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A Hybrid DEMATEL and Bayesian Best–Worst Method Approach for Inland Port Development Evaluation

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Abstract: Inland ports are gaining more and more attention as important hubs for inland cities to promote foreign trade. However, studies on the evaluation of inland ports are lacking. In this work, we aim to construct an index system and propose a multi-criteria group decision-making method to comprehensively evaluate the development of inland ports. Unlike previous studies, using pressure–state–response model as a reference, we built up a demand–risk–power–potential framework for the index system proposed in this study. To determine the different weights for each indicator, which is a typical multi-criteria decision-making problem, we innovatively combined the decision-making trial and evaluation laboratory (DEMATEL) and the Bayesian best–worst method (BBWM) based on their distinct advantages in dealing with data coupling and group decision-making. In addition, this work introduces a case study of inland ports in the Huaihai Economy Zone to validate the efficacy of the proposed evaluation model and method. After calculating and obtaining the comprehensive scores and rankings of each inland port in this case, we compared the evaluation results with those under the BBWM, TOPSIS, and CRITIC methodologies, and found that the results under the DEMATEL–BBWM methodology can provide better differentiation for inland port evaluation results. Moreover, based on the evaluation results, a performance–importance matrix is formulated to identify the areas requiring attention in the development process of each inland port. Subsequently, rational managerial insights are put forward to achieve the sustainable development of inland ports in the Huaihai Economy Zone.

Keywords: multi-criteria decision-making; group decision-making; inland port; Bayesian best–worst method; DEMATEL

MSC: 62F15

check for updates

Citation: Ma, J.; Wiegmans, B.; Wang, X.; Yang, K.; Jiang, L. A Hybrid DEMATEL and Bayesian Best–Worst Method Approach for Inland Port Development Evaluation. *Axioms* **2023**, *12*, 1116. https://doi.org/10.3390/axioms12121116

Academic Editors: Peng Wu, Jiaming Zhu, Zhifu Tao and Li-Gang Zhou

Received: 14 November 2023
Revised: 6 December 2023
Accepted: 10 December 2023
Published: 13 December 2023

1. Introduction

In China, inland ports are gaining more and more attention as important hubs for inland cities to promote foreign trade. The concept of the inland port is being enriched and diversified to be more than merely an extension of seaports [1–3]. Along with the recent trends in smart technology applications, environmental protection, and integrated global trade, inland ports provide more functions and services than before [4]. However, recent studies on inland ports generally focused on the location and planning of inland ports, and the cooperation between inland ports and other hubs [5–7]. However, studies on the comprehensive evaluation of the performance of inland port development, regarding the demand, risk, power, and potential of the inland port, are lacking.

Inland ports play a significant role in facilitating the economic growth of inland regions, promoting the transformation and upgrading of inland industries, and enhancing the integration of logistics networks with the global economy [8,9]. Nevertheless, the existing evaluation approaches used for evaluating other types of hubs, such as seaports, inland river ports, and logistics parks, fail to adequately capture the distinctive attributes associated with the development of inland ports [10–12]. Therefore, how to comprehensively assess various indicators throughout the planning, construction, operation, and expansion phases for the performance of inland port development is an urgent issue to be addressed.

Therefore, to fill the research gap in evaluating inland ports and to put forward inland port development strategies, the main research questions to be answered in this paper are as follows:

1. How can an index system be developed to comprehensively evaluate the performance of inland port development?
2. How can the performance of inland port development be objectively evaluated using a group decision-making approach based on the proposed index system?

To solve the main research question, starting from four important issues, including demand, risk, power, and potential of inland port development, we constructed an inland port evaluation system under the demand–risk–power–potential evaluation framework. The evaluation system proposed in this paper helps to sequence the construction order of each inland port within a certain area based on the evaluation scores, helps to identify the strengths and weaknesses of each inland port, and provides targeted strategies based on the evaluation results.

Moreover, this study is the first attempt to combine the decision-making trial and evaluation laboratory (DEMATEL) and Bayesian best–worst method (BBWM) to provide an approach for group decision-making problems in an inland-port-related area. The DEMATEL–BBWM approach effectively leverages the utility of the DEMATEL method in addressing the interactions between indicators [13], as well as the applicability of the BBWM in resolving group decision-making issues [14]. This method is highly rational for the evaluation of inland port development and can provide better objective and scientific suggestions for inland ports than other methods.

In addition to the scientific innovations mentioned above, this study has practical implications. China's inland ports are characterized by their large size, their dependence on rail transport, and their relatively independent relationship with seaports. However, the issue of excessive construction of inland ports has emerged in certain areas of China, resulting in intensified competition among these inland ports and the inefficient utilization of land and transportation resources [15–18]. This paper offers a valuable reference for the prioritizing of inland port building by constructing a demand–risk–power–potential indicator system and employing the DEMATEL–BBWM approach to obtain the evaluation results. It effectively enhances the utility of such construction endeavors. Additionally, it is possible to identify the primary challenges encountered during the growth of existing inland ports by employing the proposed evaluation system and methodology.

This paper is structured as follows: Section 2 provides an overview of the current literature on inland port development evaluation and the application of MCDM methods; Section 3 develops the inland port evaluation index system based on the demand–risk–power–potential framework; Section 4 introduces the basic theory of the DEMATEL and the Bayesian best–worst method to achieve the group decision-making in this research; Section 5 makes a case study regarding the inland port evaluation problem in the Huaihai Economy Zone in China, and discusses the managerial insights for the inland ports we considered based on the evaluation results; Section 6 contains the main conclusions and limitations of the study, and makes recommendations for further research.

2. Literature Review

2.1. Previous Research on Inland Port Development

Considering the overinvestment status of inland ports in both China and Europe [18,19], we attempted to develop an inland port potential evaluation system to decide on whether or not a new inland port should be built or whether an existing inland port should be expanded. Several factors should be considered when developing new inland ports or expanding existing ones [20]. Munters et al. [20] also provided an overview of social-related (including employment generation, resettlement, safety, stakeholder consultation, and working conditions), environmental-related (including minimizing emissions, waste management, protection of land, and noise pollution) and economic-related factors (including maximizing VAS, transport cost and time, productivity port area, and multimodality reliability of service) regarding the development of inland ports. Abdoulkarim et al. [21] considered the development of inland ports from variable aspects, including motivation, role, site and location, positioning, etc. Olah et al. [5] constructed an evaluation system of inland ports involving 16 clusters and 40 evaluation criteria. Although their methods of classifying influencing factors were relatively comprehensive, vague classification among factors is hard to avoid. For example, the digitalization for inland ports is considered by Gwenaelle and Rodrigue [19], but it is hard to classify under the society–environment–economy indicator system proposed by Munters et al. [20].

Other scholars [22–24] have also made relevant studies on the evaluation of inland port development. This section provides a concise overview of the common approaches and metrics used in evaluating inland ports, as well as the specific case studies conducted in previous research, as can be seen in Table 1.

Table 1. Previous research on the evaluation of inland port development.

Scholars	Method	Indicators	Cases	Year
Munters et al. [20]	Qualitative and quantitative (multi-actor multi-criteria analysis)	Society, environment, economy	Modjo inland port	2021
Gwenaelle and Rodrigue [19]	Qualitative (interviews)	Cost, sustainability, digitalization, connectivity, security, governance	Ouagarinter inland port	2020
Chang et al. [18]	Quantitative (DEA and Tobit regression)	Area, current assets, fixed assets, integrated services output, container management services output, transportation services throughput, freight forwarding services output	Eight inland ports in China	2019
Abdoulkarim et al. [21]	Qualitative	Motivation, role, site and location, positioning, freight forwarding, trade facilitation, governance, and management	Inland ports in China and Africa	2019
Olah et al. [5]	Qualitative and quantitative (benchmarking methodology)	Intermodal hub, impact/contribution/importance, settlers, characteristics, mission of the dry port development corporation (DPDC), transportation mode relevance, services, safety management, green logistics, TEN-T, SWOT, structured data, land and buildings, future development, development paths, structure of the dry port development corporation (DPC)	Inland ports in Europe	2017
Wiegmans et al. [22]	Qualitative and quantitative (benchmark and regression analysis)	Level of transshipment, rate of growth of transshipment, diversity of cargo types, number of jobs, distribution of short/medium/long distances, distance from main roads to access points	Inland ports in the Netherlands	2015
Roso and Lumsden [23]	Qualitative	General information, services, barriers, and advantages arising from the operation of dry ports	Inland ports in Europe, Africa, and Asia	2010
Yeo et al. [24]	Qualitative and quantitative (exploratory factor analysis)	Port services, hinterland conditions, availability, accessibility, logistics costs, regional centers, connectivity	Inland ports in Korea and China	2008

According to Table 1, previous studies on the evaluation of inland ports are generally carried out in a combination of qualitative and quantitative ways, while the selection of evaluation indicators varies greatly among the studies due to the difference in research focus.

The observed indicators on the performance of inland ports in the previous research provide the basis for the construction of the indicator system of this paper. In conjunction with the proposed DRPP evaluation framework in this paper, the indicators have been re-categorized to better suit the characteristics of the evaluation of the performance of inland port development.

2.2. Comparison of MCDM Methods

Multi-criteria decision-making refers to the decision-making of choosing among a finite or infinite set of conflicting and incommensurable alternatives, and the prioritization of the construction of each inland port within a certain area is a typical multi-criteria decision-making problem that needs to consider multiple indicators and the weights of each indicator. Since the multi-criteria decision-making problem was proposed [25], the analytic hierarchy process (AHP), technique for order preference by similarity to ideal solution (TOPSIS), best–worst method (BWM), Bayesian best–worst method (BBWM), decision-making trial and evaluation laboratory (DEMATEL), and criteria importance through intercriteria correlation (CRITIC) as well as other multi-criteria decision-making methods have been developed. The comparison of the characteristics of different multi-criteria decision-making methods is shown in Table 2.

Table 2. Comparison of different MCDM approaches.

Method	AHP [26]	TOPSIS [26,27]	BWM [28]	Bayesian-BWM [14]	DEMATEL [13]	CRITIC [27]
Suitability	Choosing Ranking Categorization	Choosing Ranking	Decision-making problems of single decision maker	Decision-making problems of multiple decision makers	Ranking	Choosing Ranking
Input	Results of pairwise comparisons of indicators under the same dimension	Indicator performance	The best and the worst indicator; preferences for each indicator	The best and the worst indicator; preferences for each indicator by multiple decision makers	Degree of influence of each indicator on others	Evaluating the comparative strength of indicators and the conflicting degree of indicators
Output	Scores and rankings for each program	Ranking based on best–worst distance	Weights and consistency	Combined weights and credal ranking	Causal relationships between indicators and the status of each indicator	Objective weighting and ranking of indicators
Computational complexity	High	High	Low	Medium	Medium	High
Solving software	MS Excel	Excel, Matlab, Decerns	MS Excel	Matlab, Python	Matlab, Python	Matlab, Python

According to the comparison above, the BWM and BBWM methods have lower computational complexity due to their small requirements of data. Furthermore, the Bayesian best–worst method has the following advantages over other multi-criteria decision-making methods:

- By identifying the best and worst indicators of the indicator set before making comparisons between indicators, this method enhances the decision maker's comprehension of the evaluation's extent, thereby increasing the reliability of their indicator comparisons;
- In a singular optimization model, the decision maker will generate two comparison vectors by utilizing the best and worst indicators as points of reference. This approach serves to alleviate the potential influence of anchoring bias that the decision maker may experience while conducting indicator comparisons;
- The Bayesian best–worst method lies between the single vector and full matrix comparison, and it improves the consistency of the evaluation criteria while reducing the evaluation data (and time).

