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Evaluating Governance Models in Intermodal Terminal Operations: A Hybrid Grey MCDM Approach

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Abstract: Intermodal transportation, crucial for contemporary logistics, enhances supply chain efficiency through integrated multimodal coordination. Central to this ecosystem, intermodal terminals act as pivotal points for seamless mode transitions, significantly influencing cost reduction and environmental sustainability. This research delves into the complex dynamics of intermodal terminal governance, striving to discern the most effective models while establishing a robust evaluative framework. A meticulous examination of seven distinct governance models is conducted against nine criteria, encompassing aspects such as efficiency, cost-effectiveness, regulatory compliance, and socio-economic impact. Employing a novel hybrid Multiple Criteria Decision-Making (MCDM) model, which amalgamates the Best-Worst Method (BWM) and Comprehensive Distance-based Ranking (COBRA) within a grey analytical context, the study facilitates a nuanced, uncertainty-accommodating assessment. Findings highlight the Public-Private Partnership, Concession Agreement, and Cooperative Governance models as exemplary, underscoring the benefits of synergistic public-private cooperation and community engagement. The research contributes significantly by identifying key governance models, providing a comprehensive evaluation framework, and introducing the hybrid MCDM model as an instrumental tool for decision-making within the transportation sector. Structured into five sections, the analysis progresses from an extensive literature review to a detailed methodology of the hybrid model, followed by the presentation of evaluative results, a discussion on the broader implications, and a conclusion synthesizing the principal insights. This investigation offers vital contributions to academic discourse and practical decision-making, laying groundwork for future exploration in this vital field.

Keywords: Intermodal terminal; Governance model; Multiple Criteria Decision-Making (MCDM); Grey Best-Worst Method (BWM); Grey Comprehensive Distance-based Ranking (COBRA)

1 Introduction

In the realm of contemporary logistics, intermodal transport is recognized for its pivotal role in enhancing supply chain efficiency through the integration of multiple transportation modes. Central to this system are intermodal terminals, serving as essential nodes where transitions between different transportation modes are facilitated. The efficacy of these terminals, as evidenced by reduced costs and diminished environmental impact, is largely determined by their governance models [1]. These models, constituting the frameworks for operational strategies and decision-making processes, are critical to the functioning of intermodal terminals [2]. This research focuses on dissecting the complex relationship between intermodal terminals and their governance models, aiming to identify the most effective structures and establish a comprehensive framework for their evaluation.

This study examines seven distinct governance models, each characterized by its operational philosophy. The evaluation is based on nine criteria, encompassing efficiency, cost-effectiveness, regulatory compliance, and socio-economic impact. An analysis of the strengths and weaknesses of each model provides insight into the dynamics of terminal operations. The importance of governance models in optimizing terminal performance is acknowledged, with an emphasis on their contribution to both academic and practical spheres in the transportation industry.

A Hybrid MCDM model is employed, combining the BWM and COBRA within a grey environment. This approach facilitates a detailed and inclusive assessment, capable of accommodating uncertainties inherent in the evaluation criteria. The hybrid model is thus proposed as a strategic tool for navigating the complexities of intermodal terminal governance.

The study reveals that Public-Private Partnership, Concession Agreement, and Cooperative Governance models rank as the most effective. These models demonstrate the advantages of combining public and private sector strengths, highlighting the importance of collaborative and community-centric approaches in governance.

The contributions of this study are threefold: the identification of key governance models for intermodal terminals, the development of a comprehensive framework for their evaluation and ranking, and the introduction of a hybrid MCDM model as a decision-making tool in the transportation sector.

Structured into five sections, this paper begins with an extensive literature review of intermodal transport, terminal governance, and evaluation methodologies. The methodology section details the hybrid model used for evaluating and ranking governance models. This is followed by a section presenting the evaluation results. The discussion section then explores the implications of these findings, and the paper concludes with a synthesis of the key insights and suggestions for future research in this evolving field.

2 Literature Review

The literature on intermodal transportation and terminals forms an essential foundation for comprehending the complex dynamics of modern logistics systems. Intermodal transportation, characterized by the seamless integration of diverse transport modes, stands as a benchmark of efficiency in the global supply chain. Scholarly research in this field encompasses a wide range of critical areas, reflecting the system's multifaceted nature. Key areas of focus include the efficiency and optimization of transportation systems [2], development of robust infrastructure [3], sustainability and environmental impact [4, 5], and the formulation of regulatory and policy frameworks [6]. Other significant areas of study involve risk management and resilience strategies [7], analysis of economic impacts [8], customer satisfaction and service quality [9], as well as connectivity and network design [10], and the development of regional intermodal systems [11].

Intermodal terminals, integral to this expansive network, serve as crucial nodes facilitating the seamless transition of goods across various transportation modes. Scholarly research has emphasized the vital role of these terminals in augmenting supply chain fluidity, reducing costs, and promoting environmental sustainability. Key research areas in the context of intermodal terminals encompass a range of topics, such as operational efficiency and performance [12], advancements in technological innovations for terminal operations [13], the development of sub-system technologies [14], strategic considerations of terminal location [15], and the exploration of diverse governance models [16].

