The Adaptive Hybrid MCDA for Land Use Prioritization: Case Study Dry Port Size Analysis

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Abstract. *The development of Dry Ports serves as a crucial strategy in modern logistics, enhancing supply chain efficiency and resilience. The boundary area of Dry Ports necessitates the integration of diverse analytical approaches to ensure their effective area development, within 3 Main criteria's and 16 Minor's factors. The comprehensive framework that amalgamates Multi-Criteria Decision Analysis (MCDA) including SAW, TOPSIS and VIKOR, size analysis, and land use planning represented the alternative of effective boundaries. The result revealed the size of the Dry Port context. Considering conventional and TOPSIS land acquisition prioritization presents the pricing effectiveness. Additionally, sensitivity analysis indicates that the distance between the dry port and the conventional railway network identified as the most influential factor significantly impacts effectiveness once it exceeds 35%.*

Keywords: dry port, multi criteria decision analysis, plot area, prioritization analysis

1. Introduction

The Belt and Road Initiative (BRI) is a Chinese project focused on building telecommunications, energy, and health infrastructure to connect international trade and investment connectivity [1-3]. This initiative seeks to integrate sustainable development into its global expansion strategy [4]. The rapid growth of international trade has significantly increased the demand for efficient logistics and supply chain management [5]. Thailand plays a role in a logistics hub linking Thailand and China, with dry ports serving as a key component of infrastructure development to accommodate this increasing demand. As inland intermodal terminals directly connected to seaports via rail or road, dry ports operate under the public sector's strategic framework as shown in Fig. 1.

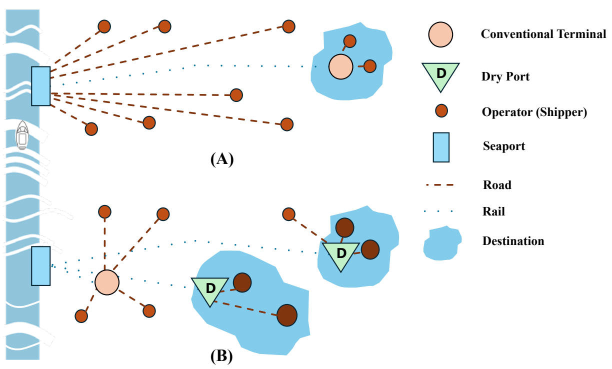


Figure 1. Schematic chart of the Comparison of conventional transport (A) and concept with implemented dry port (B) [6-7] [6], [7]

The location of a dry port significantly influences its operational efficiency [8-10] such as the port accessibility [11], and land acquisition are essential components of the planning process, directly impacting feasibility and long-term sustainability.

Recognizing this, the Port Authority of Thailand has invested in dry port development to improve logistics efficiency, alleviate congestion at seaports, and stimulate regional economic growth. By integrating multimodal transport systems of the Rail network, dry ports facilitate smoother trade operations, reduce logistics costs, and position Thailand as a strategic logistics hub within ASEAN, supporting sustainable economic development and regional connectivity initiatives [12]. However, selecting an optimal dry port size presents a complex challenge due to the numerous interrelated factors involved [13]. Addressing this issue requires comprehensive analysis, including the Location-Allocation Problem, which considers logistical, social, environmental, economic, and competitive factors [14]. The Port Authority of Thailand and the Department of Public Works and Town & Country Planning evaluate dry port development based on three core dimensions: engineering, economic, and environmental factors. Sixteen sub-criteria are incorporated into this assessment, including proximity to major transportation networks, accessibility to social infrastructure, land availability and cost, environmental impact, and socio-economic benefits. This study aims to 1. Develop an effective decision-making framework for dry port effective boundary and 2. Identify optimal land acquisition boundaries using Multi-Criteria Decision Analysis (MCDA) to establish prioritization strategies [15-16]. The research gap represents a novel frame of effective land acquisition. The research gap addressed in this study introduces a novel framework for efficient land acquisition in dry port planning. While previous studies have proposed various approaches to solving location selection problems, most emphasize hybrid MCDM methods. Several researchers have applied these methods to the dry port location problem, as summarized in Table 1.

Table 1. Literature review of MCDM method the selection of dry port location.

Author	Year	Country	Objective	MCDM method
[17]	2015	China	Optimization of the location of the dry port and the selection of potential inland cities.	Fuzzy C-Means Clustering (FCM)
[16]	2017	Thailand	An integrated method for the selection of the optimal dry port location.	CFA; MACBETH; PROMETHEE
[18]	2017	China	A decision-making framework for the hinterland-dry port-seaport logistics network is proposed, which is based on location allocation.	The ordered weighted averaging (OWA)
[19]	2019	Indonesia	In an effort to ascertain whether the current Dry Port and the upstream port are anticipated to one another.	AHP
[20]	2019	Togo	To ascertain the most suitable location for the dry port development.	ANP
[21]	2020	Western Balkans region	The potential locations for the establishment of Dry Port terminals were ranked using a new hybrid MCDM model.	Delphi; AHP; CODAS
[22]	2021	Croatia	A comprehensive analysis of a multitude of influential factors was implemented to ascertain the most suitable dry port location.	AHP
[23]	2022	India	Identification of dry port alternatives.	AHP
[24]	2023	Bangladesh	Provides a framework for determining the location for a new dry port.	fuzzy AHP; BWM; PROMETHEE
[25]	2023	Türkiye	To ascertain the most appropriate location for a potential dry port.	PROMETHEE
[26]	2024	Iran	The Stochastic Fuzzy Best-Worst Method (SFBWM) is implemented to prioritize the location of the Dry Port.	Stochastic Fuzzy Best-Worst Method (SFBWM)
[27]	2024	Vietnam	To suggest a methodological framework for the selection of the most appropriate dry port location.	BWM; ELECTRE III