At the same time, we found that the DEMATEL method also possesses a unique advantage in dealing with indicators with a coupling interaction relationship. The DEMATEL can reduce the problem of difficulty in determining the weights of indicators due to the coupling between indicators.

Moreover, we found that for multi-criteria decision problems, a large number of studies use a combination of methods currently. However, regarding the combination of the DEMATEL and BBWM method, there is still a lack of research.

Hence, this study presents a novel approach by integrating the DEMATEL and BBWM methodologies, aiming to effectively leverage the strengths of both techniques in order to yield more rational results for the evaluation of inland ports.

3. DRPP Evaluation Index System of Inland Port Development

The idea of the demand–risk–power–potential (DRPP) indicator system constructed in this paper is derived from the pressure–state–response (PSR) method of environmental quality assessment. The PSR method answers the three basic questions of sustainable development, such as "what happened, why did it happen, and what are we going to do about it", and embodies the interaction between human beings and the environment [29,30]. Similarly, the DRPP indicator system also answers the four basic questions of the performance of inland port development.

On the basis of the PSR method, this paper summarizes four types of key influencing factors by combining the characteristics of inland port development: demand, risk, power, and potential, as can be seen in Figure 1. Each factor is related to a significant question for inland port development:

- Demand is related to "why should we develop an inland port";
- Risk is related to "what are the risks involved in inland port development";
- Power is related to "what kind of inland port are we evaluating";
- Potential is related to "how strong is the development potential of the evaluated inland port".

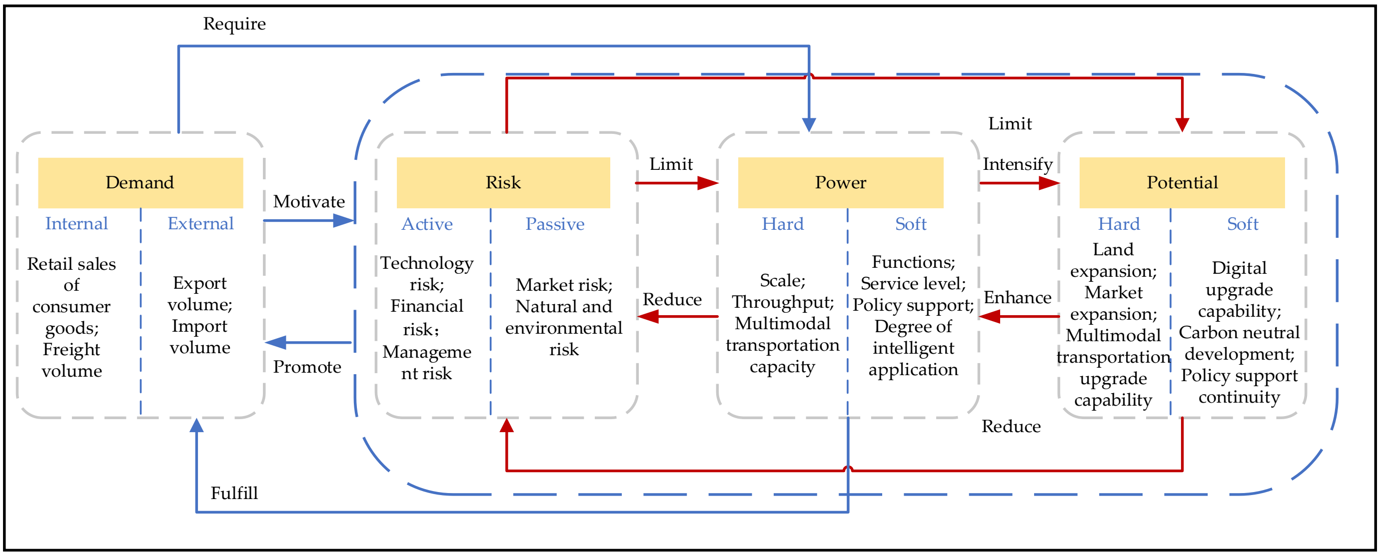

Figure 1. The demand–risk–power–potential relationship.

For the interactions between the second-level indicators as in Figure 1, we assume them to be independent of each other in this paper.

(1) Demand: why should we develop an inland port?

Demand factors are the key factors determining whether inland ports can realize sustainable and stable development. In this paper, we mainly consider the internal demand for inland port development (including the retail trade volume of consumer goods and freight volume of the inland port hinterland) and the external demand (including the export volume and import volume of the inland port hinterland). The above indicators can be obtained from provincial and municipal statistical bulletins and statistical yearbooks, which are highly accessible and can reflect both domestic and international demand served by inland port development.

(2) Risk: what are the risks involved in inland port development?

Risk factors mainly include active risks (e.g., technical risks, financial risks, management risks) and passive risks (e.g., market risks, natural environment risks). Technical risk refers to problems in the planning and construction of inland ports due to technical defects. Financial risk refers to the risk caused by the supply of funds, bank loan policy, exchange rate fluctuations involved in the investment, and financing during the development of the inland port. Management risk refers to the risk brought about by poor internal management in the process of inland port development. Market risk refers to the risk brought about by the fluctuation of the external market to the development of inland ports. Natural environment and social risks refer to the disruptions to the development process of inland ports due to adverse weather conditions, international political unrest, etc.

(3) Power: what kind of inland port are we evaluating?

Power factors in inland ports primarily encompass both hard and soft elements. Hard power factors pertain to the physical attributes of inland ports, such as their scale, throughput, multimodal transportation service capacity, and functions. On the other hand, soft power factors encompass intangible aspects, like the service level provided by inland ports, the extent of policy support they receive, and the degree to which intelligent applications are employed. The capacity of multimodal transportation services in inland ports pertains to the presence of favorable conditions for both railway and highway transportation, as well as the capability to facilitate multimodal transportation in collaboration with inland waterway, maritime, and aerial transportation modes. The term "function of an inland port" pertains to the extent to which an inland port possesses both fundamental and supplementary capabilities to cater to the intended customer group. Apart from conventional shipping and warehousing services, these additional functions encompass customs clearance, bonded operations, processing activities, packaging services, and other related functionalities. The service level of an inland port primarily encompasses a complete evaluation of operational efficiency, cargo loss rate, customer satisfaction, and other relevant factors. The measure of policy support pertains to the extent to which inland ports have been endowed with comprehensive policy assistance at the national, provincial, ministerial, and municipal levels. The level of intelligent implementation pertains to the extent to which inland ports are utilized with intelligent facilities, equipment, platform services, and other related factors.

(4) Potential: how strong is the development potential of the evaluated inland port?

The potential factors primarily encompass both hard potentials, such as the capability for inland port land expansion and the potential for market expansion, as well as soft potentials, including the potential for upgrading inland port multimodal transportation, digitalization, carbon neutral development, and the continuity of policy support for inland ports. The land expansion capability of inland ports pertains to the presence of a designated area of land that is reserved for potential future development purposes. The market growth potential of inland ports pertains to the capacity of these facilities to extend their reach and influence over markets and hinterlands subsequent to their establishment and operationalization. The potential for enhancing the intermodal transportation capabilities of inland ports pertains to the extent to which these inland ports possess the necessary circumstances to facilitate various intermodal transportation services, including but not limited to China–Europe Railway Express and sea–railway multimodal transportation services. The concept of digital upgrading for inland ports pertains to the evaluation of whether these facilities have achieved the necessary criteria for digital standardization and have the capacity to embrace ongoing digital advancements in the foreseeable future. The carbon neutrality potential of inland ports pertains to the extent to which these ports possess a well-defined approach for achieving carbon neutrality and are capable of consistently reducing their carbon emissions. The concept of continuity of policy support for inland ports pertains to the ability of existing support policies for inland ports to maintain stability throughout a specific duration.

After analyzing the above four aspects, combined with the previous research, we constructed the index system for the evaluation of inland port development in this paper as in Table 3.

Table 3. Evaluation index system for inland port development based on DRPP.

First-Level	Dimensions	Second-Level	Unit	References
Demand	Internal	Retail sales of consumer goods	Billion yuan	[31]
		Freight volume	Million tons	[24]
	External	Export volume	Billion yuan	[6]
		Import volume	Billion yuan	[6]
Risk	Active	Technology risk	Dimensionless	[19,24]
		Financial risk	Billion yuan	[5,19,24]
		Management risk	Dimensionless	[20,32]
	Passive	Market risk	Dimensionless	[5,19,20,32]
		Environment and society risk	Dimensionless	[19,20,32]
Power	Hard	Scale	km^2	[5,18,20,23]
		Throughput	10 kilo tons	[5,18,19,24]
		Multimodal transportation service	10 kilo TEU	[5,18,19,24]
		Function	Dimensionless	[18,19]
	Soft	Service level	Dimensionless	[5,18,19,21,23]
		Policy support	Dimensionless	[18]
		Degree of intelligent application	Dimensionless	[19]
Potential	Hard	Land expansion	km^2	[5,23]
		Market expansion	Billion yuan	[5,20,22]
		Multimodal transportation upgrade	Trains	[19,24]
	Soft	Digital upgrade	Dimensionless	[5,20,22]
		Carbon neutral	Dimensionless	[20]
		Policy support continuity	Dimensionless	[18,21]

4. The DEMATEL–BBWM Group Decision-Making Approach for Weight Determination of the Evaluation Indicators

4.1. The Framework of the Proposed Model

By employing a hybrid multi-criteria group decision-making evaluation method, this paper provides a comprehensive analysis of inland port evaluation, as illustrated in Figure 2. As can be seen in Figure 2, we present a theoretical framework for calculating indicator weights by employing the DEMATEL–BBWM approach, and the framework builds upon the innovative evaluation index system for inland port development.

The BBWM method introduces a novel approach to establishing the ranking of index credibility, hence enhancing the dependability of the indicators' weights for group decision-making. The DEMATEL method exhibits enhanced capability in analyzing the causal relationship between indicators, rendering it more congruent with the DRPP indicator framework system given within this paper.