In the domain of intermodal terminals, the significance of governance models in shaping operational strategies and guiding decision-making processes is increasingly recognized. Research in this area highlights the profound influence of governance structures on factors such as terminal efficiency, economic viability, and socio-environmental impacts [17, 18]. Diverse governance models have been the subject of extensive study, encompassing public-private partnerships [19], concession agreements [20], and cooperative governance strategies [21]. A comprehensive understanding of the relative strengths and limitations of these models is imperative for effective decision-making in the management and operation of intermodal terminals.

The evaluation and comparison of governance models in the field of intermodal transportation have led to the development of various methodological approaches. Among these, MCDM models have emerged as prominent tools, renowned for their ability to systematically assess the intricacies of governance structures [22, 23]. Extensive research has been conducted on the application of MCDM models across diverse decision-making scenarios, highlighting their adeptness at managing uncertainties, accommodating a range of criteria, and yielding in-depth insights. With the continuous evolution of the transportation industry, scholarly work mirrors this progression by exploring methodological enhancements in MCDM models, specifically tailored for assessing the nuances of intermodal terminal governance. This study makes a significant contribution to this evolving methodological domain by utilizing a hybrid Multiple Criteria Decision-Making model. This model uniquely combines the BWM with the COBRA approach, offering a refined and detailed methodology for the evaluation of intermodal terminal governance.

The BWM, originated by Rezaei [24], distinguishes itself among pairwise comparison methods such as AHP and ANP, owing to its noted advantages [25]. BWM excels in conducting a thorough comparison of criteria and alternatives, laying a solid foundation for determining optimal weights in scenarios characterized by ambiguity, known as grey environments [26]. This method has been effectively applied in various problem-solving contexts (e.g., Tavana et al. [27], Khan et al. [28], Görçün and Doğan [29]. In contrast, the COBRA method, as conceptualized by Krstić et al. [30], is based on the principle of calculating comprehensive distances from a spectrum of solutions, integrating both Euclidean and taxicab distances. COBRA is preferred over other distance-based methods like TOPSIS and VIKOR due to its comprehensive nature, which enhances the reliability of solutions and aids in differentiating between closely ranked alternatives [31]. Despite being relatively new, COBRA has quickly gained prominence and has been applied in various research fields (e.g., Krstić et al. [31], Tadić et al. [32], Popović et al. [33]. Both BWM and COBRA have been adapted to overcome the limitations of conventional methods, particularly in grey environments where ambiguity and uncertainty are prevalent. The grey extension of BWM is discussed by Mahmoudi et al. [26], while Krstić et al. [31] have proposed the grey extension for the COBRA method. This innovative approach is well-suited to the complex and nuanced requirements of evaluating governance models in intermodal terminal operations.

3 Hybrid Grey BWM – Grey COBRA Model

The methodology commences with the establishment of the model structure, an integral phase where the evaluation criteria and alternatives are systematically identified. This stage lays the foundation for a thorough analysis. An evaluation scale, intricately designed with linguistic expressions correlated to corresponding grey values, is employed (Table 1). This scale is pivotal in facilitating nuanced assessments by decision-makers, who represent a spectrum of stakeholders.

Table 1. Evaluation scale

Linguistic Evaluation	Grey Scale
"None" ("N")	[0, 2]
"Very low" ("VL")	[1, 3]
"Low" ("L")	[2, 4]
"Moderately low" ("ML")	[3, 5]
"Medium" ("M")	[4, 6]
"Moderately high" ("MH")	[5, 7]
"High" ("H")	[6, 8]
"Very high" ("VH")	[7, 9]
"Extremely high" ("EH")	[8, 10]

In the third step, the focus shifts to the determination of criteria weights through the application of the grey BWM [26]. In this process, decision-makers, embodying the perspectives of various stakeholders, are tasked with identifying the most and least significant criteria, thereby injecting subjective insights into their relevance. Following this, evaluations of the remaining criteria relative to these benchmarks are conducted using the established linguistic scale, culminating in the formation of grey vectors for "the best compared to the others" and "others in relation to the worst".

The subsequent phase, termed as step 3.2, is dedicated to optimizing these grey values. This phase is vital for quantifying the relative importance of each criterion, taking into account the preferences articulated by the decision-makers. It involves solving an optimization problem that addresses the inherent comparisons between elements made by each decision-maker.

$$\min \otimes \xi \; s.t. \; \begin{cases} GPD\left\{\left|\frac{\otimes W_B}{\otimes W_{sj}} - \otimes a_{B_j}\right| \leq \otimes\xi\right\} < 0.5 \\ GPD\left\{\left|\frac{\otimes W_{sj}}{\otimes W_W} - \otimes a_{jW}\right| \leq \otimes\xi\right\} < 0.5 \\ \sum_{j=1}^{m} W\left(\otimes W_{sj}\right) = 1 \\ \underline{W}_{sj} \leq \bar{W}_{sj} \\ \underline{W}_{sj} \geq 0 \\ i = 1, \ldots, n \end{cases} \tag{1}$$

