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

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Abstract – 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. This paper aims to propose a methodological framework for selecting the most suitable dry port location, with a particular emphasis on integration with inland waterway transport in developing nations. This study implements a combination of the Best-Worst Method (BWM) and Elimination Et Choix Traduisant la Realité III (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 principal criteria—economic, accessibility, location, and environmental—are utilized to assess and rank the five alternatives. The findings reveal that a reduction in transport cost is the most critical sub-criterion, while environmental considerations and railway accessibility receive the lowest priority.

Keywords: Dry port location selection; Multi-criteria decision analysis; Best-Worst Method (BWM); Elimination Et Choix Traduisant la Realité III (ELECTRE III); Vietnam

1. Introduction

The ever-increasing volume of containerized maritime goods transport and larger vessels has resulted in chronic congestion at seaports, weakening port infrastructure, and increasing container dwelling time. This has worsened the competitiveness of main seaports in many countries. Dry ports were established as a solution to this issue, thereby enhancing seaport throughput and performance, and reducing the 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 & Notteboom, 2016b).

The optimal location is one of the essential factors deciding a dry port's effectiveness. In fact, different locations can lead to varying travel distances for containers (Liang et al., 2024), as well as differing transport costs and accessibility to transport infrastructure, such as highways and railways (Nguyen & Notteboom, 2016b). However, in determining the location of dry ports, there is also a pressing need for the network of dry ports to align with

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global sustainability concerns, as strengthened by the Paris Agreement, which targets net-zero emissions by 2050, with transport playing a leading role. 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, possessing limited access to inland waterways. Meanwhile, inland waterway transport has been proven to be an economical, fuel-efficient, and low-cost mode of transport for both developed and developing nations. Its negative environmental impact is lower than that of transport by road, rail, or air (Nokelaynen, 2018). Moreover, traffic congestion on 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 & Limbourg, 2019).

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

The rest of the paper is organized as follows. Section 2 presents a literature review identifying interesting research gaps. An overview of the methodology employed in this research is provided in Section 3. Section 4 analyzes a case study in Northern Vietnam to illustrate the proposed methodology framework. Key findings are then discussed in Section 5, followed by the conclusion, limitations, and further research direction in Section 6.

2. Literature review

In this section, we discuss key findings from the literature concerning core concepts and various methods used for selecting dry port locations in developing countries. These methods include least-cost models and multi-criteria decision analysis. Additionally, we provide a list of factors that influence the selection of dry port locations in these regions. A conclusion summarizing the research gaps is provided at the end of this section.

2.1. Core concepts

In 1986, Hanappe first introduced the term "dry ports" in a scientific journal, describing it similarly as an inland terminal that serves a port. Today, several terms are used to describe this facility, including dry port, inland terminal, inland port, inland hub, inland logistics center, and freight village. Among these, "dry port" is one of the most commonly used terms (Varese et al., 2020).

Jaržemskis and Vasiliauskas (2007) characterized a dry port as "a port located in the hinterland that services an industrial or commercial region. It is connected with one or several seaports via rail and/or road transport and offers specialized services between the dry port and transmarine destinations. Typically, the dry port is container and multimodal-oriented and possesses all logistics facilities required for shipping and forwarding agents at a port." Meanwhile, Roso et al. (2009) provided a simpler definition of a dry port as "an inland intermodal terminal directly connected to seaports with high-capacity transport means, where customers can leave or pick up their standardized units as if directly at a seaport." This research primarily focuses on dry ports in integration with inland waterway transport. According to a model by Kovač et al. (2023), inland waterways can be effectively 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 emphasize the significant role of transport costs in determining the optimal location. Approaches focusing on the least transport cost include the conditional logit model, mixed-integer programming, the dynamic programming model, and the center of gravity model. Researchers have sought to address this location problem by developing mathematical programming models (Ambrosino & Sciomachen, 2014) and facility location models (Melo et al., 2009). Various metaheuristics are frequently employed to solve these issues, such as greedy algorithms (Wei & Sheng, 2017), genetic algorithms (Chang et al., 2015), and other heuristics (Ng & Cetin, 2012). Researchers have also utilized cluster analysis (Li et al., 2011), spatial models (Middela & Ramadurai, 2021), data mining, and complex network theory (Van Nguyen et al., 2020). However, Mohan and Naseer (2022) demonstrated that in the aforementioned methods, quantifiable criteria such as cost and distance are most commonly pursued, rather than qualitative parameters.

In the context of dry port location planning in developing countries, multiple stakeholders are involved, including port operators, port users, and the community. Therefore, in addition to logistics costs, many qualitative location factors driven by these stakeholders are considered (Nguyen & Notteboom, 2016a). Dry port planning should incorporate various qualitative factors such as environmental impacts, land availability, labor availability, information technology levels, regional trade facilitation, and reliability (Notteboom & Rodrigue, 2017). A study conducted by Pham and Lee (2019) in Vietnam, a developing nation, revealed that the greenest route, which incurs the smallest total emission charge, is not necessarily the best in terms of total cost. That research also carefully considered environmental factors, not solely the monetary cost. Moreover, most dry ports in developing economies are constructed and operated to support export-based industrial zones, thus they are predominantly driven by land considerations (Nguyen & Notteboom, 2016a) and are more influenced by the interests of land-based players compared to those in developed countries (Nguyen & Notteboom, 2016b). The factors influencing the selection of dry port sites can be economic or non-economic, monetary or non-monetary, quantitative or qualitative (Yıldırım & Önder, 2014).

