency in making pairwise comparisons between decision criteria was sometimes observed during the interviews. The author's re-explanation of the method and requests for stakeholders to adjust their decisions for consistency may introduce potential bias. Third, the list of decision criteria may vary slightly with input from more experts offering different perspectives. Future research should consider including customs procedures and costs at different dry ports if these vary significantly when containers are transferred from seaports to inland ports. Additionally, in this case study, each alternative dry port serves a different service area, so future research could examine a case study with alternative dry ports that act as real competitors, potentially revealing more insights into the trade-offs among different criteria.

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ABBREVIATIONS

ABBREVIATION	DEFINITION
AHP	Analytical Hierarchy Process
ANP	Analytic Network Process
BWM	Best-Worst Method
CO_2	Carbon dioxide
DP	Dry port
ELECTRE	Elimination Et Choix Traduisant la Realité
gCO_2	Gram of carbon dioxide
gCO_2/ton-km	Gram of carbon dioxide per ton-kilometer
GDP	Gross Domestic Product
GRDP	Gross Regional Domestic Product
GRP	Gross Regional Product
Ha	Hectare
ICD	Inland Container Depot
IWW	Inland Waterway
$KgCO_2$	Kilogram of carbon dioxide
Km	Kilometer
Km/h	Kilometer/hour
MCDA	Multi-criteria Decision Analysis
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
TEU	Twenty-foot Equivalent Unit
USD	United States Dollar
WASPAS	Weighted Aggregated Sum Product Assessment

1

INTRODUCTION

1. Introduction

1.1. Context

In this day and age, dry port has become an important type of transport infrastructure attracting extensive research and investment for development. This is due to the ever-increasing volume of containerized maritime goods transport and larger vessels which resulted in chronic congestion at seaports, weakening port infrastructure, increasing container dwelling time and worsening the competitiveness of main seaports in many countries. Dry ports were established as a solution to this issue, enhancing seaport throughput and performance, reducing seaport-hinterland distance (Cullinane et al., 2012; Jeevan et al., 2019). They are considered as extensions of seaports to connect the transport of goods between seaports and the hinterlands (Nguyen and Notteboom, 2016b).

The optimal location is one of the essential factors deciding a dry port's effectiveness. In fact, different locations can lead to different travel distances of containers (Liang et al., 2024), different transport costs and accessibility to transport infrastructure such as highways and railways (Nguyen and Notteboom, 2016b). However, when determining the location of dry ports, there is also a pressing need that the network of dry ports aligns with the global sustainability concerns, strengthened by the Paris Agreement with a net-zero emission target by 2050, in which transport serves as a leading factor. According to Pham and Lee (2019), a network of dry ports can reduce the amount of pollution released from logistics activities by increasing the proportion of eco-friendly modes of transport. The current situation of a myriad of dry ports is that they mainly connect with roads, while possessing limited access to inland waterways. Meanwhile, inland waterway transport has been proven to be an economic, fuel efficient and low-cost mode of transport for both developed or developing nations. Its negative environmental impact is lower than that of transport by road, rail or air (Nokelaynen, 2018). Moreover, traffic congestion in main roads can be alleviated by a higher share of goods being transported through inland waterways. In conclusion, dry ports, if being a means of encouraging intermodal transport in the hinterlands, including inland waterways, can aid in solving the sustainability problems in the logistics field worldwide (Kovač et al., 2023).

In Western Europe, dry ports have witnessed the development and crucial role of inland waterway transport. This has its roots in the fact that barge container transport has won a significant market share in a number of transport corridors between the Rhine-Scheldt-Meuse delta and the European hinterland. It is possible for these dry ports with barge container transport to overcome the limitations of the inland waterway network by connecting with rail transport (Notteboom, 2007; Caris et al., 2014). Nonetheless, in other areas of the world, especially in developing countries, this intermodal combination has been stagnant for decades with inadequate connections with other means of transport, especially rail transport, leading to relatively narrow catchment areas for inland terminals and failing to direct larger container flow volumes through inland rivers (Tawfik and Limbourg, 2019).

Solomon et al. (2021) analyzed a case study of Ghana and found that like many developing countries, Ghana's inland waterway transport systems are carried out only on the Volta Lake with diverse bottlenecks, challenging the full exploitation of the inland waterway capacity. In Bangladesh, inland waterways also play a significant role in goods transport as this nation is crisscrossed by a network of rivers. Bangladesh's inland waterway transport system possesses realistic growth potentials, but lacks expertise of inland navigability, inland management, inland port facilities, and inland connectivity (Hassan and Xuefeng, 2022). While Brazil holds the third ranking among top countries in the world with the most extensive navigable waterways, only 22% of these water systems are planned and utilized for cargo transport. The primary cause of this limitation is the significant geographical distance from major production centers and lack of investments in inland port and other transport infrastructure (Calderón-Rivera et al., 2024).

1.2. Research objective

The primary goal of this research is to propose a methodology framework to select the best dry port location focusing on the integration with inland waterway transport in developing countries, which potentially contributes to the literature. This methodology takes into account the objectives of three involved stakeholders, namely policy makers and consultants; dry port owners and operators; and dry port users. A case study in Northern Vietnam will be analyzed to illustrate the framework.

1.3. Research questions

The goal of this research can be fulfilled by addressing the following main research question:

How to determine the best dry port location for integration with inland waterway transport in developing countries?

Several sub-questions can be derived from the above main research question:

- *What criteria influence the selection of dry port location for integration with inland waterway transport in developing countries?*
- *To what extent does each criterion influence the selection of dry port location for integration with inland waterway transport in developing countries?*
- *How to gather sufficient data about the alternative dry port locations for integration with inland waterway transport (including current operated dry ports and planned ones)?*
- *How can the score and ranking of the alternative dry port locations be calculated?*

1.4. Scientific and societal relevance

With regard to scientific relevance, the literature review in section 2 reveals that extensive research has been conducted on the location selection of dry port, also dry port in the framework of inland waterway container terminals, but mainly in advanced economies. Nonetheless, there exist the stagnant combination between dry ports and inland waterways in developing nations in spite of great potential for integrating this means in countries such as Vietnam, Brazil, India, and China. Knowledge about the selection of dry port locations focusing on the integration with inland waterway transport in developing countries has not been studied thoroughly yet. This is one interesting scientific research gap that is worth scrutinizing.

In terms of societal relevance, this research brings many values to different stakeholders in developing nations. First, in these areas, dry ports are often invested by the government. Total state ownership is a common investment model for dry port development in these countries, e.g. the case in China (Beresford et al., 2012), or the case in Nigeria (Garnwa et al., 2009). In the cases where dry ports are mutually invested by the government and private sector, the government still designates the areas for investment and development. Therefore, policy makers and consultants are the most relevant decision-makers in this case. From this research, they can have a framework to select the optimal locations to invest in new dry port constructions or further development of existing dry ports to integrate with inland waterway transport in their countries when the state budget is limited and there is no possibility that all locations can be invested. This is exceptionally useful for developing countries which possess a dense network of inland waterways and express interest in solutions for environmental issues, e.g. air pollution, noise pollution, and fossil fuel depletion. Second, dry port owners, operators and dry port users, e.g. third-party logistics companies, shipping lines, and import-export companies, are also stakeholders who can apply the findings of this research to choose the best location from the enterprise perspective, contributing insights and opinions to the policy makers in the process of making decisions since they have direct operational practices with this transport facility.

1.5. Thesis structure

The rest of the research is organized as follows. In section 2, a literature review is presented, identifying interesting research gaps. An overview of the methodology employed in this research is provided in section 3. Next, section 4 analyzed a case study in Northern Vietnam to illustrate the methodology framework proposed in section 3. Discussion, conclusions and recommendations are provided in section 5, 6, 7 respectively.

2

LITERATURE REVIEW

2. Literature review

2.1. Core concepts

In 1986, Hanappe first mentioned the concept "dry ports" in a scientific journal, describing it as an inland terminal serving a port. In the contemporary world, in fact, there are more than one terms used to describe this facility, namely dry port, inland terminal, inland port, inland hub, inland logistics center, and freight village. All these terms refer to similar fundamental characteristics of an inland node. The first one is "containerization": with the vast expansion of containerization in transport, it is critical that this facility involves activities to well handle containers, performing logistics activities such as consolidation, deconsolidation, and trans-loading. The second characteristic of this facility is "dedicated link": being considered as a bridge connecting main ports with economic corridors, there is a need that this facility can connect with other modes of transport such as rail or inland waterway transport besides road transport. The third characteristic is "massification": this facility solves the capacity limitation and congestion at seaports at a lower cost (Pham and Lee, 2019).

Despite the above-mentioned similar characteristics, the difference in terminologies results from different facility appearances in various geographic areas, different scales, complexity, fields of specialization, and different roles of the facility in the whole transport network. Within this variety of terms, "dry port" is one of the most common ones (Varese et al., 2020).

Jaržemskis and Vasiliauskas (2007) described a dry port as "a port situated in the hinterland servicing an industrial or commercial region connected with one or several ports by rail and/or road transport, and offering specialized services between the dry port and the transmarine destinations. Normally the dry port is container and multimodal oriented and has all logistics facilities, which is needed for shipping and forwarding agents in a port". Meanwhile, Roso et al. (2009) discussed a simpler definition of a dry port as "an inland intermodal terminal that is directly connected to seaports with high capacity transport means, where customers can leave or pick up their standardized units as if directly to a seaport". In this research, the main focus is the dry ports in integration with inland waterway transport. Inland waterways were proven by a model of Kovač et al. (2023) that they could be integrated into existing dry port-based intermodal transport systems.

2.2. Methods used for selecting dry port location in developing countries

2.2.1. Least-cost models

Many models used for facility location attach a substantial role to transport costs in view of finding the optimal location. Least transport cost approaches include conditional logit model, mixed-integer programming, the dynamic programming model and the center of gravity model. Researchers have also tried to solve this location problem by developing mathematical programming models (Ambrosino and Sciomachen, 2014) or facility location models (Melo et al., 2009). Various metaheuristics are often used to solve these problems like greedy algorithms (Wei and Sheng, 2017), genetic algorithms (Chang et al., 2015), or heuristics (Ng and Cetin, 2012). Researchers have also used cluster analysis (Li et al., 2011), spatial models (Middela and Ramadurai, 2021), data mining, and complex network theory (Van Nguyen et al., 2020). Nonetheless, Mohan and Naseer (2022) concluded that in the above methods, quantifiable criteria like cost and distance were most attempted, not qualitative parameters.

Meanwhile, in the issue of dry port location planning in developing countries, there exist multiple stakeholders involved, such as port operators, port users, and the community. Therefore, besides logistics costs, there are many more qualitative location factors driven by these stakeholders (Nguyen and Notteboom, 2016a). Dry port planning should take into account a number of more qualitative factors such as environmental factors, land, labor availability, information technology level, regional trade facilitation level, and reliability (Notteboom and Rodrigue, 2017). One research conducted by Pham and Lee (2019) using data in Vietnam, a developing nation, showed that the greenest route, which has the smallest total emission charge, is not the cheapest route in terms of the total cost. Environmental factors were also considered carefully in that research, not only the monetary cost.

Dooms (2014) also emphasized the need for the inclusion of soft criteria in a multi-stakeholder environment, attaching importance to the high triple 'P' (people, planet and prosperity) bottom line performance while maintaining a high public trust or 'social license to operate'. Albeit this research was based on advanced economies, this is likely to hold for developing economies, but with other criteria and weighting factors of these criteria.

Furthermore, most dry ports in developing economies have been constructed and operated to serve the export-based industrial zones, so they are land-driven (Nguyen and Notteboom, 2016a) and more dominated by land-based players' interests compared to those in developed countries (Nguyen and Notteboom, 2016b). The detailed network of dry ports in developing countries can be found in Figure 1.

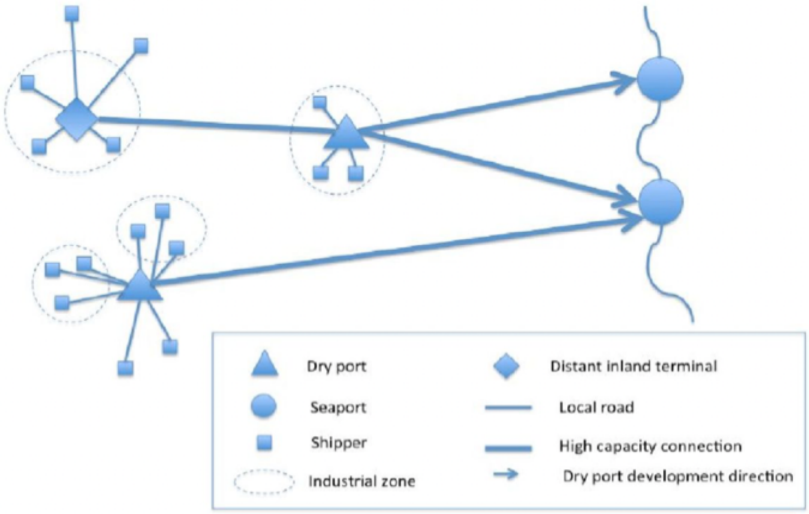

Figure 1. Dry port network in developing countries (Nguyen and Notteboom, 2016a)

Thus, there is remarkable room for the inclusion of softer indicators in dry port location analysis. The factors influencing the selection of dry port sites can be economic or non-economic, monetary or non-monetary, quantitative or qualitative (Yıldırım and Önder, 2014).

2.2.2. MCDA approach

MCDA methods can analyze both quantitative and qualitative factors, economic and non-economic factors, being particularly suitable for addressing this issue. Among Asian countries, significant research has been conducted on Chinese dry ports using various criteria through different MCDA methods. Ka (2011) employed the fuzzy AHP integrated with ELECTRE to select optimal dry ports construction projects in the New Eurasia Continental Bridges region of China, considering qualitative parameters such as politics and environment. Wang et al. (2018) considered both the natural and operating environments, along with infrastructure status as specific qualitative factors, in conjunction with quantitative ones to locate dry ports in the Tianjin Port area using the ANP. Environmental and socio-political criteria were used to evaluate three new dry port locations in the Western Balkans region to address the current market trend (Tadić et al., 2020). Meanwhile, Dang and Yeo (2018) considered connections between logistics components, logistics services, institutional frameworks, technology, human resources, logistics in manufacturing, telecommunication, international cooperation, and financial services to enhance Vietnam's logistics systems, employing the consistent fuzzy preference relations method. Chowdhury and Haque Munim (2023) proposed a framework for identifying the optimal location for a new dry port with a case study of Chittagong port, the premier port in Bangladesh, using three MCDA techniques: fuzzy AHP, BWM, and PROMETHEE.

MCDA methods can also be effectively employed when multiple stakeholders are involved in a decision-making problem. In this case, different stakeholders hold their own preferences and perceptions of the problem which might be similar, complementary or conflicting with each other's. The framework of group decision-making using MCDA is a tool to achieve consensus among stakeholders (Matsatsinis et al., 2005). There are three main approaches for group decision-making, namely sharing, comparing and aggregating. In sharing, the whole group of decision-makers aim to obtain a unified element by consensus, through a discussion of the views and the negotiation of an agreement, acknowledging the differences and trying to reduce them by explicitly discussing their cause. On the other hand, comparing aims to reach an eventual consensus based on the negotiation of independent individual results, acknowledging the differences without necessarily trying to reduce them. In aggregating, a common element is obtained by compromise, through a vote or calculation of a representative value, acknowledging the differences and trying to reduce them without explicitly discussing their cause. Until now, the most popular technique for aggregating is the geometric mean method (Mohammadi et al., 2023). Final aggregated values obtained through the geometric mean are considered "biased low" (Mazziotta and Pareto, 2016).

2.3. Factors influencing the selection of dry port location in developing countries

There are differences in the list of factors considered important by decision-makers in selecting dry port locations in developed and developing countries. While economic factors such as transport cost and time, along with accessibility factors like proximity to various means of transport, are commonly considered in both contexts, distinctions are evident in location factors. Dry ports in developing nations are predominantly land-based and are often situated near local production bases, such as industrial zones or even within economic zones, as seen in India (Ng & Gujar, 2009), South Africa (Cronje et al., 2009), and Vietnam (Nguyen and Notteboom, 2016b; Pham and Lee, 2019). Therefore, factors related to this characteristic, such as proximity to production bases and proximity to consumption markets, are more heavily weighted in the selection process in developing nations (Nguyen and Notteboom, 2016b; Pham and Lee, 2019; Chowdhury and Haque Munim, 2023; Mohan and Naseer, 2022). Some studies analyzing dry port location selection in developed countries also consider these factors, but assign them less significance, such as the low weighting of the factor "integration into the main supply chain", indicated by variables like "distance to a principal freight corridor" and "distance to a principal passenger corridor" (Pons Sánchez, 2008).