The optimal grey value (weight) for the most important criterion, denoted as $\otimes W_B = \left[\underline{W}_B, \bar{W}_B\right]$, encompasses a range defined by its lower $\underline{W}_B$ and upper $\bar{W}_B$ values. Similarly, the optimal grey value for the least important criterion, represented as $\otimes W_W = \left[\underline{W}_W, \bar{W}_W\right]$, is characterized by its lower $\underline{W}_W$ and upper $\bar{W}_W$ values. The grey measure of superiority of the most important criterion over criterion j is denoted as $\otimes a_{Bj} = \left[\underline{a}_{Bj}, \bar{a}_{Bj}\right]$ and the grey measure of superiority of criterion j over the least important criterion is denoted as $\otimes a_{jW} = \left[\underline{a}_{jW}, \bar{a}_{jW}\right]$. The white value, $W\left(\otimes W_j\right)$ is calculated by averaging its lower and upper bounds using the equation:

$$W\left(\otimes W_{si}\right) = \left(\underline{W}_{sj} + \bar{W}_{sj}\right)/2 \tag{2}$$

The Grey Possibility Degree (GPD) is attained as:

$$GPD\{\otimes x \leq \otimes y\} = \frac{\max(0, L(\otimes x) + L(\otimes y) - \max(0, \bar{x} - \underline{y}))}{L(\otimes x) + L(\otimes y)} \tag{3}$$

$$L(\otimes x)=|\bar{x}-\underline{x}|, \quad L(\otimes y)=|\bar{y}-\underline{y}| \tag{4}$$

In step 3.3, a critical consistency check is imperative to ensure the reliability of the weights obtained. This is accomplished by calculating the Consistency Ratio (CR), which quantitatively measures the consistency of the weights. A CR value approaching zero is indicative of satisfactory consistency, thereby adding an additional layer of robustness to the established weights.

$$CR=R(\otimes\xi)/CI \tag{5}$$

$$CI^2-\left(1+2\bar{a}_{BW}\right)CI+\left(\bar{a}_{BW}^2-\bar{a}_{BW}\right)=0 \tag{6}$$

$$\otimes a_{BW}=\left[\underline{a}_{BW},\bar{a}_{BW}\right]=\max_j\left\{\otimes a_{Bj},\otimes a_{jW}\right\} \tag{7}$$

where, $R(\otimes\xi)$ is the white value of the grey value $\otimes\xi$, and CI (Consistency Index).

The final weights of the criteria are computed in step 3.4, employing the optimal grey values derived from the preceding steps. This phase involves the aggregation of individual perspectives from various decision-makers, culminating in comprehensive weights that reflect a collective evaluation of the criteria.

$$\otimes W_j=\left[\underline{W}_j,\bar{W}_j\right], \forall j=1,\ldots,n \tag{8}$$

$$\underline{W}_j=\left(\prod_{s=1}^{l}\underline{W}_{sj}\right)^{1/s} \tag{9}$$

$$\bar{W}_j=\left(\prod_{s=1}^{l}\bar{W}_{sj}\right)^{1/s} \tag{10}$$

Proceeding to step 4, the ranking of alternatives is conducted using the grey COBRA method [26]. This step entails the construction of a grey decision matrix $\otimes G=\left[\otimes g_{kj}\right]_{m\times n}$, based on which the reference solutions are determined, including the Positive Ideal Solution (PIS), Negative Ideal Solution (NIS), and Average Solution (AS).

$$PIS=\left[\otimes pis_j\right]_{1\times n'} \quad \otimes\ \mathrm{pis}_j=\left[\underline{\mathrm{pis}}_j,\overline{pis_j}\right]=\begin{cases}\left[\max_k \underline{r}_{kj},\max_k \bar{r}_{kj}\right], \text{ for } j\in J^B\\ \left[\min_k \underline{r}_{kj},\min_k \bar{r}_{kj}\right], \text{ for } j\in J^c\end{cases} \tag{11}$$

$$NIS=\left[\otimes nis_j\right]_{1\times n'} \quad \otimes\ \mathrm{nis}_j=\left[\underline{\mathrm{nis}}_j,\overline{nis_j}\right]=\begin{cases}\left[\max_k \underline{r}_{kj},\max_k \bar{r}_{kj}\right], \text{ for } j\in J^B\\ \left[\min_k \underline{r}_{kj},\min_k \bar{r}_{kj}\right], \text{ for } j\in J^c\end{cases} \tag{12}$$

$$AS=\left[\otimes as_j\right]_{1\times n'} \quad \otimes as_j=\left[\underline{as}_j,\overline{as}_j\right]=\left[\mathrm{mean}_k \underline{r}_{kj},\mathrm{mean}_k \bar{r}_{kj}\right], \text{ for } j\in J^B,J^C \tag{13}$$

The ranking of the alternatives is then established based on the frequency of favorable comparisons derived from the calculated grey distances, using the following equations:

$$\otimes d(S)_k=\otimes dE(S)_k+\otimes\sigma\times\otimes dE(S)_k\times\otimes dT(S)_k, \forall k=1,\ldots,m \tag{14}$$

$$\otimes dE(PIS)_k=\left[\sqrt{\max\left(0,\sum_{j=1}^{n}\left(\underline{pis}_k-\bar{r}_{kj}\right)^2\right)},\sqrt{\max\left(0,\sum_{j=1}^{n}\left(\overline{pis}_k-\underline{r}_{kj}\right)^2\right)}\right] \tag{15}$$

$$\otimes dT(PIS)_k = \left[\left|\underline{pis_k} - \bar{r}_{kj}\right|, \left|\overline{pis}_k - \underline{r}_{kj}\right|\right] \tag{16}$$

$$\otimes dE(NIS)_k = \left[\sqrt{\max\left(0, \sum_{j=1}^{n}\left(\underline{r}_{kj} - \overline{nis}_k\right)^2\right)}, \sqrt{\max\left(0, \sum_{j=1}^{n}\left(\bar{r}_{kj} - \underline{nis}_k\right)^2\right)}\right] \tag{17}$$