2.2.2. Multi-criteria decision analysis (MCDA) approach

MCDA methods can analyze both quantitative and qualitative factors, making them 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 Analytical Hierarchy Process (AHP) integrated with Elimination Et Choix Traduisant la Realité (ELECTRE) to select optimal dry ports construction projects in the New Eurasia Continental Bridges (NECB) 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 Analytic Network Process (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, Best Worst Method (BWM), and the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE).

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 & Notteboom, 2016b; Pham & 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 &

Notteboom, 2016b; Pham & Lee, 2019; Chowdhury & Haque Munim, 2023; Mohan & 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 the many factors influencing the selection of dry port locations in developing countries is provided in Table 1.

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

Country	Research	Influencing factors
Vietnam	Nguyen & 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 & Lee (2019)	Freight demand; Proximity to the freight market; Production area; Freight shippers' location; Transport costs
Bangladesh	Chowdhury & 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; Transshipment costs; Dry port development costs; Link maintenance costs; Infrastructure maintenance costs
	Chang et al. (2015)	Dry port development costs; Storage costs; Transport costs
	Wei & Sheng (2017)	Logistics costs; Carbon emissions
	Li et al. (2011)	GRP (Gross Regional Production) 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 & Hanjra (2019)	(1) Port location: hinterland distance, hinterland connectivity, complementarity to other nodes; (2) Port efficiency: electronic data exchange (EDE), 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 (NC) cargo, special freight/odd-sized shipment
India	Mohan & 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

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. Multi-criteria decision analysis (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

This section first outlines the methodology process flow proposed in this paper, followed by detailed explanations of each method used. For data gathering, both literature review and stakeholder interview are employed. Regarding data analysis, a combination of BWM and ELECTRE III is introduced.

3.1. Methodology process flow

A flow chart of the methodology proposed in this paper is presented in Figure 1.

