

Original Research

Enhancing supply chain resilience in Bangladesh through multimodal transport integration

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Abstract: Bangladesh's road-dominated freight network is frequently disrupted by congestion, flooding, cyclones, and periodic political unrest, revealing a structural vulnerability in national supply chains. Multimodal integration, linking road, rail, and inland waterways, offers a practical pathway to maintain continuity under such shocks. A purposive panel of 12 senior experts informed a DEMATEL–TOPSIS framework across seven resilience criteria: disruption tolerance (C1), cost efficiency (C2), travel time and speed (C3), flexibility (C4), connectivity and infrastructure availability (C5), environmental impact (C6), and scalability and future readiness (C7). DEMATEL weights indicated a clear hierarchy (C4 = 0.160, C1 = 0.158, C2 = 0.143, C7 = 0.142, C5 = 0.139, C3 = 0.130, C6 = 0.128), with the highest prominence for flexibility (D+R = 1.82) and disruption tolerance (D+R = 1.79). Cause–effect analysis (D–R) identified core drivers: cost efficiency (+0.46), disruption tolerance (+0.27), and connectivity (+0.26), near-neutral contributors (flexibility +0.02; environmental impact +0.01), and downstream effects (travel time –0.45; scalability –0.57). Using these weights in TOPSIS, five integration strategies were ranked: A5 (Road + Rail + Inland Waterway) $\approx$ 0.97; A3 (Road + Inland Waterway) = 0.812; A2 (Road + Rail) = 0.632; A4 (Rail + Inland Waterway) = 0.293; A1 (Road only) = 0.016. Findings indicate that prioritizing cost efficiency, disruption tolerance, and connectivity, while embedding high flexibility, yields the greatest resilience gains, and that tri-modal integration offers the most robust national pathway beyond road-only vulnerability.

Keywords: Supply chain resilience, Disruption, Multimodal transport integration, DEMATEL, TOPSIS

1. Introduction

The efficiency and resilience of freight transport systems are critical determinants of a nation's economic stability, particularly in developing countries such as Bangladesh where logistics networks are frequently exposed to natural disasters, political instability, and infrastructure constraints [1]. Multimodal transport integration, defined as the coordinated use of two or more transportation modes, such as road, rail, and inland waterways, within a single logistics chain, has emerged as a strategic approach to improving the

performance of supply chain and mitigating disruption risks [2]. By enabling mode shifts in response to route blockages, congestion, or environmental hazards, multimodal systems can enhance operational flexibility, reduce transit times, lower costs, and improve environmental sustainability. Figure 1 depicts an illustration of multimodal supply chain.

Bangladesh's freight sector remains heavily dependent on road transport, which accounts for the majority of cargo delivery despite severe congestion, limited road capacity, and high vulnerability to flood-related disruptions. The underutilization of rail and inland waterways limits the

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nation's ability to absorb shocks and maintain uninterrupted trade flows in emergencies. Strengthening intermodal connectivity can unlock untapped capacity, diversify routing options, and reduce the systemic risks associated with single-mode dependency. For policymakers and infrastructure planners, identifying the most influential factors that determine transport resilience and selecting optimal multimodal integration strategies are crucial steps towards building a robust and future-ready supply chain network.

Despite the well-documented benefits of multimodal transport integration, existing research on supply chain resilience in Bangladesh remains fragmented and sector-specific. Most prior studies have concentrated on particular industries, such as ready-made garments or fast-moving consumer goods, or on specific geographic corridors, rather than developing a comprehensive, mode-neutral framework for national resilience planning. Consequently, the broader interconnections among transport modes and their collective contribution to resilience have been insufficiently explored.

Furthermore, while Multi-Criteria Decision-Making (MCDM) techniques have been applied to the evaluation on transport and logistics, few studies have combined causal relationship mapping (e.g., DEMATEL) with performance ranking tools (e.g., TOPSIS) to formulate evidence-based, nationwide strategies in disruption-prone environments. This methodological gap limits policymakers' ability to understand both the interdependencies among resilience factors and the comparative advantages of alternative multimodal options.

Although several research works discussed multimodal

integration in developing contexts, they rarely attempted to identify and prioritize the interlinked factors influencing its successful implementation. The absence of a unified analytical framework that simultaneously examines causal relationships (through DEMATEL) and ranks feasible strategies (through TOPSIS) represents a critical gap, which this study seeks to bridge.

Given the complexity of this decision-making environment, where multiple operational, economic, and environmental factors interact, MCDM approaches offer a structured and transparent analytical solution. In this study, the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method is employed to determine the causal relationships and relative influence strengths among resilience criteria. DEMATEL is particularly effective in situations where empirical data is limited and expert judgement is essential, as it can both rank factors and uncover their interdependencies without predefined criteria weights [3]. The resulting criteria weights are then applied in the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method, which identifies the most preferred alternative based on its proximity to the ideal solution and distance from the least desirable solution [4]. This hybrid DEMATEL–TOPSIS framework enables a comprehensive analysis, linking the structural understanding of resilience dynamics with a robust ranking of multimodal strategies at the national level.

The findings of this study are expected to provide actionable insights to government agencies, infrastructure developers, and logistics operators, supporting investment prioritization, inter-agency coordination, and the phased implementation of multimodal transport projects. By



Figure 1. Conceptualizing multimodal transport integrating supply chain

addressing the systemic challenges of Bangladesh's freight sector through an integrated methodological approach, the research aims to contribute to a more resilient, sustainable, and competitive national supply chain.