Consequently, the DEMATEL method is utilized to determine the weights of the first-level indicators in evaluating the development of inland ports, and the BBWM method is adopted for determining the weights of the second-level indicators, which fully reflects the interrelatedness and independence of the indicators.

Finally, relying on the evaluation results, the construction priority of each inland port is clarified. By constructing a performance–importance matrix, the specific challenges encountered during the inland port development process are identified, which help us to propose diversified development strategies for each inland port.

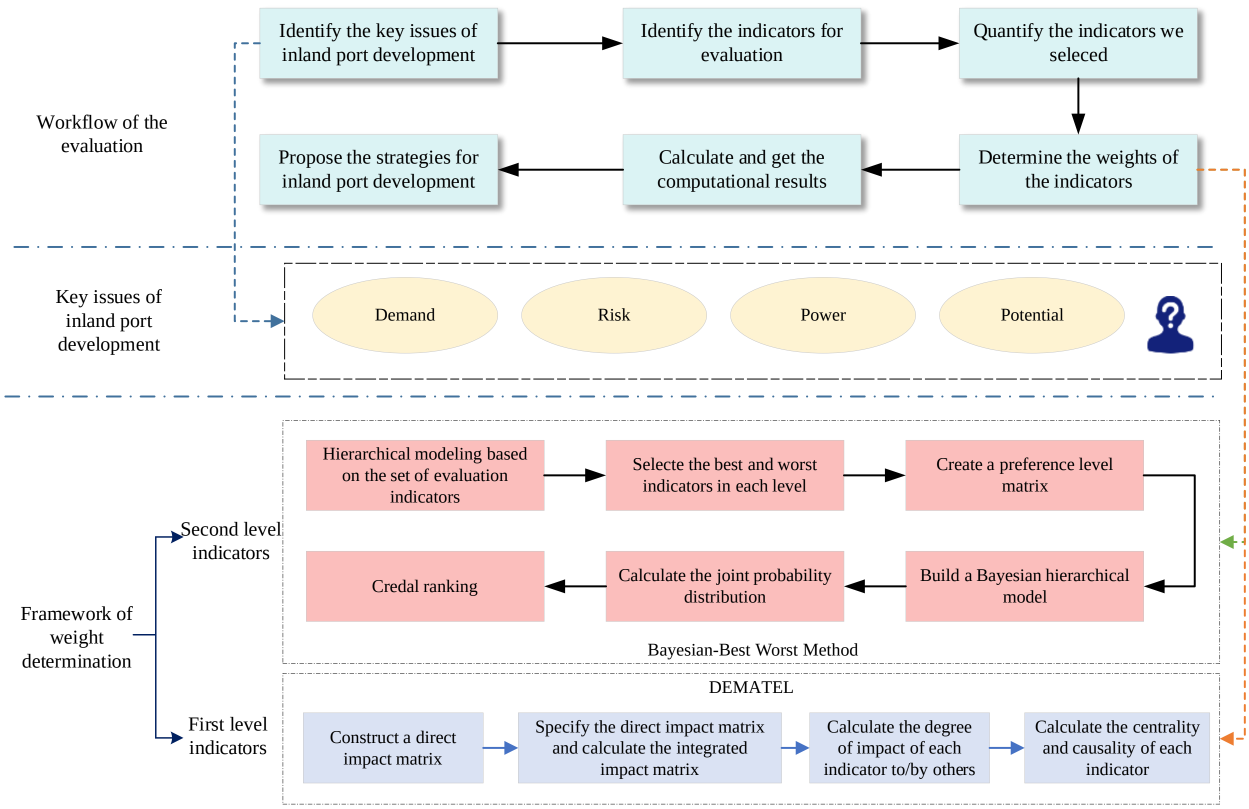

Figure 2. Framework of the evaluation process for inland port development.

4.2. DEMATEL for Weight Determination of the First-level Evaluation Indicators

The DEMATEL method is widely recognized as a highly successful approach for discerning the constituent elements of the causal chain within a complicated system [13,33]. The methodology facilitates the identification of crucial elements inside intricate systems through the evaluation of the interrelationships among components and the creation of a visual structural model. The proposed methodology offers a solution to address the issue of ambiguous key indicators resulting from their interplay.

The coupling effect link among the demand, risk, power, and potential factors, is evident in the evaluation problem of inland port development, which aligns well with the application scenario of the DEMATEL approach.

Step 1. Construct a set of indicators for the evaluation of inland port development and to identify the interactions among the indicators.

According to the opinions of relevant experts in the field of inland ports, we decided on the specific degree of mutual influence between each level of indicators of demand, risk, power, and potential. Moreover, we constructed the direct influence matrix D of the first-level indicators, in which the rows and columns are distributed according to the order of the mentioned indicators as shown in Equation (1) [33]:

$$D = \begin{pmatrix} 0 & a_{12} & \cdots & a_{1n} \\ a_{21} & 0 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 0 \end{pmatrix} \quad (1)$$

where a_{ij} represents the degree of influence of indicator i to indicator j. The degree is classified into four levels: 0, 1, 2, and 3, where the scores of 0, 1, 2, and 3 represent "No influence", "Low influence", "High influence", and "Very high influence", respectively [33,34].

Step 2. Normalize the direct impact matrix and calculate the integrated impact matrix.

The direct impact matrix of the first-level indicators for the evaluation of inland port development is normalized, and each row of data is standardized separately to the interval $[-1, 1]$. By this step, we can obtain the matrix $K = D \times \lambda$, where λ represents the standardized coefficient. On this basis, the comprehensive impact matrix T is calculated, as shown in Equation (2) [33,34]:

$$T \triangleq \lim_{m\to\infty}\left(K^1 + K^2 + \ldots + K^m\right) = K(I-K)^{-1} \tag{2}$$

Step 3. Calculate various indicator values.

The degree of influence, being influenced, centrality, and causality are computed for each first-level indicator using matrix T. The values of each indicator are computed in the following manner.

The degree of influence r_i is the sum of the elements of the rows of matrix T, indicating the degree of influence of indicator i to other indicators, as in Equation (3):

$$r_i = \sum_{j=1}^{n} t_{ij} \tag{3}$$

The degree of being influenced c_j is the sum of the elements of the columns of matrix T, indicating the degree of influence of other indicators to indicator i, as in Equation (4):

$$c_j = \sum_{i=1}^{n} t_{ij} \tag{4}$$

The centrality M_i of indicator i is the sum of r_i and c_i, $M_i = r_i + c_i$. The higher centrality of the indicator indicates the higher importance of the indicator in the overall evaluation.

The causality R_i of indicator i is the difference between r_i and c_i, $R_i = r_i - c_i$. The higher centrality of the indicator indicates the higher importance of the indicator in the overall evaluation. A positive R_i indicates that the indicator i is a cause indicator, and a negative R_i indicates that the indicator i is a contributing indicator.

Step 4. Determine the weights of first-level evaluation indicators based on centrality and causality.

Based on the centrality and causality degree of each indicator, the distance of each indicator from the origin is calculated, $d = \sqrt{M^2 + R^2}$. The longer distance means that the indicator has a stronger influence in the overall system of indicators. Thus, we should give higher weight to this kind of indicators. Moreover, the resulting distance matrix is normalized to obtain the final weights of the first-level indicators for the evaluation of inland port development.

4.3. Bayesian Best–Worst Method for Weight Determination of the Second-level Evaluation Indicators

The basic principle of the best–worst method is to obtain the final indicator weights by first identifying the best and worst indicators in a set of decision indicators, then using a number between 1 and 9 to determine the preference of the best indicator over all other indicators and the preference of all indicators over the worst criterion [28], and to calculate them through a series of comparisons. While the original best–worst method was limited to solving the case of targeting the decision maker uniquely, Mohammadi and Rezaei in 2020 proposed a new method for multi-criteria group decision-making based on the best–worst method by considering the case of group decision-making, which is known as the Bayesian best–worst method. The basic idea of the Bayesian best–worst method is to provide a priori and a posteriori probabilistic explanation for the inputs and outputs of the best–worst method, which ultimately leads to a comprehensive analysis of group decision-making [14]. Since its introduction, the Bayesian best–worst method has been widely used for multi-criteria group decision-making problems in many fields [35].

Step 1. Construct a collection of the second-level indicators $C = \{c_1, c_2, \ldots c_n\}$, and determine the best (c_B) and the worst (c_W) criteria from C.

Step 2. Conduct pairwise comparisons between the best indicator and other indicators.

In this step, the decision maker shows his/her preferences by a number between 1 and 9; the higher the number, the greater the relative importance between the criteria. The resulting best-to-others vector is $A_B = (a_{B1}, a_{B2}, \ldots a_{Bn})$, where a_{Bj} denotes the preference of the best criterion C_B over other criteria $c_j \in C$.

Step 3. Conduct pairwise comparisons between the other indicators and the worst indicator.

Similar to step 2, conduct the pairwise comparison between the other criteria and the worst criterion. The resulting others-to-worst vector is $A_W = (a_{1W}, a_{2W}, \ldots a_{nW})^T$, where a_{jW} denotes the preference of other criteria $c_j \in C$ over the worst criterion C_W.

Step 4. Estimating the probability distribution of each individual optimal weight $w^{1:K}$ and the overall optimal weight w^{BBWM} given $A_B^{1:K}$ and $A_W^{1:K}$, where k represents the decision makers and $k = 1, \ldots, K$.

The joint probability distribution is sought as in Equation (5):

$$P\left(w^{BBWM}, w^{1:K} \middle| A_B^{1:K}, A_W^{1:K}\right) \tag{5}$$

The probability of each variable then can be computed using the following rule under probability theory:

$$P(x) = \sum_y P(x, y) \tag{6}$$

where x and y are two arbitrary random variables.

To build a Bayesian model, a graphical model is plotted as in Figure 3.

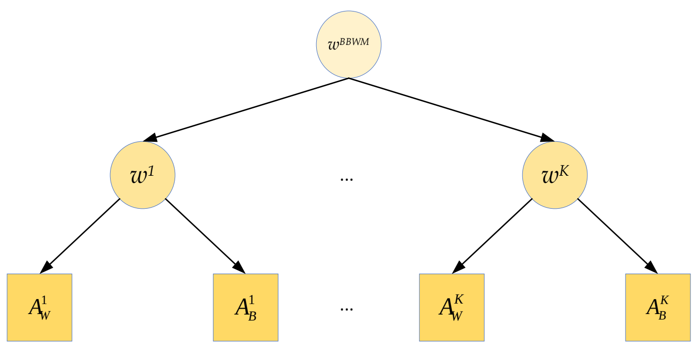

Figure 3. Probabilistic hierarchical model of the Bayesian BWM.