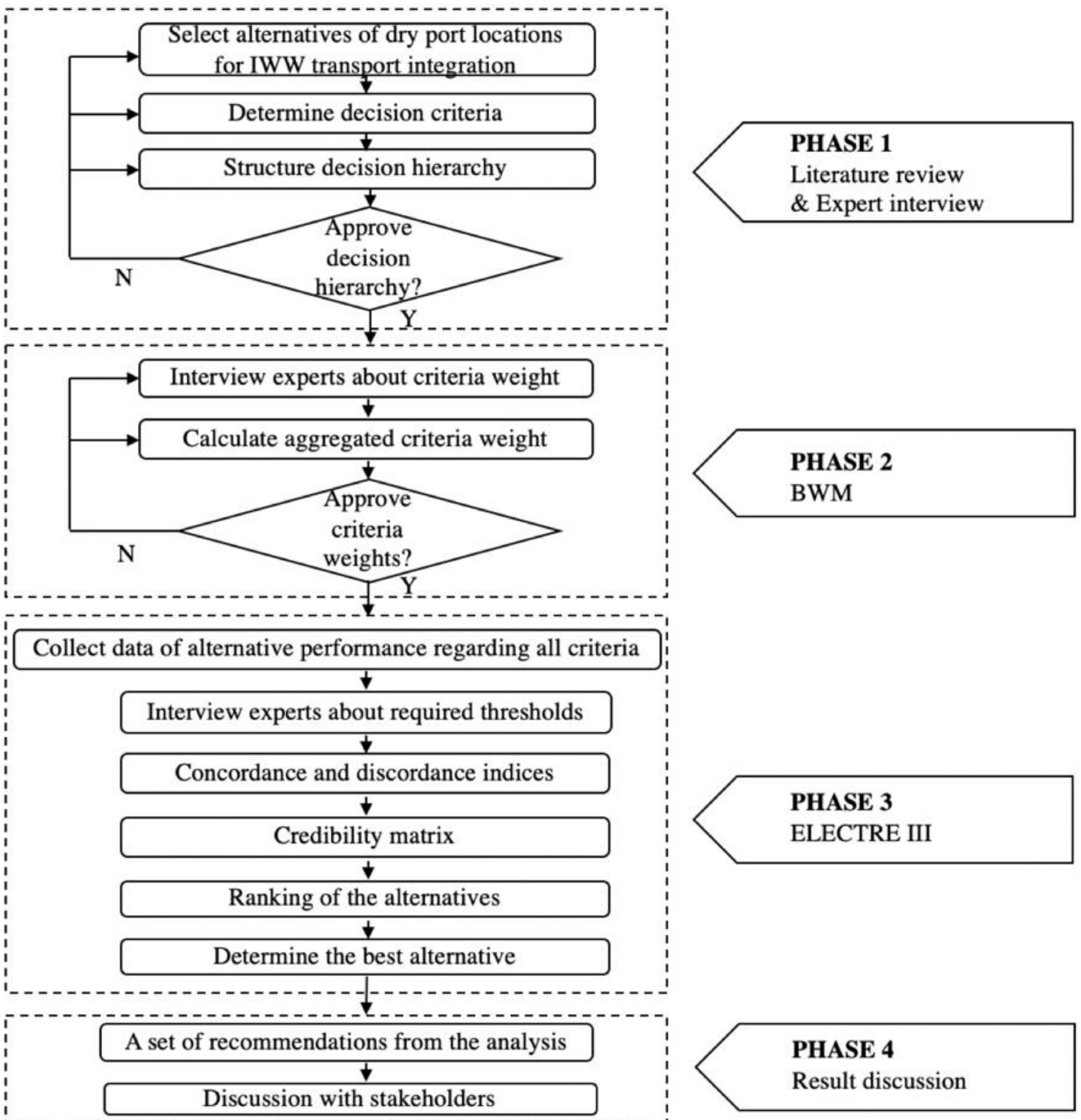

Figure 1. Flowchart of the methodology

This research proposes a methodology consisting of four phases. The first phase aims to establish a decision hierarchy, which includes all main criteria, sub-criteria, and alternative dry port locations for integration with inland waterway (IWW) transport in a developing country. The second phase involves the implementation of BWM to determine the weights of the decision criteria. The third phase entails the application of ELECTRE III method, with the expected outcome being the final ranking of all alternatives, from which the best alternative can be identified. The fourth phase involves discussions with stakeholders about the analysis results.

3.2. Data gathering: Literature review and stakeholder interview

This paper considers three main stakeholder groups involved in addressing this MCDA problem, namely policymakers and consultants, dry port investors and operators, and dry port users (Tadić et al., 2020). Interviews are conducted with representatives from these stakeholder groups. Conducting interviews with multiple decision-makers from the same stakeholder groups, who hold different viewpoints, can effectively mitigate motivational biases, such as confirmation bias (Montibeller and Von Winterfeldt, 2015). Findings from the literature review and expert interviews reveal:

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

3.3. Data analysis: BWM and ELECTRE III

As discussed in the literature review in Section 2, selecting a dry port location for integration with inland waterway transport in developing countries presents a complex challenge influenced by multiple quantitative and qualitative factors. Least-cost models, which primarily handle quantitative factors such as transport costs and distance, are effective in advanced economies but fall short in developing systems (Ng & Cetin, 2012). Therefore, this research will employ MCDA methods to evaluate the trade-offs between these conflicting quantitative and qualitative factors.

Among the plethora of MCDA methods available, no single method is universally appropriate for all decision-makers or decision-making scenarios. A hybrid MCDA approach, involving the combination of more than one MCDA method, is crucial as it has been shown to yield more precise results, effectively mitigating the limitations of individual methods and leveraging their strengths (Koohathongsumrit & Meethom, 2021). Hybrid MCDA approaches have been demonstrated to reduce subjectivity and preference biases in the decision-making processes of decision-makers (Ekel et al., 2019). In such combinations, one method can be used to analyze the weight of different criteria, while another method can be employed to rank alternatives (Sitorus et al., 2019).

3.3.1. Best-Worst Method (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 shown to provide more reliable consistency ratios than AHP. 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 with MCDA methods is the cognitive biases of decision-makers in providing judgments about criteria importance, this research aims to employ a method that is less prone to these biases, thereby enhancing the reliability of the 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) 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.

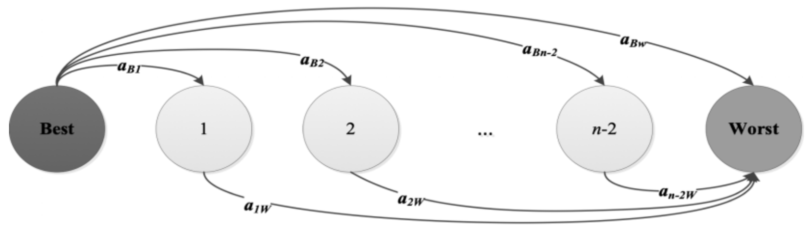

Figure 2. Pairwise comparisons in BWM (Rezaei, 2015)

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 2, to guide the scoring process.

Table 2. The fundamental scale of absolute numbers (Saaty, 2008)

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

The Best-to-Others vector would be:

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

where a_{Bj} indicates the preference of the best criterion B over criterion j.

Step 4: Determine the preference of all other criteria over the worst criterion

The Others-to-Worst vector would be:

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

where a_{jW} indicates the preference of criterion j over the worst criterion W.

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.
We calculate the global weight of each sub-criterion by multiplying the weight of the sub-criterion (if applicable) by the weight of its corresponding main criterion.
We calculate the input-based consistency ratio, CR^I, 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 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 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 3 provides the thresholds for different combinations using input-based CR^I:

Table 3. Thresholds for different combinations using input-based Consistency Ratio (Liang et al., 2020)

Criteria Scales	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

3.3.2. ELECTRE III

Regarding the method to rank alternatives, ELECTRE is a well-known family of outranking methods. ELECTRE is an analytical method designed 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:

Firstly, 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. Thirdly, 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. Fourthly, 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).