Political factors are also considered differently in the selection of dry port locations by developed and developing countries. In more advanced economies, dry ports are typically privately owned, as in the United Kingdom (Garnwa et al., 2009), or co-owned by the private sector and municipality, as in Europe (Roso and Lumsden, 2010). Conversely, in developing countries, dry ports are often funded and operated by the government. Total state ownership is a prevalent investment model for dry port development in these nations, exemplified by cases in China (Beresford et al., 2012) and Nigeria (Garnwa et al., 2009). Thus, political factors are given more consideration in developing countries when selecting dry port locations (Ka, 2011; Li et al., 2011; Augustin et al., 2019). Padilha and Adolph (2011) also highlighted that the political significance of dry ports in promoting regional integration and development holds greater importance compared to developed nations.

A critical review of many factors influencing the selection of dry port location in developing countries is provided in Table 1.

Country	**Research**	**Influencing factors**
Vietnam	Nguyen and Notteboom (2016b)	Reduction of transport cost; Reduction of transport time; Accessibility to inland waterway infrastructure; Accessibility to road infrastructure; Accessibility to railway infrastructure; Proximity to the production base; Proximity to other logistics platform; Range of service; Demand for dry port services; Investing & operating cost; Room for expansion; Investment & operational climate; Inter-project spillover effect; Complementary with other inland transport & seaport planning; Contribution to land use reorganization; Maximizing value added services and return to government; Employment generation; Minimizing transport pollution; Dry port related pollution created; Noise; Minimizing visual intrusion; Minimizing road congestion

	Pham and Lee (2019)	Freight demand; Proximity to the freight market; Production area; Freight shippers' location; Transport costs
Bangladesh	Chowdhury and Haque Munim (2023)	Proximity to the seaport; Proximity to the exporter and importer; Accessibility to high-capacity road network; Availability of rail network; Availability of other logistics platforms; Availability of land and land prices; Impact on the urban and natural environment
China	Ka (2011)	(1) Transport: transport distance, region scale of freight volume; (2) Economic level: GDP, commercial and industrial output value; (3) Infrastructure facilities: security of infrastructure facilities, logistics center; (4) Trade level: mutual complimentary of resource, import and export trade; (5) Policy environment: policy oriented, regional cooperation environment; (6) Cost: transport cost, land cost
	Feng et al. (2013)	Transport costs; Transhipment costs; Dry port development costs; Link maintenance costs; Infrastructure maintenance costs
	Chang et al. (2015)	Dry port development costs; Storage costs; Transport costs
	Wei and Sheng (2017)	Logistics costs; Carbon emissions
	Li et al. (2011)	GRP per capita; Total import and export value; Investment in fixed assets about transport; Freight traffic volume (freight volume summed by rail, water, high-way); Traffic radiation (route length summed by rail, water, high-way); Environment protection intention; Policy-oriented coefficient
	Wang et al. (2018)	Natural environment; Operating environment; Cost and infrastructure status
Indonesia	Bhatti and Hanjra (2019)	(1) Port location: hinterland distance, hinterland connectivity, complementarity to other nodes; (2) Port efficiency: electronic data exchange, container dwell time, bilateral and multilateral trade facilitation agreements; (3) Intermodal connectivity: road infrastructure, railway line, airport; (4) Port costs: cargo handling costs, fumigation, quarantine, SPS and certifications, warehousing; (5) Cargo volume: container throughput, non-containerized cargo, special freight/odd-sized shipment

India	Mohan and Naseer (2022)	(1) Economic: capital costs, operating cost; (2) Accessibility: accessibility to the rail, accessibility to major roads, accessibility to airports, accessibility to seaports, accessibility to services, accessibility to waterway; (3) Location: belonging to an industrial area, proximity to other logistics platforms, proximity to market, room for expansion, proximity to production centers and consumers, proximity to special economic zones or free trade zones; (4) Environment: noise pollution, air pollution, minimizing transport congestion, away from urban centers, away from environmentally sensitive area
Togo	Augustin et al. (2019)	(1) Economic and social factors: density of facility area, potential demand growth, hosting municipality range; (2) Environmental factors: impact on natural environment, impact on urban areas, hydrology; (3) Accessibility: accessibility to rail network, accessibility to high capacity road network, accessibility to seaports, accessibility to airports; (4) Location: weather, geology, relation with other logistics platforms, integration supply chain infrastructures, potential optimization of modal shift; (5) Political factors: political stability, administration, regional agreement

Table 1. Literature review of factors influencing the selection of dry port location in developing countries

From the above critical review, a number of factors are non-monetary, such as accessibility to different types of infrastructure, environmental factors, political factors, location factors (weather, geology, proximity to production base), which cannot be scrutinized by least-cost models or financial analyses. This underpins the preference for the implementation of MCDA methods in this research.

2.4. Conclusion of literature review

The selection of dry port locations is a well-established topic in the literature. Previous research has aimed to develop various frameworks to aid stakeholders in selecting optimal sites for dry ports. Many studies have explored dry ports within the context of inland waterway container terminals, considering their potential for sustainable logistics development. However, these studies have predominantly focused on advanced economies.

In recent years, an increasing number of researchers have recognized the stagnant integration of dry ports with inland waterways in developing nations, despite significant potential. Notably, no case study has been analyzed in Vietnam concerning the selection of dry port locations with a focus on integration with inland waterway transport, which could serve as a model for similar developing countries.

The least-cost mathematical model for dry port positioning, effective in advanced economies, proves inadequate for developing systems in this research. This is due to the need to emphasize specific qualitative criteria related to cultural, societal, and political contexts. MCDA methods are better suited to address this complexity, capable of analyzing both quantitative and qualitative factors and facilitating decision-making involving multiple stakeholders.

3

METHODOLOGY

3. Methodology

This section explains all the methods applied to answer the research questions mentioned in section 1. An overview of the methods used to solve each question is provided in Table 2.

Main research question: *How to determine the best dry port location for integration with inland waterway transport in developing countries?*	
Sub-questions	**Corresponding methods**
1. *What criteria influence the selection of dry port location for integration with inland waterway transport in developing countries?*	Literature review and stakeholder interview
2. *To what extent does each criterion influence the selection of dry port location for integration with inland waterway transport in developing countries?*	Stakeholder interview, BWM
3. *How to gather sufficient data about the alternative dry port locations for integration with inland waterway transport (including current operated dry ports and planned ones)?*	Literature review, stakeholder interview, and author's calculations based on literature review
4. *How can the score and ranking of the alternative dry port locations be calculated?*	Stakeholder interview, ELECTRE III

Table 2. Research questions and corresponding methods

3.1. Data gathering: Literature review, stakeholder interview, and author's calculations

Sub-questions in this research can be fully or partly answered by literature review and stakeholder interview. Many stakeholders are involved in the context of the above-mentioned MCDA problem. Clear determination of key stakeholders has a crucial impact on the feasibility of decision implementation, as well as the satisfaction of results for the key objects involved (Franco and Montibeller, 2010). This research takes into consideration three main stakeholders involved in solving this problem, namely policy makers and consultants; dry port investors and operators; and dry port users (Tadić et al., 2020). Therefore, interviews are made with representatives from all these three groups of stakeholders. Group decision making is employed in this research with an additional aim to mitigate the motivational biases which may happen when decision-makers show preference for the criteria in favor of their previously stated beliefs and judgments. Having interviews with more decision-makers with different viewpoints in the same groups of stakeholders can effectively reduce this type of motivational biases, i.e., confirmation bias (Montibeller and Von Winterfeldt, 2015).

Findings from literature review and expert interview indicate:

- The list of decision criteria
- All the alternative dry port locations in the selection
- Data which are used for decision criteria weighting
- Data about preference thresholds, indifference thresholds and veto thresholds which are used for alternative ranking

About performance data of the alternatives regarding all criteria and sub-criteria, these data are collected from literature review and data of local logistics companies, or calculated using the corresponding indicators found in literature review.

3.2. Data analysis: BWM and ELECTRE III

As explained in the literature review in section 2, the selection of dry port location for integration with inland waterway transport in developing countries is a complicated problem which is influenced by multiple quantitative and qualitative factors. The least-cost models for dry port positioning, which can only deal with quantitative factors like transport costs and distance, work well in advanced economies, but are insufficient for a developing system (Ng and Cetin, 2012). This has its roots in the fact that within the context of developing economies, particular qualitative and non-economic criteria are attached greater importance in the decision-making process due to cultural, societal and political context. Hence, this research will apply MCDA methods to evaluate the trade-offs between these conflicting quantitative and qualitative factors.

Within a myriad of MCDA methods, there is no perfect one which can be considered as appropriate for all decision-makers and decision-making problems. A hybrid MCDA approach, i.e., the combination of more than one MCDA methods, is crucial since a hybrid approach has been proven to provide more precise results, standing a high chance of eliminating each individual method’s drawbacks and taking advantage of several strengths (Koohathongsumrit and Meethom, 2021). It has been proven that many hybrid MCDA approaches can reduce the subjectivity and preference biases in the decision-making process of decision-makers (Ekel et al., 2019). In this combination, one method can be employed to analyze the weight of different criteria, whilst another method can be used to rank alternatives (Sitorus et al., 2019).

3.2.1. BWM

In terms of the method for eliciting criteria weight, literature indicates that AHP is the most popular MCDA method (Youssef, 2020), employed in the field of dry port location selection (Ka, 2011; Božičević et al., 2021). However, BWM has been proven to provide more reliable consistency ratios than AHP does. Additionally, BWM simplifies the process by using only integers in its comparison matrix, as opposed to AHP, which employs both integers and fractional numbers in pairwise comparisons (Rezaei, 2015).

Acknowledging that one challenge of MCDA methods is cognitive biases of decision-makers in providing judgments about criteria importance, this research aims to employ an MCDA method that is less prone to these biases, thereby enhancing the reliability of research outcomes. According to Rezaei (2022), a distinctive feature of BWM is its reliance on two separate reference points - the best or most important decision criterion and the worst or least important criterion. These two reference points can minimize the anchoring bias in decision-makers, i.e., the tendency to base evaluations and decisions on the first piece of information received, which is a common issue in elicitation methods based on a single reference point. The effectiveness of BWM in negating the impact of anchoring bias has been empirically shown, thereby enhancing the reliability and effectiveness of its results (Rezaei et al., 2024). Additionally, BWM can mitigate the equalizing bias – where decision-makers tend to assign equal weights to different criteria – as demonstrated in several studies, including Rezaei et al. (2022), which shows that BWM’s hierarchical problem structure can reduce the impact of this bias.

Given its widespread application in location choice problems (Liang et al., 2024; Stević et al., 2018; Pamučar et al., 2017) and its ability to reduce cognitive biases, BWM has been selected as the method to calculate criteria weight in this research. BWM calculates the weights of decision criteria based on a pairwise comparison between the best and worst criteria and the other criteria (Rezaei, 2015), thus aiming to enhance the reliability of this multi-criteria decision analysis. Figure 2 illustrates the pairwise comparisons in BWM.

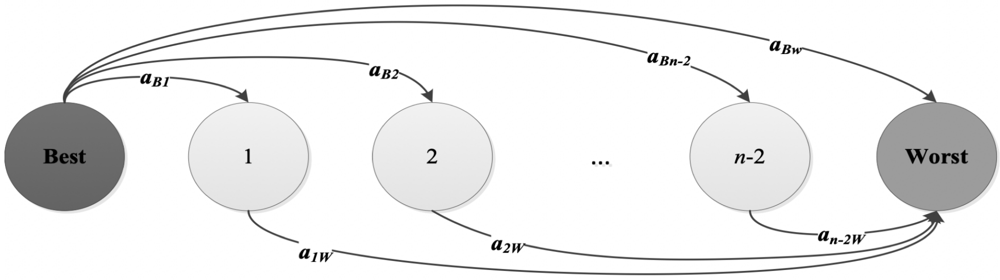

Figure 2. Reference comparisons in BWM (Rezaei, 2015)

The steps for deriving criteria weights using BWM are described as follows (Rezaei, 2015).

Step 1: Identify the decision criteria

In this step, decision-makers identify the relevant criteria. For instance, when selecting a dry port location, decision criteria might include economic factors, accessibility, location, and environmental impact.

Step 2. Identify the best and worst criteria among a set of criteria

In this step, decision-makers are tasked with identifying the most important (best) and the least important (worst) criteria from a set of decision criteria without conducting any pairwise comparisons. For instance, when selecting a dry port location, depending on the priorities of a particular decision-maker, the environment might be considered the best criterion, while economics could be viewed as the worst.

Step 3: Assess the preference of the best criterion over all others

In this step, decision-makers evaluate the preference of the best criterion to each of the other criteria using a numerical scale ranging from 1 to 9. This scale is detailed in a reference table, such as Table 3, to guide the scoring process.

Intensity of importance	***Definition***	***Explanation***
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	

3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

Table 3. The fundamental scale of absolute numbers (Saaty, 2008)

The Best-to-Others vector would be:

$$A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn})$$

Where a_{Bj} indicates the preference of the best criterion B over criterion j. It is automatically assumed that a_{BB} = 1.

Step 4: Determine the preference of all other criteria over the worst criterion using the numerical values between 1 to 9, as can be seen in Table 3.

The Others-to-Worst vector would be:

$$A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})^T$$

where a_{jW} indicates the preference of the criterion j over the worst criterion W. It is automatically assumed that a_{WW} = 1.

Step 5: Calculate the optimal criteria weights

In this step, the BWM Solver v5.0 (bestworstmethod.com), which utilizes the linear version of BWM (Rezaei, 2016), is employed to derive the optimal weights of all decision criteria in the decision-making process.

The global weight of each sub-criterion is calculated by multiplying the weight of the sub-criterion (if applicable) by the weight of its corresponding main criterion.

The input-based consistency ratio, CR^I, is calculated as outlined by Liang et al. (2020).
A comparison is fully consistent when $a_{Bj} \times a_{jW} = a_{BW}$, for all j, where a_{Bj}, a_{jW}, a_{BW} are respectively the preference of the best criterion over the criterion j, the preference of criterion j over the worst criterion, and the preference of the best criterion over the worst criterion.
For $CR^I \in [0, 1]$, the values close to 0 show more consistency, while values close to 1 show less consistency. Local input-based CR for criteria j is calculated using the formula below:

$$CR^I = max_j CR_j^I$$

where,

$$CR_j^I = \begin{cases} \dfrac{|a_{Bj} \times a_{jW} - a_{BW}|}{|a_{BW} \times a_{BW} - a_{BW}|} & a_{BW} > 1 \\ 0 & a_{BW} = 1 \end{cases}$$

This input-based CR^I has several merits when compared to output-based CR:

(1) Input-based CR^I can provide immediate feedback without going through the whole process of optimization, which simplifies the discussion and feedback with decision-makers.
(2) Input-based CR^I is easy to interpret as it is the maximum normalized discrepancy between a_{BW} and its estimated value calculated by $a_{Bj} \times a_{jW}$.
(3) The decision-makers can be provided with good guidelines on how to revise their inconsistent judgment.
(4) Input-based CR^I is independent of any research model. Regardless of BWM models applied in the research, e.g. non-linear, linear, or multiplicative models, input-based CR^I remains the same.

This value of global input-based CR^I is then compared with the associated threshold. If the value of CR^I is below the associated threshold, it is acceptable. Table 4 provides the thresholds for different combinations using input-based CR^I:

Scales \ Criteria	3	4	5	6	7	8	9
3	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667
4	0.1121	0.1529	0.1898	0.2206	0.2527	0.2577	0.2683
5	0.1354	0.1994	0.2306	0.2546	0.2716	0.2844	0.296

6	0.133	0.199	0.2643	0.3044	0.3144	0.3221	0.3262
7	0.1294	0.2457	0.2819	0.3029	0.3144	0.3251	0.3403
8	0.1309	0.2521	0.2958	0.3154	0.3408	0.362	0.3657
9	0.1359	0.2681	0.3062	0.3337	0.3517	0.362	0.3662

Table 4. Thresholds for different combinations using input-based Consistency Ratio (Liang et al., 2020)

3.2.2. ELECTRE III

Regarding the method to rank alternatives, ELECTRE is a well-known family of outranking methods. ELECTRE is an analytical method to solve multiple decision-making problems within constrained programs, utilizing straightforward logical relations and effective interactions that facilitate the full utilization of information in the decision matrix (Ka, 2011). This outranking method possesses several strengths:

First, ELECTRE acknowledges the non-compensatory nature of aggregation, unlike other utility-based approaches (Figueira et al., 2013). This is evidenced by the use of concordance and discordance indices. The concordance index calculation focuses solely on whether one alternative outranks another concerning a specific criterion, disregarding the extent of the difference in performance between the two alternatives. Additionally, the presence of veto thresholds in the calculation of the discordance index within ELECTRE methods underscores the non-compensatory foundation of these methods. A discordance index of 1 for any criterion, indicating that the performance difference concerning that criterion is smaller than the veto threshold, means that no improvement in one alternative's performance or deterioration in the others' performance can offset this veto effect (Figueira et al., 2013). Josselin and Le Maux (2017) note that the compensatory approach with aggregation methods can lead to results that are more sensitive to changes in alternative scores and the construction and trade-off of criteria. The non-compensatory approach of ELECTRE, which employs pairwise comparisons of alternatives concerning each decision criterion, can effectively address this issue. Secondly, ELECTRE allows decision-makers to consider the original data directly, without the need for transformations into artificial numerical scales. Third, ELECTRE can handle heterogeneous criteria scales, preserving the original scores of alternatives on each criterion, without requiring normalization techniques or the estimation of a value function. Fourth, ELECTRE methods have proven capable of addressing issues related to imperfect calculation or collection of data values, as well as the arbitrariness in creating the list of decision criteria through the use of two discriminating thresholds: the indifference threshold and the preference threshold (Figueira et al., 2013). This is particularly relevant to this research, as data collection and calculation from various sources often come with some inevitable imperfections. For instance, in the case study described in section 4, transport costs and times are calculated based on route distance values, which may include measurement tolerances.

