

Article

Identifying Barriers to Shipbuilding in India: A Delphi–DEMATEL Approach

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Abstract

Background: This study examines the systemic barriers constraining the development of India's shipbuilding industry and identifies leverage points for effective policy intervention. **Methods:** A mixed-methods design was adopted, combining the Delphi technique with fuzzy DEMATEL to capture expert consensus and causal interdependencies among barriers. A panel of 20 experts, drawn from academia, the government, shipbuilding and ship repair, ports, logistics, and maritime consultancy, participated in two iterative Delphi rounds. An initial list of 21 barriers was refined to 10 based on convergence thresholds. These barriers were then analysed using a seven-step fuzzy DEMATEL procedure to distinguish causal drivers from dependent factors. **Results:** High raw material costs emerged as the most dominant causal barrier, with the highest net influence ($R-C = 0.540$), followed by high working capital requirements ($R-C = 0.103$) and complex regulatory frameworks ($R-C = 0.275$). Shortages of skilled labour, inefficiencies in ship design, and delays in clearances were largely effect-type barriers shaped by upstream structural conditions. Sensitivity analysis confirmed the stability of barrier rankings under alternative expert weighting scenarios. **Conclusions:** Policy efforts should prioritise reducing input cost disadvantages, strengthening long-term policy support, and rationalising regulatory processes, rather than focusing solely on downstream operational symptoms. The study is limited to expert judgement in the Indian shipbuilding sector. Future research could extend this framework to comparative country settings or integrate causal analysis with econometric evidence to further strengthen policy design. **Contribution:** Unlike prior thematic studies, this research provides an integrated causal mapping of structural, financial, and institutional barriers specific to Indian shipbuilding, enabling policy sequencing rather than simple ranking.



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1. Introduction

India's shipbuilding industry reflects a legacy of heritage, materials, and technology, from the Wadia family-owned maritime contributions [1] and teak's enduring role [2] to the Parsi cultural narratives [3]. Today, technological innovations are reshaping the sector to enhance efficiency and reliability [4]. Despite this legacy, the industry faces substantial challenges. It competes with global leaders such as China, Japan, South Korea, and the United States [5], as well as emerging players such as Bangladesh, Indonesia, and Brazil [6].

Progress is hindered by inefficiencies, skill erosion from de-industrialisation [7], and poor infrastructure [8]. Although several studies have examined the sector's development and global connections [9], few have investigated its systemic barriers.

Globally, the shipbuilding industry is shaped by state-led industrial strategies. Asian nations dominate through subsidies, labour cost advantages, and conglomerate structures [10,11]. European shipyards, though technologically advanced, face pressure to diversify into ship repairs and offshore wind energy [11]. Several authors [12] highlight environmental sustainability as an emerging priority, while other authors [13,14] emphasise the sector's strategic and economic significance.

In the Indian context, policy and technology studies offer partial insights. Authors Abdel-Khalek et al. [15] discuss defence-driven self-reliance, while [16] links earnings persistence to high-value orders and government support; Stanić et al. [17] introduce Shipbuilding 4.0 as a transformative force; Aghion et al. [18] examine the impact of liberalisation on industrial growth; and Wada et al. [19] propose forecasting models to optimise capacity. These contributions highlight sectoral relevance but lack an integrated framework for diagnosing and prioritising development barriers.

Despite this breadth of scholarship, few studies have systematically identified the interrelated barriers hindering India's shipbuilding growth. The existing literature is fragmented across historical, comparative, and policy domains, with limited methodological depth in causal analysis. This study addresses this gap by applying the Delphi method to elicit expert consensus, employing the DEMATEL (Decision-making Trial and Evaluation Laboratory) technique to map causal relationships among barriers, and integrating both approaches to inform targeted policy recommendations. Existing India-focused studies [1,4,8] examine competitiveness, defence self-reliance, or supply chain surplus independently; there remains limited evidence on how structural, financial, institutional, capability, and demand constraints interact causally. This study addresses this gap by providing a system-level causal mapping of barriers to inform policy prioritisation. To this end, the study poses three research questions:

1. RQ1: Which barriers hinder India's shipbuilding growth?
2. RQ2: How do these barriers interact causally?
3. RQ3: Which policy levers address root causes most effectively?

The study employs a mixed-methods approach, combining expert judgement and causal analysis. To address the first question, it applies the Delphi method to construct a validated list of barriers; to address the second, it employs the DEMATEL model to analyse causal relationships among barriers; and to address the third, it derives policy recommendations informed by these findings. DEMATEL has been successfully applied in maritime studies to identify influences and dependencies among factors, thereby helping to diagnose systemic constraints in shipbuilding [20,21].

This research makes several original contributions. It offers the first in-depth, empirically grounded analysis of systemic barriers in Indian shipbuilding; integrates expert insights with causal mapping to provide a robust framework for policy intervention; and extends its implications beyond India, offering valuable lessons for other developing economies seeking to strengthen their strategic industries.

2. Literature Review

This section reviews the literature relevant to shipbuilding development and the identification of systemic barriers. The review is organised into three subsections. The first synthesises global trajectories and competitive models in shipbuilding. The second focuses on structural and policy challenges within the Indian sector. The third discusses analytical

approaches for examining interdependent barriers in complex industrial systems, with particular emphasis on the Delphi and DEMATEL methods.

2.1. Global Shipbuilding Industry

The global shipbuilding industry has experienced a pronounced shift from Western economies to East Asia, with China, South Korea, and Japan emerging as dominant producers. This transition has been driven by lower labour costs, advanced industrial infrastructure, coordinated industrial policies, and declining capacity in Western shipyards, creating opportunities for emerging economies such as India [22]. The industry remains highly capital-intensive, with sustained government support, long-term finance, and political stability playing a central role in maintaining competitiveness and growth. Comparative studies indicate that shipbuilding success depends less on firm-level efficiency and more on systemic alignment between industrial policy, domestic demand, and upstream industries such as steel and marine equipment [23,24].

China's dominance reflects comprehensive capabilities across a wide range of vessel types and strong state backing that enables rapid capacity expansion and market penetration [25]. South Korea and Japan, despite higher labour costs, have remained competitive by specialising in technologically advanced vessels and continuous process innovation, including green shipbuilding technologies [25]. China's leadership is further reinforced by its ability to source the majority of shipbuilding inputs domestically, reducing exposure to price volatility and supply chain disruptions [26].