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 for 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 the 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_kSA_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 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.

3.3.3. The combination of BWM and ELECTRE III

Considering the distinctive features of the BWM in criteria weighting and the strengths of ELECTRE III as an outranking method, particularly its non-compensatory approach as described in Sections 3.3.1 and 3.3.2, this research adopts a combination of BWM and ELECTRE III. The criteria weights derived by BWM can be considered intrinsic weights, making them suitable for use by the ELECTRE III method in the subsequent phase of alternative ranking calculations. Importantly, the hybrid BWM-ELECTRE III approach has not yet been proposed in the literature concerning the selection of dry port locations in general, and specifically for the integration with inland waterway transport. By implementing this combination, this research contributes a novel hybrid MCDA approach to the literature in this specific field.

4. Case study

This section analyzes the case study of this paper with a relevant problem defined in Northern Vietnam. The decision hierarchy is explained in detail with the choice of alternatives and decision criteria. Next, the calculations of criteria weights, as well as the process of alternative performance data collection and calculation, are mentioned. Finally, the rankings of five alternatives are obtained and the location selection is concluded.

4.1. 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. 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. In the North, there are currently four dry port locations in operation and one dry port location in the construction plan which have connections with inland waterways. The Vietnamese government should invest in developing these potential locations to expand the combination between dry ports and inland waterway transport. Nonetheless, the public budget is limited; 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. Hence, these five dry port locations can be considered as five alternatives. 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.

4.2. Decision hierarchy

4.2.1. Alternatives

A map of five alternative dry port locations and the network of surrounding rivers and highways in Northern Vietnam is provided in Figure 3.

Figure 3. Map of alternative dry port locations (illustration of the authors based on Google Maps)

Within these five dry ports, three — 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 — are established along the route connecting the Red River, Duong River, and Kinh Thay River with Hai Phong seaport, the largest international seaport in Northern Vietnam. Phuc Loc dry port in Ninh Binh province and Mong Cai dry port in Quang Ninh province are situated near the Day River and Ka Long River, respectively. Both of these dry ports have coastal connections to Hai Phong seaport. Notably, only Hai Linh dry port is connected to railway transport, as railways in the North generally lack sufficient accessibility and efficiency. Despite serving different service areas, in this case study, these five dry port locations are considered equal alternatives because they are all situated on key economic corridors of Northern Vietnam. Hai Linh dry port, Phu Dong dry port, Que Vo dry port, and Mong Cai dry port are located along the Lao Cai - Ha Noi - Hai Phong - Quang Ninh economic corridor, which links the northern midland and mountainous areas with economic centers and major seaports, fostering trade and investment cooperation between localities in Vietnam and the southwest region of China. Meanwhile, Phuc Loc dry port serves as a strategic junction between the Red River delta, the northwest mountainous region, and the north central coast region. No location is significantly preferred over others in Northern Vietnam. More detailed illustrations of transport routes by road and by inland water way from each alternative dry port to Hai Phong seaport are provided in Appendix 1.

4.2.2. Decision Criteria

As analyzed in the section of the 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 4 provides a list of the most commonly mentioned criteria.

Table 4. Most commonly mentioned factors influencing the selection of dry port location in developing countries

		Vietnam		Banglade sh	China						Indonesia	India	Togo
Criteria	Sub-criteria	Nguyen & Notteb-oom (2016b)	Pham & Lee (2019)	Chowdhu ry & 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
	Proximity to other logistics platforms	x		x	x							x	x
	Proximity to production base	x	x									x	
Location factors	Proximity to consumption market		x	x								x	
	Room for expansion	x		x								x	
	Decrease in air pollution	x		x				x	x	x		x	x
Environmental factors	Decrease in transport congestion	x										x	
	Impact on urban areas			x								x	x
Political factors	Regional cooperation environment				x								x

This list of criteria has been consulted by six experts in Vietnam 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 the literature, especially specific criteria related to the integration of dry ports with inland waterway transport. Details of these six experts can be found in Appendix 2. After the consultation, the final list of decision criteria used to evaluate the best dry port location for integration with inland waterway transport in Northern Vietnam has been synthesized in Table 5.

Table 5. Criteria used to evaluate 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 the production base	Decrease in transport congestion
	Cargo throughput capacity	Accessibility to railway infrastructure	Proximity to the consumption market	Impact on urban areas
		Accessibility to seaport infrastructure	Room for expansion	

These criteria are in conflict, and it is impossible to obtain an alternative with the best performance based on all the criteria. The indicators and measuring units of 14 sub-criteria are described in Table 6 in Section 4.4.

In terms of rank determination for sub-criteria, ten sub-criteria suggest that higher ranks are associated with higher values. These include a decrease in transport cost, cargo throughput capacity, accessibility to inland waterway infrastructure, accessibility to railway infrastructure, proximity to production bases, proximity to consumption markets, room for expansion, decrease in air pollution, decrease in transport congestion, and impact on urban areas (measured as distance to urban centers). Conversely, four sub-criteria suggest that higher ranks are associated with lower values, including an increase in transport time, accessibility to road infrastructure (measured as distance to highways), accessibility to seaport infrastructure (measured as distance to Hai Phong seaport), and proximity to other logistics platforms (measured as distance to the nearest logistics center).