2. Background and Theory

The Progress of the Thai–Chinese High-speed Railway (HSR) shown in the Fig. 2, along with the planned dry port locations from the Port Authority of Thailand's strategy for the East-North region (Fig. 3). These figures also highlight pilot free trade zones, existing dry ports, and industrial areas along the railway (images provided by the research team).

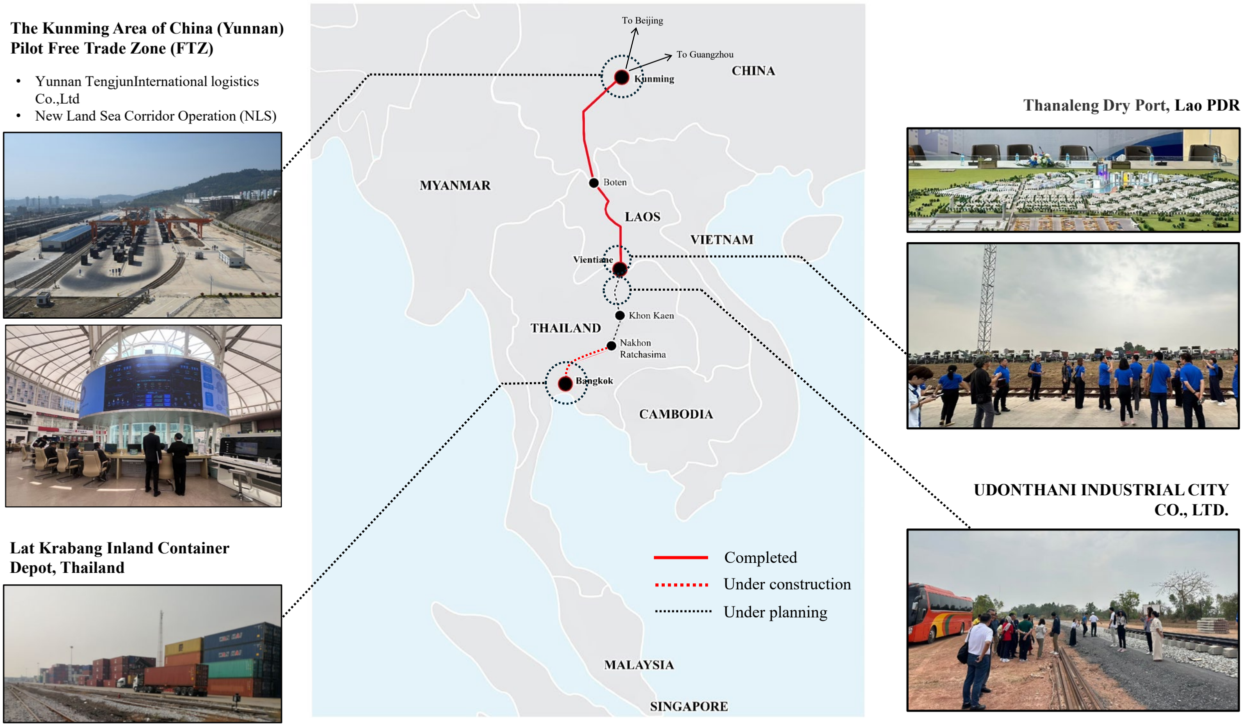


Figure 2. Progress of the Thai–Chinese High-speed Railway (HSR)

Since the HSR is expected to become the backbone of Thailand's rail transport, Transit-Oriented Development (TOD) is a key factor in ensuring effective land use planning.

Prior research from 1985 to 2012 A.D., Multi-Criteria Decision Analysis (MCDA) has been widely applied in the transportation sector, particularly in mobility management, with Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) being the most commonly used methods [29]. Since 2012, MCDA techniques have continued to be an essential tool for solving various transport-related challenges, including road network planning [30]. Between 1982 and 2019, studies on Multi-Criteria Decision-Making (MCDM) showed that the AHP method alone accounted for over 60% of research focused on road transport optimization [31-32]. The aim of this research was to present a novel framework of decision-making in order to achieve the most effective and suitable alternative selection.