Recent empirical research shows that long-term competitiveness in China and South Korea has been achieved through aggressive state-led industrial strategies rather than market-driven adjustment alone. These strategies include production and investment subsidies, preferential credit from state-owned banks, and coordinated policies supporting technological upgrading and export expansion [27,28]. In South Korea, close collaboration between government and large conglomerates transformed individual shipyards into interconnected industrial clusters with strong innovation linkages [29]. China similarly designated shipbuilding as a strategic industry, using targeted interventions to stimulate domestic investment and rapidly increase its global market share [27]. Developing economies with fragmented or short-term policy frameworks have found it difficult to replicate these outcomes.

2.2. Shipbuilding in India

The shipbuilding sector supports upstream industries such as steel and heavy engineering and contributes to broader industrial development. Despite recent expansion, India's share of the global shipbuilding market remains limited at around one per cent, reflecting persistent structural constraints including high capital and working capital requirements, outdated production technologies, fragmented supply chains, and shortages of specialised skilled labour [26]. India's share of global shipbuilding output has remained below 0.1% in recent years, compared with China (over 50%), South Korea (around 30%), and Japan (approximately 15%) [24,25].

Policy initiatives such as the Shipbuilding Financial Assistance Policy have sought to strengthen domestic capabilities. However, domestic demand for Indian-built ships remains weak due to competition from established shipbuilding nations such as South Korea and China. The sector's strong orientation towards naval and defence shipbuilding further constrains diversification into commercial segments, complicating the achievement of objectives outlined in the Maritime India Vision 2030 [30] and the Maritime Amrit Kaal Vision 2047 [31], both of which emphasise commercial shipbuilding expansion. These policy frameworks aim to increase India's share in global shipbuilding, develop world-

class shipyard infrastructure, strengthen domestic marine equipment manufacturing, and position India among the leading shipbuilding nations by 2030 and beyond [22,25].

Industry assessments project rapid growth in India's shipbuilding sector, estimating an increase from approximately USD 90 million in 2022 to USD 8120 million by 2033 [32]. Government support through financial assistance schemes and incentives for specialised and environmentally friendly vessels is expected to facilitate this expansion [33,34]. The academic literature, however, adopts a more cautious view, noting that sustained growth in leading shipbuilding nations has depended on coordinated supply chain management, stable demand creation, and long-term policy commitment rather than short-duration incentives [9].

Heavy reliance on imported raw materials and equipment exposes Indian shipyards to cost escalation and logistical risks, undermining price competitiveness. Technological integration is widely recognised as critical for productivity gains, with evidence showing that adoption of artificial intelligence and the Industrial Internet of Things can significantly improve operational efficiency in Indian shipbuilding contexts [4]. Broader infrastructure constraints, including heavy reliance on road-based freight transport, further limit maritime industrial development [35]. The dominance of defence-oriented shipbuilding adds complexity: although defence orders support learning and capacity creation, their spillovers to commercial competitiveness are uneven [9,13], and self-reliance initiatives alone are insufficient without parallel demand-side and regulatory reforms [36,37].

2.3. Delphi and DEMATEL Methods

For clarity, barriers from previous studies have been categorised into input and supply chain constraints, financial and capital-structure issues, institutional and regulatory challenges, capability-related limitations, and demand-side conditions [38]. Research on policy and operational barriers increasingly uses methods that combine expert judgement with structured analytical tools, especially in situations characterised by interdependence and uncertainty. The Delphi method and DEMATEL technique are commonly employed in studies on infrastructure planning, technology adoption, sustainability transitions, and governance reform. Delphi helps achieve expert consensus through iterative rounds of anonymised feedback, reducing bias and enhancing the reliability of identified factors [38]. Convergence was measured as the percentage agreement among panellists, and the stability of responses from Round 1 to Round 2 indicated sufficient consensus.

Once expert consensus is established, DEMATEL provides a structured approach to analysing causal relationships in complex systems. After converting qualitative judgements into quantitative matrices, the method distinguishes between influencing and influenced factors and clarifies cause-and-effect pathways [39]. Visual tools such as Impact Relation Maps further support interpretation by illustrating directional relationships among variables [38]. Since its development by Fontela and Gabus in 1976 [39], DEMATEL has been applied across performance analysis, sustainability assessment, and strategic planning [31].

Recent research highlights that the combined use of Delphi and DEMATEL is well-suited to examining interdependent policy and operational barriers, as it integrates expert judgement with explicit causal mapping [38]. Applications in maritime and industrial settings show that this approach can reveal critical driving factors that are often overlooked by traditional ranking or regression-based techniques [40,41]. Despite the growing application of Delphi–DEMATEL in maritime research, no study has systematically mapped the interdependent barriers constraining Indian shipbuilding within an integrated industrial policy framework. This gap provides the rationale for the present analysis.

The studies summarised in Table 1 [21,42–46] further demonstrate DEMATEL's effectiveness in identifying directional relationships among barriers, while Delphi

contributes a reliable and validated factor base. Despite this growing body of evidence, integrated Delphi–DEMATEL applications in shipbuilding remain limited, particularly in developing economic contexts. This gap provides a clear justification for the present study and its focus on diagnosing systemic constraints to inform policy and institutional interventions. Compared with hierarchical approaches such as ISM or weight-based methods such as AHP, fuzzy DEMATEL captures both the intensity and direction of interdependencies [21], making it particularly suitable for analysing systemic industrial constraints under limited quantitative data.

Table 1. DEMATEL barrier-focused studies.

Source	Application Area	Methodology	Findings
[21]	Sustainable supply chain management in the maritime sector	Fuzzy Delphi–DEMATEL–ISM	Analysed barriers such as regulatory uncertainty, financial constraints, and stakeholder misalignment; built a hierarchical causal structure to overcome them.
[42]	Marine accidents during pilotage	DEMATEL	Analysed GISIS accident data and expert input; identified dominant causal factors (human error, communication, and environment) affecting navigational safety during pilotage.
[43]	Northern Sea Route (NSR) commercialisation	Fuzzy DEMATEL	Ranked critical risks limiting NSR operations; highlighted climate severity, ice conditions, and geopolitical uncertainty as leading constraints.
[44]	Reverse logistics implementation	Hybrid IF–DEMATEL–EDAS	Analysed barriers to reverse logistics adoption; identified cost, infrastructure, and stakeholder issues; provided prioritisation for overcoming barriers.
[45]	Sustainable transportation in India	Grey–DEMATEL	Examined constraints across economic, socio-political, environmental, and technical dimensions; mapped causal relationships; highlighted dominant constraints hindering sustainable transport.
[46]	Digitalisation of maritime logistics	DEMATEL	Identified and ranked adoption barriers (lack of digital infrastructure, cybersecurity risks, and resistance to change); mapped causal links showing how certain barriers trigger others.