4.3. Criteria weights

In this case study, interviews were conducted with representatives from all three groups of stakeholders: policymakers and consultants (four experts), dry port investors and operators (five experts), and dry port users (sixteen experts). Details of these experts can be found in Appendix 2. During these interviews, the experts shared their perspectives on the importance of four main criteria and fourteen sub-criteria in the decision-making process for selecting the optimal dry port location for integration with inland waterway transport in Northern Vietnam. In this case study, all experts are assumed to have equal weight in the decision-making process, and the geometric mean is used to calculate the aggregated weights. The geometric mean method is currently the most popular technique for aggregation (Mohammadi et al., 2023). It is important to note that final aggregated values obtained through the geometric mean are considered "biased low" (Mazziotta & Pareto, 2016).

Recognizing the unequal number of interviewees per group and to avoid implicit prioritization—i.e., assigning higher decision-making power to the stakeholder group with more experts—the aggregated criteria weights for each stakeholder group are calculated first, followed by the overall aggregated criteria weights for all three groups. Each group is assumed to be homogeneous. The aggregated criteria weights for each stakeholder group are calculated using the following formula:

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

w_j: aggregated weight of criterion j

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

n: total number of experts in each group

The total aggregated weights are finally normalized to get a sum equaling to 1.

The final weights of the main criteria and sub-criteria are provided in Figure 4 and Figure 5.

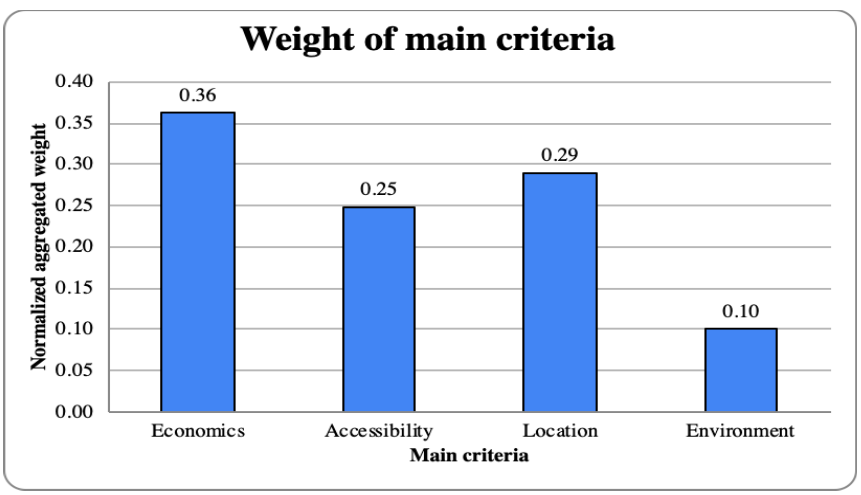

Figure 4. Normalized aggregated weight of main criteria

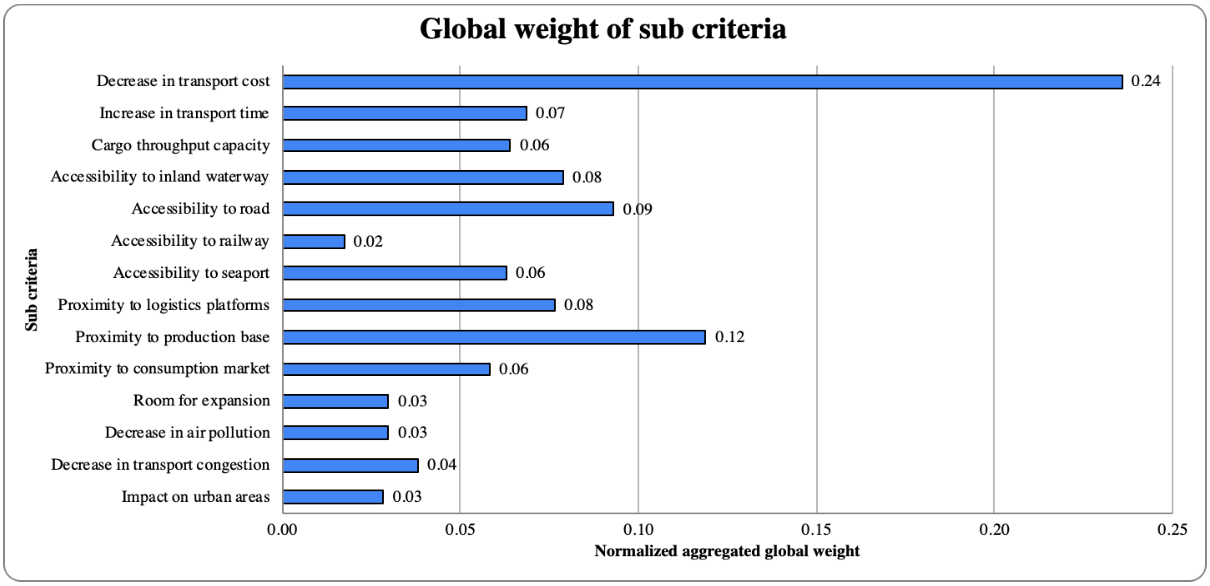

Figure 5. Normalized aggregated global weight of sub-criteria

4.4. 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 Table 6.