It is clear that the variable w^k depends on both A_B^k and A_W^k, while w^{BBWM}, in turn, depends on w^k, while either A_B^k or A_W^k are independent of w^{BBWM} according to the direction of the arrow. This independence feature can be described as in Equation (7):

$$P\left(A_W^k \middle\| w^{BBWM}, w^K\right) = P\left(A_W^K \middle\| w^K\right) \tag{7}$$

Applying Bayes' theorem to Equation (1), we can obtain the following Equation (8):

$$\begin{aligned} &P\left(w^{BBWM}, w^{1:K} \middle| A_B^{1:K}, A_W^{1:K}\right) \propto P\left(A_B^{1:K}, A_W^{1:K} \middle\| w^{BBWM}, w^{1:K}\right) P\left(w^{BBWM}, w^{1:K}\right) \\ &= P\left(w^{BBWM}\right) \prod_1^K P\left(A_W^K \middle\| w^K\right) P\left(A_B^K \middle\| w^K\right) P\left(w^K \middle\| w^{BBWM}\right) \end{aligned} \tag{8}$$

Step 5. Derive the prior distribution and calculate the posterior distribution to obtain the weights of each indicator.

To compute the above equation, we need to determine the distributions of each related element. A_B^k and A_W^k are the inputs of BWM. According to the Bayesian structure as in

Figure 3, they can be modeled by a multinomial distribution due to the property of the integer, which is shown in Equations (9) and (10):

$$A_W^k \Big| w^k \sim multinomial\left(w^k\right), \forall k = 1, \ldots, K. \tag{9}$$

$$A_B^k \Big| w^k \sim multinomial\left(\frac{1}{w^k}\right), \forall k = 1, \ldots, K. \tag{10}$$

For the multinomial distribution of weight w, the Dirichlet distribution is used as the prior distribution because of its non-negativity and sum-to-one properties, as in Equation (11):

$$Dir(w||\alpha) \sim \frac{1}{B(\alpha)} \prod_{j=1}^{n} w_j^{\alpha_j - 1}, \alpha \in R^n. \tag{11}$$

Therefore, when w^{agg} is given, one can expect each and every w^k to be in its proximity. The models of w^k are as in Equation (12):

$$w^k \Big|\Big| w^{BBWM} \sim Dir(\gamma \times w^{BBWM}), \forall k = 1, \ldots, K \tag{12}$$

For the non-negative parameter γ, the gamma distribution is adopted to model the distribution of γ due to its wide range of applications in prior distributions, as in Equation (13):

$$\gamma \sim gamma(a, b) \tag{13}$$

where a and b are the shape parameters of the gamma distribution, and in choosing the parameters of the gamma distribution, we can use either great likelihood estimation or Bayesian estimation.

Finally, the prior distribution over w^{BBWM} can be expressed as in Equation (14):

$$w^{BBWM} \sim Dir(\alpha) \tag{14}$$

where the parameter α is set to be 1.

However, the model we built up until now does not output a closed-form solution. To deal with this, we introduced Markov chain Monte Carlo (MCMC) to compute the posterior distribution in Equation (8). Moreover, we used the "just another Gibbs sampler" (JAGS) to generate randoms samples in Equation (8).

Step 6. Calculate the credal ranking for indicators.

When faced with multi-criteria decision-making problems, the relative significance of indicators is frequently determined by comparing whether one indicator's (mean) weight is greater than that of another indicator. However, in the group decision-making process, the concept of credal ranking needs to be introduced. By constructing the posterior distribution of indicator weights, credal ranking can calculate the degree to which one indicator is superior to another and evaluate the superiority relationship among indicators in a more objective manner. Compared with interval-based ranking, fuzzy ranking, and ranking based on gray-scale relational analysis, credal ranking is based on the Dirichlet distribution, while other ranking methods often explore the superiority or inferiority relationship among indicators by constructing two numbers/intervals.

Based on Mohammadi and Rezaei's idea [14], we introduce the calculation process of credal ranking in this study as follows.

For the indicator set $C = \{c_1, c_2, \ldots c_n\}$, the credal raking is the set of confidence orders for each pair of indicators (c_i, c_j), while $c_i \in C, c_j \in C$.

A new Bayesian test is constructed with the goal of determining the certainty of each confidence order. The test is designed with the posterior distribution of w^{BBWM}. The mathematical equation of c_i is more important than c_j is shown as in Equation (15):

$$P(c_i > c_j) = \int I_{(w_i^{BBWM} > w_j^{BBWM})} P(w^{BBWM}) \tag{15}$$

where $P(w^{BBWM})$ represents the posterior probability of w^{BBWM}, I denotes a logic parameter that evaluates to 1 when the subscript condition of I is true, and 0 otherwise.

This integral can be estimated from samples obtained by means of Markov chain Monte Carlo (MCMC). With Q samples from the posterior distribution, the confidence level can be expressed as Equations (16) and (17):

$$P(c_i > c_j) = \frac{1}{Q}\sum_{q=1}^{Q} I\left(w_i^{BBWM_q} > w_j^{BBWM_q}\right) \tag{16}$$

$$P(c_j > c_i) = \frac{1}{Q}\sum_{q=1}^{Q} I\left(w_j^{BBWM_q} > w_i^{BBWM_q}\right) \tag{17}$$

where w^{BBWM_q} denotes the q^{th} sample of w^{BBWM} in the MCMC sample.

Thus, for each pair of indicators, the confidence level at which one indicator is more important than the other can be calculated as above. Confidence rankings can also be transformed into traditional rankings in this way. Obviously, $P(c_i > c_j) + P(c_j > c_i) = 1$. Therefore, an indicator c_i is considered to be more important than c_j when and only when $P(c_i > c_j) > 0.5$.

5. Case Study

5.1. Case Background and Data Description

5.1.1. Case Background

The Huaihai Economic Zone is located at the beginning of the eastern part of the Asia–Europe Continental Bridge, close to the Central Plains Economic Zone in the west, the Yangtze River Delta Economic Zone in the south, and the Bohai Economic Zone in the north [36]. The Huaihai Economic Zone is the hub zone for east–west integration and north–south exchange in China, and plays a pivotal role in the implementation of the strategy of accelerated development in the east of China, the rise of central China, and the development of the west of China.

In this case, the six inland ports to be constructed in the Huaihai Economic Zone, namely Xuzhou, Suzhou, Yudong, Linyi, Yanzhou, and Zaozhuang inland ports are taken as the evaluation objects, and the proposed evaluation system is applied to obtain the evaluation results of each inland port. The inland ports are ranked relying on the evaluation results so as to determine the construction sequence of each inland port. Furthermore, the managerial insights of each inland port are determined by analyzing the weight–performance matrix as in Section 5.3.2.

5.1.2. Data Sources and Data Preprocessing

For quantitative indicators, the data were obtained according to the statistical yearbook [37] and the inland port planning program [38,39]; for qualitative indicators, the Delphi method and the five-level evaluation method were used to obtain the indicator scores. It should be noted that in the process of obtaining the initial scores for qualitative indicators, there are also a variety of methods that can be used to do so, and the Delphi method and the five-level evaluation method used in this paper are selected for their strong operability. Since the scenario oriented in this example is a small data scenario, in order to retain the potential weight relationship reflected by the standard deviation in the original data, the obtained scores of each indicator are normalized by max-min de-measurement as shown in Equation (18):

$$x' = \frac{x - x_{\min}}{x_{\max} - x_{\min}} \tag{18}$$

where x_i represents the original score of indicator x for inland port i, $x_{\min}$ represents the minimum original score of indicator x, $x_{\max}$ represents the maximum original score of indicator x, and x_i' represents the normalized score of indicator x for inland port i.

Following the process of normalization, the scores for each indicator are transformed and assigned to the range [0, 1]. This can be observed in Table 4, which displays the normalized scores for each indicator of each inland port under the case we proposed.

Table 4. Normalized score of each indicator for each inland port.

First-Level	Second-Level	Code	XZIP	SZIP	YDIP	LYIP	YZIP	ZZIP
Demand	Retail sales of consumer goods	A1	1.000	0.068	0.163	0.617	0.469	0.000
	Freight volume	A2	0.929	0.636	0.000	0.939	1.000	0.554
	Export volume	A3	0.947	0.060	0.000	1.000	0.524	0.309
	Import volume	A4	0.527	0.000	0.028	0.770	1.000	0.124
Risk	Technology risk	B1	1.000	0.500	0.500	0.000	0.750	1.000
	Financial risk	B2	0.000	1.000	0.900	0.600	1.000	0.600
	Management risk	B3	0.667	0.000	0.667	0.000	1.000	1.000
	Market risk	B4	0.800	0.600	0.800	0.000	1.000	0.800
	Environment and society risk	B5	1.000	0.000	1.000	0.500	1.000	1.000
Power	Scale	C1	1.000	0.000	0.000	0.286	0.000	0.714
	Throughput	C2	1.000	0.000	0.125	0.250	0.250	0.500
	Multimodal transportation service	C3	1.000	0.043	0.000	0.000	0.043	0.362
	Function	C4	1.000	0.333	0.000	0.000	0.667	1.000
	Service level	C5	0.500	0.250	0.500	0.000	0.750	1.000
	Policy support	C6	1.000	0.000	0.000	0.000	0.500	0.500
	Degree of intelligent application	C7	1.000	0.000	0.500	0.000	0.750	0.750
Potential	Land expansion	D1	1.000	0.000	0.333	0.333	0.000	1.000
	Market expansion	D2	0.667	0.333	0.000	0.000	1.000	0.667
	Multimodal transportation upgrade	D3	1.000	0.125	0.000	0.000	0.375	0.750
	Digital upgrade	D4	1.000	0.500	0.500	0.000	1.000	1.000
	Carbon neutral	D5	1.000	0.500	0.000	0.000	1.000	1.000
	Policy support continuity	D6	1.000	0.500	0.500	0.000	0.750	0.750

5.2. Determine the Weights of Evaluation Indicators

5.2.1. Determine the Weights of the First-Level Indicators for Inland Ports in the Huaihai Economic Zone with DEMATEL

According to the steps of the DEMATEL method, and relying on expert opinion, the evaluation matrix shown in Equation (19) was constructed, in which D is the direct impact matrix between different first-level indicators, K is the direct impact matrix after normalization, and T is the comprehensive impact matrix.

$$\begin{gathered} D = \begin{pmatrix} 0 & 1 & 3 & 2 \\ 1 & 0 & 3 & 2 \\ 2 & 3 & 0 & 3 \\ 3 & 2 & 1 & 0 \end{pmatrix} \Rightarrow K = \begin{pmatrix} -1 & -0.33 & 1 & 0.33 \\ -0.33 & -1 & 1 & 0.33 \\ 0.33 & 1 & -1 & 1 \\ 1 & 0.33 & -0.33 & -1 \end{pmatrix} \\ \Rightarrow T = \begin{pmatrix} -0.305 & 0.112 & 0.352 & 0.310 \\ 0.095 & -0.288 & 0.352 & 0.310 \\ 0.319 & 0.426 & -0.214 & 0.517 \\ 0.310 & 0.103 & 0.103 & -0.379 \end{pmatrix} \end{gathered} \tag{19}$$

Based on the constructed comprehensive influence matrix, we calculated the degree of influence of each indicator. From this, the centrality and causality of each indicator were calculated and shown in Figure 4.