Research objectives

- Identify and analyze the most influential criteria affecting the resilience of Bangladesh's national freight transport system.
- Determine the cause–effect relationships among these criteria using DEMATEL.
- Evaluate and rank multimodal transport integration strategies at the national scale using a DEMATEL–TOPSIS framework.

The remainder of this study is structured as follows: Section 2 reviews the relevant literature on multimodal transport integration and supply chain resilience, identifying the theoretical and empirical foundations for the study. Section 3 details the research methodology, including the application of the DEMATEL–TOPSIS hybrid approach. Section 4 presents and discusses the results of the analysis, highlighting the most influential resilience criteria and the ranking of multimodal strategies. Section 5 concludes the study with implications, acknowledges its limitations, and suggests directions for future research.

2. Literature review

Multimodal transport integration has increasingly been recognized as a pivotal approach to improving freight efficiency, reducing environmental impact, and enhancing the resilience of supply chain in the face of diverse disruptions. Saha et al. [1] emphasized the importance of an integrated intermodal freight transportation system for Bangladesh, highlighting Chattogram Port's vulnerability to container yard congestion due to inadequate hinterland connectivity. They proposed leveraging road, rail, and river networks to develop an expansive intermodal chain that is capable of preventing supply chain disruptions. This perspective aligns with the broader discourse presented by Kurniawan [5], whose review identified cost efficiency, crisis resilience, environmental sustainability, technological integration, and network design as central dimensions of multimodal logistics performance. The study underlined that real-time digital integration and synchro-modal strategies can significantly improve operational adaptability during crises, although regulatory and infrastructural disparities continue to constrain implementation, particularly in developing economies.

The measurement and assessment of transport resilience have also gained traction. Aparicio et al. [6] proposed the LINES methodology for multimodal resilience analysis, demonstrating its utility in identifying actionable vulnerabilities through a dynamic, multi-layered modeling approach. Their work emphasized that understanding

network topology and traffic flow dynamics is essential for resilience planning. Similar resilience-focused frameworks have been applied beyond freight contexts; for example, Chowdhury et al. [7] explored resilience strategies in the tourism supply chain during extreme disruptions such as the COVID-19 pandemic, concluding that combined strategies addressing both risks and resilience capabilities are more effective than isolated measures.

The significance of connectivity and visibility in sustaining resilient supply chains is further supported by Emon and Khan [8], who examined the manufacturing sector in Bangladesh. Their findings revealed that supply chain connectivity positively influences information sharing, which in turn enhances economic, social, and environmental outcomes. This echoes Bag et al. [9], who asserted that resilience can be strengthened by cultivating adaptive leadership, visibility, flexibility, collaboration, and redundancy, with impacts extending from firm-level endurance to community resilience.

Sector-specific insights also provide relevant lessons for national freight strategies. In the ready-made garments (RMG) sector of Bangladesh, Ali et al. [10] identified fourteen capability factors that determine resilience during pandemic-induced disruptions, underscoring the need for balanced strength between capabilities and vulnerabilities. Similarly, Chowdhury et al. [11] highlighted that flexibility in resilience strategy portfolios, particularly when aligned with risk nullification, can be crucial for maintaining supply chain performance during severe disruptions. In the Fast Moving Consumers Goods (FMCG) sector, Aslam and Li [12] emphasized the critical roles of resilient suppliers and transportation capacity, noting that network complexity must be managed to prevent bottlenecks, while flexibility enhances adaptability to market volatility.

Barriers to multimodal freight adoption remain a key obstacle, as demonstrated by Karam et al. [13], who identified 31 barriers spanning terminal operations, network gaps, regulatory issues, and interoperability challenges. These barriers reinforce the importance of policy and infrastructure alignment in enabling multimodal integration. Digital transformation also plays a pivotal role in post-crisis adaptation; Kashem et al. [14] found that supplier diversification, digital technology adoption, and flexible manufacturing can enhance both operational efficiency and resilience.

The integration of digital capabilities with physical infrastructure is further supported by Shahadat et al. [15], who demonstrated that innovativeness, visibility, and digital integration significantly improve supply chain performance in Bangladesh's apparel industry, although collaboration gaps remain. At the system optimization level, Okyere et al. [16] applied a genetic algorithm to design a sustainable multimodal freight system, showing significant cost savings and environmental benefits through optimized road–rail–waterway integration. From a technological perspective, Shakur et al. [17] examined Industry 4.0 adoption challenges in FMCG supply chains, concluding

that substantial investment, compatible infrastructure, and structured value chains are prerequisites for achieving resilience through automation and digitalization.

Finally, the robustness of multimodal networks has been analyzed by He et al. [18], who developed a network modeling approach to assessing the vulnerability of interdependent transport nodes. Their findings indicated that multimodal systems can exhibit scale-free robustness against random disruptions, but targeted failures at critical nodes can severely degrade performance, underscoring the need for strategic maintenance and redundancy.

Collectively, these studies highlighted that enhancing national supply chain resilience through multimodal transport integration requires a multifaceted approach that combines infrastructure development, digital capability building, barrier mitigation, and flexible resilience strategies. While the technical and managerial frameworks exist, the challenge for Bangladesh lies in context-specific adaptation, cross-agency coordination, and phased investment planning to develop a transport system that is efficient, sustainable, and disruption-tolerant.