Table 6. Alternative performance regarding all criteria

Criteria	Sub-criteria	Indicators	Indicator source	Measuring units	Data source	Hai Linh dry port	Phu Dong dry port	Que Vo dry port	Phuc Loc dry port	Mong Cai dry port
Economic factors	Decrease in transport cost	Cost saved by using inland waterway transport service in dry port	Nguyen & Notteboom (2016b); Pham & Lee (2019)	USD per route from dry port to Hai Phong seaport per TEU	The author's calculations	165	100	44	125	155
	Increase in transport time	Time increased by using inland waterway transport service in dry port	Expert discussion	Hours per route from dry port to Hai Phong seaport per TEU	The author's calculations	16.7	10.6	8.4	12.3	18.4
	Cargo throughput capacity	Expected container throughput by 2030	Bhatti & Hanjra (2019); Expert discussion	TEU/year	Decision No. 979/QĐ-TTg by Vietnam's Prime Minister, dated 22 August 2023	65	260,000	200,000	115,000	113

	Accessibility to inland waterway infrastructure	Number of inland waterway routes accessed	Nguyen & Notteboom (2016b); Expert discussion	Number	Decision No. 979/QĐ-TTg by Vietnam's Prime Minister, dated 22 August 2023	2	1	1	1	1
Accessibility factors	Accessibility to road infrastructure	Distance to highways	Bhatti & Hanjra (2019); Nguyen & Notteboom (2016b); Mohan & Naseer (2022); Augustin et al. (2019)	Kilometers	Google Maps; Decision No. 979/QĐ-TTg by Vietnam's Prime Minister, dated 22 August 2023	1	0.8	5.5	3.5	0.5
	Accessibility to railway infrastructure	Number of railways accessed	Nguyen & Notteboom (2016b); Augustin et al. (2019); Expert discussion	Number	Decision No. 979/QĐ-TTg by Vietnam's Prime Minister, dated 22 August 2023	1	0	0	0	0
	Accessibility to seaport infrastructure	Distance to Hai Phong seaport	Mohan & Naseer (2022)	Kilometers	Google Maps	187	122	72.3	147	181

Location factors	Proximity to other logistics platforms	Distance to the nearest logistics center	Ka (2011); Nguyen & Notteboom (2016b)	Kilometers	Google Maps; 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)	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 Hai Phong)	147 km (to Cai Lan Logistics Center - VOSA Quang Ninh)
	Proximity to production base	Number of industrial zones in operation and in construction plan in the same province	Mohan & Naseer (2022); Expert discussion	Number	Map of industrial zones in Northern Vietnam	7	12	15	5	17
	Proximity to consumption market	Gross regional domestic product (GRDP) per capita 2023	Li et al. (2011); Chang et al. (2015); Expert discussion	Billion USD	Statistics Office of each province or city	3.8	51.2	8.7	2.1	12.4
	Room for expansion	Expected area of dry port expansion until 2050	Nguyen & Notteboom (2016b); Mohan & Naseer (2022); Expert discussion	Hectares	Decision No. 979/QĐ-TTg by Vietnam's Prime Minister, dated 22 August 2023	0	40	15	25	0

Decrease in air pollution	Amount of CO_2 reduced per TEU per route by using inland waterway transport	Nguyen & Notteboom (2016b); Blancas and El-Hifnawi (2014)	$KgCO_2$	The author's calculations	127.75	92.75	19.6	105.25	99.5
Decrease in transport congestion	Number of accessed highways with reduced traffic by using inland waterway transport service in dry port	Nguyen & Notteboom (2016b); Expert discussion	Number	Decision No. 979/QĐ-TTg by Vietnam's Prime Minister, dated 22 August 2023	2	3	1	3	3
Impact on urban areas	Distance to urban center	Mohan & Naseer (2022); Augustin et al. (2019)	Kilometers	Google Maps	6	13	22	6	4

4.5. Alternative rankings

The performance data were provided to the experts to obtain their opinions on the required thresholds: the preference threshold (p_j), the indifference threshold (q_j), and the veto threshold (v_j). A total of 24 experts participated in the interviews to determine these thresholds. The aggregated preference threshold, aggregated indifference threshold, and aggregated veto threshold were calculated using the arithmetic mean. The results of these aggregated thresholds are presented in Table 7.

Table 7. Aggregated preference thresholds, indifference thresholds, veto thresholds

	Decrease in trans. cost	Increase in trans. time	Cargo through put capacity	Access. to inland waterway	Access. to road	Access. to railway	Access. to seaport	Prox. to other logistics platforms	Prox. to production base	Prox. to consumption market	Room for expansion	Decrease in air pollution	Decrease in trans. congestion	Impact on urban areas
wj	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
qj	23	4	29,493	1	1	0	37	16	3	7	5	20	1	4
pj	62	9	108,368	2	2	1	79	44	7	26	14	55	2	10
vj	89	14	153,819	2	3	1	109	57	10	36	26	93	3	13

The preference thresholds, indifference thresholds, and veto thresholds presented in Table 7 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 8 and Table 9, respectively.