$$\otimes dT(PIS)_k = \left[\left|\underline{r}_{kj} - \overline{nis}_k\right|, \underline{\left|\ \bar{r}_{kj} - nis_k\ \right|}\right] \tag{18}$$

$$\otimes dE(AS)_k^+ = \left[\sqrt{\max\left(0, \sum_{j=1}^{n}\tau^+\left(\underline{r}_{kj} - \overline{as}_k\right)^2\right)}, \sqrt{\max\left(0, \sum_{j=1}^{n}\tau^+\left(\bar{r}_{kj} - \underline{as}_k\right)^2\right)}\right] \tag{19}$$

$$\otimes dT(AS)_k^+ = \left[\tau^+\left|\underline{r}_{kj} - \overline{as}_k\right|, \tau^+\left|\bar{r}_{kj} - \underline{as_k}\right|\right] \tag{20}$$

$$\tau^+ = \begin{cases} 1 \;\; if \otimes as_j < \otimes r_{kj} \\ 0 \;\; \text{if} \otimes as_j > \otimes r_{kj} \end{cases} \tag{21}$$

$$\otimes dE(AS)_k^- = \left[\sqrt{\max\left(0, \sum_{j=1}^{n}\tau^-\left(\underline{as}_k - \bar{r}_{kj}\right)^2\right)}, \sqrt{\max\left(0, \sum_{j=1}^{n}\tau^-\left(\overline{as}_k - \underline{r}_{kj}\right)^2\right)}\right] \tag{22}$$

$$\otimes dT(AS)_k^- = \left[\tau^-\left|\underline{as_k} - \bar{r}_{kj}\right|, \tau^-\left|\overline{as}_k - r_{kj}\right|\right] \tag{23}$$

$$\tau^- = \begin{cases} 1 \;\; \text{if} \otimes as_j > \otimes r_{kj} \\ 0 \;\; if \otimes as_j < \otimes r_{kj} \end{cases} \tag{24}$$

The grey comprehensive distances are then calculated as:

$$\otimes dC_k = \frac{\otimes d(PIS)_k - \otimes d(NIS)_k - \otimes d(AS)_k^+ + \otimes d(AS)_k^-}{4}, \forall k = 1, \ldots, m \tag{25}$$

In the final step, the alternatives are arranged in descending order based on their occurrences, where the GPD values obtained by comparing each alternative $\otimes dC_k$ value to all others, are less than 0.5.

4 Evaluation of Intermodal Terminals Governance Models

This section delves into a detailed evaluation of various intermodal terminal governance models, focusing on their distinct characteristics and the criteria that shape their assessment. Utilizing a specifically designed hybrid MCDM model, the analysis thoroughly examines each governance model against nine essential criteria. The ranking that follows sheds light on the efficacy and appropriateness of each model in the context of intermodal terminal governance. Moreover, a sensitivity analysis is performed to test the robustness of the results. This analysis explores the influence of changing criteria weights on the overall rankings, offering a more comprehensive understanding of the evaluation process. Such a holistic approach not only highlights the strengths and limitations of each governance model but also contributes significantly to the ongoing discussion about enhancing the efficiency of intermodal terminal operations.

4.1 Intermodal Terminals Governance Models

The exploration of intermodal terminal governance models reveals a varied landscape, where each model presents unique structures and mechanisms that impact the ownership, operational strategies, and overall management of these crucial transport hubs. Models range from those managed by public entities, prioritizing public service and societal objectives, to private enterprises driven by market efficiency, and collaborative models that bridge the gap between public and private sectors. This comprehensive analysis covers a spectrum of models, including regulated monopolies and community-owned initiatives, each characterized by its specific benefits, challenges, and stakeholder implications. The subsequent sub-sections provide an in-depth examination of these governance models. These detailed discussions aim to highlight the distinguishing features and merits of each model, offering a thorough understanding of the diverse approaches that shape the governance of intermodal terminals.

The ***Public Ownership and Operation*** (GM_1) governance model is characterized by the direct ownership and management of an intermodal terminal by a public entity, such as a government agency or local authority. Under this model, strategic and operational responsibilities of the terminal lie predominantly with the government, which uses public funding for its establishment, development, and maintenance. The primary focus of this approach is public service, aiming to align terminal operations with broader societal objectives including regional development, job creation, and improving infrastructure accessibility. The government's dual role as both the owner and operator provides comprehensive regulatory oversight, ensuring adherence to established standards and safety regulations. Advantages of the GM_1 model include its strong alignment with public interests, the stability afforded by government backing, and heightened levels of transparency and accountability to the public. However, this model may encounter challenges such as bureaucratic inefficiencies, reliance on government funding which could be constrained by budgetary limitations, and a potential shortfall in market-driven incentives, which could impact operational efficiency and innovation. For the GM_1 model to be successful, it is imperative to have robust governance structures and strategic planning in place, ensuring the terminal's operations effectively meet public needs while adhering to high standards of performance and accountability.