Given these insights, the present study adopts a hybrid DEMATEL–TOPSIS approach to address two critical gaps: (1) identifying and ranking the most influential resilience criteria in Bangladesh’s freight transport system, and (2) evaluating and prioritizing multimodal integration strategies—road, rail, and inland waterways, at the national

scale. DEMATEL is employed to determine the causal relationships and influence strengths among resilience factors, while TOPSIS is used to assess the relative performance of strategic alternatives based on DEMATEL-derived weights. This integrated methodological framework enables both a deep understanding of resilience dynamics and a robust, evidence-based ranking of multimodal strategies for national implementation.

3. Methodology

This study adopts a structured methodological framework, as illustrated in Figure 2. A purposive sampling approach was used to select a panel of 12 experts, consistent with established practices in supply chain and MCDM research [19]. The inclusion criteria required each expert to possess more than 15 years of professional experience, hold at least a graduate degree, have a background in supply chain management in either academia or industry, and demonstrate both an understanding of the research topic and a willingness to complete the survey questionnaire. The following subsections provide a detailed description of the methods employed in this study. An anonymized summary of the expert panel is presented in Table 1.

Table 1. The summary of expert panel (n = 12; all experts met the inclusion criteria)

Expert ID	Affiliation	Highest degree	Primary specialization	Years of experience	Sector exposure (examples)
E1	Academia	PhD	Supply chain resilience & risk	18	Ports/Terminals, RMG
E2	Industry	MSc	Intermodal logistics & 3PL operations	17	FMCG, E-commerce
E3	Academia	PhD	MCDM/DEMATEL methodology	16	Cross-sector
E4	Industry	MBA	Freight network planning & visibility	20	FMCG, Cold Chain
E5	Academia	PhD	Multimodal transport policy & planning	22	Rail, Inland Waterways
E6	Industry	MSc	Port logistics & yard capacity	19	Ports/Terminals
E7	Academia	PhD	Operations & analytics	16	Manufacturing, RMG
E8	Industry	MBA	Procurement & supplier collaboration	21	FMCG, Heavy Industry
E9	Academia	PhD	Transportation systems & resilience investment	23	Public Infrastructure
E10	Industry	MSc	Rail scheduling & intermodal coordination	18	Rail, ICD/Depot
E11	Academia	PhD	Maritime logistics & port governance	24	Ports/Terminals
E12	Industry	MBA	Demand planning & S&OP	17	FMCG, Retail