Table 8. Concordance matrix

Dry port	1. Hai Linh	2. Phu Dong	3. Que Vo	4. Phuc Loc	5. Mong Cai
1. Hai Linh	1.00	0.70	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 9. Credibility 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

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 effective discrimination between alternatives in previous MCDA research utilizing ELECTRE methods (Preethi and Chandrasekar, 2015; da Costa et al., 2022). Table 10 shows the results of credibility matrix after the cut-off level of 0.6 is applied. The final qualification and ranking of five alternatives are presented in Table 11.

Table 10. Credibility matrix with cut-off 0.6

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 11. Qualification and ranking

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

4.6. Location selection

Phu Dong dry port holds the first ranking with the highest final qualification score. The gap in qualification between the first and second rankings is significant. Therefore, based on the results of this case study, Phu Dong dry port should be selected as the best location for the Vietnamese government to invest in developing the integration between this dry port and inland waterway transport.

5. Discussion

The list of decision criteria used in this case study is based on existing literature, but new insights from Vietnamese experts have been added to highlight important criteria influencing this specific location choice problem. Regarding the weights of the main criteria, economic is the most important criterion in this decision-making process, with a weight of 0.36. According to the experts, in Vietnam, the majority of companies, including logistics and import-export companies, prioritize profit. For emerging companies in a developing country, a strong financial background enhances their opportunities to expand in both local and international markets. Conversely, the environment is the least important criterion. Although environmental factors are gaining attention in Vietnam and many logistics companies are researching the transition to greener modes of transport, including inland waterway transport, these initial efforts are insufficient to make the environment a crucial factor compared to economic, location, and accessibility.

In terms of the weights of sub-criteria, a decrease in transport cost has the highest weight of 0.24. High transport costs remain a significant issue for Vietnamese companies as they account for approximately 60% of total logistics costs (Hoa et al., 2020), substantially affecting profits, especially with fluctuations in fuel prices. All other sub-criteria have weights below 0.1. Accessibility to railway infrastructure has the lowest weight among the sub-criteria (0.02). In Northern Vietnam, railway networks have not been optimized for goods transport. Only one dry port in the list, Hai Linh dry port in Phu Tho province, is connected to the railway, yet it cannot fully leverage this mode's operational schedules.

Regarding the final rankings of the five alternatives, Phu Dong dry port in Hanoi holds the first rank. This is attributed to its strong performance on criteria with the highest weights, such as a decrease in transport cost (weight of 0.24), proximity to production base (weight of 0.12), accessibility to road infrastructure (weight of 0.09), and proximity to other logistics platforms (weight of 0.08). Notably, for certain criteria, this alternative dry port location significantly outperforms the others in performance data, such as cargo throughput capacity, proximity to consumption markets, and room for expansion. Hai Linh dry port ranks second. This is understandable, as it has the highest performance data for the most important criterion, decrease in transport cost, and it is the only alternative connected to the railway network. However, it cannot be ranked first because it performs poorly in certain criteria, such as cargo throughput capacity, proximity to consumption markets, and room for expansion.

The research findings have been discussed and validated with Vietnamese experts. They concur with all the weights of the criteria, and the final alternative rankings are considered helpful and valuable.

6. Conclusion, limitations, and further research direction

In conclusion, this research presents a methodology framework for determining the optimal dry port location for integration with inland waterway transport in developing countries. A case study in Northern Vietnam, involving five alternative dry port locations, is proposed to test this methodology framework. 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.

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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Appendix

Appendix 1. Transport routes by road and by inland water way from each dry port to Hai Phong seaport

Figure A1. Transport routes by road and by inland water way from Hai Linh dry port to Hai Phong seaport

Figure A2. Transport routes by road and by inland water way from Phu Dong dry port to Hai Phong seaport