According to a comprehensive literature review by Govindan and Jepsen (2016), ELECTRE III is the most popular of the ELECTRE methods and has been chosen for this research due to its superior performance in managing inaccurate, imprecise, and uncertain data (Chen et al., 2024). The ranking procedure in the ELECTRE III model is provided in Figure 3 (Chen et al., 2024).

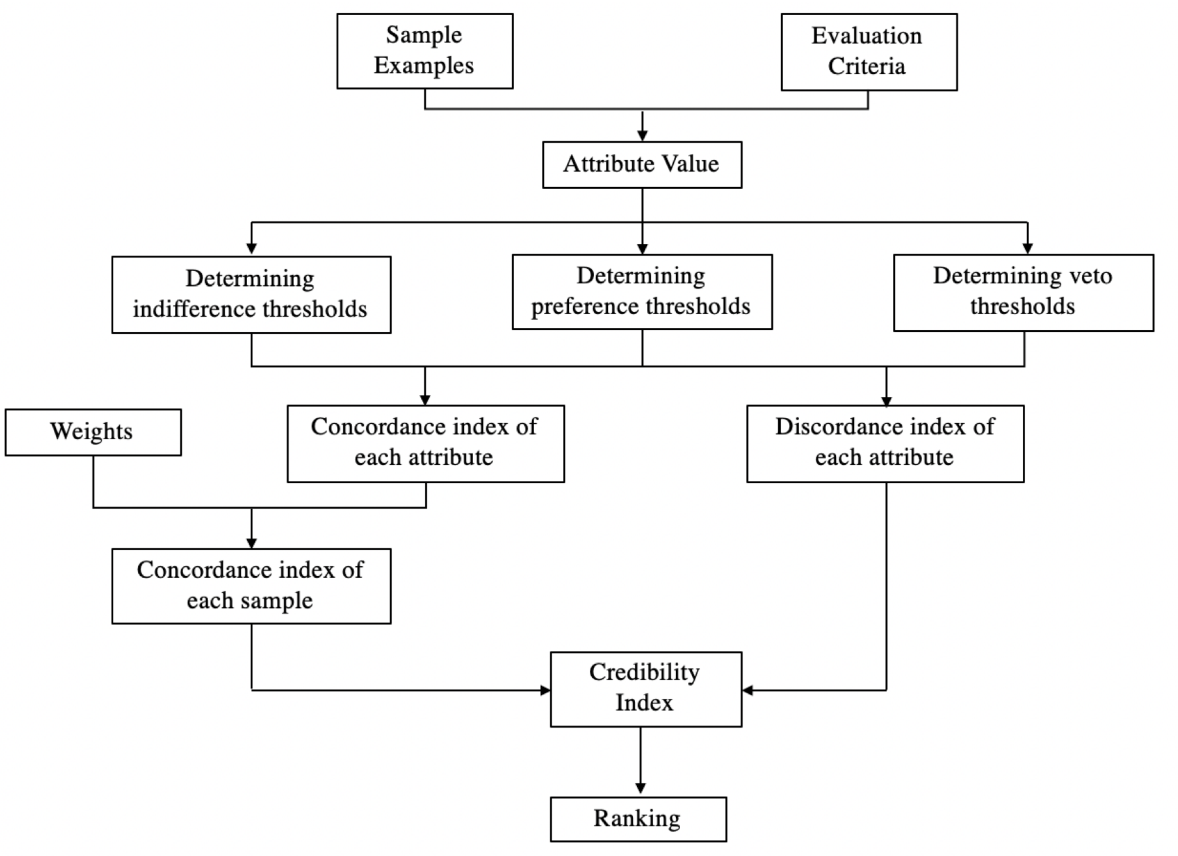

Figure 3. Ranking procedure in the ELECTRE III model (Chen et al., 2024)

Several steps of deriving alternative rankings by ELECTRE III are described in detail as follows (Figueira et al., 2013).

Step 1: Determine the required thresholds

The criteria c_j being evaluated based on three distinct thresholds:

- Preference threshold p_j: this threshold justifies the preference in favor of one of the two alternatives.
- Indifference threshold q_j: this threshold does not justify the preference in favor of one of the two alternatives, but indifference.
- Veto threshold v_j: this threshold expresses the power attributed to a given criterion to deny the assertion "alternative a outranks alternative b", when the difference of the performances of this criterion between alternative b and alternative a is greater than this threshold.

These thresholds facilitate the establishment of enhanced relationships and enable the accommodation of data uncertainty, in which:

$$v_j \geq p_j \geq q_j \geq 0$$

Step 2: Determine the concordance index

The following equation, which has a fuzzy form, is used for criterion c_j, and between alternative A_k and A_l:

$$\begin{cases} c_j(k,l) = \dfrac{X_j(A_k) + p_j - X_j(A_l)}{p_j - q_j} \ if \ q_j < X_j(A_k) - X_j(A_l) \leq \ p_j \\ c_j(k,l) = 1 \ if \ X_j(A_k) - X_j(A_l) \leq \ q_j \\ c_j(k,l) = 0 \ if \ p_j < X_j(A_k) - X_j(A_l) \end{cases}$$

where $X_j(A_k)$ is the evaluation of A_k on criterion j.

After calculating all $c_j(k,l)$ values, a global concordance index is calculated using the following equation:

$$C_{kl} = \frac{\sum_j p_j . c_j(k,l)}{\sum_j p_j}$$

This process is applied to all pairs of alternatives, and the result is used to create a concordance matrix. The elements of this matrix are defined as "the percentage of criteria where one alternative is at least as good as the other".

Step 3: Determine the discordance index

The index of discordance is obtained using the fuzzy concept by the following equation:

$$\begin{cases} d_j(k,l) = 1 \; if \; v_j < X_j(A_k) - X_j(A_l) \\ d_j(k,l) = \dfrac{X_j(A_k) - X_j(A_l) - p_j}{v_j - p_j} \; if \; p_j \leq X_j(A_k) - X_j(A_l) \leq \; v_j \\ d_j(k,l) = 0 \; if \; X_j(A_k) - X_j(A_l) < \; p_j \end{cases}$$

This calculation is applied to all pairs of alternatives A_k and A_l considering all decision criteria c_j.

Step 4: Determine outranking credibility degree and build the credibility matrix

After a concordance and discordance measure is calculated for each pair of alternatives considering each decision criterion, an outranking degree must be obtained by combining these two measures, to evaluate the reliability of the hypothesis $A_k S A_l$ (A_k is at least as good as A_l). The credibility is calculated by the following equation:

$$S(k,l) = \begin{cases} C_{kl} \; if \; d_j(k,l) \leq C_{kl} \\ C_{kl}. \prod_{j \in \bar{F}} \dfrac{1 - d_j(k,l)}{1 - C_{kl}} \end{cases}$$

- If $d_j(k,l) \leq C_{kl}$, the C_{kl} should not be modified. Otherwise, the hypothesis is questionable and C_{kl} should be modified.
- If $d_j(k,l) = 1$, there is no base to conclude that A_k is at least as good as A_l, so credibility for this criterion and pair of alternatives is 0.

A cut-off point is applied afterwards. If the value of S_{kl} is equal or higher than the cut-off point, it is converted to 1, otherwise it is converted to 0. All the values of S_{kl} after conversion are used to create a credibility matrix which will be used for the final ranking.

Step 5: Exploitation (descending and ascending distillations)

Two ascending and descending partial pre-orders are made and the intersection of the two (along with some other considerations) are taken into account for finding a final ranking. Final qualification value of each location alternative equals the sum of credibility indices of that alternative to all other alternatives minus the sum of credibility indices of all other alternatives to that alternative.

3.3. The combination of BWM and ELECTRE III

With the effort to employ the hybrid MCDA approaches to reduce the subjectivity and preference biases in the decision-making process of decision-makers (Ekel et al., 2019), the simplest way is the application of MCDA methods which are integrated with fuzzy logic, e.g. the fuzzy AHP, fuzzy WASPAS, and fuzzy ELECTRE. These fuzzy approaches have the ability to mitigate the impact of decision-makers' hesitation, yet they cannot address the weaknesses of each individual MCDA method (Koohathongsumrit and Luangpaiboon, 2024). Another way to propose the hybrid MCDA approaches is to make use of other methods together with an MCDA method in a study, e.g. mathematical models or ordinal priority approach. This type of combination has also been analyzed by Koohathongsumrit and Luangpaiboon (2024) and the researchers confirmed that this combined approach cannot compensate for the demerits of each individual method, also requiring advanced knowledge of methods to implement them together.

The superior solution is to implement more than one MCDA methods in a study in order to alleviate each method's drawbacks and utilize their strengths separately in weighing the priority of criteria and ranking the alternatives (Koohathongsumrit and Luangpaiboon, 2024). Considering BWM's outstanding features in criteria weighting and ELECTRE III's strengths as an outranking method, especially with its non-compensatory approach, as described in section 3.1 and section 3.2, this research employs a combination of BWM and ELECTRE III. The criteria weights found by the BWM method can be interpreted as intrinsic weights (Figueira et al., 2013), being suitable to be employed by the ELECTRE III method in the next phase of alternative ranking calculations. Importantly, the hybrid BWM - ELECTRE III approach has yet to be proposed in literature about the selection of dry port location in general and the selection of dry port location for integration with inland waterway transport in particular. By implementing this combination, this research also contributes to literature a new hybrid MCDA approach in this specific field.

3.4. Methodology process flow

A flow chart of different phases of methodology is provided in Figure 4.

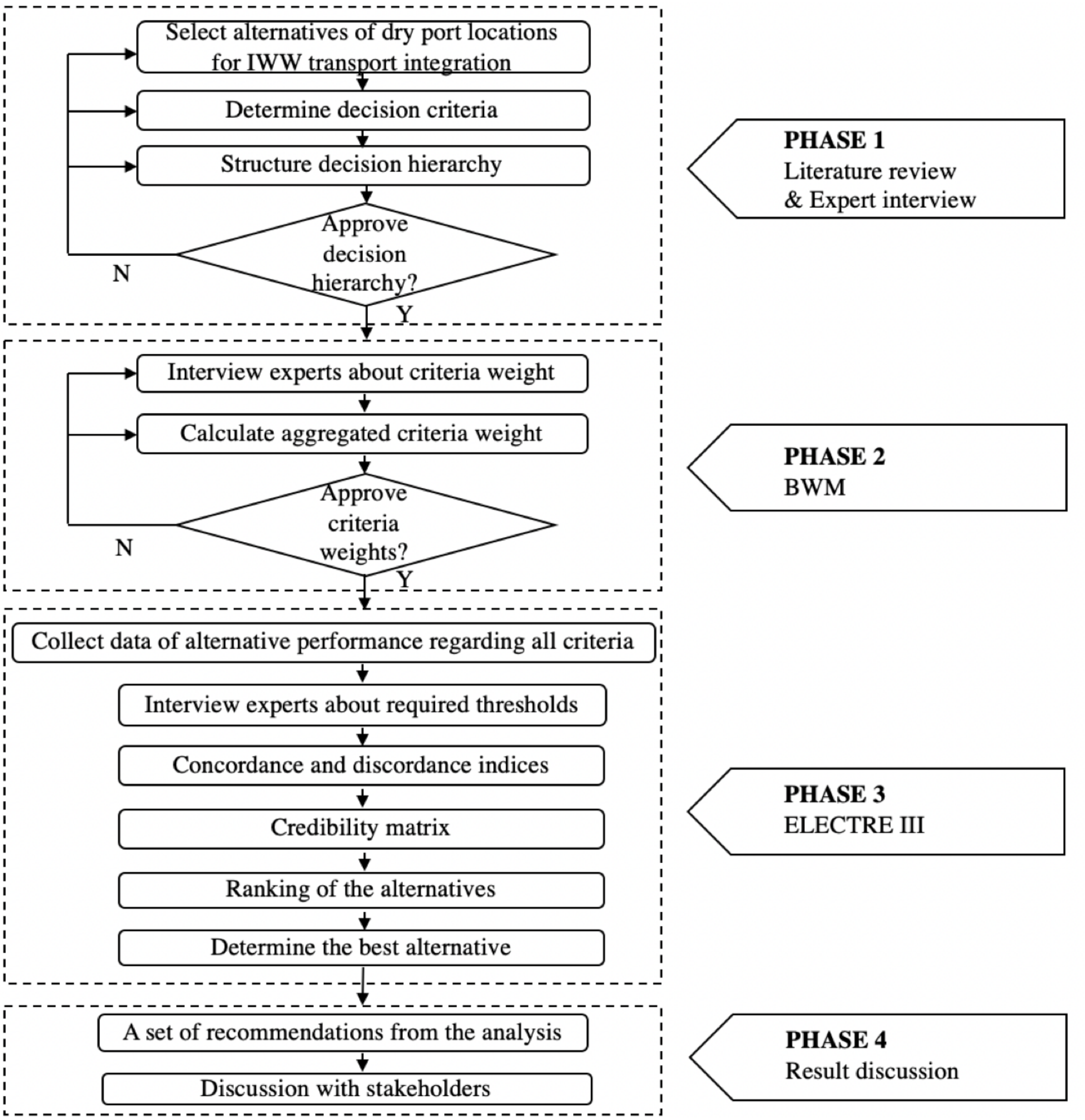

Figure 4. Flow chart of methodology

There are four phases involved in the methodology suggested by this research. The first phase aims at finding a decision hierarchy, which consists of all decision criteria (main criteria and sub-criteria), as well as all alternatives of dry port locations for integration with inland waterway transport in a developing country. The second phase is the implementation of the BWM method with the expected result being all the weights of decision criteria. The third phase is the implementation of ELECTRE III method with the expected result being the final ranking of all the alternatives, from which the best alternative can be found. The fourth phase is the discussion and recommendation with stakeholders about the analysis results.

4

CASE STUDY

4. Case study

4.1. Context

A case study in Northern Vietnam is analyzed to illustrate the framework. According to the Ministry of Transport of Vietnam (Decision No. 320/QD-BGTVT, dated 28 March 2024), Vietnam is currently having fourteen official dry ports, ten of which are located in the Northern part of the country. However, in the North, only four dry ports are currently integrated with inland waterways to connect with sea ports. In the period from 2024 to 2030, the Vietnamese government has also announced the prioritized development plan for one more dry port with this form of integration in the North.

There are differences in the characteristics of geography and infrastructure relating to dry port development between the North and the South of Vietnam. In the South, dry ports have utilized the advantages of inland waterway transport which accounts for 35% – 40% of goods transport, mitigating the congestion in seaports and urban road traffic. This is thanks to the dense network of inland waterways in this region. The situation is different in the South where inland waterway transport heavily relies on two main rivers: Red river and Duong river. The connection between dry ports, inland waterways and seaports in the North is not as efficient as that in the South, especially when the majority of dry ports in the North have newly been established (Vietnam Logistics Report 2023, the Ministry of Industry and Trade of Vietnam).

4.2. Problem definition

At present, the rate of imports and exports by containers through dry ports in Northern Vietnam is only 10% of the total data (Vietnam Logistics Report 2023, the Ministry of Industry and Trade of Vietnam). The over-reliance on road transport with the use of approximately 20,000 container trucks in the North has generated acute problems of road infrastructure degradation, traffic congestion and environmental impacts, especially high CO_2 emissions. Within these problems, green issues attract exceptional concern as in the 2021 United Nations Climate Change Conference, Vietnam's Prime Minister announced the country's commitment to a net-zero emission target by 2050. The government has set the objective until 2030 for the transport sector to increase the productivity of dry ports in the North by expanding the link with inland waterway transport, optimizing the delivery of export and import goods while reducing logistics costs, traffic congestion, and environmental impacts. As stated above, in the North, there are currently four dry port locations in operation and one dry port location in the planning phase which have connections with inland waterways. The Vietnamese government aims to invest in developing these potential locations to expand the combination between dry ports and inland waterway transport. Nonetheless, the public budget is limited, the government also needs to mobilize the investment capital and seek international cooperation. Hence, not all five dry port locations can be invested for development simultaneously, the most potential alternative dry port location should be chosen for development first. Afterwards, the development in this optimal location can become the standard dry port model integrated with inland waterway transport in Northern Vietnam.