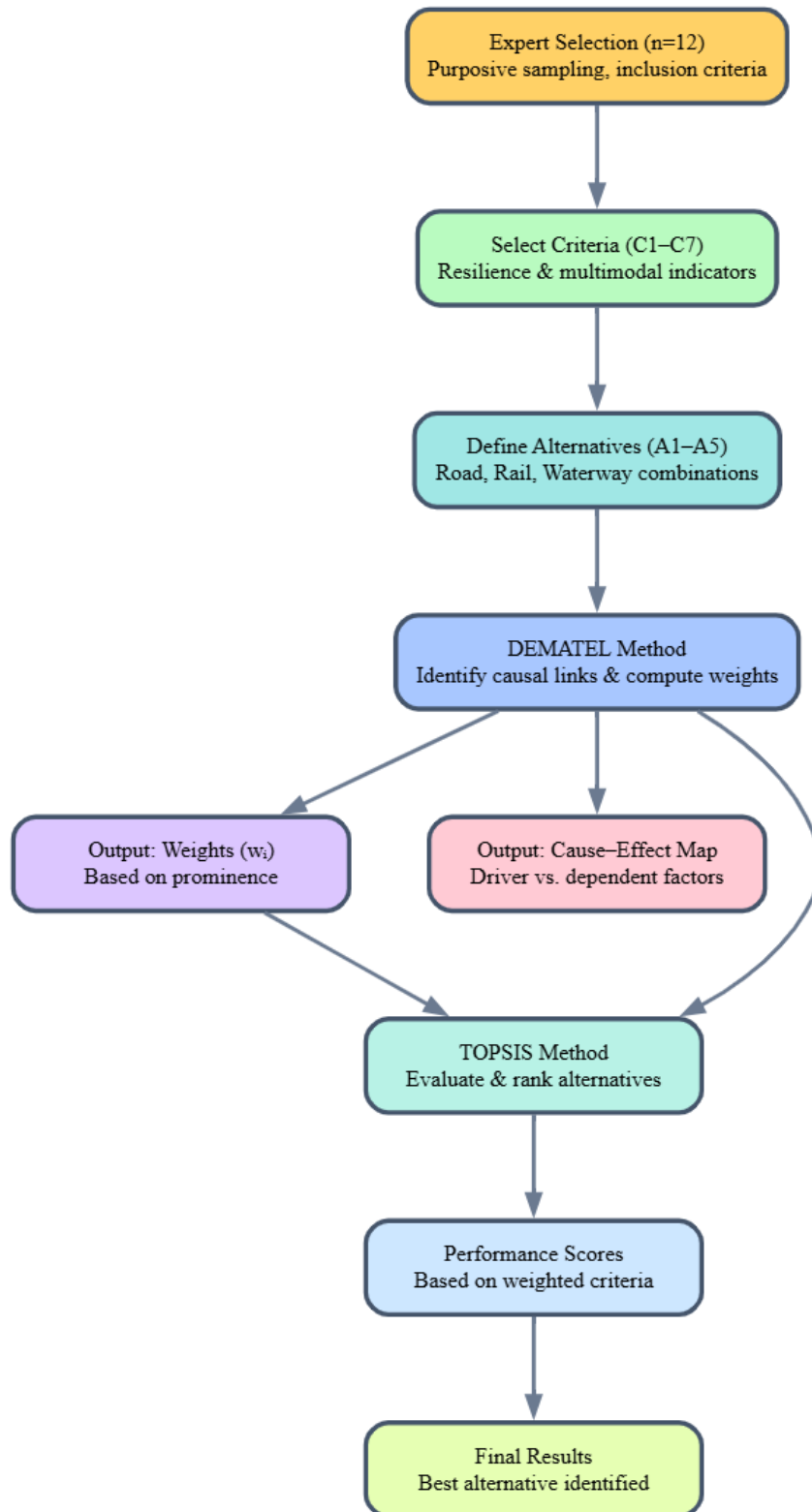


Figure 2. Methodological framework of the study

3.1 Criteria and alternative selection

In this study, the criteria were identified through an extensive review of relevant literature on multimodal transport integration, supply chain resilience, and national freight system performance, complemented by expert consultations to ensure contextual relevance for Bangladesh. Seven criteria were finalized for evaluation (See Table 2). These criteria capture the operational, economic, environmental, and strategic dimensions necessary for assessing resilience in the national freight transport system.

The strategic alternatives represent the feasible options of multimodal integration for Bangladesh's freight sector, considering current infrastructure, geographic conditions, and development potential. Five alternatives were defined (see Table 3). These alternatives provide a range of integration scenarios, from the current dominant single-mode road transport to a fully integrated tri-modal network.

3.2 DEMATEL method

The DEMATEL method can analyze subjective judgement from decision-makers with a numerical approach. For this, a semi-structured survey questionnaire needs to be prepared to collect experts' feedback. Procedures of the DEMATEL [20] are as follows:

Step 1: A direct comparison relation matrix is developed for each expert by utilizing that expert's feedback. The feedback is collected with a 5-point linguistic scale, as shown in Table 4.

Mathematically, the matrix can be expressed as Equation (1) for the k^{th} expert.

$$Z = [z_{ij}^k] \quad (1)$$

Step 2: Aggregated direct comparison relation matrix is achieved by the arithmetic mean of multiple experts' feedback.

Step 3: Normalization of the direct comparison relation matrix is calculated by using Equations (2) and (3).

$$L = \frac{1}{\max_{1 \leq i \leq n} \sum_{j=1}^n z_{ij}} \quad (2)$$

$$X = L \times Z \quad (3)$$

Where L is the normalization factor, Z is the aggregated direct comparison relation matrix, and X is the normalized matrix.

Step 4: The total-relation matrix (T) is figured out by Equation (4).

$$T = X \times (I - X)^{-1} \quad (4)$$

Where I stands for the identity matrix.

Step 5: The row (D_i) and column (R_j) sums are computed.

For each row (i) and column (j), the sum can be obtained from the total-relation matrix (T) by using Equations (5) and (6).

$$D_i = [\sum_{j=1}^n T_{ij}] \forall i \quad (5)$$

$$R_j = [\sum_{i=1}^n T_{ij}] \forall j \quad (6)$$

Step 6: The overall prominence (P_i) and the net effect (E_i) are computed by Equations (7) and (8).

$$P_i = [D_i + R_i] \forall i = j \quad (7)$$

$$E_i = [D_i - R_i] \forall i = j \quad (8)$$

The higher the value of P_i for a criterion, the greater the prominence (i.e., influence, importance, and visibility) of that criterion in terms of the overall relationship with other criteria. If $E_i > 0$ for a criterion, then that criterion is a causal (or a driver) criterion. Conversely, if $E_i < 0$ for a criterion, then that criterion is an effect (or a driven) criterion. These values are plotted on a two-dimensional axis (P_i vs. E_i) for each factor to create the cause-effect diagram.

Step 7: The threshold value is set, and the digraph is plotted using the information from the total-relation matrix (T). How one criterion influences another can be depicted by the obtained directed graph (digraph). To avoid comparably negligible effects, analysts or decision-makers need to set a threshold value (θ). The threshold value can be determined from the mean value (μ) and standard deviation (σ) of the elements of the total-relation matrix, T . If $T_{ij} > \theta$ for any criterion i , then it influences or causes the other criterion j , and a directed arrow is incorporated into the analysis. A digraph showing causal relations can be plotted from the data set: $((D_i + R_j), (D_i - R_j)) \forall i = j$.

3.3 TOPSIS method

The TOPSIS method can be used to select the best alternative among multiple options by evaluating with some selected criteria with specific weights. The detailed method [21] is shown below:

Step 1: Form the initial decision matrix as shown in Equation (9). The performance ratings for each alternative under each criterion were obtained from experts using a five-point Likert scale, creating the initial decision matrix for TOPSIS.