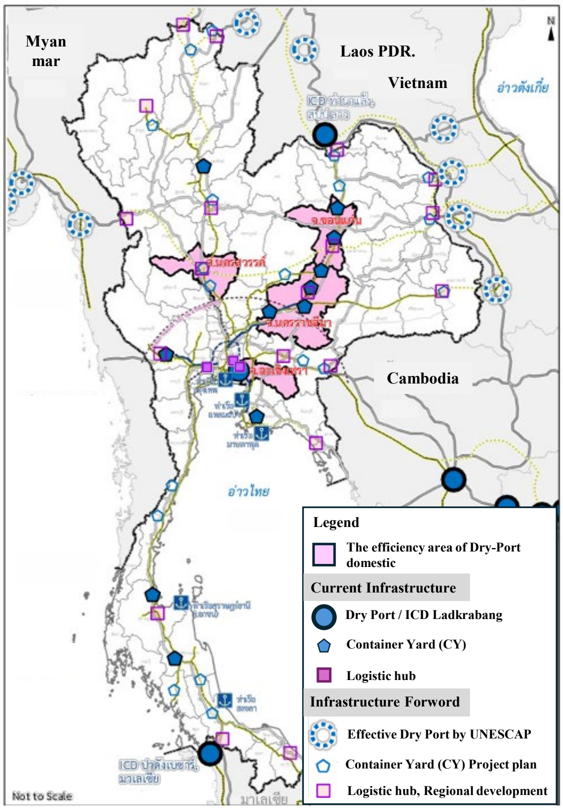


Figure 3. Dry Port Location plan [28]

3. General requirements

Decision Analysis framework context [33], Multi-Criteria Decision Analysis (MCDA) has become a powerful tool for managing complex decision-making processes. By integrating both quantitative and qualitative criteria, MCDA offers a systematic approach to evaluating potential infrastructure development projects [34]. This includes assessing factors such as plot area suitability, resolving conflicting objectives, and assisting stakeholders in making well-informed decisions. The objectives of this study are (1) to develop an advanced framework for site selection analysis integrating by MCDA and (2) to identify the effective plot area in the Dry port focused location. The research methodology framework shown in fig. 4.