3. Methods

This study adopts a two-stage mixed-methods approach to identify and analyse systemic barriers affecting the development of the shipbuilding industry in India. In the first stage, expert judgement is elicited through the Delphi method to identify and refine a set of critical barriers. In the second stage, the fuzzy DEMATEL technique is applied to examine the causal relationships among the selected barriers. This integrated framework is

well-suited to policy and industry contexts characterised by interdependent constraints and limited availability of reliable quantitative data.

3.1. Research Design and Framework

The research design integrated the Delphi technique with the fuzzy DEMATEL approach to combine expert consensus building with causal relationship analysis. An initial list of 21 barriers (Table 2) was developed through a review of the academic literature, policy documents, and industry reports on shipbuilding and maritime industrial development. These barriers were evaluated by a panel of twenty experts drawn from academia, government agencies, shipbuilding and ship repair, ports and terminal operations, logistics, procurement, and maritime consultancy. All panel members had at least 10 years of professional experience and held senior decision-making or advisory roles. Verbal informed consent was obtained from each panel member prior to participation.

Table 2. Details of the 21 identified barriers.

Code	Barrier
B1	Time-consuming process for obtaining clearances
B2	Inadequate policy support
B3	Complex regulatory framework
B4	High working capital requirement
B5	Low demand in commercial shipbuilding
B6	High raw material costs
B7	Lack of private participation
B8	Limited capacity of private-sector shipyards
B9	Limited availability of skilled labour
B10	Inefficiencies in ship design and process engineering
B11	Limited access to long-term financing
B12	High cost of borrowing
B13	Uncertainty in shipbuilding subsidy schemes
B14	Lack of a cluster-based industrial ecosystem
B15	Weak supply chain integration
B16	Limited R&D and innovation capability
B17	Outdated production infrastructure
B18	Intense competition from East Asian shipyards
B19	Exchange rate volatility
B20	Delays in payment from buyers
B21	Limited export promotion support

The Delphi process was conducted over two rounds. In the first round, experts assessed the relevance and significance of the identified barriers. In the second round, participants received anonymized group feedback, enabling them to revise their assessments. Applying a 75% agreement threshold, 10 barriers demonstrating convergence were retained for DEMATEL analysis. This process ensured stability of expert judgement while reducing individual bias.

In the second stage, fuzzy DEMATEL was employed to analyse causal interactions among the final set of barriers. Experts conducted pairwise evaluations to indicate the degree to which one barrier influences another, using a predefined linguistic scale ranging from no influence to a very strong influence. These assessments were converted into triangular fuzzy numbers to capture uncertainty in expert judgement. The analysis followed a seven-step procedure: construction of the fuzzy direct-relation matrix, defuzzification, normalisation, computation of the total-relation matrix, and calculation of prominence and relation indices. The sum of rows represents the influence exerted by each barrier, while the sum of columns reflects the influence received. The difference between these values was used to classify barriers into cause-and-effect groups. Detailed computational steps are provided in Appendix A, and the pairwise evaluation questionnaire is presented in Appendix B.

To assess robustness, a sensitivity analysis (SA) was conducted by varying the weights assigned to experts from different professional backgrounds. This enabled examination of the stability of barrier rankings and causal classifications under alternative weighting scenarios.

3.2. Delphi Method

The Delphi method is a structured empirical technique for eliciting consensus among experts on complex issues [47,48]. It was selected for this study due to its iterative design, anonymity of responses, and capacity to synthesise diverse viewpoints while minimising the influence of dominant individuals [49]. Experts participated in multiple questionnaire rounds, with anonymised summaries of group responses provided after each round to facilitate convergence of opinion. Compared with conventional survey methods, Delphi enables deeper exploration of critical factors and is particularly suitable when empirical data are limited and expert knowledge is central [48,49].

3.3. Fuzzy DEMATEL Method

Fuzzy set theory provides an effective means of modelling ambiguous and imprecise information using linguistic variables. In this study, triangular fuzzy numbers, as shown in Table 3, were employed due to their simplicity and computational efficiency [50,51]. Linguistic evaluations were transformed into quantitative values suitable for DEMATEL analysis. The fuzzy DEMATEL technique enables a systematic examination of interdependencies among barriers by distinguishing between influencing and influenced factors, thereby revealing the system's underlying causal structure.

Table 3. Fuzzy linguistic scale (adapted from Buckley [50]).

Preference in Terms of Score	Description of Linguistic Variable	Equivalent TFNs
0	No influence (No)	(0, 0, 0.25)
1	Very low influence (VL)	(0, 0.25, 0.5)
2	Low influence (L)	(0.25, 0.5, 0.75)
3	High influence (H)	(0.5, 0.75, 1.0)
4	Very strong influence (VH)	(0.75, 1.0, 1.0)

4. Data Collection

Our study utilised the Delphi method in three distinct phases: expert panel selection, barrier identification, and two iterative rounds of discussion to prioritise critical barriers. We followed the structured process described by [52] to formulate our queries. This

approach aligns with recent maritime research methodologies, such as those employed by [52] in their study of Arctic shipping challenges. The research aimed to encompass multiple domains in the Indian maritime sector, reflecting the sector's complexity, as highlighted by Notteboom et al. [53] in their comprehensive review of port research.

A total of 20 expert participants from diverse industry backgrounds contributed to the feedback process. These experts represented stakeholders from academia, the government, maritime consultancy and research, port and terminal operations, procurement and supply chain management, shipbuilding and ship repair, and shipping and logistics. Participation criteria required a minimum of 10 years of professional experience to ensure a high level of expertise. The selected experts held decision-making roles in their respective fields. The study incorporated insights from professionals across these sectors, including academicians and consultants from leading shipping and maritime trade firms. The distribution of the Delphi participants' industry backgrounds is presented in Table 4.