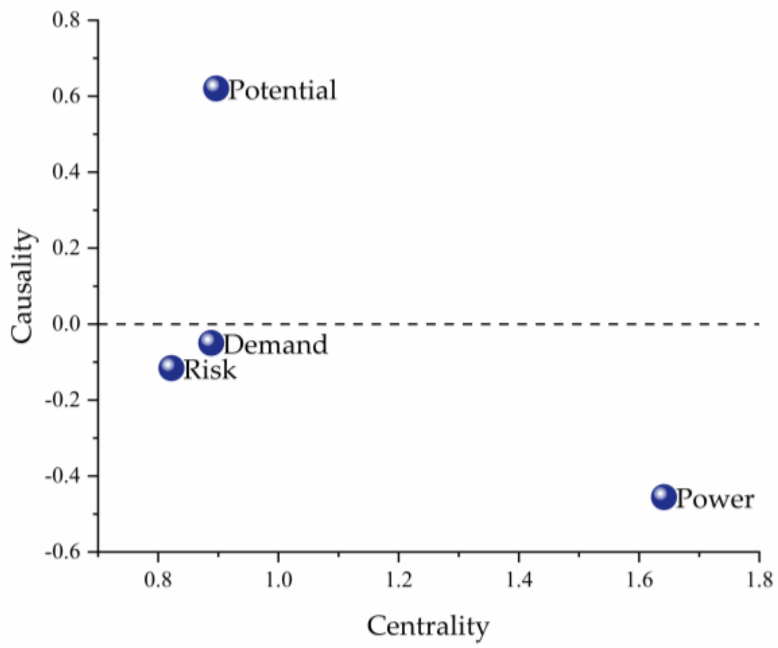

Figure 4. Centrality and causality of the first-level indicators.

As can be seen from Figure 4, from the point of view of centrality, the centrality of the power indicator is significantly greater than that of the other three types of indicators, indicating that the power indicator has a higher degree of importance in the overall evaluation indicators. In terms of causality, the potential indicator is positive, while the causality of the other three indicators is negative, indicating that the potential indicator is a cause indicator, and the other three indicators are leading indicators.

After calculating and normalizing the distance of each indicator from the origin, $d = \sqrt{M^2 + R^2}$, we obtained the weights of the first-level indicators as follows:

$$w_{Demand} = 0.1971, w_{Risk} = 0.1839, w_{Power} = 0.3774, w_{Potential} = 0.2416$$

5.2.2. Determine the Weights of the Second-Level Indicators for Inland Ports in the Huaihai Economic Zone with the Bayesian Best–Worst Method

In order to maintain the evaluation's rationality and pertinence, the evaluation experts' areas of expertise should be confined to inland-port-related matters. In addition, taking into account the comparability, operability, and representativeness of the evaluation experts, the research in this case is carried out on a sample of sixteen experts, consisting of eight academic scholars and eight enterprise experts. The background of the experts is shown in Table A1 in Appendix A.

According to the BBWM method proposed in Section 4.3, the experts' opinions on the importance of each indicator are firstly presented in the form of heat map, as shown in Figure 5. Figure 5a presents a comparison between "each indicator" and "optimal indicator"; the darker the color and the smaller the graph, the greater the significance of the indicator. In contrast, Figure 5b presents a comparison between "each indicator" and "worst indicator" using the optimal indicator as the reference point; the lighter color and the larger the graph, the greater the significance of the indicator.

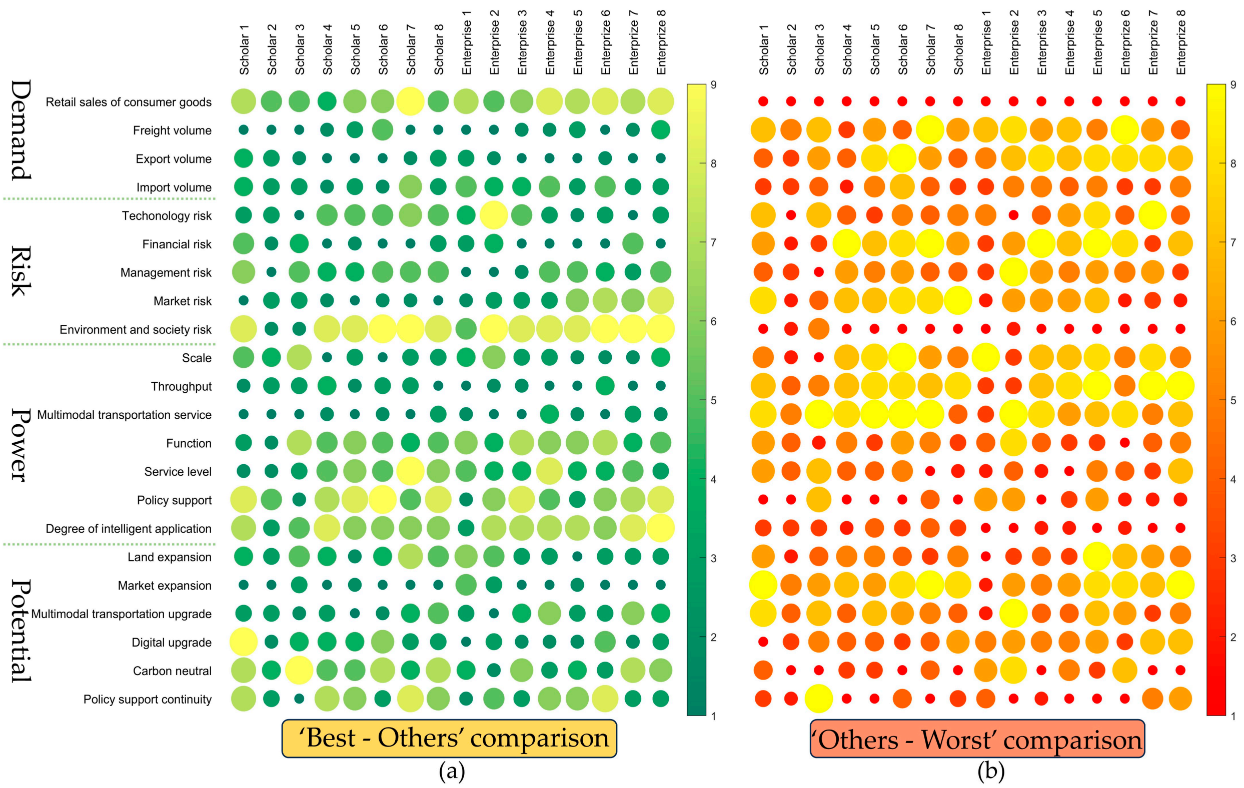

Figure 5. (**a**) Heat map of "best indicator-other indicators" comparison and (**b**) Heat map of "other indicators-worst indicator" comparison.

For example, in the 'Best-Others' comparison, scholar 1 selected 'Freight Volume' as the most important indicator under the demand dimension, so we used a circle with the darkest and smallest color to represent the scholar's opinion in the corresponding position (first column, second row) in Figure 5a. For the indicator of 'Retail sales of consumer goods', all scholars and industry experts believed it was not very important compared to other indicators under the demand dimension, so the circles in row one hold a larger and lighter circle than row two, row three, and row four in Figure 5a. A similar situation is seen in the 'Others-Worst' comparison in Figure 5b.

The decision-making opinions of each expert are determined using the BBWM method in MATLAB software, based on the evaluation opinions of each expert on each indicator. This process yields the comprehensive weights of each indicator, as well as the weights of scholars and the weights of industry experts, as depicted in Figure 6. The analysis of Figure 6 reveals that both scholar experts and enterprise experts hold similar views on the overall importance of most indicators. However, there are discernible discrepancies between the scholars and industry experts when it comes to the relative importance of specific indicators. For example, for the market risk indicator (B4), scholars believe that its importance is the highest among all risk-related indicators, with a relative weight of 0.2953, but industry experts believe that its relative weight is only 0.1704. Through further interviews with industry experts, it is found that industry experts believe that the market risk belongs to the passive risk, whereas enterprises are more inclined to pay attention to active types of risk that can be avoided in the development of inland ports. It can be seen that the opinions of both scholars and industry experts have certain rationality, so in the actual evaluation process, the opinions of multi-decision makers should be considered to evaluate the development by introducing the group decision-making method. Moreover, the Bayesian best–worst method can reasonably summarize and analyze the opinions of multiple decision makers to obtain the comprehensive weights of each indicator.

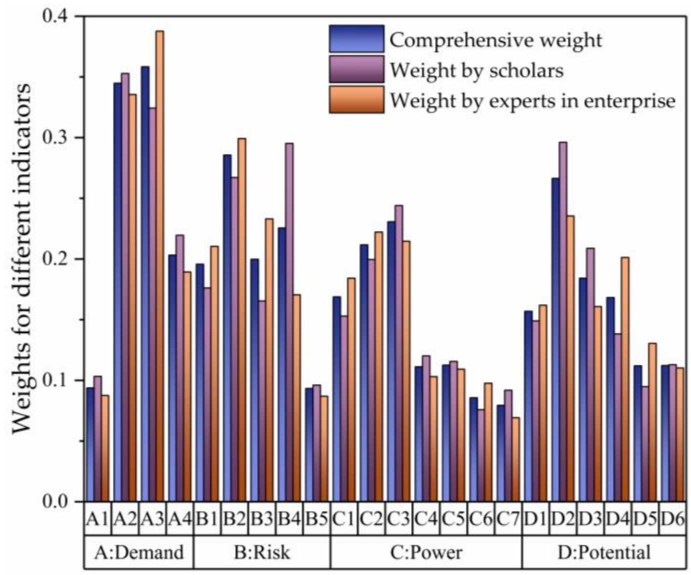

Figure 6. Comparison of comprehensive weights, scholar expert weights, and enterprise expert weights.

The methods and code for implementing the Bayesian best–worst method in MATLAB can be found on this website: https://bestworstmethod.com/software/ (accessed on 10 March 2023).

The ranking of the confidence level of each second-level indicator under each dimension is shown in the weighted directed graph, as in Figure 7.