Table 2. Selected criteria for assessing resilience in the freight transport system

Code	Criterion	Description
C1	Disruption tolerance	Ability of the transport system to maintain operations during natural disasters, political unrest, and other disruptions.
C2	Cost efficiency	Economic viability of the system, including operational, maintenance, and infrastructure costs.
C3	Travel time and speed	Average transit time and efficiency in goods movement across modes.
C4	Flexibility	Capability to reroute or shift freight between modes in response to disruptions.
C5	Connectivity and infrastructure availability	Extent and quality of infrastructure supporting multimodal links and intermodal terminals.
C6	Environmental impact	Level of emissions and ecological footprint generated by the transport system.
C7	Scalability and future readiness	Potential for capacity expansion and adaptation to future economic and trade growth.

Table 3. Selected alternatives to be evaluated

Code	Alternative	Description
A1	Road Only (Baseline)	Current predominant single-mode road transport network without a significant intermodal integration.
A2	Road + Rail	Integration between truck transport and railway freight to improve long-haul efficiency and reduce congestion.
A3	Road + Inland Waterway	Integration of road transport with river and canal routes to enhance the capacity in flood-prone or coastal areas.
A4	Rail + Inland Waterway	Coordination of rail freight with river-based cargo movement, bypassing congested or damaged road networks.
A5	Road + Rail + Inland Waterway (Fully Integrated)	Comprehensive tri-modal system enabling dynamic routing and optimal resource utilization under varying conditions.

Table 4. 5-point linguistic scale for expert's evaluation collection for DEMATEL

Linguistic term	Numerical values
No influence	0
Low influence	1
Medium influence	2
High influence	3
Very high influence	4

		C1	C2	...	Cj	
	A1	X ₁₁	X ₁₂	...	X _{1j}	
	A2	X ₂₁	X ₂₂	...	X _{2j}	
D =	...	...	...	...	...	
	...	...	...	...	...	
	Ai	X _{i1}	X _{i2}	...	X _{ij}	m × n

(9)

Here, A_i denotes the alternatives and C_j denotes the evaluating criteria. There are *m* alternatives and *n* criteria.

Step 2: Normalize the decision matrix by the formula of vector normalization shown in Equation (10).

$$\bar{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{j=1}^m X_{ij}^2}} \quad (10)$$

Step 3: Determine the PIS by Equation (11) and NIS by Equation (12) for the beneficial criteria.

$$V_j^+ = \max (X_{1j}, X_{2j}, ..., X_{ij}) \quad (11)$$

$$V_j^- = \max (X_{1j}, X_{2j}, ..., X_{ij}) \quad (12)$$

For the non-beneficial criteria, PIS will be determined by Equation (13) and NIS will be determined by Equation (14).

$$V_j^+ = \min (X_{1j}, X_{2j}, ..., X_{ij}) \quad (13)$$

$$V_j^- = \max (X_{1j}, X_{2j}, ..., X_{ij}) \quad (14)$$

Step 4: Determine the Euclidean distance of the normalized values from the PIS with Equation (15) and NIS with Equation (16).

$$S_i^+ = \sqrt{\sum_{j=1}^n (\bar{X}_{ij} - V_j^+)^2} \quad (15)$$

$$S_i^- = \sqrt{\sum_{j=1}^n (\bar{X}_{ij} - V_j^-)^2} \quad (16)$$

Step 5: Compute the performance scores of the alternatives with Equation (17)

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad (17)$$

Step 6: Utilize the weights of the criteria obtained from the DEMATEL method to achieve weighted performance

scores. Select the best alternative by generating a ranking with descending order of the performance scores.

3.4 Calculations

Responses from the previously mentioned 12 experts were aggregated with the simple arithmetic mean. The calculated aggregated direct comparison relation matrix is shown in [Table 5](#).

After normalizing by using Equations (2) and (3), the total relation matrix was developed by Equation (4). The obtained total relation matrix as shown in [Table 6](#).

A ranking based on the descending value of the Prominence (D+R) can be found in [Table 7](#).

In this study, the identified challenges are categorized into two groups: the Cause group (with a positive net effect) and the Effect group (with a negative net effect). The classification, arranged in descending order of the net effect value (D–R), is presented in [Table 8](#).

For the ranking of strategic alternatives using the TOPSIS method, the initial decision matrix was normalized. Considering the weights of the criteria, the matrix was then weighted and normalized, as shown in [Table 9](#).

In this study, six criteria: Disruption Tolerance (C1), Cost Efficiency (C2), Travel Time and Speed (C3), Flexibility (C4), Connectivity and Infrastructure Availability (C5), and Scalability and Future Readiness (C7), are considered beneficial (the higher the value, the better), while Environmental Impact (C6) is treated as a non-beneficial criterion (the lower the value, the better).

The calculated Euclidean distances from the PIS and the NIS for the 5 alternatives are presented in [Table 10](#).

The calculated performance scores and the corresponding rankings of the alternatives, arranged in descending order of the scores, are presented in [Table 11](#).