4.3. Decision hierarchy

4.3.1. Alternatives

Using information obtained from literature review, this research takes into account five alternatives of dry port location in total, i.e., four currently-operated dry ports and one dry port in prioritized planning phase. These five alternatives satisfy the requirement of possessing the same nature (Franco and Montibeller, 2010). Within these five alternatives, one dry port location will be chosen for a pilot project investing in the expansion in connecting with inland waterway transport. The methodology framework in section 3 will be employed to select the best dry port location for integration with inland waterway transport in this case study.

A map of five alternative dry port locations and the network of surrounding rivers and highways in Northern Vietnam is provided in Figure 5.

Figure 5. Map of alternative dry port locations (illustration of the author based on Google Maps)

Within these five dry ports, there are three dry ports, i.e., Hai Linh dry port in Phu Tho province, Phu Dong dry port in Ha Noi city, and Que Vo dry port in Bac Ninh province, established along the route of Red river – Duong river – Kinh Thay river connecting with Hai Phong seaport, the biggest international seaport in Northern Vietnam. Phuc Loc dry port in Ninh Binh province and Mong Cai dry port in Quang Ninh province have been established near Day river and Ka Long river respectively. Both these two dry ports can connect with Hai Phong seaports through coastal routes. Remarkably, only Hai Linh dry port in Phu Tho province has connections with railway transport due to the fact that railways do not show sufficient accessibility and efficiency in the North, according to experts. Despite serving different service areas, in this case study, these five dry port locations can be seen as equal alternatives because all of them are located on crucial economic corridors of Northern Vietnam. Hai Linh dry port, Phu Dong dry port, Que Vo dry port, and Mong Cai dry port lie on Lao Cai – Ha Noi – Hai Phong – Quang Ninh economic corridor, connecting the northern midland and mountainous areas with the economic centers and major seaports, promoting trade and investment cooperation between localities of Vietnam and the southwest region of China. Meanwhile, Phuc Loc dry port in Ninh Binh province is a strategic intersection point between three regions which are Red River delta, northwest mountainous region, and north central coast region. No location is significantly preferred to other ones in Northern Vietnam.

4.3.2. Decision criteria

As analyzed in section 2 of literature review, many studies have been conducted to figure out different criteria affecting the decision-making process of dry port locations in developing countries. Table 5 provides a list of the most commonly mentioned criteria.

Criteria	**Sub-criteria**	**Vietnam**		**Bangladesh**	**China**						**Indonesia**	**India**	**Togo**
		Nguyen & Notteb-oom (2016b)	Pham & Lee (2019)	Chowdhury & Haque-Munim (2023)	Ka (2011)	Feng et al. (2013)	Chang et al. (2015)	Wei & Sheng (2017)	Li et al. (2011)	Wang et al. (2018)	Bhatti & Hanjra (2019)	Mohan & Naseer (2022)	Augustin et al. (2019)

Economic factors	Decrease in transport cost	x	x		x	x	x	x					
	Dry port investing cost	x				x	x		x			x	
	Cargo throughput capacity				x				x		x		
Accessibility factors	Accessibility to inland waterway infrastructure	x										x	
	Accessibility to road infrastructure	x		x							x	x	x
	Accessibility to railway infrastructure	x									x	x	x
	Accessibility to airport											x	x
	Accessibility to seaport infrastructure			x								x	x
Location factors	Proximity to other logistics platforms	x		x	x							x	x
	Proximity to production base	x	x									x	
	Proximity to consumption market		x	x								x	
	Room for expansion	x		x								x	
Environme	Decrease in	x		x				x	x	x		x	x

ntal factors	air pollution												
	Decrease in transport congestion	x										x	
	Impact on urban areas			x								x	x
Political factors	Regional cooperation environment				x								x

Table 5. Most commonly mentioned factors influencing the selection of dry port location in developing countries

This list of criteria has been consulted with six experts in Vietnam as follows to evaluate the suitability of each criterion in the case of Northern Vietnam, and to come up with additional influencing criteria that have not been analyzed in literature, especially certain criteria related to the integration of dry ports with inland waterway transport.

- Deputy Director General of Agency of Foreign Trade, Ministry of Industry and Trade of the Socialist Republic of Vietnam
- Professor in Vietnam Maritime University
- Professor in Foreign Trade University, Vietnam
- Director of Vina Logistics Co., Ltd
- Director of Loka port Logistics Co., Ltd
- Director of Nam Hai Dinh Vu Port Co., Ltd.

More detail of all experts can be found in Appendix 1.

After the consultation, one criterion has been added to the list, i.e., increase in transport time. The explanation here is that the movement from road transport to multimodal transport including inland waterway transport can significantly increase the total transport time, also measuring the additional transshipment time. This is also a big concern, especially for dry port users such as third-party logistics companies and import-export companies.

On the other hand, three criteria have been removed from the list, i.e., dry port investing cost, accessibility to airport and political factors. First, dry port investing costs are not considered in this research because the case study focuses more on the effectiveness of dry ports when integrating with inland waterways, which represents the expected impacts (Walter and Scholz, 2007). The authority has set the budget for this investment until 2030, also having published plans for mobilizing the investment capital and seeking international cooperation if necessary, so the investment in one standard dry port location is ensured to be implemented, which is within the budget plan. For simplicity of this research, the experts agreed with an assumption that there is no differentiation in the investing costs among these five locations. Second, accessibility to airports is not a necessary criterion due to the focus of the research on the integration of dry ports with inland waterways which do not have access to airports in the case of Northern Vietnam. Third, political factors, e.g. political stability, regional agreements, or regional administration, have been removed from the final list as all five provinces or cities with dry ports analyzed in this case study have the same political features under the orientation of only one Party in the North of Vietnam. Regarding the development plans, all four currently operated dry ports, namely Hai Linh, Que Vo, Phuc Loc, and Mong Cai, have the same development plan according to Decision No. 979/QĐ-TTg by Vietnam's Prime Minister, dated 22th August 2023. Only Phu Dong dry port belongs to the list of prioritized projects as it has yet to be constructed. However, this dry port's superior characteristics can be illustrated in some other factors such as room for expansion, cargo throughput capacity, and accessibility factors.

Hence, the final list of decision criteria used to evaluate the best dry port location for integration with inland waterway transport in Northern Vietnam are synthesized in Table 6 as follows.

Main criteria	**Economic factors**	**Accessibility factors**	**Location factors**	**Environmental factors**
Sub-criteria	Decrease in transport cost	Accessibility to inland waterway infrastructure	Proximity to other logistics platforms	Decrease in air pollution
	Increase in transport time	Accessibility to road infrastructure	Proximity to production base	Decrease in transport congestion
	Cargo throughput capacity	Accessibility to railway infrastructure	Proximity to consumption market	Impact on urban areas

		Accessibility to seaport infrastructure	Room for expansion	

Table 6. Criteria used to evaluate the best dry port location for integration with inland waterway transport in Northern Vietnam

This list of criteria follows the hierarchical structure, which is common in the MCDA field, to indicate the relationship of different main criteria and sub-criteria, illustrating the level of ordering, comparison, or grouping within the list of criteria (Koen, 2008).

In the next part, each criterion will be scrutinized regarding indicators and measuring methods in this research.

a. Decrease in transport cost

The indicator of this criterion is the amount of money saved by using inland waterway transport service in a dry port instead of using only road transport. Measuring unit is USD per route from a dry port to Hai Phong seaport per TEU.

Some assumptions are made before the calculations. For road transport, transport cost is calculated for the route from a nearby production base (e.g. an industrial zone) to Hai Phong seaport, the main seaport in Northern Vietnam. For multimodal transport including inland waterway transport, transport cost is calculated from a nearby production base (e.g. an industrial zone) through a dry port to reach Hai Phong seaport. All the costs and fees are calculated for a container 20 feet (1 TEU), without value added tax, excluding customs fee, infrastructure fee, terminal and highway surcharge.

According to Pham and Lee (2019), transport cost by using transport mode *m* from location *l* to destination *d* can be calculated based on distance *(D)* and fixed marginal charge *(MC)*, given by the formula: $C_{m,l,d} = MC_m \times D_{l,d}$. Marginal charges of truck and barge transport are provided by two local logistics companies, being 1.21 USD/km and 0.2 USD/km respectively. Besides, transferring costs in the dry port areas also need to be added in the calculation in case of intermodal transport using inland waterways. Not all types of transferring costs are published by five alternative dry ports in this research, especially when one out of these five dry ports –

Phu Dong dry port – has not been fully established and operated. Therefore, the fee of lifting one TEU off from truck to dry port, fee of loading one TEU from dry port onto barge, and fee of unloading one TEU from barge to Hai Phong seaport have been consulted with a local logistics company with their own truck and barge operations.

Transport cost by road transport and transport cost by multimodal transport (including road and inland waterway) are calculated separately by the following equations:

Transport cost (road) = fee of lifting one TEU onto truck + trucking fee from production base to dry port + trucking fee from dry port to Hai Phong seaport + fee of lifting one TEU off from truck to Hai Phong seaport

Transport cost (intermodal) = fee of lifting one TEU onto truck + trucking fee from production base to dry port + fee of lifting one TEU off from truck to dry port + fee of loading one TEU from dry port onto barge + barge transport fee from dry port to Hai Phong seaport + fee of unloading one TEU from barge to Hai Phong seaport

Decrease in transport cost = (trucking fee from dry port to Hai Phong seaport + fee of lifting one container off from truck to Hai Phong seaport) - (fee of lifting one TEU off from truck to dry port + fee of loading one TEU from dry port onto barge + barge transport fee from dry port to Hai Phong seaport + fee of unloading one TEU from barge to Hai Phong seaport)

in which,

- Trucking fee from dry port to Hai Phong seaport = 1.21 (USD/km) x road distance from dry port to Hai Phong seaport
- Fee of lifting one TEU off from truck to Hai Phong seaport = 30 USD (data from Hai Phong port service quotation 2024, Notice No. 884/TB-CHP signed by Nguyen Tuong Anh - General Director of Hai Phong Port Co., Ltd.)
- Fee of lifting one TEU off from truck to dry port = 23.7 USD (data from a local logistics company)
- Fee of loading one TEU from dry port onto barge = 13.8 USD (data from a local logistics company)

- Barge transport fee from dry port to Hai Phong seaport = 0.2 (USD/km) x river distance from dry port to Hai Phong seaport
- Fee of unloading one TEU from barge to Hai Phong seaport = 16.9 USD (data from a local logistics company)

b. Increase in transport time

The indicator of this criterion is the amount of time increased by using multimodal transport including inland waterway transport service in dry port instead of using only road transport. Measuring unit is hours per route from a dry port to Hai Phong seaport per TEU.

As this case study does not focus on the transport route from a specific industrial zone or import-export company, it is not a sufficient representative to calculate transport time from a specific industrial zone or company to Hai Phong seaport, then compare the value with transport time from that specific industrial zone or company through a dry port to Hai Phong seaport. Hence, this research only compares the part of transport time from each dry port to Hai Phong seaport by road and by barge. Transport time by truck is derived from Google Maps, while transport time by barge is calculated as follows:

Transport time (barge) = river distance from dry port to Hai Phong seaport / average velocity of a fully-loaded barge

Increase in transport time = transport time (barge) - transport time (truck)

Within five alternative dry ports, the inland waterway route from Que Vo dry port to Hai Phong seaport has been selected by Vietnam Inland Waterway Administration as the standard inland waterway route for container transport in Northern Vietnam since 2020, with the distance of 100 kilometers of inland waterways and the transport time of 10 hours (Vietnam Ministry of Transport, 2023). From this, the average velocity of the barge can be calculated, having the value of 10 km/h.

Some assumptions are made in this calculation. First, velocity of barges and river flows are assumed to be the same for these five inland waterway routes. Second, this research does not take into account the waiting time at the dry port for meeting barge schedules on a daily or weekly basis. Third, transport time by road is for the normal state of traffic, not considering possible delays in traffic jams.

Road distance, river distance from each dry port to Hai Phong seaport have been calculated based on Google Maps and information from local logistics companies. The illustrations of different routes can be found in Figures 6 – 10.

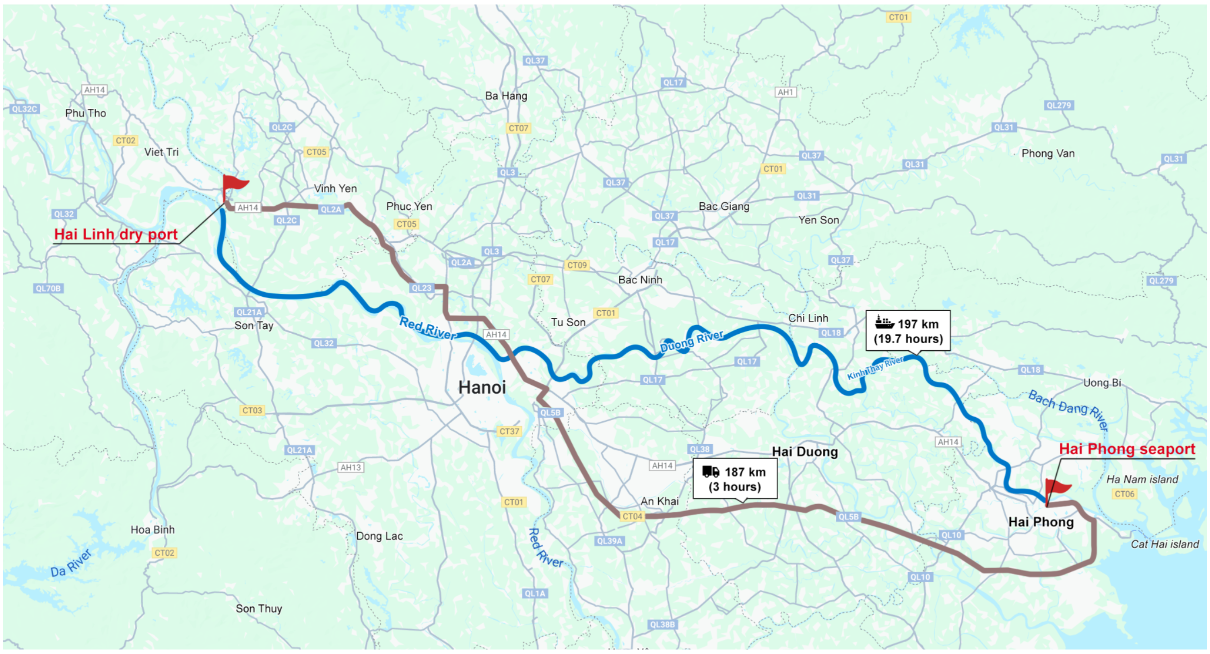

Figure 6. Transport routes by road and by inland water way from Hai Linh dry port to Hai Phong seaport

Figure 7. Transport routes by road and by inland water way from Phu Dong dry port to Hai Phong seaport

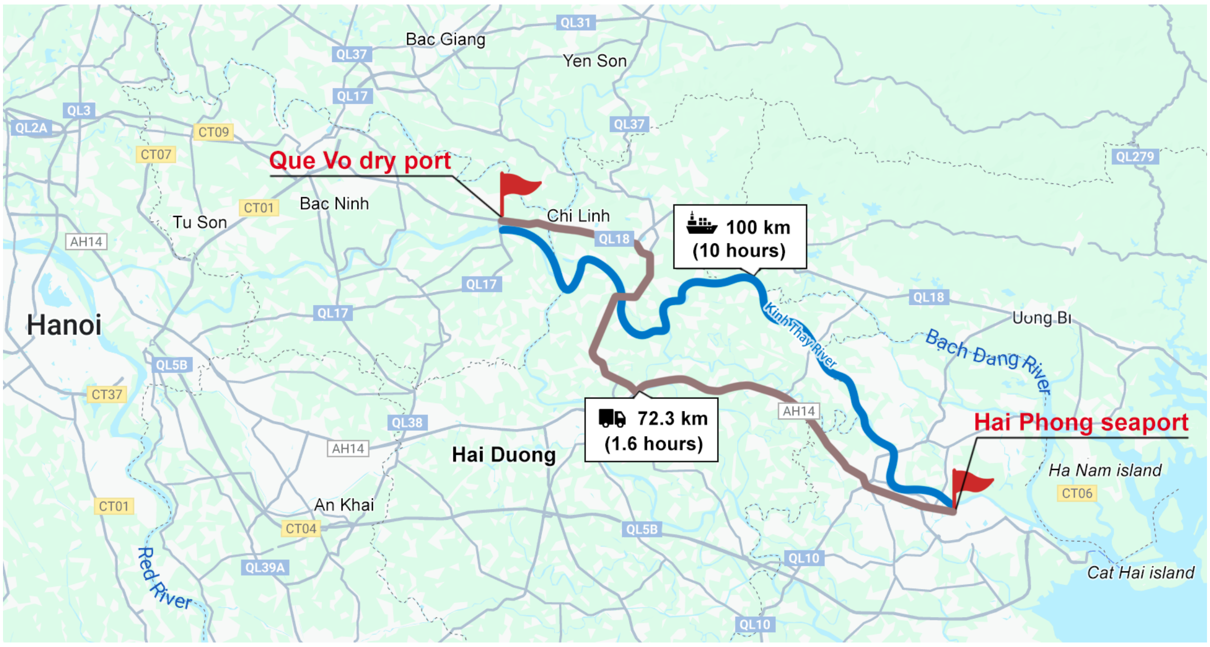

Figure 8. Transport routes by road and by inland water way from Que Vo dry port to Hai Phong seaport