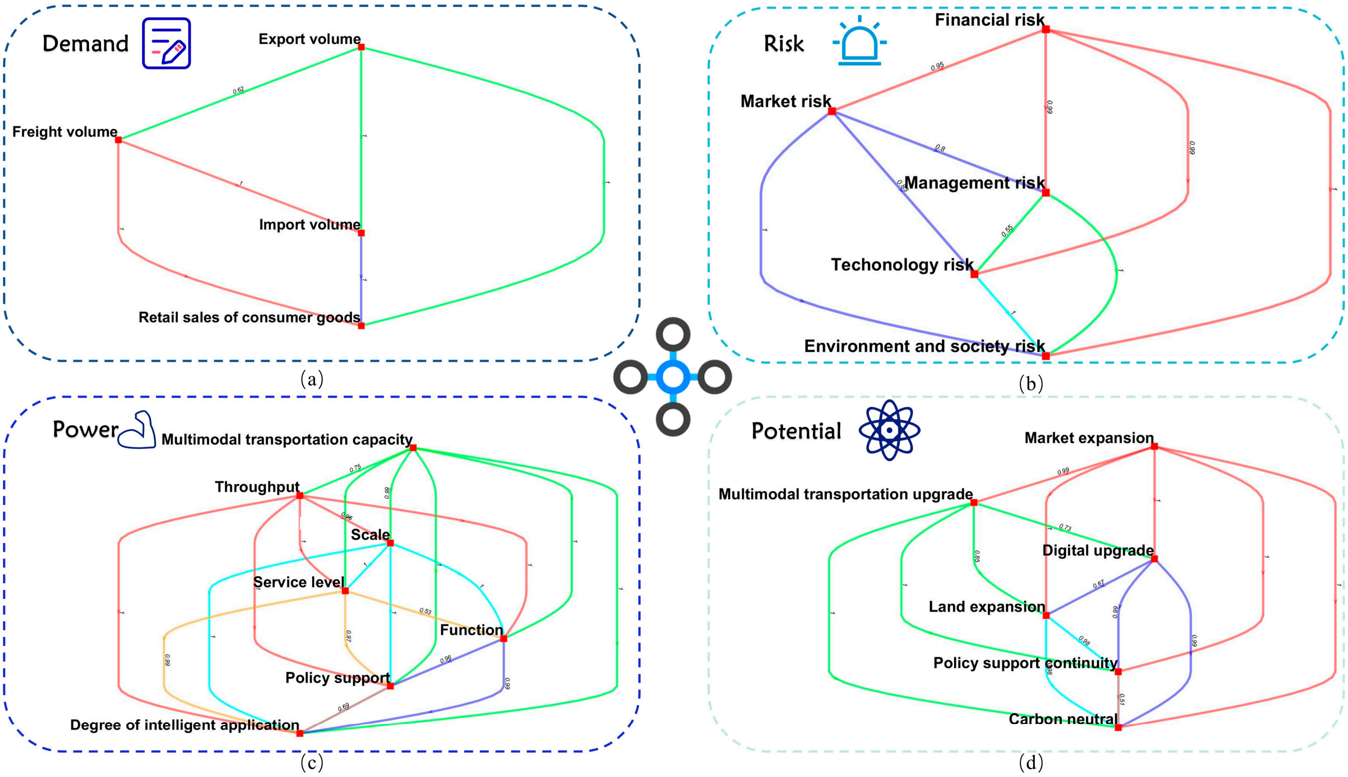

Figure 7. Credal ranking of the second-level indicators for the following first-level indicators: (**a**) Demand; (**b**) Risk; (**c**) Power; (**d**) Potential.

In Figure 7, the indicators are distributed from the top to the bottom according to their importance, and the nodes in the figure represent the indicators, while the edges $A \xrightarrow{d} B$ indicate that indicator A is more important than indicator B with a confidence level of d.

Taking the demand indicators as an example, it can be observed from Figure 7a that the confidence levels of exports and freight volume surpass that of imports and retail sales of consumer goods, with a value of 1. This signifies that exports and freight volume hold a significantly higher level of importance compared to imports and retail sales of consumer goods within the context of the demand indicators.

At the same time, the confidence level that export volume is more important than freight volume is 0.61, suggesting that, on average, experts hold the belief that export volume possesses a slightly higher level of significance than freight volume in this case.

For the risk, power, and potential indicators, specific second-level indicator weighting relationships can also be derived from Figure 7.

5.2.3. Calculate the Global Weights of Each Indicator

The global weights of each second-level indicator in relation to the overall goal of evaluating inland port development can be determined by integrating the weights obtained from the BBWM method for second-level indicators with the weights determined through the DEMATEL method for first-level indicators. These global weights are presented in Figure 8.

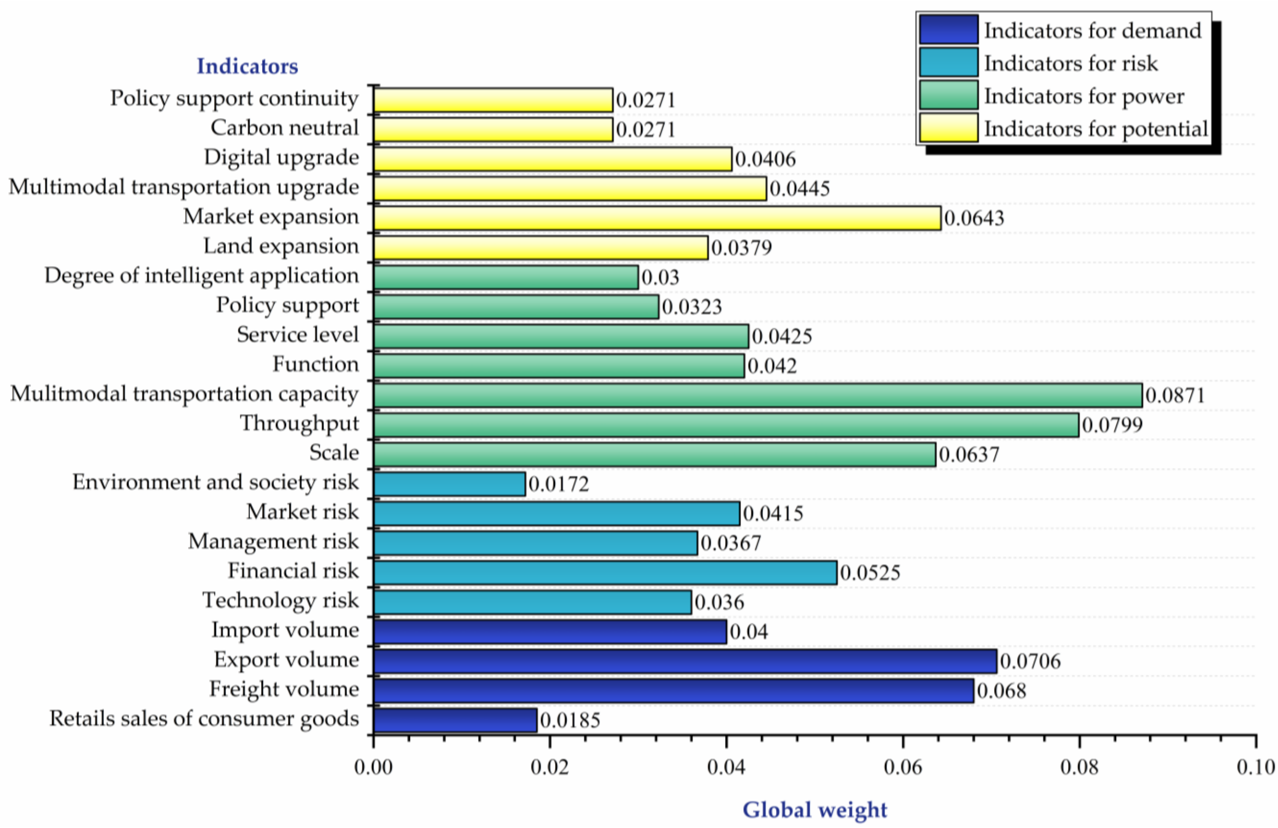

Figure 8. Global weights of each indicator.

The analysis presented in Figure 8 provides a clear depiction of the relative weights assigned to each second-level indicator on a global scale. It is evident that among the twenty-two indicators considered, multimodal transportation capacity, throughput, export volume, freight volume, and market expansion potential emerge as the top five indicators in terms of importance. Notably, the indicator with the highest weight is multimodal transportation capacity, which is assigned a weight of 0.0871.

The indicators that hold the least significance are the environment and society risk indicator, as well as the retail sales of consumer goods. These indicators carry weights of merely 0.0172 and 0.0185, respectively.

5.3. Discussion Based on the Evaluation Results

5.3.1. Evaluation Results

The comprehensive scores and rankings of the inland ports in the Huaihai Economic Zone are derived by integrating the basic scores as presented in Table 4, with the respective global weights of each indicator, as depicted in Figure 8, in accordance with the evaluation model and evaluation method put forward in this paper.

In Section 2.2, the benefits of utilizing the BBWM method in the subjective assignment method have been elucidated. Therefore, in this part, the DEMATEL–BBWM method is compared with the BBWM method, as well as the TOPSIS and CRITIC methods, which rely on indicator data for objective evaluation, as shown in Table 5.

Table 5. Inland port scores and rankings among different evaluation methods.

Evaluation Method	DEMATEL–BBWM		BBWM		TOPSIS		CRITIC	
	Score	Ranking	Score	Ranking	Score	Ranking	Score	Ranking
Xuzhou inland port	0.8568	1	0.8295	1	0.7413	1	0.7963	1
Suzhou inland port	0.2468	5	0.2872	5	0.2833	6	0.2844	6
Yudong inland port	0.2370	6	0.2744	6	0.3599	5	0.3239	5
Linyi inland port	0.2675	4	0.3169	4	0.3796	4	0.3352	4
Yanzhou inland port	0.6198	3	0.6885	2	0.5511	3	0.6990	2
Zaozhuang inland port	0.6613	2	0.6601	3	0.5545	2	0.6570	3
Standard deviation (SD)	0.2657		0.2445		0.1686		0.2259	

As shown in Table 5, in general, the difference in the rankings of the inland ports under the various methods is relatively small. However, the Xuzhou inland port secures the top position in each ranking approach, suggesting that its construction prospects are comparatively more favorable. Simultaneously, the evaluation findings presented in this case suggest that the establishment of inland ports in Xuzhou, Zaozhuang, and Yanzhou holds a specific degree of precedence during the inland port construction endeavor within the Huaihai Economic Zone.

According to the findings presented in Table 5, it is evident that the standard deviations of the scores for both the DEMATEL–BBWM method and the BBWM method are relatively high, indicating a better description of the differentiation in the evaluation of the performance of inland port development. Conversely, the TOPSIS method, which solely relies on the original performance of each indicator without assigning weights, exhibits a relatively small standard deviation in the evaluation results for the development among inland ports. Consequently, the degree of difference in the evaluation outcomes is relatively indeterminate.