Table 5. Aggregated direct relation matrix

	C1	C2	C3	C4	C5	C6	C7
C1	0	3.67	3.33	0.33	2.33	2.67	0.67
C2	1.33	0	2.67	3.67	2.67	2.33	3.33
C3	1.33	1.33	0	0.33	0.67	1.67	1.33
C4	1.33	2.67	2.67	0	2.67	1.33	3.67
C5	3.67	1.33	2.67	2.33	0	1.33	1.67
C6	2.67	0	0.33	2.33	2.33	0	3.67
C7	0.67	0.67	1.67	3.67	0	1.33	0

Table 6. Total relation matrix

	C1	C2	C3	C4	C5	C6	C7	D
C1	0.08	0.16	0.2	0.11	0.13	0.16	0.19	1.03
C2	0.12	0.05	0.18	0.2	0.14	0.14	0.21	1.04
C3	0.08	0.07	0.05	0.06	0.06	0.09	0.1	0.51
C4	0.11	0.12	0.17	0.09	0.13	0.1	0.2	0.92
C5	0.18	0.09	0.18	0.15	0.06	0.11	0.15	0.92
C6	0.13	0.04	0.08	0.14	0.11	0.05	0.18	0.73
C7	0.06	0.05	0.1	0.15	0.03	0.07	0.06	0.52
R	0.76	0.58	0.96	0.9	0.66	0.72	1.09	

Table 7. A rank of the challenges with prominence scores

Challenges	D	R	D+R	Weights
C4	0.92	0.9	1.82	0.160
C1	1.03	0.76	1.79	0.158
C2	1.04	0.58	1.62	0.143
C7	0.52	1.09	1.61	0.142
C5	0.92	0.66	1.58	0.139
C3	0.51	0.96	1.47	0.130
C6	0.73	0.72	1.45	0.128

Table 8. Cause-effect division of the challenges

Challenges	D	R	D-R	Group
C2	1.04	0.58	0.46	Cause
C1	1.03	0.76	0.27	
C5	0.92	0.66	0.26	
C4	0.92	0.9	0.02	
C6	0.73	0.72	0.01	
C3	0.51	0.96	-0.45	Effect
C7	0.52	1.09	-0.57	

Table 9. Weighted normalization of initial decision-matrix for TOPSIS

	C1	C2	C3	C4	C5	C6	C7
A1	0.063	0.064	0.068	0.061	0.058	0.092	0.057
A2	0.107	0.089	0.096	0.099	0.092	0.070	0.082
A2	0.130	0.106	0.086	0.112	0.097	0.061	0.094
A4	0.062	0.082	0.073	0.093	0.057	0.077	0.074
A5	0.126	0.103	0.101	0.128	0.106	0.059	0.105

Table 10. Euclidian distance from PIS and NIS

	S_i^+	S_i^-
A1	0.132	0.002
A2	0.050	0.086
A3	0.027	0.115
A4	0.105	0.043
A5	0.004	0.131

Table 11. Ranking of the strategic alternatives

	Scores	Ranking
A5	0.969	1
A3	0.812	2
A2	0.632	3
A4	0.293	4
A1	0.016	5

4. Results and discussion

The analysis of criteria weights reveals a clear hierarchy of importance in enhancing supply chain resilience through multimodal transport integration in Bangladesh (see Table 6).

Flexibility (C4, 0.160) is the highest-weighted factor. This indicates that the ability to reroute cargo and switch between transport modes during disruptions is considered the most critical aspect of resilience. In a country prone to floods, cyclones, and political unrest, flexibility directly determines whether supply chains can continue functioning when one mode becomes inoperable.

Disruption Tolerance (C1, 0.158) ranks second, closely aligned with flexibility. This highlights that the capacity to withstand shocks, whether environmental, infrastructural, or socio-political, is essential for maintaining continuity of trade flows. Together, flexibility and disruption tolerance form the backbone of a resilient multimodal system.

Cost Efficiency (C2, 0.143) and Scalability and Future Readiness (C7, 0.142) occupy the next tier of importance. This reflects the dual concern of ensuring immediate economic viability while also preparing the transport system for long-term growth in trade and industrial activity. For Bangladesh, where logistics costs are relatively high compared to global standards, cost-efficient multimodal solutions are attractive. At the same time, scalability ensures that infrastructure investments are not short-lived but adaptable to expanding demand.

Connectivity and Infrastructure Availability (C5, 0.139) received a slightly lower weight but remains a vital enabler. Although infrastructure is often a visible bottleneck in Bangladesh, experts emphasized that infrastructure alone cannot ensure resilience without flexibility and disruption tolerance. Nonetheless, improvements in intermodal

terminals, port linkages, and rail, waterway facilities will directly enhance the effectiveness of multimodal integration.

Travel Time and Speed (C3, 0.130), though important for competitiveness, was given a lower relative weight. This suggests that while speed is desirable, resilience under disruption is a higher priority than marginal gains in transit time. For instance, a slightly slower but dependable multimodal route may be preferred over a faster yet disruption-prone road-only option.

Environmental Impact (C6, 0.128) ranks lowest, showing that sustainability, while acknowledged, is still not prioritized as highly as economic and operational concerns in the Bangladeshi context. This does not diminish its relevance, lower emissions and the ecological benefits of waterways and railways are valuable, but it indicates that resilience planning is primarily driven by immediate operational reliability rather than long-term environmental outcomes. In the context of Bangladesh, Environmental Impact (C6) received a lower weight because Bangladeshi logistics stakeholders currently face pressing cost, reliability, and lead-time constraints, coupled with infrastructure bottlenecks that prioritize continuity of flows over greener options. Limited regulatory incentives and market pressures for emissions reduction also reduce the environmental salience in near-term decisions. It is explicitly noted that this is a contextual limitation rather than a value judgement. As green policies, reporting requirements, and technological capabilities strengthen, the relative importance of C6 is expected to increase.