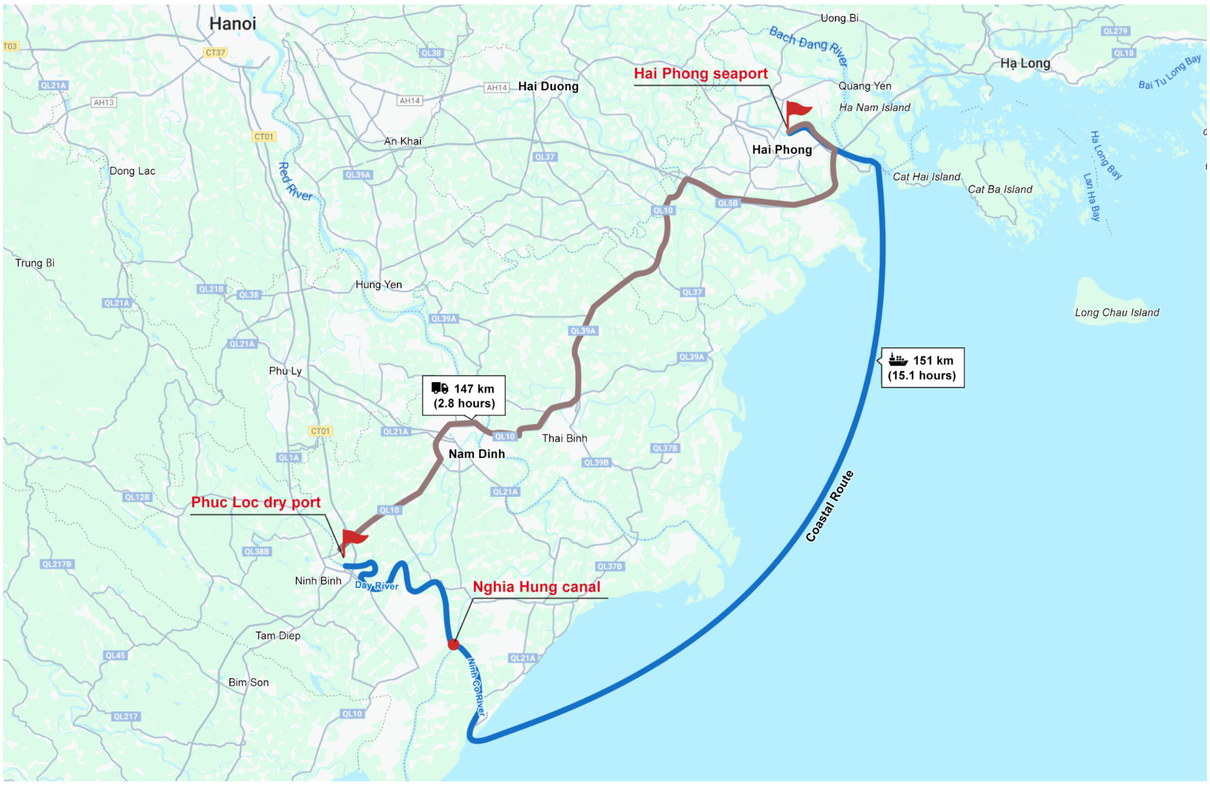

Figure 9. Transport routes by road and by inland water way from Phuc Loc dry port to Hai Phong seaport

Figure 10. Transport routes by road and by inland water way from Mong Cai dry port to Hai Phong seaport

c. Decrease in air pollution

The indicator of this criterion is the amount of CO_2 reduced per TEU per route by using inland waterway transport service in a dry port instead of using only road transport.

According to Blancas and El-Hifnawi (2014), the estimations for Vietnam until 2030 about the emission factors are as follows:

Average truck fleet emission factor for Vietnam: 80 (gCO_2/ton-km)

Average inland waterway transport fleet emission factor: 50 (gCO_2/ton-km)

Assuming that the gross weight of 1 fully-loaded TEU is equal to 25 tons, the reduction in CO_2 amount can be calculated with the following equation:

Reduction in CO_2 amount = 25 x (80 x road distance from dry port to Hai Phong seaport – 50 x river distance from dry port to Hai Phong seaport) (gCO_2)

d. Other criteria

The indicators and measuring units of the remaining 11 criteria have been described in Table 7.

Criteria	Indicators	Indicator sources	Measuring units	Data sources
Cargo throughput capacity	Expected container throughput by 2030	Bhatti and Hanjra (2019); Expert discussion	TEU/year	Decision No. 979/QĐ-TTg by Vietnam's Prime Minister, dated 22 August 2023
Accessibility to inland waterway infrastructure	Number of inland waterway routes accessed	Nguyen and Notteboom (2016b); Expert discussion	Number	Decision No. 979/QĐ-TTg by Vietnam's Prime Minister, dated 22 August 2023
Accessibility to road infrastructure	Distance to highways	Bhatti and Hanjra (2019); Nguyen and Notteboom (2016b); Mohan and Naseer (2022); Augustin et al. (2019)	Km	Google Maps; Decision No. 979/QĐ-TTg by Vietnam's Prime Minister, dated 22 August 2023
Accessibility to railway infrastructure	Number of railways accessed	Nguyen and Notteboom (2016b); Augustin et al. (2019); Expert discussion	Number	Decision No. 979/QĐ-TTg by Vietnam's Prime Minister, dated 22 August 2023
Accessibility to seaport infrastructure	Distance to Hai Phong seaport	Mohan and Naseer (2022)	Km	Google Maps
Proximity to other logistics platforms	Distance to the nearest logistics center	Ka (2011); Nguyen and Notteboom (2016b)	Km	List of logistics centers in Northern Vietnam: 1. ICD Vinh Phuc logistics center (Vinh Phuc province) 2. KM Cargo Services Center (Hai Phong city) 3. Cai Lan - VOSA logistics center (Quang Ninh province)

				4. Green logistics center - Dinh Vu industrial zone (Hai Phong city)
Proximity to production base	Number of industrial zones in operation and in construction plan in the same province	Mohan and Naseer (2022); Expert discussion	Number	Map of industrial zones in Northern Vietnam
Proximity to consumption market	GRDP per capita 2023	Li et al. (2011); Chang et al. (2015); Expert discussion	Billion USD	Statistics Office of each province or city
Room for expansion	Expected area of dry port expansion until 2050	Nguyen and Notteboom (2016b); Mohan and Naseer (2022); Expert discussion	Ha	Decision No. 979/QĐ-TTg by Vietnam's Prime Minister, dated 22 August 2023
Decrease in transport congestion	Number of accessed highways with reduced traffic by using inland waterway transport service in dry port	Nguyen and Notteboom (2016b); Expert discussion	Number	Decision No. 979/QĐ-TTg by Vietnam's Prime Minister, dated 22 August 2023
Impact on urban areas	Distance to urban center	Mohan and Naseer (2022); Augustin et al. (2019)	Km	Google Maps

Table 7. Indicators of other criteria

Looking at the accessibility factors in more detail, in this research, accessibility to different transport infrastructure, namely road, inland waterway, railway, and seaport, is calculated by distance to the transport networks or infrastructure densities. The reality has more complexities as there is a possibility that only one main infrastructure corridor still gives better accessibility than several smaller, derelict infrastructures. However, for simplicity and practical reasons for data collecting, this research opts for a simpler approach. This will be explained more in the section of discussion.

The four main criteria and fourteen sub-criteria used in this case study satisfy five necessary properties of criteria employed in an MCDA evaluation model (Franco and Montibeller, 2010). First, they are unambiguous, all having quantitative indicators. Second, they are comprehensive, indicating possible consequences if alternatives are implemented. Third, they are direct, presenting direct consequences if alternatives are implemented. Fourth, they are operational as data related to criteria can be collected in practice. Fifth, they are understandable when the value trade-offs using the criteria can be interpreted by the decision-makers.

In terms of rank determination of sub-criteria, ten sub-criteria indicate higher ranks of alternatives with higher values, namely decrease in transport cost, cargo throughput capacity, accessibility to inland waterway infrastructure, accessibility to railway infrastructure, proximity to production base, proximity to consumption market, room for expansion, decrease in air pollution, decrease in transport congestion, and impact on urban areas (the indicator is distance to urban center). On the other hand, four sub-criteria indicate higher ranks of alternatives with lower values, namely increase in transport time, accessibility to road infrastructure (the indicator is distance to highways), accessibility to seaport infrastructure (the indicator is distance to Hai Phong seaport), and proximity to other logistics platforms (the indicator is distance to the nearest logistics center).

4.3.3. Decision hierarchy

The decision hierarchy is provided in Figure 11 following the top-down structure. This structure starts by the overall objective, which is then decomposed into main criteria and finally followed by corresponding sub-criteria.

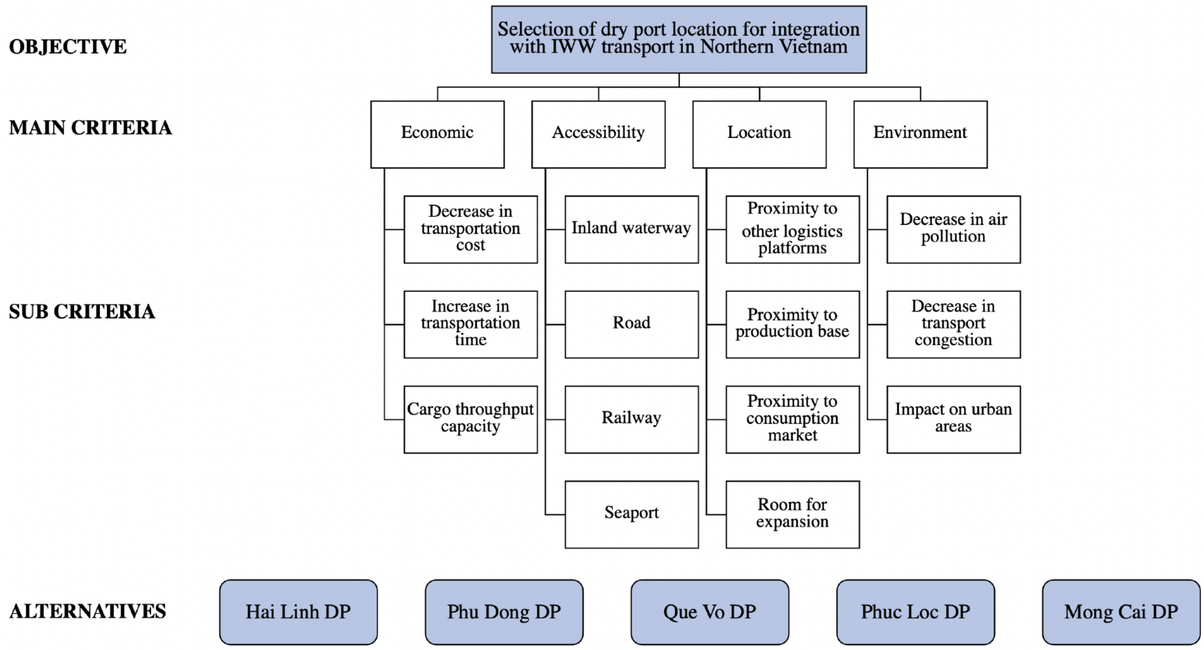

Figure 11. Decision hierarchy

4.4. Criteria weights

In this case study, interviews were carried out with all three groups of stakeholders: policy makers and consultants (four experts), dry port investors and operators (five experts), and dry port users (sixteen experts). More details about experts interviewed in this research can be found in Appendix 1.

During the interviews, the experts provided their opinions about the importance of four main criteria and fourteen sub-criteria in the decision-making process of selecting the optimal dry port location for integration with inland waterway transport in Northern Vietnam. Detailed questions during the interviews can be found in Appendix 2. In this case study, all experts are assumed to have the same weight in the decision-making process, and geometric mean is applied to calculate the aggregated weights according to the reasons provided in section 2.2.2. Acknowledging that the numbers of interviewees per group are not the same, in order to avoid implicit prioritization, i.e., assigning higher decision-making power to the stakeholder group with more experts, the aggregated criteria weights of each stakeholder group are calculated first, followed by the total aggregated criteria weights of all three groups. Each group is assumed to be homogeneous. The aggregated criteria weights of each stakeholder group are calculated with the below formula:

$$w_j = \sqrt[n]{w_{j1} w_{j2} \dots w_{jn}}$$

where,

w_j: aggregated weight of criterion j

$w_{j1}, w_{j2}, \dots, w_{jn}$: weight of criterion j by expert 1, 2, ..., n

n: total number of experts in each group

The total aggregated weights are finally normalized to get a sum equaling to 1. The formula of normalization is:

$$w_{j\_normalized} = \frac{w_j}{\sum w_j}$$

Final weights of all the main criteria and sub-criteria are provided in Figures 12 and 13.

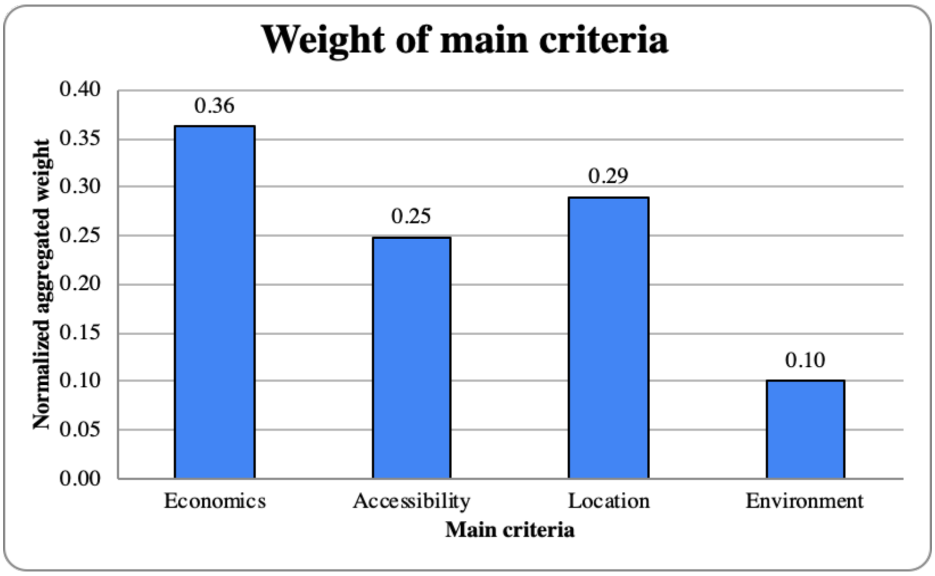

Figure 12. Normalized aggregated weight of main criteria

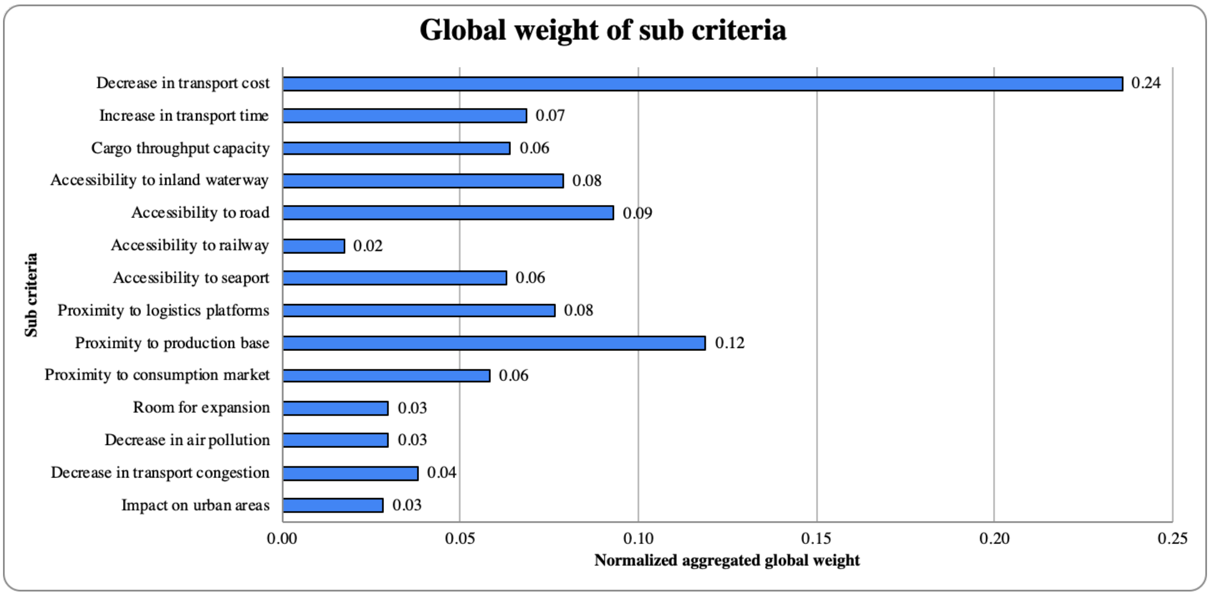

Figure 13. Normalized aggregated global weight of sub-criteria

Besides, in Figures 14 – 16, main criteria weights of each expert group have been analyzed to capture the difference in preference of various stakeholders involved in the selection of dry port selection for integration with inland waterway transport in Northern Vietnam.