The ***Private Ownership and Operation*** (GM_2) governance model involves the ownership and direct management of an intermodal terminal by a private entity or consortium. In this framework, a private organization is responsible for both strategic decision-making and daily operational management, with funding predominantly sourced from private channels. This model is grounded in market-driven efficiency and innovation, where the private sector views the terminal as a commercial venture aimed at achieving profitability and maintaining a competitive edge. Distinguished from public ownership models, GM_2 is characterized by limited government intervention, with operations being primarily influenced by market dynamics. This market orientation often leads to heightened cost-effectiveness and a keen responsiveness to customer needs. Key advantages of this model include the potential for enhanced operational efficiency, innovation spurred by market competition, and agility in adapting to evolving industry trends. However, this model may face challenges in adequately representing public interests, as private entities might place a higher emphasis on profitability, potentially overlooking broader societal objectives. The GM_2 model is fundamentally driven by market principles, capitalizing on private sector expertise to optimize terminal operations. While it offers the benefits of innovation and market responsiveness, it necessitates vigilant regulatory oversight to ensure a balance is struck between private ambitions and the public good.

The ***Public-Private Partnership (PPP)*** (GM_3) governance model represents a synergistic collaboration between public and private entities in the ownership, financing, and operational management of an intermodal terminal. This model aims to capitalize on the advantages of both sectors by combining public oversight with private sector efficiency. Within the PPP framework, the public sector usually maintains a certain level of ownership or control, while private partners contribute their expertise, investment capacity, and innovative approaches. A characteristic feature of the PPP model is the shared distribution of risks and responsibilities. Typically, the private sector undertakes the day-to-day operational management, while the public sector oversees regulatory compliance and standards. The strengths of this model lie in its ability to fuse public sector accountability with the efficiency and investment capabilities of the private sector. By amalgamating resources and expertise, PPPs strive to establish intermodal terminals that are both sustainable and economically sound. However, this model can be challenged by the intricacies of negotiation processes, potential conflicts between public and private interests, and the necessity for comprehensive contractual agreements to ensure a fair allocation of risks and rewards. The PPP governance model is designed to utilize the combined strengths of the public and private sectors, promoting cooperative engagement in the development and operation of intermodal terminals. Its overarching goal is to balance public service objectives with the efficiency and innovation inherent in the private sector, within a mutually advantageous partnership structure.

The ***Concession Agreements*** (GM_4) governance model entails the allocation of exclusive rights to a private entity for the development, operation, and maintenance of an intermodal terminal over a designated period. In this arrangement, a government or public authority enters into a contractual agreement, granting a concession to a private operator. The private party under this model is entrusted with significant responsibilities, encompassing the financing, construction, and management of the terminal. In exchange for these responsibilities, the private operator is typically allowed to collect user fees or tariffs, as stipulated in the concession agreement. A key aspect of this model is the retention of regulatory oversight by the government, aimed at ensuring adherence to set standards and protecting public interests. The GM_4 model's primary advantages include the transfer of financial and operational risks to the private sector, which can drive efficiency and spur innovation. The private operator is incentivized to enhance terminal performance and customer service to maximize investment returns. However, this model may confront challenges such as the necessity for meticulously structured concession agreements that equitably address the interests of both the private operator and the public authority. Additionally, issues related to pricing, service quality, and the need for effective regulatory frameworks to address public concerns may arise. The GM_4 model offers a structured approach for private sector participation in intermodal terminal operations through exclusive rights. Its focus lies in harmonizing private sector efficiency with public welfare, underpinned by clearly defined contractual terms and vigilant regulatory supervision.

The ***Cooperative Governance*** (GM_5) model is characterized by a collaborative approach involving a consortium of stakeholders, such as public entities, private companies, and, in some cases, community organizations, in the joint ownership and operation of an intermodal terminal. This model diverges from exclusive private ownership by emphasizing collective efforts and shared responsibilities across multiple parties. Stakeholders in this model actively collaborate, pooling resources, expertise, and investment to develop and manage the intermodal terminal. The decision-making process and responsibilities are distributed among the participating entities, with governance structures implemented to ensure effective communication and consensus-building. The cooperative model's strengths lie in its capacity to amalgamate a diverse array of perspectives and resources, thereby fostering a collaborative atmosphere that accommodates the interests of various stakeholders. Such an approach can result in solutions that are both holistic and tailored to regional needs. Nonetheless, the model may encounter challenges related to effective coordination among stakeholders, reconciling conflicting interests, and establishing clear governance frameworks to facilitate decision-making and resolve disputes. The GM_5 model places a strong emphasis on cooperation and shared responsibilities among a diverse group of stakeholders in the ownership and operation of intermodal terminals. Its objective is to harness the unique strengths of each participant to achieve collective goals while catering to the specific requirements of the local community. The success of this model hinges on the establishment and maintenance of robust governance mechanisms.

The ***Regulated Monopoly*** (GM_6) governance model assigns exclusive rights to a single private entity for the operation of an intermodal terminal within a defined geographical area. This model grants the private operator a monopoly in terminal operations, under the condition of stringent regulatory oversight. Such oversight is crucial to prevent the abuse of market power and to ensure alignment with public interests. A designated regulatory body is tasked with setting and enforcing standards related to terminal operations, service quality, and pricing structures. The granting of monopoly rights by the government is predicated on the expectation that the private operator will deliver consistent, high-quality services and uphold infrastructural standards. This regulatory body plays a pivotal role in monitoring the operator's compliance, intervening as necessary to protect consumer rights and interests. One of the primary advantages of the GM_6 model is the stability it offers, with the single operator focused on optimizing terminal operations, unimpeded by competitive pressures. The model is designed to balance the inherent efficiencies of a monopoly with the imperative to avoid monopolistic practices. However, the model may confront challenges, particularly the risk of diminished competition potentially leading to a lack of incentives for innovation and operational improvements. Thus, effective and vigilant regulation is essential to maintaining an equilibrium between monopolistic efficiency and safeguarding public interests. In essence, the Regulated Monopoly model confers exclusive operational rights to a private operator, coupled with regulatory oversight to ensure fair practices and the protection of public interests. Its goal is to capitalize on the efficiency benefits of a monopoly setup while mitigating potential negative impacts through comprehensive regulation.