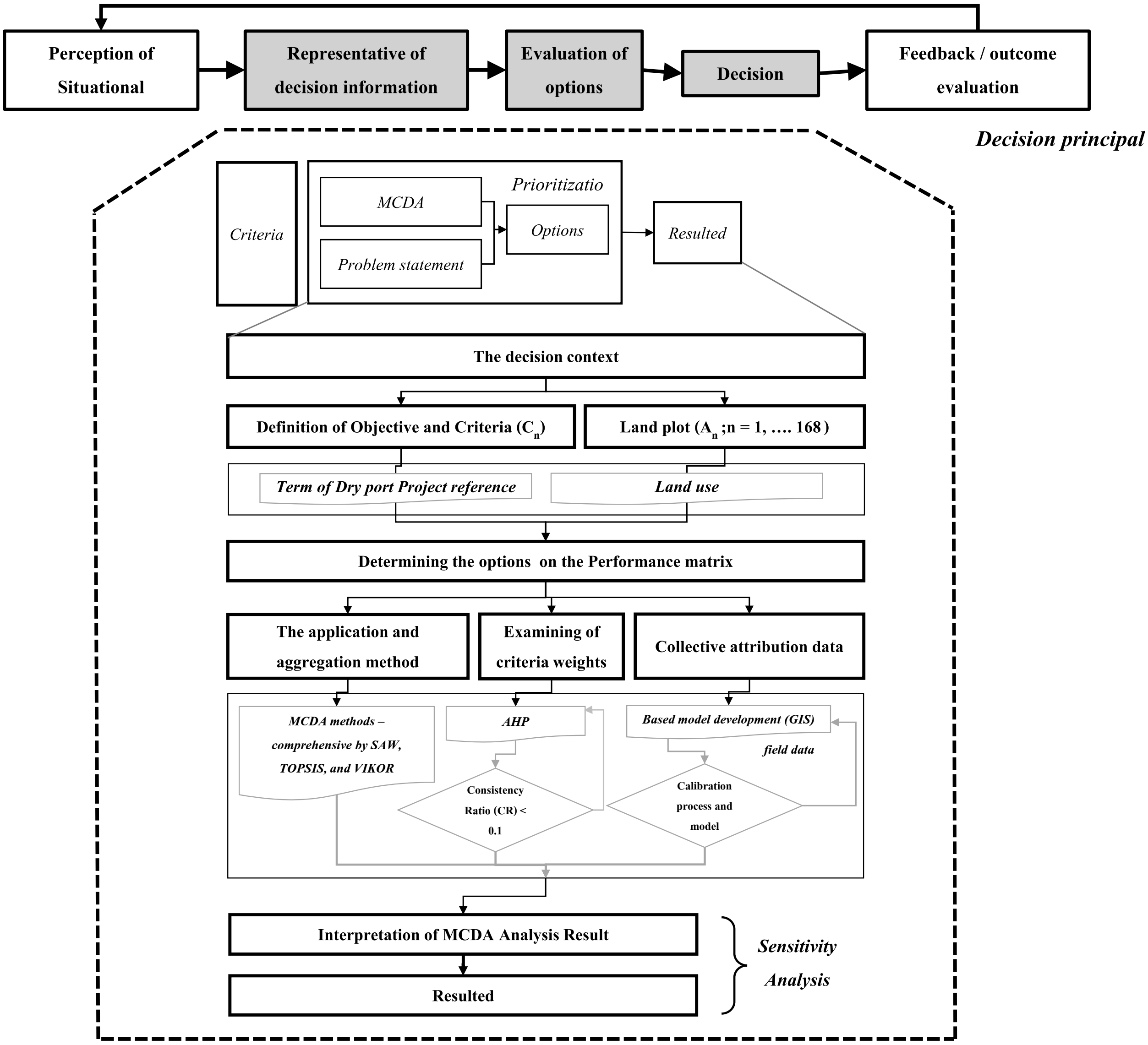


Figure 4. The Typical Research Procedures of MCDA and the Research Hypothesis

4. The MCDA Methods

Multiple-Criteria Decision Analysis [35] was integrated with a decision tree framework and a set of descriptors [36], which included: 1. The variables and the weights of the criteria and weight variations and 2. The application of Multi-Criteria Decision Analysis techniques for evaluation. This study employed three MCDA techniques, selected based on the complexity of the decision-making process: (1) Simple Additive Weight (SAW), (2) The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [37] and (3) and VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) These methods were applied within the research scope to develop a structured approach for prioritizing and selecting an optimal land-use strategy. A comparative analysis of MCDA techniques is presented in Table 2.

Abbreviation

R_{ij} = The index eigenvalue normalization

x_{ij} = The number of eigenvalue vectors

Si* = The Euclidean distance for ideal solution

Si- = The distance from non-ideal solution.

V_{ij} = The weighted normalized value

V_j* = The separation of each alternative from the positive-ideal one.

V_j- = The separation of each alternative from the negative-ideal one.

C_i* = The relative closeness for each of criteria

$L_{p,j}$ = The ranking on the measure

w_i = The weight of the i^{th} criterion

f_{ij} = Present the set of j with criteria i^{th}

Q_j = Index value

v = Introduced as weight of strategy of S_j and R_j

S_j = The maximum group utility

R_j = The minimum individual regret of opponent

To determine the weighting criteria, interviews were conducted with 8 experts, including three traffic engineering specialists, two economists, and two environmental impact experts—all of whom were involved in high-level decision-making processes. Each expert assigned pairwise weights at different hierarchy levels, which were then analyzed to assess the relative importance of each decision component. The weight consistency was verified using the Consistency Ratio (C.R.), which required a value below 0.10, and the Geometric Consistency Ratio (G.C.R.), which also had to meet the threshold of less than 0.10 [38-39].

5. Land use and Distance Analysis

The experts assigned the highest priority to the Engineering criteria, with a weight of 0.525, followed by Environmental Impact, which was weighted at 0.2625. The Economic criteria received the lowest priority, with a weight of 0.2125. Regarding the priority of sub-criteria in land use planning, the distance between the dry port and the conventional railway network had the highest weight of 0.2756, followed by the distance between the dry port and the arterial road, which was weighted 0.2494, as shown in Fig. 5. For the Economic criteria, the dry port area and land price had the highest priority, with a weight of 0.877, as shown in Fig. 6. This was followed by the ability of manufacturing unit management at 0.77 and land ownership at 0.478, as presented in Fig. 7. Within the Environmental Impact criteria, the distance from heritage buildings was assigned the highest weight of 0.1313, as shown in Fig. 8, followed by the distance from schools and hospitals by 0.755 and 0.558, respectively.

The details of the weight priorities assigned by the experts and the selection criteria for alternative sites play a crucial role in establishing an effective framework for land acquisition. Consequently, a review of existing studies on dry port site selection was conducted to identify and classify suitability parameters, the results of which are summarized in Table 3. For spatial analysis and data processing, the study utilized the following tools and software: 1. ArcGIS, 2. QGIS, 3. Microsoft Excel, and 4. Custom Macro and VBA in-house programming.