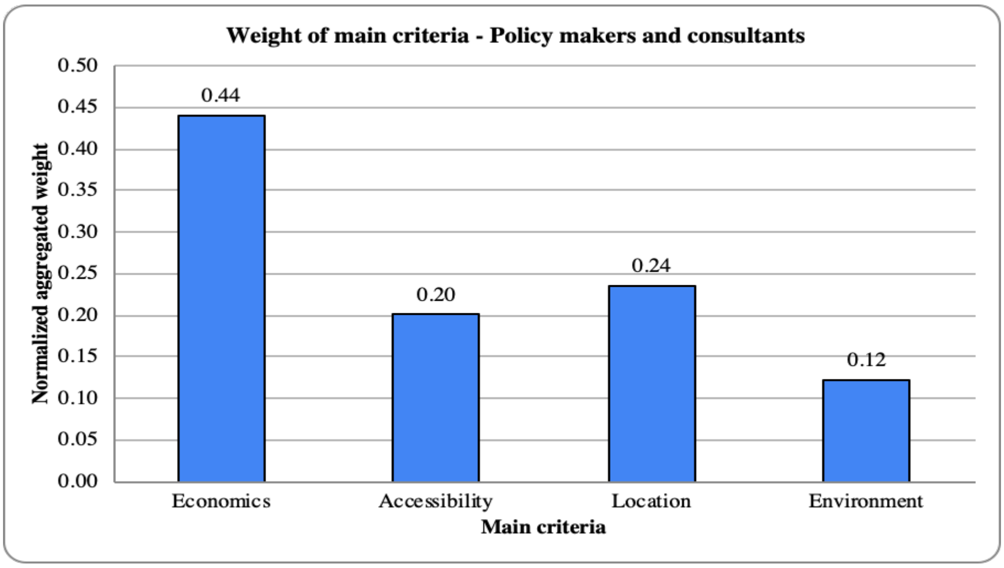

Figure 14. Normalized aggregated weight of main criteria of Group 1: Policy makers and consultants

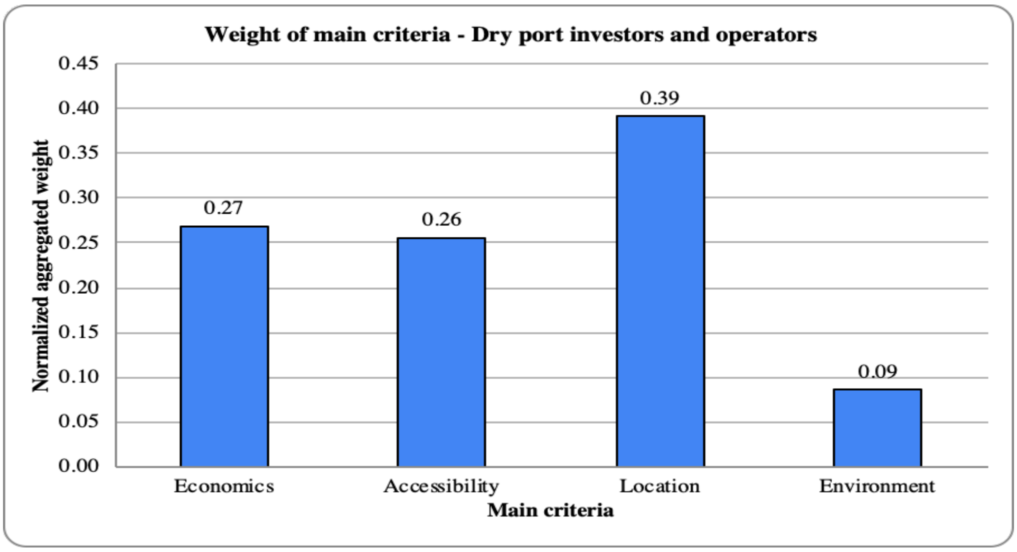

Figure 15. Normalized aggregated weight of main criteria of Group 2: Dry port investors and operators

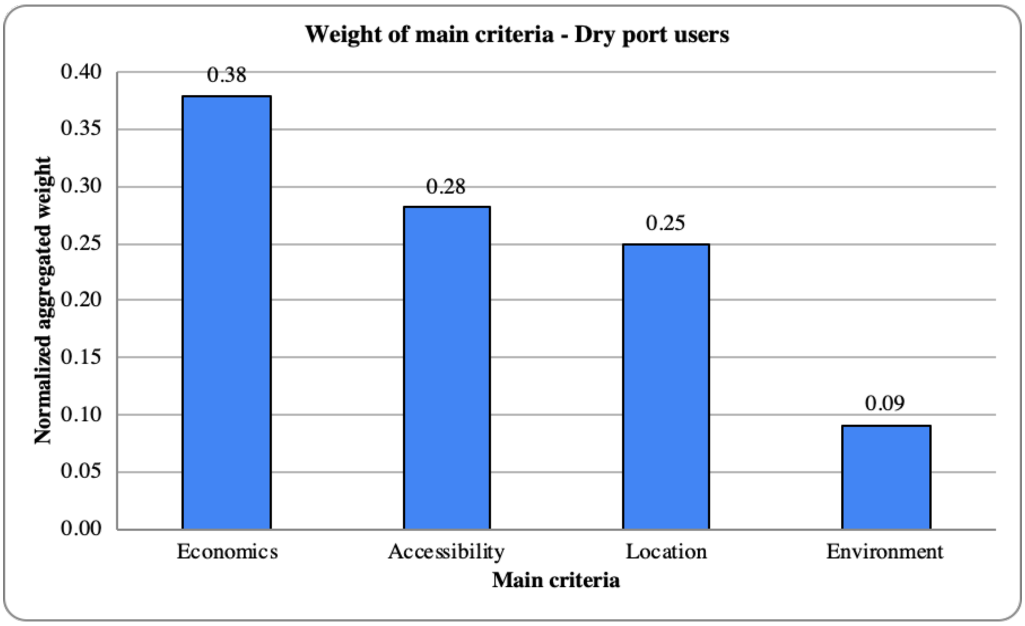

Figure 16. Normalized aggregated weight of main criteria of Group 3: Dry port users

4.5. Performance data

All the data of performance of five alternatives regarding all sub-criteria have been collected or calculated with the corresponding indicators described in section 4.3.2. The results of performance data are shown in Table 8.

Criteria	Sub-criteria	Indicators	Measuring units	Hai Linh DP	Phu Dong DP	Que Vo DP	Phuc Loc DP	Mong Cai DP

Economic factors	Decrease in transport cost	Cost saved by using inland waterway transport service in dry port	USD per route from dry port to Hai Phong seaport per TEU	165	100	44	125	155
	Increase in transport time	Time increased by using inland waterway transport service in dry port	Hours per route from dry port to Hai Phong seaport per TEU	16.7	10.6	8.4	12.3	18.4
	Cargo throughput capacity	Expected container throughput by 2030	TEU/year	65	260,000	200,000	115,000	113
Accessibility factors	Accessibility to inland waterway infrastructure	Number of inland waterway routes accessed	Number	2	1	1	1	1
	Accessibility to road infrastructure	Distance to highways	Km	1	0.8	5.5	3.5	0.5
	Accessibility to railway infrastructure	Number of railways accessed	Number	1	0	0	0	0
	Accessibility to seaport infrastructure	Distance to Hai Phong seaport	Km	187	122	72.3	147	181
Location factors	Proximity to other logistics platforms	Distance to the nearest logistics center	Km	30 km (to ICD Vinh Phuc Logistics Center)	56 km (to ICD Vinh Phuc Logistics Center)	73 km (to ICD Vinh Phuc Logistics Center)	152 km (to Green Logistics Center - Dinh Vu	147 km (to Cai Lan Logistics Center - VOSA

							Hai Phong)	Quang Ninh)
	Proximity to production base	Number of industrial zones in operation and in construction plan in the same province	Number	7	12	15	5	17
	Proximity to consumption market	GRDP per capita 2023	Billion USD	3.8	51.2	8.7	2.1	12.4
	Room for expansion	Expected area of dry port expansion until 2050	Ha	0	40	15	25	0
	Decrease in air pollution	Amount of CO_2 reduced per TEU per route by using inland waterway transport	$KgCO_2$	127.75	92.75	19.6	105.25	99.5
	Decrease in transport congestion	Number of accessed highways with reduced traffic by using inland	Number	2	3	1	3	3

		waterway transport service in dry port						
	Impact on urban areas	Distance to urban center	Km	6	13	22	6	4

Table 8. Alternative performance regarding all criteria

For three sub-criteria - decrease in transport cost, increase in transport time, and decrease in air pollution - the performance data have been obtained by the author's own calculations based on the indicators stated in literature review, expert discussion, and the separate data obtained from local logistics companies. These data have not been calculated before by any organizations and cannot be found in literature as primary data. The results of these calculations have been discussed and validated with Vietnamese experts before being used for the next phase of alternative ranking determination.

Pareto dominance has been checked, ensuring that it is impossible to obtain an alternative with the best performance regarding all the criteria, or an alternative with better performance in at least one criterion without being worse in any other criteria when compared to the remaining four alternatives.

4.6. Rankings of alternatives

The performance data were provided to the experts to obtain their opinions on the required thresholds: preference threshold (p_j), indifference threshold (q_j), and veto threshold (v_j). A total of twenty-four experts participated in the interviews to determine these thresholds. The aggregated preference threshold, aggregated indifference threshold, and aggregated veto thresholds have been calculated using the arithmetic mean. Similar to the calculation of criteria weights, in order to avoid implicit prioritization, the aggregated thresholds of each stakeholder group are calculated first, followed by the total aggregated thresholds of all three groups.

Results of aggregated thresholds can be found in Table 9.

Dry port	Decrease in transport cost	Increase in transport time	Cargo throughput capacity	Accessibility to inland waterway infrastructure	Accessibility to road infrastructure	Accessibility to railway infrastructure	Accessibility to seaport infrastructure	Proximity to other logistics platforms	Proximity to production base	Proximity to consumption market	Room for expansion	Decrease in air pollution	Decrease in transport congestion	Impact on urban areas
1. Hai Linh	165	16.7	65	2	1	1	187	30	7	3.8	0	127.75	2	6
2. Phu Dong	100	10.6	260,000	1	0.8	0	122	56	12	51.2	40	92.75	3	13
3. Que Vo	44	8.4	200,000	1	5.5	0	72.3	73	15	8.7	15	19.6	1	22
4. Phuc Loc	125	12.3	115,000	1	3.5	0	147	152	5	2.1	25	105.25	3	6
5. Mong Cai	155	18.4	113	1	0.5	0	181	147	17	12.4	0	99.5	3	4
w_j	0.24	0.07	0.06	0.08	0.09	0.02	0.06	0.08	0.12	0.06	0.03	0.03	0.04	0.03
q_j	23	4	29,493	1	1	0	37	16	3	7	5	20	1	4
p_j	62	9	108,368	2	2	1	79	44	7	26	14	55	2	10
v_j	89	14	153,819	2	3	1	109	57	10	36	26	93	3	13

Table 9. Aggregated preference thresholds, indifference thresholds, veto thresholds

Preference thresholds, indifference thresholds and veto thresholds in Table 9 are used for calculations to create the concordance matrix, credibility matrix, final qualification, and rankings. The results of concordance matrix and credibility matrix are presented in Table 10 and Table 11, respectively.

Dry port	1. Hai Linh	2. Phu Dong	3. Que Vo	4. Phuc Loc	5. Mong Cai
1. Hai Linh	1.00	0.70	0.64	0.90	0.88
2. Phu Dong	0.71	1.00	0.96	0.99	0.75
3. Que Vo	0.55	0.52	1.00	0.59	0.60
4. Phuc Loc	0.71	0.55	0.67	1.00	0.74

5. Mong Cai	0.90	0.66	0.67	0.88	1.00

Table 10. Concordance matrix

Dry port	**1. Hai Linh**	**2. Phu Dong**	**3. Que Vo**	**4. Phuc Loc**	**5. Mong Cai**
1. Hai Linh	1.00	0.00	0.00	0.72	0.00
2. Phu Dong	0.00	1.00	0.96	0.99	0.75
3. Que Vo	0.00	0.00	1.00	0.27	0.00
4. Phuc Loc	0.00	0.00	0.00	1.00	0.00
5. Mong Cai	0.00	0.00	0.00	0.60	1.00

Table 11. Concordance matrix

A cut-off level of 0.6 is used in this case study. This cut-off level has been shown to provide good performance and good discrimination between alternatives in previous MCDA research utilizing ELECTRE methods (Preethi and Chandrasekar, 2015; da Costa et al., 2022). Of course, there is some uncertainty about this input data, hence, the cut-off level will be tested in the section of sensitivity analysis to check whether changes in this data affect the final ranking of dry port location alternatives. Table 12 shows the results of the credibility matrix after the cut-off level of 0.6 is applied. The final qualification and ranking of five alternatives are presented in Table 13.

Dry port	**1. Hai Linh**	**2. Phu Dong**	**3. Que Vo**	**4. Phuc Loc**	**5. Mong Cai**	**SUM**
1. Hai Linh	1	0	0	1	0	2
2. Phu Dong	0	1	1	1	1	4
3. Que Vo	0	0	1	0	0	1
4. Phuc Loc	0	0	0	1	0	1
5. Mong Cai	0	0	0	0	1	1

SUM	1	1	2	3	2	

Table 12. Credibility matrix with cut-off 0.6

Dry port	Strengths	Weaknesses	Qualification	Ranking
1. Hai Linh	2	1	1	2
2. Phu Dong	4	1	3	**1**
3. Que Vo	1	2	-1	3
4. Phuc Loc	1	3	-2	5
5. Mong Cai	1	2	-1	3

Table 13. Credibility matrix with cut-off 0.6

4.7. Location selection

The first ranking belongs to Phu Dong dry port which is the only alternative with a positive final score of qualification. The gap of qualification between the first ranking and the second one is significant. Hence, according to the result of this case study, Phu Dong dry port should be selected as the best location for the Vietnamese government to make investment in developing the integration between this dry port and inland waterway transport.

4.8. Sensitivity analysis

Acknowledging some uncertainty about the input data, this research conducts sensitivity analyses in order to examine the stability rate in the final rankings with changes in model parameters.

4.8.1. Sensitivity analysis with criteria weights

First, a sensitivity analysis is carried out by applying changes in the criteria weights as the author acknowledges that the criteria weight might vary due to changes in stakeholder preferences or the inclusion of additional stakeholders, e.g. more stakeholders in the group of policy makers and consultants. A sensitivity analysis is helpful in offering insights into the extent to which the final rankings might be affected by the modest modifications in the criteria weights. This analysis involves increasing and decreasing the weight of each criterion, ranging from 10% to 20%, while the weights of the remaining criteria are held constant during these adjustments. The resulting changes in the final rankings of five alternatives are observed and presented in Table 14.

Sub-criteria	Decrease in transport cost	Increase in transport time	Cargo throughput capacity	Accessibility to inland waterway infrastructure	Accessibility to road infrastructure	Accessibility to railway infrastructure	Accessibility to seaport infrastructure
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
+10%	No change	No change	No change	No change	No change	No change	No change
+20%	No change	No change	No change	No change	No change	No change	No change
-10%	No change	No change	No change	No change	No change	No change	No change
-20%	No change	No change	No change	No change	No change	No change	No change
Sub-criteria	**Proximity to other logistics platforms**	**Proximity to production base**	**Proximity to consumption market**	**Room for expansion**	**Decrease in air pollution**	**Decrease in transport congestion**	**Impact on urban areas**
	C8	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**
+10%	No change	No change	No change	No change	No change	No change	No change
+20%	No change	No change	No change	No change	No change	No change	No change
-10%	No change	No change	No change	No change	No change	No change	No change
-20%	No change	No change	No change	No change	No change	No change	No change

Table 14. Effect of changing criteria weights

As can be seen from Table 14, the final rankings of alternatives are not affected by any changes in criteria weight by 10% and 20%.

4.8.2. Sensitivity analysis with thresholds

Similar to criteria weights, three types of threshold used in the calculation of alternative rankings, i.e., indifference thresholds, preference thresholds, and veto thresholds, are obtained from the interviews with stakeholders. There might exist uncertainty in the determination of these thresholds, therefore, a sensitivity analysis is conducted with these thresholds, involving increasing and decreasing each threshold from 10% to 20%, while the remaining two thresholds are held constant during these adjustments. The resulting changes in the final rankings of five alternatives are observed and presented in Table 15.