The ***Community-Owned Model*** (GM_7) for intermodal terminal governance is characterized by the collective ownership and management of the terminal by a group of local stakeholders. This group typically includes local businesses, residents, and community organizations. The model's cornerstone is local involvement, with an emphasis on shared ownership and collaborative decision-making, ensuring that operations reflect the interests and priorities of the surrounding community. In this framework, stakeholders work together to pool resources, invest in infrastructure, and manage the intermodal terminal in a unified manner. The primary objective is to tailor terminal operations to the specific needs and aspirations of the local community, fostering a sense of communal responsibility and contributing to regional economic growth. The advantages of the GM_7 model are manifold. It places a strong emphasis on catering to local interests and actively involves the community in terminal operations. This direct connection between terminal activities and the well-being of the local area can lead to job creation and enhanced community development, with decisions being made in consideration of the unique requirements of the community. However, the model does face certain challenges. These include the need for effective governance mechanisms to facilitate decision-making among a diverse group of stakeholders, as well as managing potential conflicts of interest. Striking a balance between local priorities and the efficient operation of the terminal is crucial and requires meticulous coordination. The GM_7 aims to engage local stakeholders in both the ownership and operational aspects of an intermodal terminal, thereby cultivating a sense of community investment and ensuring that terminal operations are closely aligned with regional needs. The successful implementation of this model hinges on establishing strong governance structures and fostering effective collaboration among the various stakeholders involved.

4.2 Criteria for the Evaluation of Governance Models

In the comprehensive evaluation of intermodal terminal governance models, a structured framework comprising ten key criteria is employed to facilitate a thorough assessment. Each criterion provides vital insights into the effectiveness and appropriateness of the various governance models under consideration. The criteria encompass a range of factors, from the essential elements of operational efficiency and cost-effectiveness to the dynamic aspects of innovation, technological advancement, and risk management. These dimensions offer a detailed lens for analyzing the diverse strategies employed in intermodal terminal management. Additionally, the evaluation framework considers the critical importance of public interest and regulatory compliance. These aspects are instrumental in ensuring that terminal operations are aligned with societal needs and adhere to established regulatory standards. Financial viability is another crucial criterion, reflecting the need for terminals to sustain a sound financial base. The framework also includes criteria related to the terminal's capacity for growth, the extent and effectiveness of stakeholder collaboration, and the broader social and economic impacts of the governance model. These factors contribute to a comprehensive evaluative approach, aiming to balance operational efficiency with the wider implications for society and the economy. Each criterion is listed and explained in detail below:

Cost-effectiveness (C_1) - Cost-effectiveness examines the financial sustainability of a governance model. It encompasses not only the operational costs but also the initial investment in infrastructure. A well-structured model balances costs, ensuring that the terminal's economic viability is maintained over the long term without compromising quality of service.

Efficiency (C_2) - Efficiency in intermodal terminals extends beyond timely operations. It involves the seamless coordination of various transportation modes, minimizing dwell times, and optimizing the use of infrastructure. A robust governance model should prioritize efficiency to ensure smooth and timely movement of goods, minimizing congestion and delays.

Innovation and Technology (C_3) - The criterion of innovation and technology evaluates a governance model's adaptability to advancements in the industry. Successful models embrace cutting-edge technologies, from intelligent tracking systems to automated processes, fostering continuous improvement and future readiness.

Risk Management (C_4) - Risk management is critical for navigating uncertainties in the market. A governance model should delineate clear mechanisms for identifying, assessing, and mitigating risks. Whether financial, operational, or market-related, an effective model ensures resilience and adaptability to changing conditions.

Public Interest and Accessibility (C_5) - Beyond operational considerations, public interest and accessibility assess how well the terminal serves the community. This involves evaluating safety measures, environmental impact, and the accessibility of the terminal to various stakeholders. A successful governance model ensures that the terminal integrates seamlessly into its surroundings while meeting the needs of the broader public.

Regulatory Compliance (C_6) - Adhering to regulations and standards is fundamental for a governance model. Whether set by local authorities or industry-specific bodies, compliance ensures legal adherence, safety, and the maintenance of high operational standards. An effective model includes robust mechanisms to stay abreast of and comply with evolving regulations.

Financial Viability (C_7) - Financial viability goes beyond revenue generation. It encompasses the ability to secure a return on investment, sustain profitability, and attract necessary funding for ongoing operations and infrastructure development. A sound governance model ensures a healthy financial outlook, attracting investors and supporting long-term growth.

Capacity for Growth (C_8) - The criterion of capacity for growth assesses how well a governance model accommodates increasing demand and future expansion. Scalability and adaptability are crucial, ensuring that the terminal can handle higher volumes without significant disruptions or the need for extensive modifications.