The results highlight that resilience in Bangladesh's supply chains is primarily determined by flexibility and disruption tolerance, supported by economic feasibility and strategic scalability. Infrastructure and speed play enabling roles, while environmental sustainability, though important

globally, is given relatively less weight in the local context. The DEMATEL analysis provides insights into both the prominence (D+R) of each criterion and its causal role (D–R) in the resilience system. Prominence indicates overall importance, while the sign of D–R distinguishes whether a factor primarily acts as a cause (positive) or an effect (negative) (see Figure 3).

Cost Efficiency (C2, D–R = 0.46, D+R = 1.62) emerged as the most influential causal factor. Its strong positive D–R suggests that improvements in cost efficiency drive changes in other dimensions of resilience. This aligns with the practical reality that reduced transport costs directly influence scalability, connectivity, and even environmental performance.

Disruption Tolerance (C1, D–R = 0.27, D+R = 1.79) and Connectivity and Infrastructure Availability (C5, D–R = 0.26, D+R = 1.58) also belong to the cause group. Both are highly prominent and play central roles in shaping other factors. Their inclusion as causes is intuitive—when the network is robust to disruptions and infrastructure is available, other attributes such as flexibility and speed naturally improve.

Flexibility (C4, D–R = 0.02, D+R = 1.82) falls very close to neutral but slightly on the causal side, meaning it marginally influences other factors rather than being strongly influenced. Its very high prominence (highest D+R) confirms it as a cornerstone of resilience.

Environmental Impact (C6, D–R = 0.01, D+R = 1.45) is also nearly neutral, but just within the cause group. This suggests that policies targeting greener transport could gradually shape other resilience factors, though its influence is relatively weak compared to cost and infrastructure.

Travel Time and Speed (C3, D–R = –0.45, D+R = 1.47) is primarily an outcome, not a driver. It reflects the cumulative impact of improvements in cost, flexibility, and infrastructure. In practice, better multimodal integration shortens travel time, but travel time itself does not directly influence resilience drivers.

Scalability and Future Readiness (C7, D–R = –0.57, D+R = 1.61) is the most significant effect factor. It is shaped by causal drivers such as cost efficiency, infrastructure, and flexibility. This result is logical: the long-term adaptability of Bangladesh's freight system will depend on how well these causal drivers are managed today.

The cause–effect structure highlights that Cost Efficiency (C2), Disruption Tolerance (C1), and Connectivity (C5) are key levers for enhancing supply chain resilience. Flexibility (C4) sits at the boundary but has the highest prominence, making it a practical focal point for interventions. In contrast, Speed (C3) and Scalability (C7) are downstream outcomes; once causal drivers are improved, these effects will follow.

The TOPSIS analysis produced closeness coefficients (CC) that clearly differentiate the strategic alternatives for multimodal transport integration in Bangladesh. The ranking sequence is as follows: A5: Road + Rail + Inland Waterway > A3: Road + Inland Waterway > A2: Road +

Rail > A4: Rail + Inland Waterway > A1: Road Only (see Figure 4).

A5 (fully integrated, CC ≈ 0.97) ranks highest, confirming that a tri-modal system provides the greatest resilience and adaptability. By combining road, rail, and waterways, this option maximizes flexibility (C4), disruption tolerance (C1), and scalability (C7). It also minimizes overreliance on any single mode, a critical advantage in Bangladesh, where road networks are frequently disrupted by congestion, flooding, or political unrest. The high weight of flexibility and disruption tolerance in the criteria strongly justifies why A5 emerges as the most effective option. However, implementing a fully integrated road–rail–inland waterway system would require substantial capital investment, strong inter-agency coordination, and supportive regulatory frameworks, which may necessitate a phased implementation approach.

A3 (Road + Inland Waterway, CC ≈ 0.81) performs strongly, ranking second. Bangladesh's extensive river network makes inland waterways a valuable backup during natural disasters, when roads are blocked or damaged. This alternative also reduces environmental impact (C6) compared to road-dominated freight. However, limitations in seasonal navigability and port handling infrastructure prevent it from outperforming the fully integrated system. A2 (Road + Rail, CC ≈ 0.63) occupies third place. Rail provides efficient long-haul transport and bulk cargo movement, significantly reducing road congestion and costs (C2). However, the absence of waterways limits its flexibility, particularly during weather-related disruptions in flood-prone regions. This explains its lower performance relative to A3.

A4 (Rail + Inland Waterway, CC ≈ 0.29) offers certain resilience benefits, particularly in bulk transport and environmentally sustainable freight, but its lack of road connectivity makes it less practical for last-mile delivery. As road access remains the backbone of freight distribution, A4 is disadvantaged compared with A2 and A3.

A1 (Road Only, CC ≈ 0.16) ranks lowest. Despite currently being the dominant mode, it is highly vulnerable to disruption, with poor flexibility and a high environmental impact. The result emphasizes the risks of continued overdependence on road transport in Bangladesh.

These results demonstrate that shifting from a road-only system to a multimodal framework is essential for resilience. While a fully integrated tri-modal system (A5) offers the most robust solution, intermediate strategies such as road–waterway integration (A3) can provide significant resilience gains in the short to medium term. This ranking highlights the importance of prioritizing investments in infrastructure connectivity (C5), disruption tolerance (C1), and flexibility (C4), which were identified as the most influential drivers of resilience in earlier analyses.