On the other hand, it should be noted that the CRITIC method does not adequately capture the construction advantages of the Xuzhou inland port when compared to the Zaozhuang and Yanzhou inland ports. This limitation arises from the fact that the weights assigned to the indicators are solely based on the relative strengths and conflicts of the indicators themselves, without taking into account the specific characteristics of the actual inland port development. Moreover, in contrast to the independent BBWM technique, the DEMATEL–BBWM method incorporates the interdependencies among the first-level indicators, resulting in more rational evaluation outcomes. Based on the aforementioned study, it can be inferred that the DEMATEL–BBWM method, as presented in this paper, is more suited for assessing the issue of inland port development. Furthermore, we suggest that the order of construction of the inland ports in the Huaihai Economic Zone should be Xuzhou, Zaozhuang, Yanzhou, Linyi, Yudong, and Suzhou, according to the evaluation results of the DEMATEL–BBWM method.

5.3.2. Managerial Insights of Inland Port Development in the Huaihai Economic Zone

For the inland ports with lower scores, including Linyi, Yudong, and Suzhou inland ports, we suggest they firstly focus on strengthening their performance in transportation capacity, throughput, export volume, freight volume, and market expansion potential, which are the top five indicators in terms of importance in inland port development.

For the other three inland ports, to enhance the clarity of the evaluation results for the Xuzhou, Zaozhuang, and Yanzhou inland ports in this case, the performance–importance matrix theory is employed. As illustrated in Figure 9, the weight–performance matrices for each inland port are constructed. The weight for each indicator in the performance–weight matrix is derived from the DEMATEL–BBWM method.

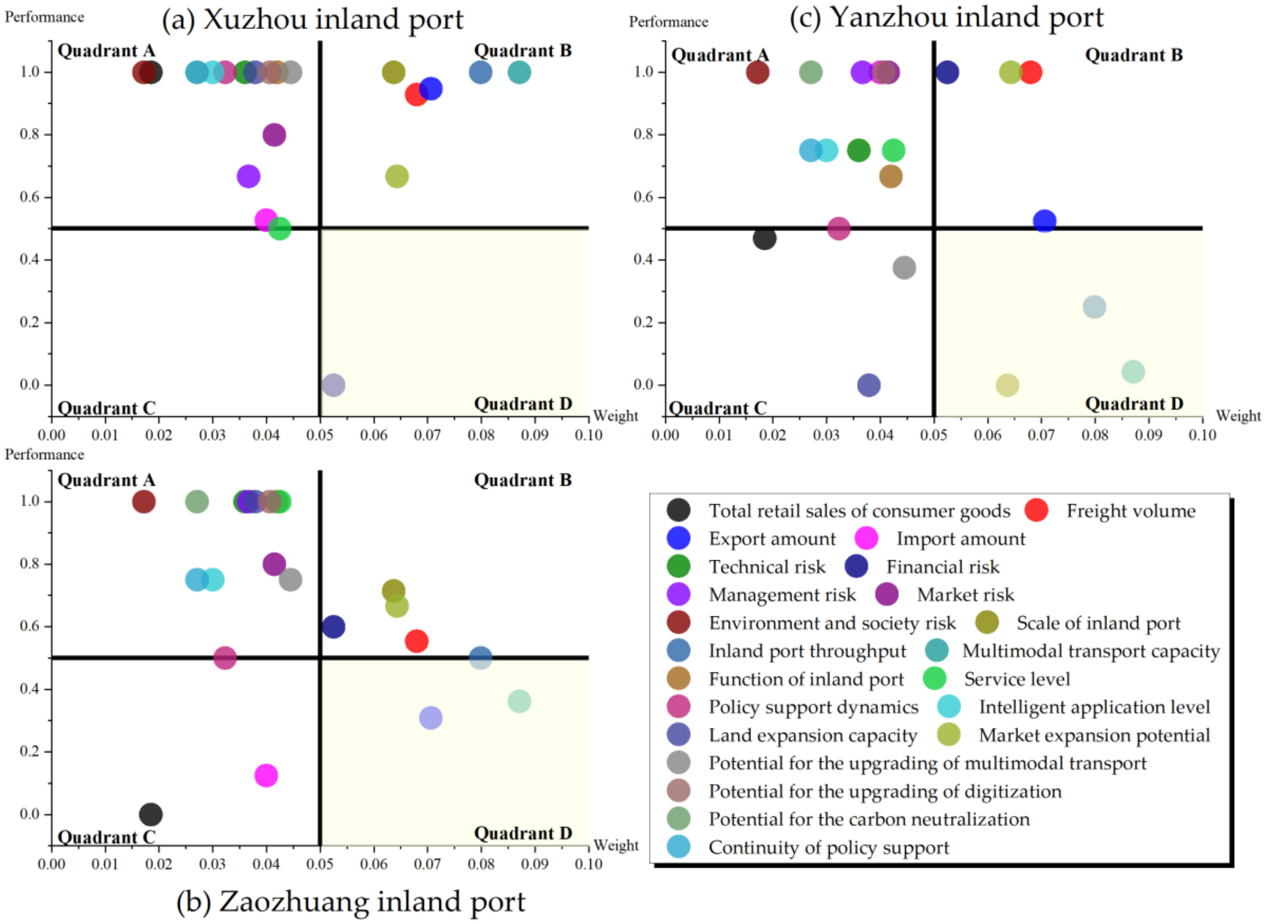

Figure 9. Indicator weight–performance matrix for: (**a**) Xuzhou inland port; (**b**) Zaozhuang inland port; (**c**) Yanzhou inland port.

In Figure 9, the matrix is partitioned into four quadrants, namely quadrants A, B, C, and D, with the axis of indicator performance set at 0.5 and the axis of indicator weight set at 0.05. In the figure, an indicator falling in quadrant A indicates that the indicator has a lower weight but performs better, an indicator falling in quadrant B indicates that the indicator has a higher weight and performs better, an indicator falling in quadrant C indicates that the indicator has a lower weight and performs worse, and an indicator falling in quadrant D indicates that the indicator has a higher weight but performs poorly. Obviously, it is imperative to minimize the occurrence of the indicator falling in quadrant D while considering inland port development.

In other words, if the development evaluation indicator C_i of an inland port is categorized in quadrant D, it is crucial to prioritize appropriate measures aimed at enhancing the performance of this indicator to provide strong support for the development of inland ports in the Huaihai Economic Zone. When resources (including costs, policies, etc.) are limited, priority should be given to optimizing indicators that fall in quadrant D, which will maximize the level of inland port performance under the same conditions.

(1) Strategies for Xuzhou inland port development

According to the findings presented in Figure 9a, it is evident that the financial risk indicator of the Xuzhou inland port carries a greater weight but exhibits poorer performance. Consequently, it is recommended that during the planning, construction, and operation of the Xuzhou inland port, a strategy should be adopted to innovate the diversified investment mode. This entails actively exploring the "industry+fund" approach, leveraging the fund's potential, attracting a diverse range of investment entities, and encouraging the involvement of social capital in the development of the inland port. By implementing these measures, the aim is to mitigate the financial risk in the development process of the Xuzhou inland port.

(2) Strategies for Zaozhuang inland port development

Based on the analysis of Figure 9b, it is evident that the Zaozhuang inland port exhibits subpar performance in terms of both export volume and multimodal transport capacity. Notably, these two indicators carry significant weight in evaluating the inland port's overall development. Consequently, the subsequent development and optimization efforts should prioritize addressing these specific areas.

- Accelerate the level of foreign trade development in the inland port hinterland.

In the process of developing an inland port, it is imperative to prioritize the utilization of the inland port for export-oriented economic growth. This entails leveraging the Zaozhuang inland port as a hub for consolidating foreign trade resources from the surrounding region. In addition to strengthening the existing import and export activities, it is crucial to implement a range of strategies aimed at fostering the growth of enterprises engaged in foreign trade. The ultimate objective is to achieve a mutually beneficial and symbiotic relationship between the Zaozhuang inland port and the export-oriented economy of the surrounding hinterland.

- Utilize the leading role of the China–Europe Railway Express to promote inland port multimodal transportation capacity.

In the process of Zaozhuang inland port development, the development concept of "channel with logistics, logistics with trade, trade with industry, industry with city" should be adhered to, giving full play to the leading role of the China–Europe Railway Express [40], strengthening the digital empowerment, technology empowerment, and innovating and exploring "China-Europe Railway Express + cold chain", " China-Europe Railway Express + e-commerce", and other multimodal transportation modes suitable for the development of the Zaozhuang inland port.

(3) Strategies for Yanzhou inland port

As can be seen from Figure 9c, the indicators of inland port scale, multimodal transportation capacity, and throughput are located in quadrant D. Therefore, Yanzhou inland port should consider the managerial insights for the above indicators, as follows:

- Upgrade the infrastructure of the Yanzhou inland port and explore the application of digital technology in the Yanzhou inland port.

For development of the Yanzhou inland port, it is imperative to expedite the expansion and enhancement of infrastructure, ensure a rational expansion of the inland port's capacity, enhance the container loading and unloading procedures, and optimize the operational efficiency of the inland port. Simultaneously, we should actively investigate the implementation of digital technology within the Yanzhou inland port. This entails constructing an intelligent inland port platform, thereby facilitating the transformation and advancement of the customer, customs, and China–Europe Railway Express company interaction modes.

- Strengthen the railway–inland waterway multimodal transportation services and extend the collection and dispatching network of inland ports.

During the development process of the Yanzhou inland port, it is crucial to effectively utilize the benefits offered by the Jining section of the Beijing–Hangzhou Grand Canal. This can be achieved by enhancing the railway–inland waterway multimodal transport services, establishing efficient railway collection and dispatching channels, introducing innovative approaches such as the "railway-inland waterway" fixed train mode, and exploring novel methods of direct transportation that integrate rail–water and canal–sea multimodal systems.

6. Conclusions

The evaluation of inland ports is a complex and systemic issue. The methodology proposed in this paper provides new ideas for the construction of an indicator system as well as for group decision-making problems. Meanwhile, it can also be found in the case study of this paper that the indicators related to the development of cross-border trade in the hinterland, multimodal transportation capacity and potential, and the scale and function of the inland ports account for a higher weight, so we need to strengthen the attention and optimization of the above aspects in the process of the development of inland ports.

The contribution of this work can be summarized as follows:

- In light of the assessment of inland port development, a novel evaluation model called the "Demand-Risk-Power-Potential" evaluation model has been proposed in this paper. This model builds upon the "Pressure-State-Response" evaluation model and offers a distinctive approach to categorizing and selecting indicators for inland ports;
- This study is the first attempt to combine the DEMATEL and BBWM methods. The proposed DEMATEL–BBWM method offers a novel approach to address the MCDM problem, particularly in scenarios where there the first-level indicators are in interaction with each other, and the second-level indicators require group decision-making to determine their weights;
- This study applies the performance–importance matrix to clarify the different development focus for each inland port. We find that when combining the evaluation results with the matrix, it is easy to quickly pinpoint the problems in inland port development. Targeted strategies can also be proposed. However, the problems vary from one inland port to another, as specific managerial insights can only be determined based on the actual evaluation results.