Social and Economic Impact (C_9) - Beyond operational metrics, the social and economic impact of a governance model considers its contributions to the community and region. This involves job creation, support for local businesses, and broader economic development. A comprehensive model ensures that the terminal positively influences the social and economic fabric of its surroundings.

4.3 Results of Evaluation and Ranking of Governance Models

In the evaluation and ranking of intermodal terminal governance models, a diverse panel of decision-makers was convened, bringing together individuals with extensive experience across various sectors. This panel included representatives from government agencies, terminal operating companies, investment entities, transportation companies, and local community groups. Such a composition ensured a broad and inclusive perspective in the assessment process.

The evaluation data were subjected to rigorous statistical processing and unification, integrating the diverse viewpoints into a coherent and standardized analytical framework. This method was instrumental in harmonizing the different evaluations, leading to a unified and objective assessment of both criteria weights and the governance models. The approach was carefully designed to minimize potential biases and discrepancies, thereby laying a solid foundation for the application of the hybrid MCDM model.

The decision-making process began with stakeholders identifying the most crucial (best) and least significant (worst) criteria. A linguistic scale, detailed in Table 1, was then utilized to evaluate all other criteria relative to these benchmarks. This systematic and standardized procedure ensured consistency across the various criteria assessments. The linguistic evaluations were then synthesized, with dominant statistical assessments identified and presented in Table 2. Utilizing Eqs. (1)-(10) from the grey BWM methodology, the grey criteria weights were calculated to determine the relative importance of each criterion. The outcomes of this comprehensive process are also documented in Table 2.

Table 2. Synthesized criteria evaluations and final grey weights

Criterion	Best over Other	Other over Worst	Grey Weight
C_1	"L"	"H"	[0.11, 0.15]
C_2	j_B	"EH"	[0.26, 0.36]
C_3	"VL"	"VH"	[0.15, 0.23]
C_4	"ML"	"MH"	[0.09, 0.1]
C_5	"M"	"M"	[0.07, 0.08]
C_6	"MH"	"ML"	[0.06, 0.07]
C_7	"VH"	"VL"	[0.04, 0.05]
C_8	"EH"	j_W	[0.03, 0.03]
C_9	"H"	"L"	[0.05, 0.06]

Table 3. Evaluations of governance models

	GM_1	GM_2	GM_3	GM_4	GM_5	GM_6	GM_7
C_1	"VL"	"L"	"M"	"VL"	"ML"	"L"	"M"
C_2	"ML"	"M"	"MH"	"ML"	"ML"	"L"	"L"
C_3	"VH"	"VH"	"H"	"MH"	"M"	"ML"	"MH"
C_4	"MH"	"MH"	"MH"	"M"	"ML"	"M"	"MH"
C_5	"M"	"M"	"M"	"M"	"M"	"ML"	"M"
C_6	"VL"	"L"	"ML"	"MH"	"M"	"M"	"H"
C_7	"ML"	"VL"	"M"	"L"	"L"	"VL"	"L"
C_8	"VL"	"L"	"M"	"VL"	"ML"	"L"	"M"
C_9	"ML"	"M"	"MH"	"ML"	"ML"	"L"	"L"

Table 4. Governance models final ranking

	GM_1	GM_2	GM_3	GM_4	GM_5	GM_6	GM_7
$\otimes dC_k$	[-16.5, 27.8]	[-21.9, 18.4]	[-41.6, 12.7]	[-28.8, 15.1]	[-22.2, 17.7]	[-17.3, 24.9]	[-16.5, 29.5]
GPD (Riskk <= Riskk)							
GM_1	/	0.588	0.703	0.642	0.593	0.522	0.49
GM_2	0.412	/	0.634	0.561	0.506	0.433	0.404
GM_3	0.297	0.366	/	0.423	0.37	0.311	0.291
GM_4	0.358	0.439	0.577		0.445	0.377	0.351
GM_5	0.407	0.494	0.63	0.555		0.427	0.398
GM_6	0.478	0.567	0.689	0.623	0.573		0.469
GM_7	0.51	0.596	0.709	0.649	0.602	0.531	
Rank	**6**	**4**	**1**	**2**	**3**	**5**	**7**

The decision-makers conducted a comprehensive evaluation of the intermodal terminal governance models using the criteria established earlier. Adhering to the scale provided in Table 1, these assessments were carried out with meticulous attention to detail and thoroughness. The amalgamated results of these evaluations, encapsulating the views of the diverse panel of stakeholders, are detailed in Table 3.

Subsequently, by applying Eqs. (11)-(25) from the grey COBRA methodology, the conclusive results were derived. These results formed the foundation for the ranking of the various intermodal terminal governance models, with the final results and corresponding rankings presented in Table 4.

The evaluation outcomes reveal that the Public-Private Partnership (PPP) model ranks highest among the intermodal terminal governance models, followed by the Concession Agreement model and the Cooperative Governance model. This ranking effectively illustrates the relative strengths and efficacies of each governance model, providing critical insights for decision-makers tasked with optimizing terminal operations.