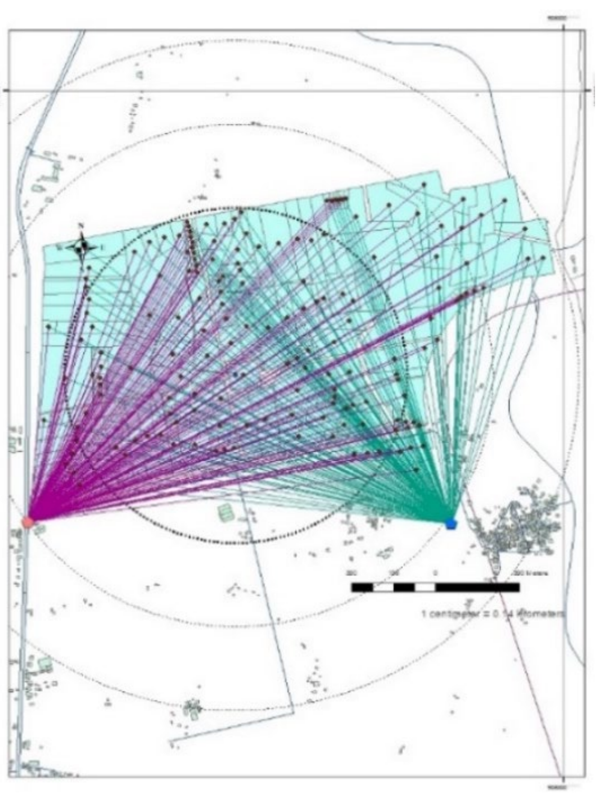


Figure 5. Distance between Dry port to Arterial Road and Conventional railway network

Table 3 The weight priorities of the indicators for decision-making AHP to ANP [23], [40]

	Dimension	Main Parameter (1)	Weight (%) (1)	Sub Parameter (2)	Sources	Weight (%) (2)	Unit	Weight (%) (1) x (2)
1.	Engineering	Demand of Container freight	52.5	The ability of station expansion in future	[23], [41-43]	N.A.	N.A.	-
2.				Distance between Dry port and Arterial Road	[20], [23], [41], [43-45]	47.5	km	24.94
3.				Distance between Dry port and Conventional railway network	[20], [23], [41], [43-45]	52.5	km	27.56
4.		Logistic connection		Congestion	[23], [43]	N.A.	N.A.	-
5.		Transport traffic		Safety Transport	[46]	N.A.	N.A.	-
6.	Economic	Location of Dry port	21.25	The ability of Manufacturing unit management	[23]	36.25	km	7.70
7.		Cost of land acquisition		Dry port area and land price	[43-45], [47]	41.25	USD	8.77
8.				Land ownership	Opinion Survey	22.5	Right	4.78
9.		Construction Cost		Construction Cost	[23], [43], [45]	N.A.	N.A.	-
10.		Infrastructure development cost		Electrical, Sanitary and Communication infrastructure cost	[10], [41], [45]	N.A.	N.A.	-
11.	Environment	Physical of Environment	26.25	Distance from School	Opinion Survey	28.75	km	4.59
12.				Distance from Hospital	Opinion Survey	21.25	km	3.28
13.				Distance from Temple	Opinion Survey	50	km	5.25
14.		Biological Environment		Land use impact and Urban mobility	[41], [43-45]	N.A.	N.A.	-
15.		Land use impact and Urban mobility		N.A.	[41], [43-45]	N.A.	N.A.	-
16.		Distance from heritage building		Distance from heritage building	Opinion Survey		km	13.13