Change in indifference thresholds	**(q_j) + 10%**	**(q_j) + 20%**	**(q_j) - 10%**	**(q_j) - 20%**
Ranking	No change	No change	No change	No change
Change in preference thresholds	**(p_j) + 10%**	**(p_j) + 20%**	**(p_j) - 10%**	**(p_j) - 20%**
Ranking	No change	No change	No change	No change
Change in veto thresholds	**(v_j) + 10%**	**(v_j) + 20%**	**(v_j) - 10%**	**(v_j) - 20%**
Ranking	Phuc Loc: 5	Phuc Loc: 5	No change	No change

Table 15. Effect of changing thresholds

No change in the final rankings is observed when the indifference thresholds or preference thresholds undergo an increase or decrease by 10% or 20%. When it comes to changes in veto thresholds, the decrease by 10% or 20% in veto thresholds does not lead to any change in the final rankings, but the increase by 10% or 20% in this type of threshold makes Phuc Loc dry port become the worst alternative, having lower qualification score than Que Vo dry port and Mong Cai dry port. However, this alteration has no impact on the first ranking and the final selection of the invested dry port.

4.8.3. Sensitivity analysis with cut-off level

In the final creation of the credibility matrix and calculation of the qualification, a cut-off level of 0.6 is applied, which comes from the literature. However, in reality, there might be another cut-off level according to the perspective of decision-makers. A sensitivity analysis is conducted with this cut-off level, testing whether there are changes in the final rankings with a cut-off level ranging from 0.1 to 0.9. The resulting changes in the final rankings of five alternatives are observed and presented in Table 16.

Cut-off level	0.1	0.2	0.3	0.4	0.5	**0.6**	0.7	0.8	0.9

Ranking	Hai Linh & Que Vo: 2 Mong Cai: 4 Phuc Loc: 5	No change	No change	No change	No change	**Original cut-off level**	Hai Linh & Mong Cai: 2 Que Vo & Phuc Loc: 4	Hai Linh & Mong Cai: 2 Que Vo & Phuc Loc: 4	Hai Linh & Mong Cai: 2 Que Vo & Phuc Loc: 4

Table 16. Effect of changing cut-off level

The result of this sensitivity analysis indicates that the use of a cut-off level from 0.2 to 0.6 leads to the same final rankings. If the cut-off level is 0.1, Que Vo dry port increases its qualification and shares the same second ranking with Hai Linh dry port. Mong Cai dry port and Phuc Loc dry port hold the fourth and the fifth ranking respectively. On the other hand, if the cut-off level is equal or higher than 0.7, the final rankings also witness changes with Hai Linh dry port and Mong Cai dry port share the second ranking, while Que Vo dry port and Phuc Loc dry port share the fourth ranking. However, these changes definitely have no impact on the first ranking and the final selection of the invested dry port – Phu Dong dry port.

4.8.4. Sensitivity analysis with weights of stakeholder groups

Changes in the weights of stakeholder groups are applied to observe any changes in the final rankings. An important assumption in this case study is that all three groups of stakeholders, namely policy makers and consultants, dry port investors and operators, and dry port users, have the same decision-making power. This assumption is agreed by Vietnamese experts for the simplicity of this research. However, in reality, the policy makers and consultants are the most relevant decision-makers in this case and might have higher weight in the decision-making process than the other stakeholders. Hence, this sensitivity analysis involves the increase in the weight of this stakeholder group by two times, three times, and four times, while the weights of the remaining two stakeholder groups are held constant during these adjustments. The resulting changes in the final rankings of five alternatives are observed and presented in Table 17.

Change in weight of Group 1: Policy makers and consultants	Twofold increase	Threefold increase	Fourfold increase
Weight of Group 1 after normalization	0.5	0.6	0.67
Weight of Group 2 after normalization	0.25	0.2	0.17

Weight of Group 3 after normalization	0.25	0.2	0.17
Ranking	No change	No change	Que Vo: 4 Phuc Loc: 5

Table 17. Effect of changing weight of stakeholder group 1: policy makers and consultants

The result of this analysis shows that when the weight of stakeholder group 1 is two or three times higher than the weight of stakeholder group 2 and 3, no change is observed in the final rankings. Only when the weight of stakeholder group 1 is 0.67, four times higher than that of the other two groups, do the final rankings witness certain changes with Que Vo dry port and Phuc Loc dry port decreasing their rankings, holding the fourth and the fifth ranking correspondingly. However, the first ranking and the final selection of the invested dry port still stay unchanged.

4.8.5. Sensitivity analysis with performance data calculated by the author

Lastly, the author acknowledges some uncertainty existing in the calculations of performance data of five alternatives with regard to three sub-criteria – decrease in transport cost, increase in transport time, and decrease in air pollution. Certain assumptions are made with these calculations due to the lack of data provided by local logistics companies operating real transport routes analyzed. Even though the results of these calculations have been validated with Vietnamese experts, a sensitivity analysis is necessary to observe any changes in the final rankings if changes in these performance data are applied. This involves increasing and decreasing performance data of each sub-criterion - decrease in transport cost, increase in transport time, and decrease in air pollution - from 10% to 20%, while the remaining performance data are held constant during these adjustments. The resulting changes in the final rankings of five alternatives are observed and presented in Table 18.

Sub criteria	**Decrease in transport cost**	**Increase in transport time**	**Decrease in air pollution**
	C1	**C2**	**C12**
+10%	No change	No change	No change
+20%	No change	No change	No change
-10%	No change	Que Vo: 4	No change

-20%	No change	Que Vo: 4	No change

Table 18. Effect of changing performance data calculated by the author

The result of this analysis shows that the final rankings of alternatives are not affected by changes in performance data of two sub-criteria “decrease in transport cost” and “decrease in air pollution” by 10% and 20%. When the performance data of the sub-criterion “increase in transport time” decrease by 10% and 20%, Que Vo dry port changes its ranking to the fourth position. However, this change definitely has no impact on the first ranking and the final selection of the invested dry port – Phu Dong dry port.

5

DISCUSSION

5. Discussion

5.1. Discussion of main results

The list of decision criteria used in this case study is based on the literature, but new insights are added by Vietnamese experts to shed light on important criteria influencing this specific location choice problem.

With regard to the weights of main criteria, economics is the most important main criterion in this decision-making with the weight of 0.36. Two groups of stakeholders, i.e., policy makers and consultants (group 1) and dry port users (group 3), both assign top priority to this criterion. This was explained by the experts during the interviews that in Vietnam, the majority of companies, including logistics companies and import-export companies, attach the greatest importance to the profit. For emerging companies in a developing country, strong financial backgrounds strengthen their opportunities to expand local and international markets. A major difference can be observed in the preference of dry port investors and operators (group 2) who assign top priority to location, not economics. Insights from experts in this group indicate that specific location factors such as the proximity to the production base and the proximity to the consumption market are real back-up of any dry port, ensuring resources and demand for the operation of dry ports. High weight from group 2 leads to the overall second ranking of the importance of location in this decision-making, having the overall weight of 0.29. The next important criterion is accessibility with the weight of 0.25, followed by environment which is the least important criterion. In Vietnam, environmental factors have attracted more attention these days, many logistics companies are researching the transition to greener modes of transport, including inland waterway transport, feeling increasing concern about the zero-emission goal and the market of carbon certificates in the near future. Nonetheless, these first attempts are not sufficient to make the environment a crucial factor in this location decision when compared with economics, location and accessibility.

In terms of the weights of sub-criteria, decrease in transport cost has the highest weight of 0.24, doubling the weight of the second ranked sub criterion which is proximity to production base. High transport cost is continuously an acute issue of Vietnamese companies as this is the highest cost accounting for approximately 60% of the total logistics costs (Hoa et al. 2020), substantially affecting the profit, especially with the fluctuations in fuel prices, which explains the highest priority given to this criterion. All other sub-criteria have weights under 0.1. The least important sub-criteria are mainly environmental criteria, which is understandable from the afore-mentioned explanation. However, accessibility to railway infrastructure is the sub-criterion with the lowest weight in the list (0.02). In fact, in the North of Vietnam, railway networks have not been optimized for goods transport. According to the Logistics Report of Vietnam (2023), the proportion of goods transported by railway only accounted for 0.2% of the total amount of goods transport in 2023, whereas this figure was 73% and 21.6% for road transport and inland waterway transport respectively. Only one dry port in the list, i.e., Hai Linh dry port in Phu Tho province, possesses the connection with railway, yet not being able to take advantage of this mode's operational schedules. Therefore, the majority of stakeholders assign very low weights to the sub criterion of accessibility to railway infrastructure.

When it comes to the final rankings of five alternatives, Phu Dong dry port in Ha Noi capital city has the first ranking. This can be explained by the performance data of five alternatives regarding all criteria. Phu Dong dry port expresses good performance regarding the criteria with the highest weights, i.e., decrease in transport cost (the weight is 0.24), proximity to production base (the weight is 0.12), accessibility to road (the weight is 0.09), and proximity to other logistics platforms (the weight is 0.08). Remarkably, for certain criteria, this alternative dry port location substantially exceeds the others in the performance data, i.e., cargo throughput capacity, proximity to consumption market, and room for expansion. These performance differences are often higher than the preference thresholds and veto thresholds of these criteria, contributing to high scores of this alternative in the credibility matrix. Hai Linh dry port holds the second ranking. This is understandable since this alternative has the highest performance data regarding the most important criterion which is decrease in transport cost and it is the only one alternative possessing the connection with railway network, which can be observed in the performance of the criterion accessibility to railway infrastructure. However, this alternative cannot be ranked the first in the alternative list because it has very low performance in certain criteria such as cargo throughput capacity, proximity to consumption market, and room for expansion.

The sensitivity analyses indicate that the changes in criteria weights, ELECTRE III thresholds, cut-off level, decision power of the group of policy makers and consultants, and the performance data calculated by the author create no impact on the final selection of the optimal dry port location in this case study. In other words, the results obtained are relatively stable despite the uncertainty of some parameters in reality.

5.2. Reflection on research methodology

The use of MCDA adds value to this case study research compared to an economic analysis as it not only captures the effect of economic-related factors such as transport cost and transport time, but also highlights the effect of other non-economic factors, namely accessibility, location and environmental factors. Even though economic factors in general and decrease in transport cost in particular is still the most important factor in this decision-making problem, certain location and accessibility factors are also assigned significant weights such as proximity to production base, accessibility to road infrastructure, accessibility to inland waterway infrastructure, and proximity to other logistics platforms. The least-cost models can capture the effect of the most important factor - economic factor, but is not sufficient in the case of dry port location selection for integration with inland waterway transport in a developing country like Vietnam with many non-economic factors having their roles.

The richness of stakeholder interviews is well captured in the implementation of BWM and ELECTRE III. For the determination of alternatives and decision criteria, six experts, being policy makers, university professors, and directors of logistics companies, added their insights to the literature and reached an agreement on the final list of decision criteria and alternatives that are appropriate for the specific case of Northern Vietnam. This practice is valuable as the findings from literature only indicate the general list with some decision criteria which are not suitable for this case study. Moreover, the interviews with Vietnamese experts also reveal the need to include Phu Dong dry port which has not been operated yet and its construction is in the government's plan, not similar to the four other alternatives. Data obtained from the literature also focus on these four currently-operated alternatives, and the expert interviews positively contribute to the fulfillment of this research's list of alternative dry port locations. In the interviews conducted with stakeholders to obtain the criteria weights for BWM calculations, all three groups of stakeholders have the interviewees: group 1 - policy makers and consultants (four experts), group 2 - dry port investors and operators (five experts), and group 3 - dry port users (sixteen experts). This is an acceptable number of stakeholders to avoid biases in human decision-making. Although it is more challenging to approach group 1 and group 2, the differences in preference of three groups of stakeholders have been clearly reflected in the results of criteria weight. During the interviews, not only the pairwise comparisons between criteria were made, but the stakeholders also provided the explanations for their decisions, which assists the author in thoroughly discussing the final results. When it comes to the interviews to obtain the thresholds for ELECTRE III calculations of alternative rankings, a variety of perspectives about indifference thresholds, preference thresholds, and veto thresholds are also captured, and the final aggregated thresholds reflect objective and biased low results.

5.3. Scientific contribution

This research contributes to the literature a methodology framework to determine the best dry port location for integration with inland waterway transport in developing countries, addressing the current research gap. A case study in Northern Vietnam is scrutinized for the first time in this field.

The combination of BWM and ELECTRE III is a new hybrid MCDA approach in literature about the selection of dry port location in general and the selection of dry port location for integration with inland waterway transport in particular. The method combination in this research has proven its suitability, exploiting BWM's advantages in criteria weighting and ELECTRE III's merits in alternative ranking. The criteria weights obtained by BWM can be easily and suitably used for alternative ranking by ELECTRE III. Different phases of this new methodology framework are well connected.

5.4. Societal contribution

The research findings have been discussed and validated with Vietnamese experts. They agree with all the weights of criteria. The final alternative rankings are considered helpful and valuable. Despite being the only dry port in the construction plan, Phu Dong dry port has the first ranking, which is in line with the priority plan of the government until 2030. The second ranking of Hai Linh dry port strengthens the motivation of the government to implement the key project of enhancing the clearance height of Duong bridge which is currently limiting the operation of inland waterway transport from Hai Linh dry port to Hai Phong seaport. This project was also stated in the Logistics Report of Vietnam (2023). The results encourage the experts to carefully reassess all the dry port options as currently the inland waterway from Que Vo dry port to Hai Phong seaport has been set as the standard inland water route for the North of Vietnam, but this dry port only stands in the third place after Phu Dong dry port and Hai Linh dry port. For some dry port investors and operators, the proof about the first ranking of Phu Dong dry port attracts their interest about the cooperation with this dry port in the near future as its construction will be finished soon according to the priority plan of the government. The experts believe that the results of this research can hopefully contribute to dry port development in Northern Vietnam in the near future.

This methodology framework can be generalized for application in other developing countries that express concern about dry port location selection for integration with inland waterway transport. The case study's suggested insights and findings about the list of decision criteria, criteria weights, and different preferences of three stakeholder groups can serve as a reference source for other developing nations that possess similar characteristics to Northern Vietnam. The first important characteristic is that dry ports are land-based and often situated near local production bases. This is a significant difference when compared to dry port systems in developed countries and explains the high importance of location factors such as proximity to production base in the decision-making. Second, the developing areas should possess a high potential of inland waterway networks. This potential is demonstrated through not only the number of existing rivers, but also their possible connection to the main sea port and suitable clearance height of bridges which may otherwise limit the operation of inland waterway transport. Third, dry ports are located to serve different areas but can still be considered as alternatives to a decision-making problem due to their co-existence in crucial economic corridors or centers. Fourth, policy makers and consultants, dry port investors and operators, and dry port users are also key stakeholders involved in the decision-making process. Last, there is a high degree of political stability in the area and regional administrations of the dry port locations have relatively similar political features. If there exist remarkable differences in political environments of alternative dry port locations in that developing country, this methodology framework can still be applied, but political factors should be a part of the decision criteria list.

5.5. Limitations

First, regarding the participation of stakeholders in this research, policy makers and consultants are the main decision-makers. Although the opinions of dry port operators, dry port investors, and dry port users are also taken into account, the weights of these stakeholder groups may not be the same in a real-life situation. Due to the limitation of research resources, this research opts for simplicity when the same weights are assigned to all three stakeholder groups. The sensitivity analysis also indicates that higher decision power of policy makers and consultants does not lead to an impact on the final dry port selection. However, if a more detailed analysis is conducted to figure out more practical weights of each stakeholder group in this case study in Northern Vietnam, more accurate results can be achieved regarding criteria weights and relevant thresholds.

Second, stakeholders' inconsistency in making pairwise comparisons between decision criteria was sometimes recognized during the interviews. The fact that the author re-explained the method and asked the stakeholders to adjust their decisions for consistency might lead to potential bias. Third, some stakeholders do not possess profound understanding and expertise in the calculations of specific criteria's indicators, especially the environmental factors, e.g. the amount of CO_2 reduced per TEU per route by using inland waterway transport measured by $kgCO_2$. Therefore, the indifference thresholds, preference thresholds, and veto thresholds provided by these stakeholders may reduce the validity.

Last, the list of decision criteria in reality may be slightly different when more experts are consulted with other perspectives. In this case study, political factors are left aside due to the similar features of policies and agreements of main economic corridors in five provinces or cities in Northern Vietnam with dry ports analyzed. Nonetheless, this may act as a limitation for this case study to represent other developing countries since political factors may play a crucial role in this decision-making problem in other areas. Literature review also indicates that political factors are differently considered in the selection of dry port location by developed and developing countries, but this is not illustrated in the case study. Other relevant research in other developing nations may need to carefully consider this criterion to check whether it should be included in the list of decision criteria.