Table 4. Delphi participants' profiles.

Industry Sector	Count
Shipbuilding & Ship Repair	5
Shipping & Logistics	4
Procurement & Supply Chain	3
Port & Terminal Operations	2
Maritime Consultancy & Research	2
Government	2
Academia	2
	20

Additional details about the participants are provided in Appendix C. In line with participant requests, the names of their affiliations have been kept confidential.

An initial draft of shipbuilding barriers was constructed through a comprehensive literature review [11,26,27]. Given the distinct economic contexts of previous studies, the identified barriers were adapted to the Indian context. A Delphi study established a final list of 21 barriers through expert consensus. The authors identified the ten most critical barriers, presented in Table 5, based on a convergence score analysis across two Delphi rounds. These ten barriers described below form the foundation for the subsequent DEMATEL analysis.

Table 5. Barriers identified from expert observations for DEMATEL analysis (Authors' compilation).

No.	Potential Barriers	Convergence (%)
B1	Time-consuming Process for Obtaining Clearances	100
B2	Inadequate Policy Support	93
B3	Complex Regulatory Framework	78
B4	High Working Capital Requirement	98
B5	Low Demand in Commercial Shipbuilding	96
B6	High Raw Material Costs	94
B7	Lack of Private Participation	94
B8	Limited Capacity of Private Sector Shipyards	90
B9	Limited Availability of Skilled Labour	97
B10	Inefficiencies in Ship Design and Process Engineering	76

- *Time-consuming Process for Obtaining Clearances (B1)*: The process of obtaining clearances is lengthy and time-consuming due to multiple agencies, including, but not limited to, environmental clearances, land acquisition, coastal regulation zone (CRZ) clearances, power, water supply, etc. This poses a barrier for the shipbuilding industry, as time delays affect both project cost and implementation.
- *Inadequate Policy Support (B2)*: The shipbuilding industry in India lacks adequate policy support, unlike the global leaders. These leading global shipbuilding countries, such as Japan, South Korea, and China, have received substantial government incentives, including capital investments, loan deferments, easy financing, trade incentives, and research and development incentives, which are absent in India.
- *Complex Regulatory Framework (B3)*: The shipbuilding industry is governed by various regulations, including the CRZ regulations, environmental regulations, taxation regulations, safety standards, etc. These issues mentioned create compliance burdens and procedural delays, which act as a barrier to the shipbuilding industry.
- *High Working Capital Requirement (B4)*: The shipbuilding industry requires heavy working capital, which constitutes around 25% to 30% of the overall ship cost. In India, although human resources are relatively less expensive than their global counterparts, the import of raw materials and equipment, as well as the high cost of finance, increases working capital requirements, creating a barrier to the Indian shipbuilding industry.
- *Low Demand in Commercial Shipbuilding (B5)*: The fluctuating global demand for shipbuilding, high operating costs, and competition from major shipbuilding countries such as Japan, South Korea, and China have affected the demand for the shipbuilding industry in India. As defence orders dominate, they attempt to limit diversification.
- *High Raw Material Costs (B6)*: The raw materials used by the shipbuilding industry which are sourced domestically are limited. As a result, critical components such as equipment, machinery, steel, etc. are imported from foreign countries. The high costs of transportation and logistics further raise prices. Rising raw material costs negatively affect the profitability of the shipbuilding industry, reducing its competitiveness globally.
- *Lack of Private Participation (B7)*: The limited incentives for private investment, limited competition, lack of infrastructure facilities, higher working capital, access to funding, etc. limit the private sector from venturing into the shipbuilding industry.
- *Limited Capacity of Private-Sector Shipyards (B8)*: The Indian shipbuilding sector faces a lack of infrastructure, a lack of research and development for optimising the production processes, a lack of skilled labour, etc. These factors limit the output of Indian shipyards, thereby decreasing their global competitiveness.
- *Limited Availability of Skilled Labour (B9)*: The Indian shipbuilding sector faces a shortage of skilled labour due to limited institutions providing specialised training and education in shipbuilding and marine engineering. The industry's specific skills are also less developed than those of global leaders in the shipbuilding sector. Research and development in the shipbuilding sector is also limited in India.
- *Inefficiencies in Ship Design and Process Engineering (B10)*: The inefficiencies are due to the fragmentation of the design process and a lack of research and development in the sector, leading to outdated designs and methodologies. The shortage of skilled engineers and designers in the shipbuilding industry also contributes to inefficiencies in ship design and development.

After selecting the ten most critical barriers to the shipbuilding industry, the panel was asked to perform pairwise comparisons among the barriers (see Table 6).

Table 6. Direct-relation matrix (DRM): linguistic assessment data by an expert (Authors’ analysis).

Barrier	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0	3	1	4	2	3	2	2	3	1
B2	3	0	2	3	2	1	2	3	2	2
B3	2	1	0	2	2	2	1	2	3	2
B4	4	3	2	0	3	4	3	3	4	3
B5	2	3	2	3	0	2	2	1	2	2
B6	4	2	2	4	3	0	3	4	3	4
B7	1	2	2	3	2	3	0	2	2	1
B8	2	2	1	3	2	3	2	0	2	2
B9	3	1	2	3	2	3	2	2	0	2
B10	2	2	1	3	2	3	2	2	2	0

5. Results and Sensitivity Analysis

5.1. Calculations

According to the definitions of triangular fuzzy numbers (TFNs) outlined in Table 4, and using formulas in Appendix A, the expert panel’s linguistic assessments were converted into fuzzy values (Table 7). This process resulted in the development of 30 individual fuzzy assessment matrices. Defuzzification (Step 3 of the fuzzy DEMATEL methodology) was employed to construct the average initial direct-relation matrix and transform the fuzzy numbers into crisp values. The resulting average fuzzy initial direct-relation matrix for shipbuilding development barriers in India is presented in Table 8.

Table 7. Fuzzy assessment data (Authors’ analysis).