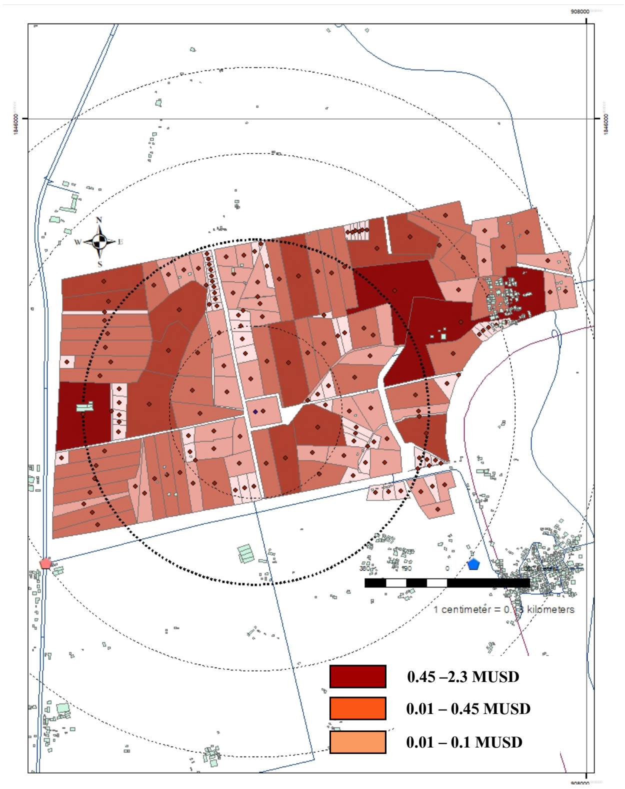


Figure 6. Dry port area and land price

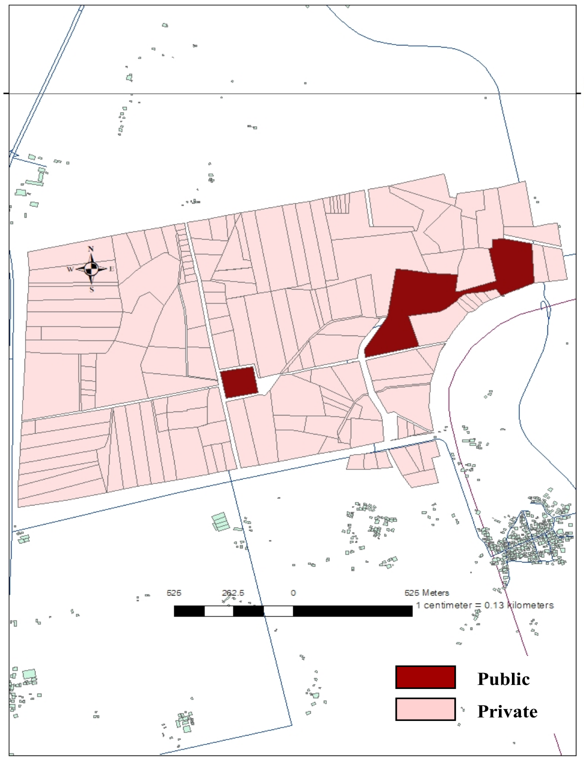


Figure 7. Land ownership

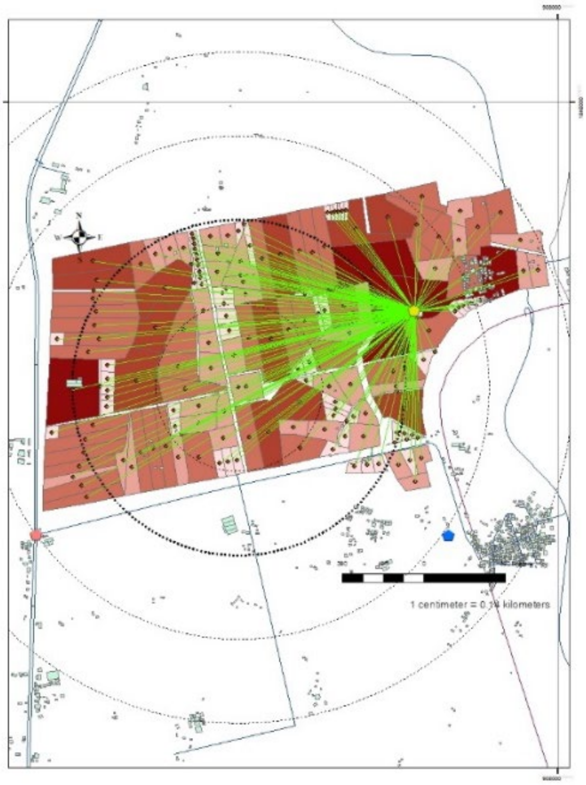


Figure 8. Distance to Heritage Building (temple)

6. Results and Discussions

The Critical site selection was depending on the Demand of Fright Transport. The case study, Nampong Khon Kaen is the flagship Location to Promote Dry-Port area. This research introduces a new framework for size analysis, utilizing MCDA techniques to enhance site selection. The most optimal boundary area was identified, as shown in Figs 9-11.