To make the policy implications actionable, the research specifies priority investments and pilots with indicative leads and timelines. First, build last-mile road–waterway transshipment terminals at peri-urban nodes along priority

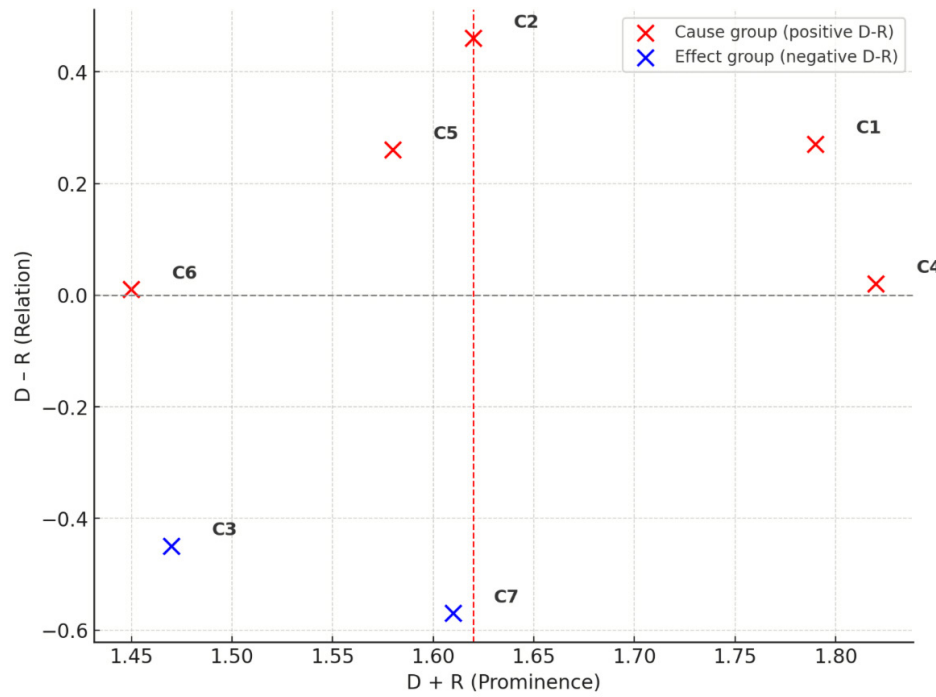


Figure 3. Cause-effect diagram of the criteria



Figure 4. Ranking of the strategic alternatives

corridors (lead: BIWTA/RHD/LGED; pilot in 12–24 months), enabling seamless truck–barge interchange. Second, ICD and rail-siding upgrades linked to Chattogram and major dry ports to increase intermodal throughput (lead: Bangladesh Railway/CPA; 2–3 years). Third, barge schedule coordination and targeted dredging on congested reaches to stabilize voyage times (lead: BIWTA/CPA; pilot within 18 months). Fourth, establish cold-chain cross-docks at agro-production hubs to reduce spoilage and expand multimodal reach (lead: MoC/LGED/private PPPs; 1–2 years). Finally, implement digital cargo visibility and slot-booking platforms to reduce dwell time and improve asset utilization across modes (lead: MoS/CPA/BR with private tech partners; 12–18 months). These concrete steps translate the strategy into implementable projects while aligning with near-term capacity and budget realities.

5. Conclusion

This study shows that resilience in Bangladesh’s freight system depends primarily on actionable levers, cost efficiency, disruption tolerance, and network connectivity, with flexibility standing out as the practical focal point that ties these levers together. In contrast, travel speed and long-term scalability function mainly as downstream outcomes that improve once the core drivers are strengthened. The study (i) identified the most influential criteria for resilience, (ii) mapped their cause–effect structure with DEMATEL, and (iii) evaluated and ranked feasible multimodal strategies via DEMATEL–TOPSIS, thus meeting all stated objectives and providing a clear, actionable pathway for policy and investment.

A key, distinctive result is the clear superiority of a fully integrated road–rail–inland waterway network. This tri-modal option minimizes dependence on a single mode and best supports adaptive routing during disruptions. Road–waterway integration emerges as a strong transitional pathway, while road-only remains the weakest and most disruption-prone arrangement. These findings collectively underline that transitioning from a single-mode posture to a genuinely multimodal framework is essential for national resilience.

Another notable insight is that environmental considerations, though important, are currently weighted below immediate operational and economic concerns in the local context. This suggests the need to integrate sustainability more deliberately into resilience planning, rather than treating it as a secondary outcome.

Policymakers and operators should prioritize investments and governance reforms that: (i) strengthen intermodal connectivity through terminals, last-mile interfaces, and synchronized timetables; (ii) reinforce the system against floods, cyclones, and recurrent bottlenecks through redundancy and contingency routing; and (iii) institutionalize flexibility through operating protocols, data sharing, and dynamic mode-shifts. In the near term,

upgrading road–waterway linkages can deliver meaningful gains while the tri-modal backbone is developed.

The analysis relies on expert elicitation and a structured MCDM pipeline; while appropriate for decision support under limited observed data, judgements may reflect expert priors and sectoral experience. The scope is national and context-specific, which may constrain direct transferability to other settings.

Subsequent research can (i) validate and refine criteria weights using observed freight flows and disruption case studies; (ii) simulate network behavior under seasonal hydrology and extreme events; (iii) integrate cost–benefit and distributional effects; and (iv) incorporate explicit environmental and social indicators into multi-objective planning for a just, low-carbon transition.

Conflict of interests

The authors declare no conflict of interests.

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Availability of data and materials

All data and materials used in this study are available from the corresponding author upon reasonable request.

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