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	(0, 0, 0.25)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.75, 1.0, 1.0)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)
B2	(0.5, 0.75, 1.0)	(0, 0, 0.25)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)
B3	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0, 0, 0.25)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)
B4	(0.75, 1.0, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0, 0, 0.25)	(0.5, 0.75, 1.0)	(0.75, 1.0, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)
B5	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0, 0, 0.25)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)
B6	(0.75, 1.0, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.75, 1.0, 1.0)	(0.5, 0.75, 1.0)	(0, 0, 0.25)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)
B7	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0, 0, 0.25)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)
B8	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0, 0, 0.25)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)
B9	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0, 0, 0.25)	(0.25, 0.5, 0.75)
B10	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0, 0, 0.25)

Table 8. The detailed defuzzified matrix for each barrier pair (Authors' analysis).

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0.04	0.75	0.25	0.96	0.50	0.75	0.50	0.50	0.75	0.25
B2	0.75	0.04	0.50	0.75	0.50	0.25	0.50	0.75	0.50	0.50
B3	0.50	0.25	0.04	0.50	0.50	0.50	0.25	0.50	0.75	0.50
B4	0.96	0.75	0.50	0.04	0.75	0.96	0.75	0.75	0.96	0.75
B5	0.50	0.75	0.50	0.75	0.04	0.50	0.50	0.25	0.50	0.50
B6	0.96	0.50	0.50	0.96	0.75	0.04	0.75	0.96	0.75	0.96
B7	0.25	0.50	0.50	0.75	0.50	0.75	0.04	0.50	0.50	0.25
B8	0.50	0.50	0.25	0.75	0.50	0.75	0.50	0.04	0.50	0.50
B9	0.75	0.25	0.50	0.75	0.50	0.75	0.50	0.50	0.04	0.50
B10	0.50	0.50	0.25	0.75	0.50	0.75	0.50	0.50	0.50	0.04

Subsequently, formulas (Equations (A3) and (A4)) were utilised to establish a fuzzy normalised direct-relation matrix for the barriers (Table 9). This matrix represents the average fuzzy normalised initial direct-relation matrix. Formula (A5) was then applied to determine the total direct-relation matrix displayed in Table 10. Next, formulas (Equations (A6) and (A7)) were used to calculate the row sum (R) and column sum (C), respectively. These values offer insights into the cause-and-effect relationships between India's barriers to shipbuilding development.

Table 9. Average fuzzy normalised initial direct-relation matrix for barriers (Authors' analysis).

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0.006	0.105	0.035	0.134	0.070	0.105	0.070	0.070	0.105	0.035
B2	0.105	0.006	0.070	0.105	0.070	0.035	0.070	0.105	0.070	0.070
B3	0.070	0.035	0.006	0.070	0.070	0.070	0.035	0.070	0.105	0.070
B4	0.134	0.105	0.070	0.006	0.105	0.134	0.105	0.105	0.134	0.105
B5	0.070	0.105	0.070	0.105	0.006	0.070	0.070	0.035	0.070	0.070
B6	0.134	0.070	0.070	0.134	0.105	0.006	0.105	0.134	0.105	0.134
B7	0.035	0.070	0.070	0.105	0.070	0.105	0.006	0.070	0.070	0.035
B8	0.070	0.070	0.035	0.105	0.070	0.105	0.070	0.006	0.070	0.070
B9	0.105	0.035	0.070	0.105	0.070	0.105	0.070	0.070	0.006	0.070
B10	0.070	0.070	0.035	0.105	0.070	0.105	0.070	0.070	0.070	0.006

Table 10. Average total direct-relation matrix for barriers (Authors' analysis).

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0.263	0.310	0.204	0.420	0.289	0.359	0.283	0.300	0.349	0.249
B2	0.329	0.204	0.220	0.372	0.271	0.280	0.264	0.309	0.299	0.259
B3	0.270	0.205	0.140	0.305	0.244	0.278	0.207	0.251	0.299	0.236
B4	0.450	0.373	0.284	0.395	0.384	0.462	0.375	0.397	0.447	0.370

Table 10. Cont.

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B5	0.294	0.288	0.217	0.362	0.205	0.300	0.258	0.243	0.292	0.255
B6	0.447	0.343	0.281	0.507	0.383	0.348	0.374	0.419	0.420	0.393
B7	0.256	0.249	0.213	0.353	0.259	0.323	0.192	0.268	0.284	0.221
B8	0.299	0.261	0.188	0.369	0.270	0.337	0.263	0.218	0.296	0.260
B9	0.338	0.239	0.225	0.381	0.278	0.348	0.271	0.287	0.247	0.268
B10	0.299	0.261	0.188	0.369	0.270	0.337	0.263	0.279	0.296	0.200

Subsequently, the datasets (R+C) and (R−C) were computed and presented in Table 11. The data from (R+C) and (R−C) were used to construct the cause-and-effect diagram in Figure 1, which visually represents the causal relationships identified in the barriers.

Table 11. Calculation of R+C and R−C datasets and barrier rankings (Author analysis).

Barriers	R	C	R+C	Rank (R+C)	R−C	Rank (R−C)
B1	3.026	3.245	6.271	3	−0.218	9
B2	2.807	2.733	5.541	7	0.074	4
B3	2.435	2.161	4.596	10	0.275	2
B4	3.936	3.833	7.769	1	0.103	3
B5	2.715	2.853	5.568	6	−0.138	7
B6	3.913	3.373	7.286	2	0.540	1
B7	2.619	2.750	5.369	9	−0.131	6
B8	2.762	2.970	5.731	5	−0.208	8
B9	2.881	3.229	6.110	4	−0.347	10
B10	2.762	2.712	5.473	8	0.050	5

Note: R (Sum of Rows): Represents the total influence the barrier gives. C (Sum of Columns): Represents the total influence received by the barrier. R+C (Prominence): Indicates the importance of the barrier. R−C (Relation): Helps to identify if the barrier is a cause (positive) or an effect (negative).

The DEMATEL analysis reveals a clear distinction between causal and effect barriers in the Indian shipbuilding system. High raw material costs (B6) emerge as the most dominant causal factor, exerting a strong influence on multiple downstream constraints, including working capital stress, private-sector participation, and capacity utilisation. The total-relation matrix indicates that elevated raw material costs (B6) intensify working capital pressures (B4) and reduce incentives for private participation (B7), thereby constraining shipyard capacity expansion (B8). This transmission pathway highlights the upstream cost structure as a systemic driver. Policy responses to B6 may include incentives for domestic marine-grade steel production, tariff rationalisation, logistics cost reduction, and procurement aggregation mechanisms. High working capital requirements (B4), complex regulatory frameworks (B3), and inadequate policy support (B2) also fall in the causal group, indicating that cost, finance, and institutional design constitute the core structural drivers shaping sectoral performance. In contrast, barriers such as delays in obtaining clearances (B1), limited availability of skilled labour (B9), and constrained private shipyard capacity (B8) are primarily effect-type barriers, reflecting outcomes of upstream systemic weaknesses rather than independent sources of underperformance. This pattern suggests that policy interventions targeting surface-level operational issues are unlikely to

yield sustained improvements unless underlying cost, financing, and regulatory drivers are addressed.