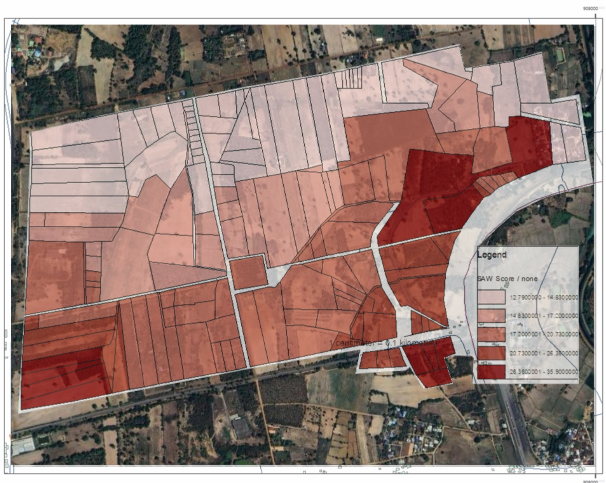


Figure 9. The Prioritizes of Dry Port land plot, by SAW Scores

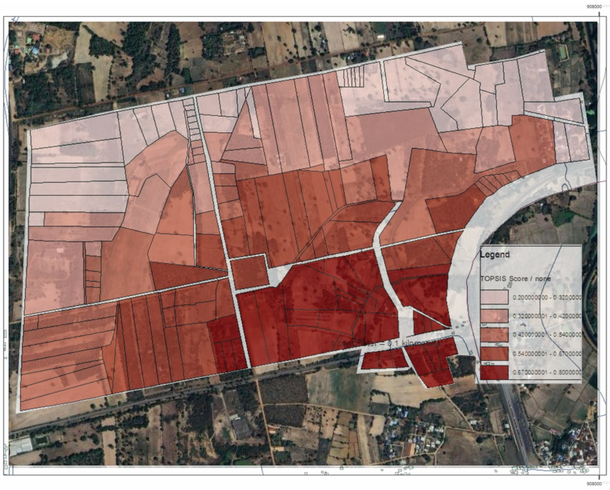


Figure 10. The Prioritizes of Dry Port land plot, by TOPSIS Scores

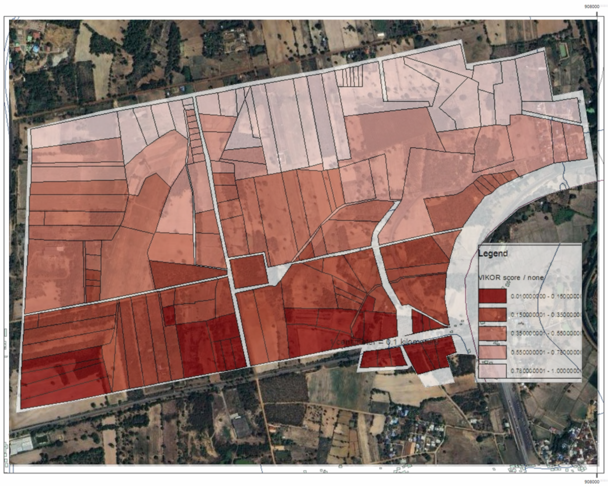
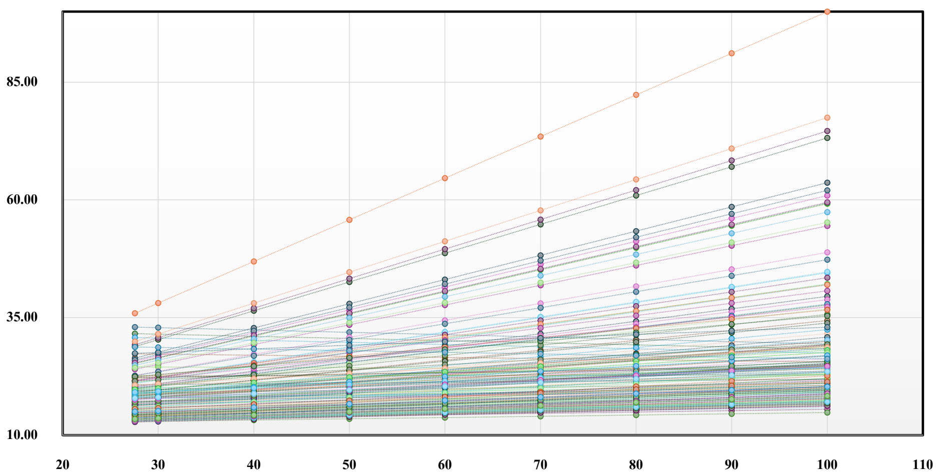


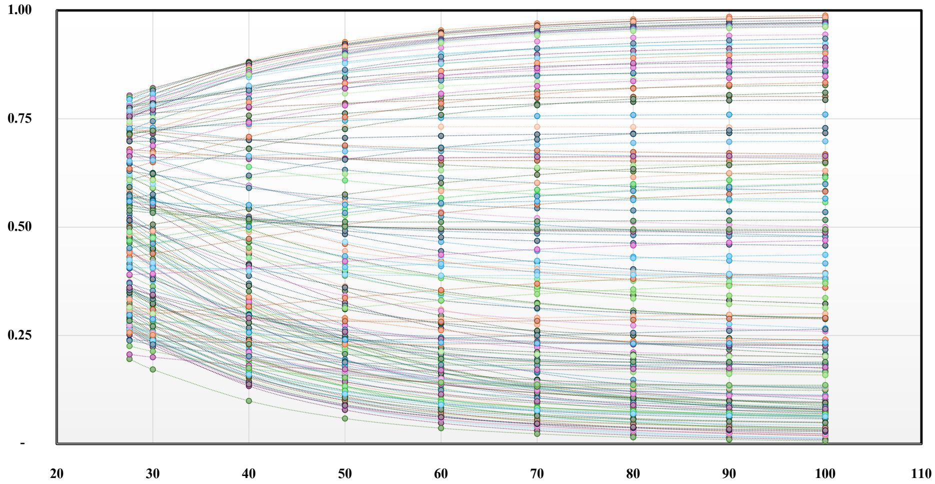
Figure 11. The Prioritizes of Dry Port land plot, by VIKOR Scores

The effective selection of land acquisition for dry port sites is essential for improving logistics efficiency and supply chain sustainability. This study demonstrated that the application of Multi-Criteria Decision Analysis (MCDA) significantly enhances the decision-making process by refining plot area boundary selection. MCDA's ability to balance conflicting objectives while integrating both quantitative and qualitative factors leads to more strategic and well-informed decisions.