4.4 Sensitivity Analysis

The execution of a sensitivity analysis is a critical component in verifying the reliability and stability of the results obtained, especially when such results inform crucial decision-making processes. In this research, the importance of sensitivity analysis is underscored by its role in ensuring the consistency of the rankings of intermodal terminal governance models, even when variations in criteria weights occur. To facilitate this analysis, twelve distinct scenarios were constructed. Each scenario involved a systematic alteration of the weights of the three most critical criteria, reducing them incrementally by 25%, 50%, 75%, and 100%. The rankings resulting from these varied scenarios were then methodically compared against those derived from the baseline scenario. The comparison revealed a notable absence of significant changes in the final rankings across the different scenarios, indicating a robust stability in the results. This consistency suggests that the rankings obtained from the baseline scenario provide an accurate reflection of the most effective intermodal terminal governance models. Thus, these findings bolster the overall credibility and reliability of the study. For visual clarity and comparison, Figure 1 illustrates the rankings obtained across the various scenarios, offering a comprehensive visual representation of the sensitivity analysis outcomes.

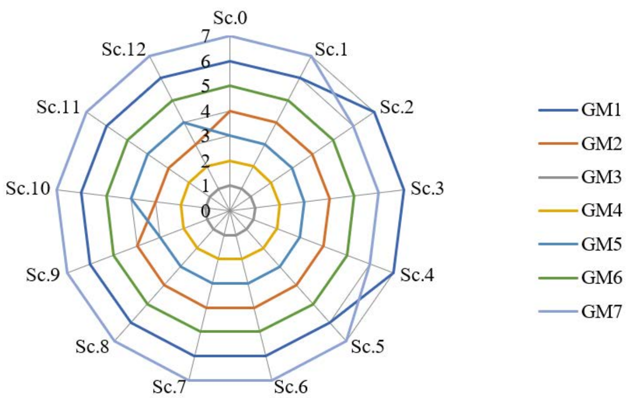

Figure 1. Sensitivity analysis results

5 Discussion

The application of the Hybrid MCDM model in the evaluation and ranking of intermodal terminal governance models has yielded significant insights. The models identified as most effective—Public-Private Partnership (PPP), Concession Agreement, and Cooperative Governance—demonstrate a blend of resilience and community involvement, distinguishing them as superior approaches for optimal governance of intermodal terminals.

A limitation identified in this study is the incomplete representation of all potential stakeholders in the evaluation process. While key stakeholders such as government agencies, terminal operators, investors, local communities, and transportation companies were considered, the perspectives of technology providers, specific environmental advocacy groups, and certain local interest groups were not extensively explored. Additionally, the viewpoints of international stakeholders and regulatory bodies at the supra-national level, as well as potential user groups, were not incorporated, limiting the breadth of the analysis. Acknowledging this limitation, future research should aim to include these groups for a more comprehensive understanding of the impacts of governance models in the broader context of the industry.

Moreover, the study's approach of assigning equal weight to all stakeholders simplifies the complex dynamics of influence and priorities among them. In reality, stakeholders vary in their impact on decision-making and have different objectives. This simplification, while facilitating analysis, may not fully capture the intricacies of stakeholder interactions within the transportation and logistics sector. Future research endeavors could adopt more refined stakeholder analysis methods, considering the varying influence and priorities of different groups, to enhance the validity and applicability of the findings.

Theoretically, this study contributes to the understanding of intermodal terminal governance models by methodically evaluating and ranking seven distinct models. It establishes a theoretical basis for further exploration in the field of intermodal transport and logistics. Practically, the study offers valuable guidance for stakeholders in the transportation industry, including government bodies, terminal operators, and investors. The top-performing models identified—PPP, Concession Agreement, and Cooperative Governance—provide actionable insights for enhancing terminal efficiency and sustainability. The evaluation criteria serve as a practical tool for assessing terminal performance, while the hybrid MCDM model presented in this study offers a comprehensive framework for navigating the complexities of governance model selection.

In summary, this study not only enhances theoretical understanding but also offers practical tools and strategies for stakeholders to optimize intermodal terminal operations, contributing to the efficiency of the wider transportation network.

6 Conclusion

This research has rigorously explored the domain of intermodal terminal governance models, utilizing a hybrid MCDM model for the evaluation and ranking of seven distinct models against a set of nine judiciously selected criteria. The findings have identified Public-Private Partnership (PPP), Concession Agreement, and Cooperative Governance as the models exhibiting the highest performance. These results hold substantial value for both scholarly discussions and practical applications within the transportation sector.

The primary contributions of this paper encompass the identification of key governance models for intermodal terminals, the development of an extensive framework for their evaluation and ranking, and the innovative employment of a Hybrid MCDM model, specifically adapted to the intricacies of terminal governance. The application of this model, in its initial deployment in this context, paves the way for future enhancements and broader applicability in diverse decision-making scenarios.

The study's findings offer profound implications, equipping stakeholders with critical insights to optimize the efficiency and sustainability of intermodal terminal operations. The focus on collaborative models, particularly PPP and Cooperative Governance, highlights the significance of inclusive decision-making and community involvement, heralding a shift towards more comprehensive and balanced approaches to governance.

Looking ahead, this study opens multiple avenues for further research. Future inquiries could delve into the evolving nature of intermodal terminal governance amid changing technological advancements, environmental considerations, and global supply chain transformations. Moreover, a deeper examination of the socio-economic impacts of various governance models could yield a more complete understanding of their effects. The transportation industry's ongoing evolution necessitates continual research to adapt governance strategies to new challenges and opportunities, ensuring relevance and efficacy in a rapidly changing global context.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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