6
CONCLUSIONS

6. Conclusions

In conclusion, this research sheds light on the methodology framework to determine the optimal dry port location for integration with inland waterway transport in developing countries, which encompasses four phases. The first phase is the use of literature review and expert interviews to determine the decision hierarchy consisting of the list of alternative dry port locations and decision criteria. The second phase is the implementation of BWM to calculate aggregated weights of all decision criteria based on data of criteria weights obtained from expert interviews. These criteria weights are then employed in the third phase in which ELECTRE III is exploited to calculate alternative rankings and determine the best alternative dry port location. Finally, results are discussed with stakeholders.

A case study in Northern Vietnam with five alternative dry port locations is proposed to test this methodology framework. Twenty-five relevant Vietnamese experts, divided into three groups which are policy makers and consultants (group 1), dry port investors and operators (group 2), and dry port users (group 3), participate in providing insights for this research. There are four main criteria considered in this case study which are economic, accessibility, location, and environmental criteria. Economic criteria are evaluated by three sub-criteria, namely decrease in transport cost, increase in transport time, and cargo throughput capacity, whereas accessibility is divided into accessibility to inland waterway infrastructure, road infrastructure, railway infrastructure, and seaport infrastructure. When it comes to location, four sub-criteria, i.e., proximity to other logistics platforms, proximity to production base, proximity to consumption market, and room for expansion, are considered. Regarding environmental criteria, decrease in air pollution, decrease in transport congestion, and impact on urban areas are three sub-criteria. Albeit there are differences in the preference of three expert groups, according to the final aggregated results, the most important criterion is economics, followed by location and accessibility. Environment is the least important criterion in the selection of dry port location for integration with inland waterway transport in Northern Vietnam. With regard to sub-criteria, decrease in transport cost is assigned the highest weight which is twelve times higher than the weight of accessibility to railway, the least important sub-criterion. Phu Dong dry port, located in Hanoi capital city, surpasses the other four alternatives to be chosen as the best location for the Vietnamese government to make investment in developing the integration between this dry port and inland waterway transport. Sensitivity analyses indicate that the results obtained are relatively stable despite the uncertainty of some parameters in reality such as criteria weights, ELECTRE III thresholds, cut-off level, decision power of the group of policy makers and consultants, and performance data calculated by the author. The research findings have been validated with Vietnamese experts.

This research contributes to the literature by addressing the research gap about dry port location selection for integration with inland waterway transport in developing countries. A case study in Northern Vietnam as well as the combination of BWM and ELECTRE III are scrutinized for the first time in this field. This methodology framework can be generalized for application in other developing countries with concern about dry port location selection for integration with inland waterway transport.

7
RECOMMENDATIONS

7. Recommendations

First, future study should take a closer look at different weights of stakeholder groups, rather than assigning the same weights to all stakeholders. Multi-actor multi-criteria analysis (MAMCA) can be considered as a tool with a more detailed stakeholder analysis with different levels of decision power assigned to different groups of decision-makers for evaluation of transport projects (Macharis et al., 2009). Second, although geometric mean is the most popular technique for aggregating the criteria weights of different decision-makers (Mohammadi et al., 2023), Bayesian BWM using probability distributions can also be applied for group decision-making, which has been proven as an empowerment to BWM in describing the preferences of a group of decision-makers (Mohammadi and Rezaei, 2020). Third, it would be worth analyzing the cut-off level in ELECTRE III calculations not only from literature review, but also from the involvement of expert opinions to reach the most practical cut-off level. Fourth, regarding the list of decision criteria, according to the discussion with Vietnamese experts in the case study, future research should consider including customs procedures and costs in different dry ports if procedures and costs of customs supervision when containers are transferred from seaports to inland ports vary within different dry port locations. In order to collect the data of this factor, the research should receive the support of local authorities and logistics companies. Last, in the case study of this research, each alternative dry port serves a different service area, so it would be interesting for future research to scrutinize another case study with alternative dry ports which act as real competitors, which may reveal more insights into the trade-offs among different criteria.

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Appendices

Appendix 1. List of Vietnamese experts participating in the case study

Stakeholder group	No	Interview about the criteria list	Interview about criteria weights and thresholds	Organization	Position	Gender	Other relevant background
Policy makers and consultants	1	X		Agency of Foreign Trade, Ministry of Industry and Trade of the Socialist Republic of Vietnam	Deputy Director General	Male	Honor President of Vietnam Association for Logistics Manpower Development
	2	X		School of Economics and International Business, Foreign Trade University, Vietnam	Head of Scientific Management and Development Department	Female	
	3	X	X	Vietnam Maritime University	Deputy Head of Economics Department	Male	Director of Mekong - Japan Logistics Training Center Vice President of Vietnam Association for Logistics Manpower Development
	4		X	General Department of Vietnam Customs	Customs Specialist	Male	
	5		X	General Department of Vietnam Customs	Customs Specialist	Male	

	6	X	X	Vina Logistics Co., Ltd.	General Director	Male	Former Director of Sotrans Logistics Co., Ltd. Former Representative of Jacky Meader Freight Forwarder & ABX Logistics (Belgium) Lecturer of Logistics in many Vietnam universities
Dry port investors and operators	7	X	X	Loka Port Co., Ltd.	General Director	Male	Vice President of Hai Phong Logistics Association
	8		X	A local logistics corporation	Senior Director Assistant	Male	
	9		X	A local logistics corporation	Business Development Senior	Male	
	10		X	T&Y Superport ICD Vinh Phuc	Business Development Manager	Male	Former Deputy Manager of Business Development Department of Hateco Logistics Center (ICD Long Bien, Hanoi, Vietnam)
	11	X	X	Nam Hai Dinh Vu Port Co., Ltd.	General Director	Male	
Dry port users	12		X	A local logistics corporation	Intermodal Product Specialist	Female	
	13		X	A local logistics corporation	Customer Service Representative	Female	

	14		X	A local logistics corporation	Senior Sea Freight Operation Executive	Male	
	15		X	A local logistics corporation	Sea Freight Supervisor	Male	
	16		X	SITC - DINHVU Logistics Co., Ltd.	Former Head of Operation Department	Male	
	17		X	MSJ Agency	Customer Service representative	Male	
	18		X	Hoang Dieu Port Co., Ltd.	Business Development Executive	Female	
	19		X	A local logistics corporation	District Sales Executive	Male	
	20		X	Sun-wa Technos Vietnam Co., Ltd.	Supply Chain Department Manager	Female	
	21		X	AHTT SERVICE AND TRADING COMPANY LIMITED	General Director	Female	
	22		X	Hoang Nguyen Trading and Transport Service Company Limited	General Director	Male	
	23		X	Hoang Phuong Service and Trading Company Limited	General Director	Female	
	24		X	A local import-export company	General Manager	Male	
	25		X	A local import-export company	Logistics Manager	Female	
	26		X	B.Braun Vietnam Co., Ltd.	Former Supply Planner	Male	
	27		X	VOSCO Agency and Logistics JSC.	Vice Head of Project Department	Male	

Table A1. List of Vietnamese experts participating in the case study

Appendix 2. An example of expert answers in the questionnaire

1. Interview for criteria weight (BWM)

According to Vietnam Transport Development and Strategy Institute (2023), the Northern part of Vietnam has ten official dry ports, however, only four of them have currently integrated with inland waterways to connect with sea ports. In 2024, the Vietnamese government has also announced the development plan for one more dry port with this form of integration in the North. The government has set the objective until 2030 to increase the productivity of dry ports by expanding the link with inland waterway transport, optimizing the delivery of export and import goods while reducing logistics costs and environmental impacts. Hence, within these five alternatives in total, one dry port location can be chosen for a pilot project investing in the expansion in connecting dry ports with inland waterways. The framework in this research will be employed to select the best dry port location in this case study.

In Table A2, you can find the list of main criteria and sub-criteria to select the best dry port location for integration with inland waterway transport in Northern Vietnam.

Main criteria	Economic factors	Accessibility factors	Location factors	Environmental factors
Sub-criteria	Decrease in transport cost	Accessibility to inland waterway infrastructure	Proximity to other logistics platforms	Decrease in air pollution
	Increase in transport time	Accessibility to road infrastructure	Proximity to production base	Decrease in transport congestion
	Cargo throughput capacity	Accessibility to railway infrastructure	Proximity to consumption market	Impact on urban areas
		Accessibility to seaport infrastructure	Room for expansion	

Table A2. Criteria used to evaluate the best dry port location for integration with inland waterway transport in Northern Vietnam

We construct a set of pairwise-comparison matrices for the main criteria and sub-criteria.
To make comparisons, we use **a scale of absolute numbers** indicating how many times more important or dominant one criterion is over another criterion. Table A3 exhibits the scale.

Intensity of importance	***Definition***	***Explanation***
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

Table A3. The fundamental scale of absolute numbers

Now, please state how many times one criterion is preferred to the others by entering the number from the scale in Table A3.

1. Pairwise comparison matrix for main criteria

● Could you determine, according to you, the most important and the least important main criterion, along {*Economics, Accessibility, Location, Environment*}.

Most important	**Least important**
Location	*Environment*

● Could you determine the preference of your most important criterion over the 2 other criteria using the scale (Table A3). *You may leave the case "importance of your most important criterion over your most important criterion" empty as we automatically consider scale "1".*

	Economics	Accessibility	Location	Environment
Your most important criteria	*3*	*4*	*1*	*6*

● Could you determine the preference of all criteria over your least important criterion, using the scale (Table A3). *You may leave the case "importance of your least important criterion over your least important criterion" empty as we automatically consider scale "1".*

	Your least important criteria
Economics	*3*
Accessibility	*2*
Location	*6*
Environment	*1*

2. Pairwise comparison matrix for sub-criteria with respect to the economics

● Could you determine, according to you, the most important and the least important criterion, along {*Decrease in transport cost, Increase in transport time, Cargo throughput capacity*}.

Most important	Least important
Decrease in transport cost	*Cargo throughput capacity*

● Could you determine the preference of your most important criterion over the 3 other criteria using the scale (Table A3). *You may leave the case "importance of your most important criterion over your most important criterion" empty as we automatically consider scale "1".*

	Decrease in transport cost	Increase in transport time	Cargo throughput capacity
Your most important criteria	*1*	*3*	*5*

● Could you determine the preference of all criteria over your least important criterion, using the scale (Table A3**).** *You may leave the case "importance of your least important criterion over your least important criterion" empty as we automatically consider scale "1".*

	Your least important criteria
Decrease in transport cost	*5*
Increase in transport time	*2*
Cargo throughput capacity	*1*

3. Pairwise comparison matrix for sub-criteria with respect to the accessibility

● Could you determine, according to you, the most important and the least important criterion, along {*Accessibility to inland waterway, Accessibility to road, Accessibility to railway, Accessibility to seaport*}.

Most important	Least important
Accessibility to inland waterway	*Accessibility to railway*

● Could you determine the preference of your most important criterion over the 2 other criteria using the scale (Table A3). *You may leave the case "importance of your most important criterion over your most important criterion" empty as we automatically consider scale "1".*

	Accessibility to inland waterway	Accessibility to road	Accessibility to railway	Accessibility to seaport
Your most important criteria	*1*	*3*	*8*	*2*

● Could you determine the preference of all criteria over your least important criterion, using the scale (Table A3). *You may leave the case "importance of your least important criterion over your least important criterion" empty as we automatically consider scale "1".*

	Your least important criteria
Accessibility to inland waterway	*8*

Accessibility to road	*5*
Accessibility to railway	*1*
Accessibility to seaport	*6*

4. Pairwise comparison matrix for sub-criteria with respect to the location

- Could you determine, according to you, the most important and the least important criterion, along {*Proximity to other logistics platforms, Proximity to production base, Proximity to consumption market, Room for expansion*}.

Most important	Least important
Proximity to production base	*Room for expansion*

- Could you determine the preference of your most important criterion over the 2 other criteria using the scale (Table A3). *You may leave the case "importance of your most important criterion over your most important criterion" empty as we automatically consider scale "1".*

	Proximity to other logistics platforms	Proximity to production base	Proximity to consumption market	Room for expansion
Your most important criteria	*6*	*1*	*3*	*7*

- Could you determine the preference of all criteria over your least important criterion, using the scale (Table A3). *You may leave the case "importance of your least important criterion over your least important criterion" empty as we automatically consider scale "1".*

	Your least important criteria
Proximity to other logistics platforms	*2*
Proximity to production base	*7*
Proximity to consumption market	*5*
Room for expansion	*1*

5. Pairwise comparison matrix for sub-criteria with respect to the environment

● Could you determine, according to you, the most important and the least important criterion, along {*Decrease in air pollution, Decrease in transport congestion, Impact on urban areas*}.

Most important	Least important
Decrease in transport congestion	*Impact on urban areas*

● Could you determine the preference of your most important criterion over the 2 other criteria using the scale (Table A3). *You may leave the case "importance of your most important criterion over your most important criterion" empty as we automatically consider scale "1".*

	Decrease in air pollution	Decrease in transport congestion	Impact on urban areas
Your most important criteria	*3*	*1*	*4*

● Could you determine the preference of all criteria over your least important criterion, using the scale (Table A3). *You may leave the case "importance of your least important criterion over your least important criterion" empty as we automatically consider scale "1".*

	Your least important criteria
Decrease in air pollution	*1*
Decrease in transport congestion	*4*
Impact on urban areas	*1*

2. Interview for alternative ranking (ELECTRE III)

According to Vietnam Transport Development and Strategy Institute (2023), the Northern part of Vietnam has nine official dry ports, however, only four of them have currently integrated with inland waterways to connect with sea ports. In 2024, the Vietnamese government has also announced the development plan for one more dry port with this form of integration in the North. This research considers these five alternatives in Table A4.

No	Dry port	Location
1	Hai Linh dry port	Viet Tri City, Phu Tho Province, Vietnam
2	Phuc Loc dry port	Ninh Binh City, Ninh Binh Province, Vietnam
3	Mong Cai dry port	Mong Cai City, Quang Ninh Province, Vietnam
4	Que Vo dry port	Que Vo District, Bac Ninh Province, Vietnam
5	Phu Dong dry port	Gia Lam District, Ha Noi City, Vietnam

Table A4. Five alternative dry port locations in Northern Vietnam

In this part, we make use of ELECTRE III to provide the ranking of these five alternatives. The values of fourteen sub-criteria of each alternative dry port have been provided.

Criteria	**Economic factors**			**Accessibility factors**			
Sub-criteria	**Decrease in transport cost**	**Increase in transport time**	**Cargo throughput capacity**	**Accessibility to inland waterway infrastructure**	**Accessibility to road infrastructure**	**Accessibility to railway infrastructure**	**Accessibility to seaport infrastructure**
Measuring method	*Compare intermodal transport cost (using inland waterway transport) with the road system*	*Compare intermodal transport time (using inland waterway transport) with the road system*	*Expected cargo throughput capacity by 2030*	*Number of inland waterway routes accessed*	*Distance to highways*	*Number of railways accessed*	*Distance to Hai Phong seaport*
Unit	*USD per TEU per route from dry port to Hai Phong seaport*	*Hours per TEU per route from dry port to Hai Phong seaport*	*TEUs/year*	*Number*	*Km*	*Number*	*Km*
Min value	44	8.5	65	1	0.5	0	72.3
Max value	165	18.5	260,000	2	3.5	1	187

Preference threshold *Please determine a difference in values that you feel 01 dry port is preferred to another*	*40*	*2*	*15,000*	*1*	*1*	*1*	*30*
Indifference threshold *Please determine a difference in values that you feel 02 dry ports are indifferent*	*20*	*1*	*10,000*	*0*	*0.5*	*0*	*25*
Veto *Please determine a significant difference in values that makes 01 dry port always your preferred option (even when other dry ports are better in other criteria)*	*40*	*10*	*70,000*	*2*	*1*	*1*	*100*

Criteria	**Location factors**				**Environmental factors**		
Sub-criteria	**Proximity to other logistics platforms**	**Proximity to production base**	**Proximity to consumption market**	**Room for expansion**	**Decrease in air pollution**	**Decrease in transport congestion**	**Impact on urban areas**
Measuring method	*Distance to the nearest logistics center*	*Number of industrial zones in the same province*	*GRDP per capita 2023*	*Expected area of dry port expansion until 2050*	*CO_2 reduced per TEU per route by using inland waterway transport*	*Number of accessed highways with reduced traffic*	*Distance to urban center*

Unit	*Km*	*Number*	*Billion USD*	*Ha*	*KgCO$_2$*	*Number*	*Km*
Min value	30	5	2.1	0	19.6	1	4
Max value	152	17	51.2	40	127.75	3	22
Preference threshold *Please determine a difference in values that you feel 01 dry port is preferred to another*	*20*	*5*	*1*	*10*	*20*	*1*	*5*
Indifference threshold *Please determine a difference in values that you feel 02 dry ports are indifferent*	*15*	*3*	*0.5*	*2*	*10*	*0*	*3*
Veto *Please determine a significant difference in values that makes 01 dry port always your preferred option (even when other dry ports are better in other criteria)*	*25*	*7*	*5.5*	*20*	*100*	*2*	*7*