During the research process of this work, we encountered challenges in acquiring quantitative data for some specific indicators. To address this issue, we decided to employ the Delphi technique and the five-level scoring method to establish the initial scores of these indicators. It is important to note that this approach introduces a certain level of subjectivity. Additionally, for the DEMATEL–BBWM method proposed in this study, we ignored the potential relationships between the second-level indicators. In subsequent investigations, it is important to enhance and elaborate upon the pertinent indicators, while also converting qualitative indicators into quantitative measures in order to mitigate the inherent subjectivity during the evaluation process. Moreover, the independence among the second-level indicators needs to be verified when using the proposed DEMATEL–BBWM method.

Author Contributions: Conceptualization and formal analysis, J.M. and B.W.; methodology and software, J.M. and K.Y.; investigation, J.M., X.W. and L.J.; resources, data curation, writing—original draft preparation, J.M.; writing—review and editing, B.W. and K.Y.; supervision, B.W. and X.W.; funding acquisition, X.W. and K.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Fundamental Research Funds for the Central Universities (No. 2023JBMC044), and the China Scholarship Council (No. 202007090091).

Data Availability Statement: All data generated or analyzed during this study are included in this article.

Acknowledgments: I would like to thank Patrick Witte, for his guidance on this paper.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Background of Experts.

Type of Experts	Education	Workplace	Number of Experts
Scholars	PhD	Beijing Jiaotong University	4
	PhD	Central South University	2
	PhD	Tongji University	2
Enterprise experts	Master	JD Company	2
	Bachelor	Xuzhou Huaihai International Inland Port Holding Investment & Development Group Co., Ltd.	2
	Master	China Railway Nanchang Group Co., Ltd.	1
	Bachelor	China Railway Nanchang Group Co., Ltd.	1
	Master	China Railway Container Transportation Company	2

References

1. Wiegmans, B.; Witte, P.; Roso, V. Directional Inland Port Development: Powerful Strategies for Inland Ports beyond the Inside-Out/Outside-in Dichotomy. *Res. Transp. Bus. Manag.* **2019**, *35*, 100415. [CrossRef]
2. UNESCAP. *Intergovernmental Agreement on Dry Ports*; UNESCAP: Bangkok, Thailand, 2013. Available online: https://www.unescap.org/resources/intergovernmental-agreement-dry-ports (accessed on 1 May 2013).
3. Witte, P.; Wiegmans, B.; Roso, V.; Hall, P.V. Moving beyond land and water: Understanding the development and spatial organization of inland ports. *J. Transp. Geogr.* **2020**, *84*, 102676. [CrossRef]
4. Varese, E.; Marigo, D.S.; Lombardi, M. Dry Port: A Review on Concept, Classification, Functionalities and Technological Processes. *Logistics* **2020**, *4*, 29. [CrossRef]
5. Oláh, J.; Nestler, S.; Nobel, T.; Popp, J. Ranking of Dry Ports in Europe—Benchmarking. *Period. Polytech. Transp. Eng.* **2017**, *46*, 95–100. [CrossRef]
6. Wei, H.; Dong, M. Import-Export Freight Organization and Optimization in the Dry-Port-Based Cross-Border Logistics Network under the Belt and Road Initiative. *Comput. Ind. Eng.* **2019**, *130*, 472–484. [CrossRef]
7. Xie, J.; Sun, Y.; Huo, X. Dry Port-Seaport Logistics Network Construction under the Belt and Road Initiative: A Case of Shandong Province in China. *J. Syst. Sci. Syst. Eng.* **2021**, *30*, 178–197. [CrossRef]
8. Wang, Y.; Yeo, G.-T. Transshipment Hub Port Selection for Shipping Carriers in a Dual Hub-Port System. *Marit. Policy Manag.* **2019**, *46*, 701–714. [CrossRef]
9. Nguyen, P.N.; Woo, S.-H. Port Connectivity and Competition among Container Ports in Southeast Asia Based on Social Network Analysis and TOPSIS. *Marit. Policy Manag.* **2021**, *49*, 779–796. [CrossRef]
10. Liu, L.; Park, G.-K. Empirical Analysis of Influence Factors to Container Throughput in Korea and China Ports. *Asian J. Shipp. Logist.* **2011**, *27*, 279–303. [CrossRef]
11. Gorsuch, R.L. *Factor Analysis*; Psychology Press: London, UK, 2013; ISBN 9780203781098.
12. Wan, C.; Zhao, Y.; Zhang, D.; Yip, T.L. Identifying Important Ports in Maritime Container Shipping Networks along the Maritime Silk Road. *Ocean Coast. Manag.* **2021**, *211*, 105738. [CrossRef]
13. Koca, G.; Yıldırım, S. Bibliometric analysis of DEMATEL method. *Decis. Mak. Appl. Manag. Eng.* **2021**, *4*, 85–103. [CrossRef]
14. Mohammadi, M.; Rezaei, J. Bayesian Best-Worst Method: A Probabilistic Group Decision Making Model. *Omega* **2019**, *96*, 102075. [CrossRef]
15. Wang, C.; Xie, F.; Xu, L. Which Terminals Should Expand Investment: A Perspective of Internal Non-Cooperative Competition in a Port? *Marit. Policy Manag.* **2020**, *47*, 718–735. [CrossRef]
16. Zhang, D.; Jiang, J.; Li, S.; Li, X.; Zhan, Q. Optimal Investment Timing and Size of a Logistics Park: A Real Options Perspective. *Complexity* **2017**, *2017*, 2813816. [CrossRef]
17. Kotowska, I.; Mańkowska, M.; Pluciński, M. Inland Shipping to Serve the Hinterland: The Challenge for Seaport Authorities. *Sustainability* **2018**, *10*, 3468. [CrossRef]
18. Chang, Z.; Yang, D.; Wan, Y.; Han, T. Analysis on the Features of Chinese Dry Ports: Ownership, Customs Service, Rail Service and Regional Competition. *Transp. Policy* **2019**, *82*, 107–116. [CrossRef]
19. Gwenaëlle, O. *Rodrigue Balima Highlighting Performance Indicators for Dry Ports in Landlocked Countries: The Case of Burkina Faso*; Springer: Berlin/Heidelberg, Germany, 2021; pp. 145–162. [CrossRef]

20. Munters, A.; Wiegmans, B.; Tavasszy, L. Sustainable Inland Port Development: Integrated Framework Applied to Modjo Dry Port Ethiopia. *World Rev. Intermodal Transp. Res.* **2021**, *10*, 106. [CrossRef]
21. Abdoulkarim, H.T.; Fatouma, S.H.; Munyao, E.M. Dry Ports in China and West Africa: A Comparative Study. *Am. J. Ind. Bus. Manag.* **2019**, *9*, 448–467. [CrossRef]
22. Wiegmans, B.; Witte, P.; Spit, T. Characteristics of European inland ports: A statistical analysis of inland waterway port development in Dutch municipalities. *Transp. Res. Part A Policy Pract.* **2015**, *78*, 566–577. [CrossRef]
23. Roso, V.; Lumsden, K. A review of dry ports. *Marit. Econ. Logist.* **2010**, *12*, 196–213. [CrossRef]
24. Yeo, G.-T.; Roe, M.; Dinwoodie, J. Evaluating the Competitiveness of Container Ports in Korea and China. *Transp. Res. Part A Policy Pract.* **2008**, *42*, 910–921. [CrossRef]
25. Zionts, S. MCDM—If Not a Roman Numeral, Then What? *Interfaces* **1979**, *9*, 94–101. [CrossRef]
26. Wangchen Bhutia, P. Appication of AHP and Topsis Method for Supplier Selection Problem. *IOSR J. Eng.* **2012**, *02*, 43–50. [CrossRef]
27. Rostamzadeh, R.; Ghorabaee, M.K.; Govindan, K.; Esmaeili, A.; Nobar, H.B.K. Evaluation of Sustainable Supply Chain Risk Management Using an Integrated Fuzzy TOPSIS-CRITIC Approach. *J. Clean. Prod.* **2018**, *175*, 651–669. [CrossRef]
28. Rezaei, J. Best-Worst Multi-Criteria Decision-Making Method. *Omega* **2015**, *53*, 49–57. [CrossRef]
29. Wang, Q.; Li, S.; Li, R. Evaluating Water Resource Sustainability in Beijing, China: Combining PSR Model and Matter-Element Extension Method. *J. Clean. Prod.* **2019**, *206*, 171–179. [CrossRef]
30. Wolfslehner, B.; Vacik, H. Evaluating Sustainable Forest Management Strategies with the Analytic Network Process in a Pressure-State-Response Framework. *J. Environ. Manag.* **2008**, *88*, 1–10. [CrossRef]
31. Anderson, C.M.; Opaluch, J.J.; Grigalunas, T.A. The Demand for Import Services at US Container Ports. *Marit. Econ. Logist.* **2009**, *11*, 156–185. [CrossRef]
32. Liang, R.; Xue, Z.; Chong, H.-Y. Risk Evaluation of Logistics Park Projects' Lifecycle during the COVID-19 Pandemic: Failure Mode and Effects Analysis. *J. Constr. Eng. Manag.* **2022**, *149*, 04022153. [CrossRef]
33. Wang, Z. Research on Navigation Safety of Sea Routes Nonboring Wind Power Project Based on DEMATEL-ANP. Master's Thesis, Dalian Maritime University, Dalian, China, June 2022.
34. Wu, W.-W.; Lee, Y.-T. Developing Global Managers' Competencies Using the Fuzzy DEMATEL Method. *Expert Syst. Appl.* **2007**, *32*, 499–507. [CrossRef]
35. Li, L.; Wang, X.; Rezaei, J. A Bayesian Best-Worst Method-Based Multicriteria Competence Analysis of Crowdsourcing Delivery Personnel. *Complexity* **2020**, *2020*, 4250417. [CrossRef]
36. Tao, K.; Chao, Y. Rethinking Port Role as Transport Corridor under Symbiosis Theory-Case Study of China-Europe Trade Transportation. *Int. J. Sustain. Dev. World Policy* **2019**, *8*, 51–61. [CrossRef]
37. PRC National Development and Reform Commission (NDRC) Notification on the Issuance of the Huaihe River Ecological and Economic Belt Development Plan. 2018. Available online: https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/201811 (accessed on 25 November 2018).
38. China Statistics Bureau. *China Statistics Yearbook (2022)*; China Statistics Press: Beijing, China, 2022; ISBN 9787503799501.
39. Xuzhou "Walk Out" Service Platform Development Plan for the Construction of Xuzhou Huaihai International Inland Port (2021–2025). Available online: http://doc.jiangsu.gov.cn/zcq/newsinfo.html?id=17455 (accessed on 1 December 2022).
40. Ma, J.; Wang, X.; Yang, K.; Jiang, L. Uncertain Programming Model for the Cross-Border Multimodal Container Transport System Based on Inland Ports. *Axioms* **2023**, *12*, 132. [CrossRef]