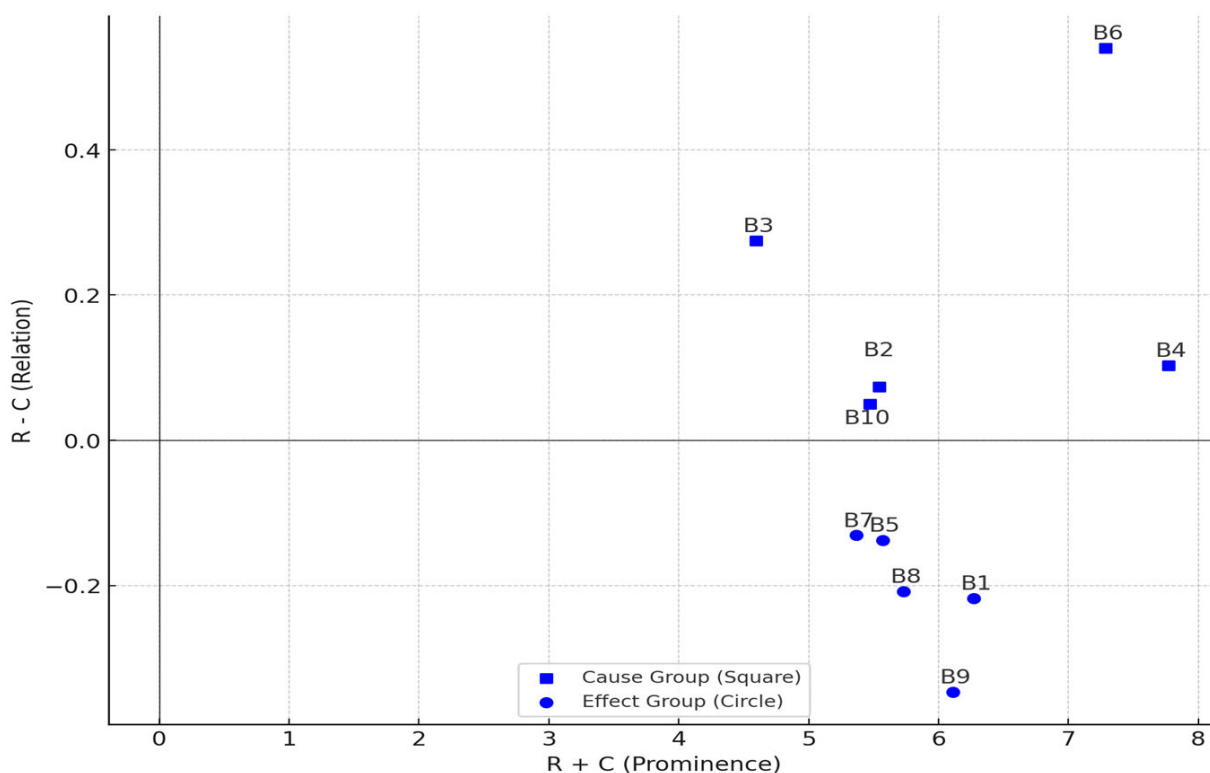


Figure 1. Cause-and-effect diagram of barriers to shipbuilding development in India (Authors’ analysis).

5.2. Sensitivity Analysis

Sensitivity analysis (SA) is essential as it tests whether model results remain stable under varying assumptions or expert weights, ensuring the robustness of MCDM outcomes. Studies applying fuzzy DEMATEL demonstrate that sensitivity checks strengthen the reliability of causal structures and minimise methodological bias [13,43,44].

A sensitivity analysis was performed to assess the robustness of the results obtained from the preceding analysis. This involved evaluating variations in cause-and-effect relationships resulting from assigning different weights to industry experts. The primary objective was to examine the consistency of the decision-making process and detect any potential biases that may have influenced the outcomes. Sensitivity analysis confirms that the relative ranking and causal classification of barriers remain stable across alternative expert weighting scenarios, indicating the robustness of the findings.

Given the impracticality of conducting sensitivity runs for all possible weight combinations, arising from assigning two distinct weights to each expert, a more efficient approach was adopted. One expert from each participant domain (Experts 1–5) was assigned a higher weight, while the remaining experts were given equal weights. The specific weight allocations for each expert in each scenario are presented in Table 12. The weighting scenarios represent stress tests simulating stakeholder dominance rather than probabilistic weights. The stability of rankings across runs indicates structural robustness.

Table 12. Sensitivity analysis weights assigned to five experts.

Sensitivity Run	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5
1	0.6	0.1	0.1	0.1	0.1
2	0.1	0.6	0.1	0.1	0.1
3	0.1	0.1	0.6	0.1	0.1
4	0.1	0.1	0.1	0.6	0.1
5	0.1	0.1	0.1	0.1	0.6

Sensitivity Analysis 1

Barriers	R+C	Rank (R+C)	R-C	Rank (R-C)
B1	6.27	3	-0.22	9
B2	5.54	7	0.07	4
B3	4.60	10	0.27	2
B4	7.77	1	0.10	3
B5	5.57	6	-0.14	7
B6	7.29	2	0.54	1
B7	5.37	9	-0.13	6
B8	5.73	5	-0.21	8
B9	6.11	4	-0.35	10
B10	5.47	8	0.05	5

Sensitivity Analysis 2

Barriers	R+C	Rank (R+C)	R-C	Rank (R-C)
B1	6.27	3	-0.22	9
B2	5.54	7	0.07	4
B3	4.60	10	0.27	2
B4	7.77	1	0.10	3
B5	5.57	6	-0.14	7
B6	7.29	2	0.54	1
B7	5.37	9	-0.13	6
B8	5.73	5	-0.21	8
B9	6.11	4	-0.35	10
B10	5.47	8	0.05	5