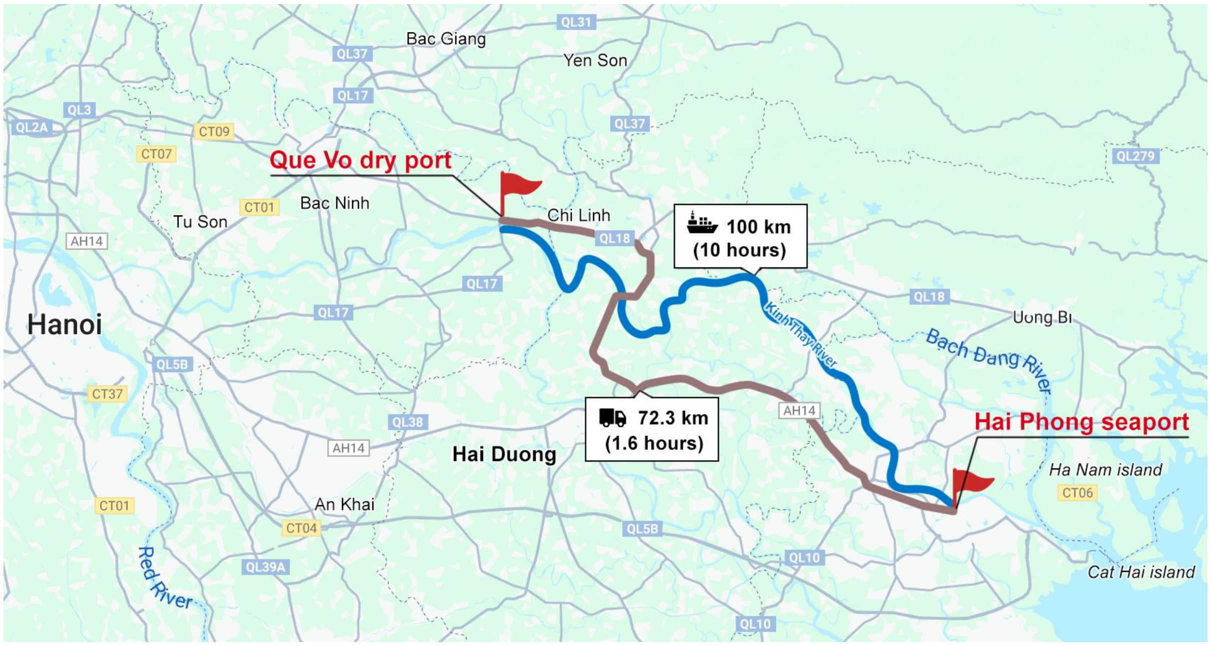

Figure A3. Transport routes by road and by inland water way from Que Vo dry port to Hai Phong seaport

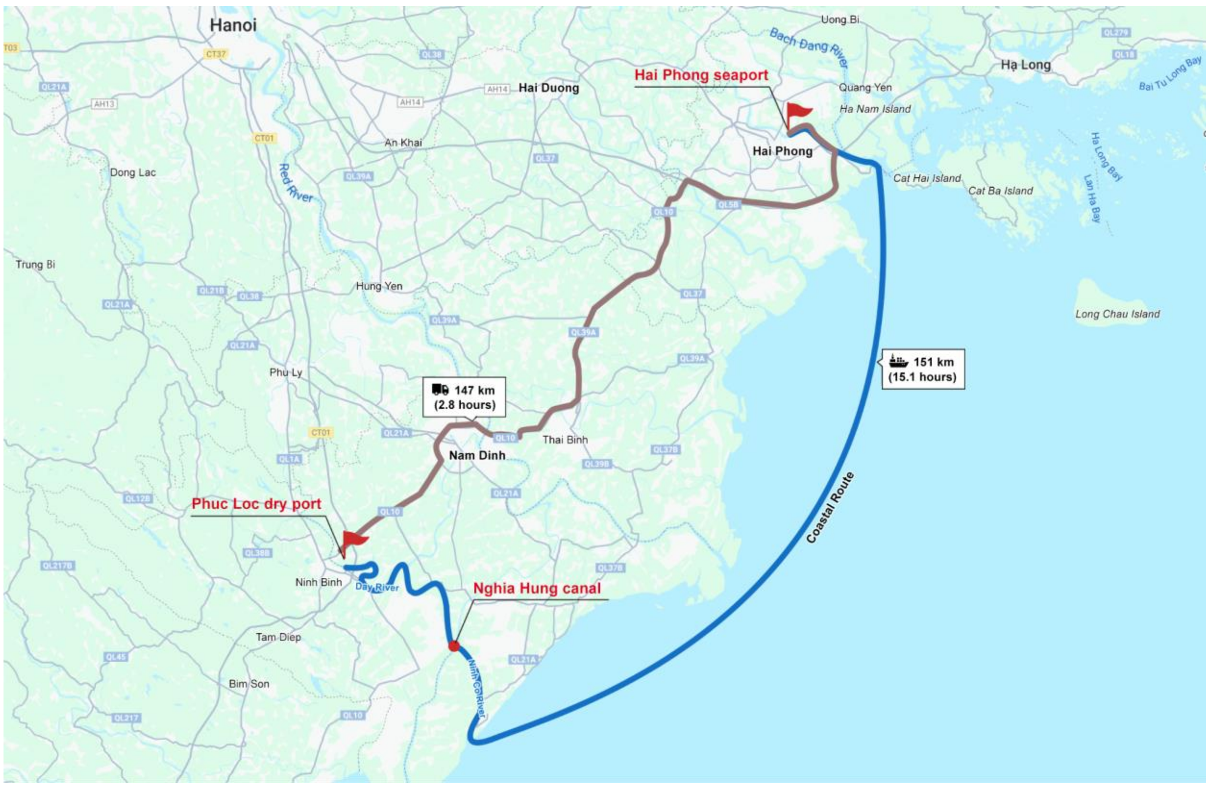

Figure A4. Transport routes by road and by inland water way from Phuc Loc dry port to Hai Phong seaport

Figure A5. Transport routes by road and by inland water way from Mong Cai dry port to Hai Phong seaport

Appendix 2. List of experts participating in the case study

Table A1. 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	Male	

			Operation Executive	
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