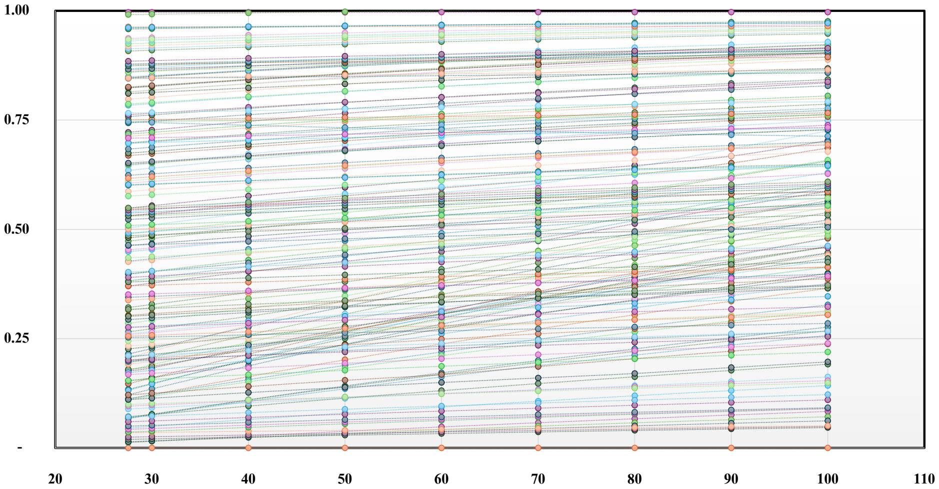
The sensitivity characteristics of the MCDA methods were further evaluated through Sensitivity Analysis (SA) to determine which technique provides the most reliable ranking of alternatives when subjected to variations in data or weight assignments. Fig. 12 illustrates the changes in ranking under different scenarios using SAW, TOPSIS, and VIKOR. The results indicate that the SAW and TOPSIS techniques became significantly sensitive at approximately 35%, whereas the VIKOR technique exhibited sensitivity at around 42.5%.



(a)



(b)



(c)

Figure 12. Sensitivity analysis of MCDA tools by (a) SAW (b) TOPSIS (c) VIKOR

Eventually, this study confirms that a comparative MCDA approach is a robust and effective tool for dry port size selection. The adoption of MCDA in dry port planning is recommended for policymakers, as demonstrated in the dot plot (Fig. 13), which presents the relationship between cumulative land use area and cumulative pricing under both conventional and MCDA techniques, aligning with the overall project objectives.

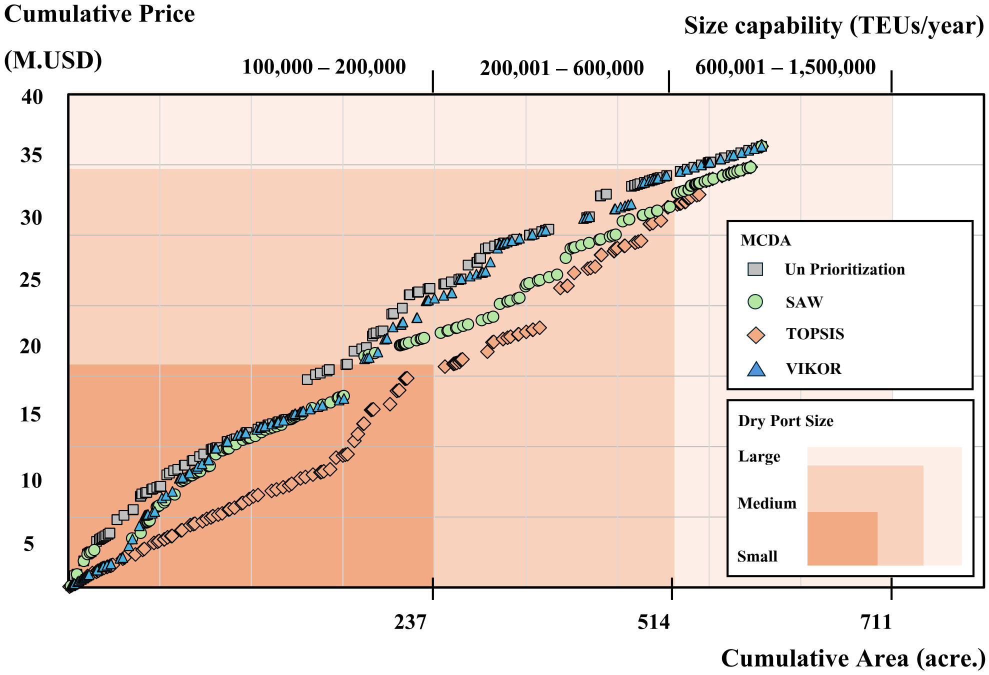


Figure 13. The compare of dot plot between Conventional and MCDA techniques

7. Conclusion

Traditional land acquisition practices typically categorize land parcels into small, medium, and large sizes using simplistic classification methods. This study introduces a novel approach by incorporating Multi-Criteria Decision Analysis (MCDA) to align land use and pricing strategies with project objectives. By integrating MCDA techniques, this framework enhances the prioritization process within infrastructure development projects, providing a more effective and data-driven decision-making model.

Among the various MCDA methodologies, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) has proven particularly effective in optimizing small land parcel acquisitions. In the case of small-sized dry ports, a comparison between conventional prioritization and TOPSIS-based prioritization demonstrates an improvement in pricing efficiency of over 27%.

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