Sensitivity Analysis 3

Barriers	R+C	Rank (R+C)	R-C	Rank (R-C)
B1	6.27	3	-0.22	9
B2	5.54	7	0.07	4
B3	4.60	10	0.27	2
B4	7.77	1	0.10	3
B5	5.57	6	-0.14	7
B6	7.29	2	0.54	1
B7	5.37	9	-0.13	6
B8	5.73	5	-0.21	8
B9	6.11	4	-0.35	10
B10	5.47	8	0.05	5

Barriers	R+C	Rank (R+C)	R-C	Rank (R-C)
B1	6.27	3	-0.22	9
B2	5.54	7	0.07	4
B3	4.60	10	0.27	2
B4	7.77	1	0.10	3
B5	5.57	6	-0.14	7
B6	7.29	2	0.54	1
B7	5.37	9	-0.13	6
B8	5.73	5	-0.21	8
B9	6.11	4	-0.35	10
B10	5.47	8	0.05	5

Sensitivity Analysis 5

Barriers	R+C	Rank (R+C)	R-C	Rank (R-C)
B1	6.27	3	-0.22	9
B2	5.54	7	0.07	4
B3	4.60	10	0.27	2
B4	7.77	1	0.10	3
B5	5.57	6	-0.14	7
B6	7.29	2	0.54	1
B7	5.37	9	-0.13	6
B8	5.73	5	-0.21	8
B9	6.11	4	-0.35	10
B10	5.47	8	0.05	5

6. Discussion and Policy Implications

This section interprets the results of the fuzzy DEMATEL analysis and translates the identified causal relationships into policy-relevant insights for the Indian shipbuilding

sector. The discussion is anchored in the cause-and-effect structure derived from the DEMATEL model, with robustness confirmed through sensitivity analysis.

Figure 1 presents the cause-and-effect diagram of barriers to shipbuilding development in India, constructed using the R–C values derived from the total-relation matrix. The figure distinguishes between causal (influencing) barriers and effect (influenced) barriers, with barriers positioned on the positive side of the horizontal axis exerting a net influence on the system and those on the negative side largely shaped by upstream conditions. Also, as shown in Figure 1, high raw material costs (B6) emerge as the most dominant causal barrier, exerting a strong influence across the system. This indicates that cost-related disadvantages are structural, affecting working capital availability, private-sector participation, and overall capacity utilisation. High working capital requirements (B4), complex regulatory frameworks (B3), and inadequate policy support (B2) also fall in the causal group, underscoring the central role of financial structure and institutional design in shaping sectoral outcomes.

In contrast, barriers such as delays in obtaining clearances (B1), limited availability of skilled labour (B9), and constrained private-sector shipyard capacity (B8) are placed in the effect group. Their location in the cause-and-effect diagram suggests that these challenges are largely outcomes of upstream cost, finance, and policy constraints rather than independent drivers of underperformance. This distinction is important for policy design, as it implies that interventions focused solely on administrative streamlining or workforce development are unlikely to yield sustained improvements unless foundational causal barriers are addressed simultaneously.

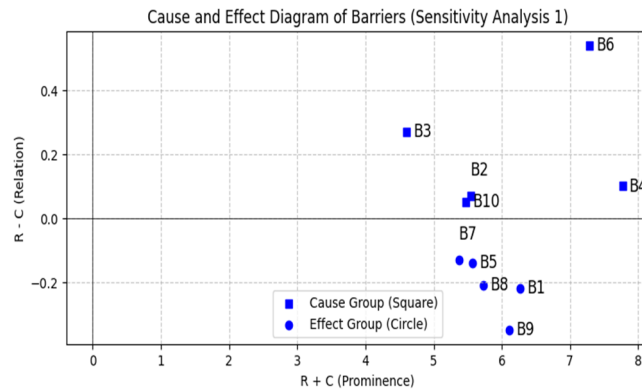
The causal structure revealed in Figure 1 has direct implications for policy intervention. The dominance of high raw material costs (B6) points to the need for targeted measures to address the input cost disadvantages faced by Indian shipyards. International experience from leading shipbuilding nations such as China and South Korea shows that competitiveness has been supported through domestic sourcing of marine-grade steel, long-term procurement arrangements, and close integration between shipyards and upstream industries. In the Indian context, incentives for domestic production of shipbuilding inputs, preferential pricing mechanisms for shipyards, and improved logistics connectivity represent feasible short- to medium-term interventions.

High working capital requirements (B4) reflect financial vulnerability arising from long construction cycles and milestone-based payment structures. In established shipbuilding economies, similar constraints have been mitigated through state-backed credit facilities, export financing instruments, and risk-sharing mechanisms. Adapting these instruments to India would require shipbuilding-specific credit guarantee schemes, structured milestone financing, and greater involvement of public financial institutions. Such measures are institutionally feasible and can be implemented over a medium-term horizon.

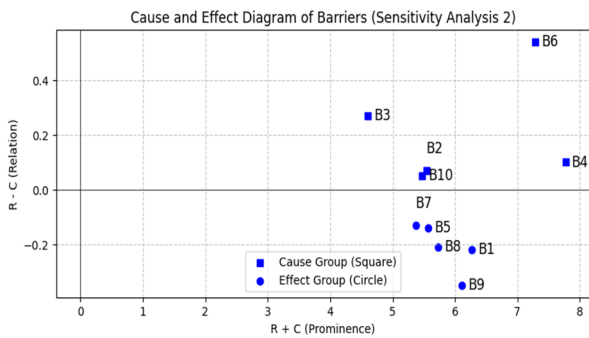
Institutional constraints, represented by complex regulatory frameworks (B3) and inadequate policy support (B2), further inhibit long-term investment and capacity planning. Fragmented approval processes and time-bound incentive schemes generate uncertainty and discourage private participation. By contrast, the sustained competitiveness of China and South Korea has been underpinned by stable, long-term shipbuilding policies and coordinated industrial strategies. For India, regulatory simplification through a single-window clearance mechanism and articulation of a long-term shipbuilding roadmap aligned with national maritime and industrial visions would address these institutional frictions and improve investor confidence.

The robustness of the identified causal structure is assessed through sensitivity analysis. Figure 2a–e present the results of multiple sensitivity runs conducted under alternative expert weighting scenarios. Across all sensitivity runs, the relative ranking and causal

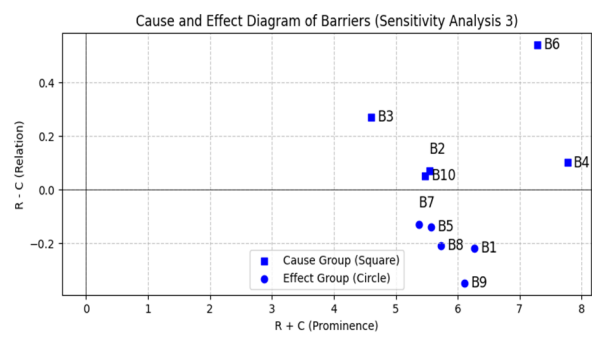
classification of barriers remain stable, with high raw material costs (B6) and high working capital requirements (B4) consistently identified as dominant causal drivers. This stability confirms that the results are not sensitive to variations in expert weighting and reinforces confidence in the policy relevance of the findings.



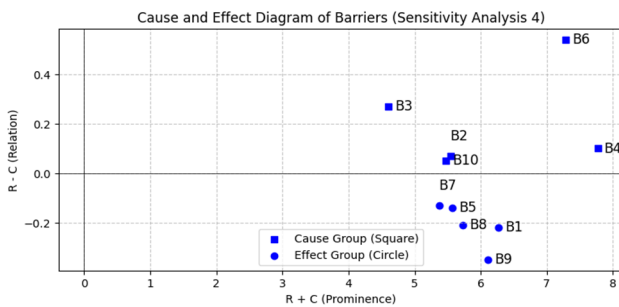
(a)



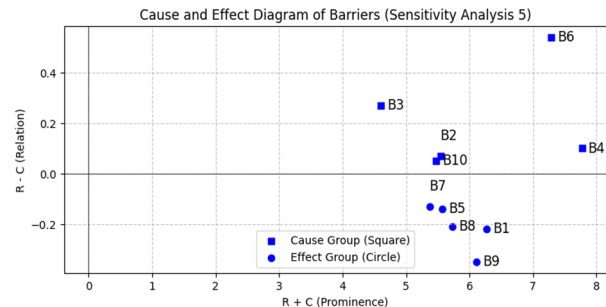
(b)



(c)



(d)



(e)

Figure 2. (a–e). Sensitivity analysis results for shipbuilding barriers in India (Authors’ analysis). (a) Shipbuilding barriers in India (Run 1). (b) Shipbuilding barriers in India (Run 2). (c) Shipbuilding barriers in India (Run 3). (d) Shipbuilding barriers in India (Run 4). (e) Shipbuilding barriers in India (Run 5).

The integrated interpretation of Figures 1 and 2 indicates that an effective shipbuilding policy in India requires a sequenced, coordinated approach. Short-term priorities should focus on regulatory clarity and targeted cost mitigation. Medium-term measures should strengthen access to finance and integrate supply chains, while longer-term strategies should concentrate on capacity expansion, skill development, and technological upgrading. By aligning policy interventions with the causal structure identified in Figure 1 and supported by the robustness analysis in Figure 2a–e, policymakers can move beyond fragmented initiatives and address the root causes of underperformance, thereby supporting

sustained development of the Indian shipbuilding industry. The findings have implications beyond India for emerging shipbuilding economies facing similar cost structures and institutional constraints. The causal sequencing logic may inform policy prioritisation in comparable industrial contexts.

7. Conclusions

This study provides the first empirically grounded causal analysis of barriers to shipbuilding development in India by integrating expert consensus from the Delphi method with fuzzy DEMATEL-based causal mapping. Rather than treating constraints as isolated or independent factors, the analysis demonstrates that the performance of the Indian shipbuilding sector is shaped by a clearly defined causal structure. The findings indicate that a small set of upstream structural and institutional barriers exerts a disproportionate influence on sectoral outcomes. In particular, high raw material costs, inadequate policy support, and complex regulatory frameworks emerge as dominant causal drivers. At the same time, challenges such as skill shortages, inefficiencies in ship design and process engineering, and weak commercial demand are largely downstream effects. This distinction is critical, as it suggests that many commonly cited operational bottlenecks are symptoms of deeper systemic constraints rather than primary causes of underperformance.

From a policy perspective, the results point to the importance of prioritising interventions that address these upstream drivers. Reducing input cost disadvantages through incentives for domestic production of shipbuilding materials, improving access to finance by mitigating working capital constraints, and simplifying regulatory processes through coordinated and predictable approval mechanisms offer the most significant leverage for systemic improvement. Measures such as strengthening training institutions, promoting digitalisation in ship design and production processes, and expanding shipyard capacity remain necessary components of sectoral development. However, the analysis indicates that their effectiveness is contingent on progress in resolving foundational cost, financial, and institutional barriers. Taken together, the findings reinforce international evidence that Industry 4.0 technologies and productivity-enhancing innovations deliver meaningful gains only when embedded in coherent policy and institutional frameworks that reduce uncertainty and support long-term investment.

The study is subject to certain limitations that should be acknowledged. The analysis relies primarily on expert judgement collected through Delphi rounds, which, despite careful panel selection and convergence checks, may reflect subjective perceptions. Future studies may incorporate sector-based weighting or alternative defuzzification techniques for further robustness testing. In addition, the study does not include longitudinal performance data or quantitative benchmarking against leading global shipbuilding nations, limiting the ability to empirically validate the identified causal pathways. The focus on the Indian context also constrains the generalisability of the findings to other developing economies with different industrial and institutional characteristics.

Future research could address these limitations in several ways. Comparative applications of the Delphi–DEMATEL framework across emerging shipbuilding economies, including other BRICS countries, would help test the robustness of the causal structure identified in this study. Integrating econometric modelling or firm-level performance data could further strengthen causal inference by triangulating expert-based insights with quantitative evidence. Methodological extensions combining fuzzy DEMATEL with complementary techniques such as ISM or EDAS may also provide deeper insight into hierarchical relationships among barriers. Finally, as global shipbuilding increasingly aligns with sustainability transitions, future studies should explore how digitalisation,

decarbonisation, and green shipbuilding practices interact with institutional and cost-related constraints to reshape competitiveness over time.

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Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

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Abbreviations

The following abbreviations are used in this manuscript:

ANP	Analytic Network Process
CAGR	Compound Annual Growth Rate
CRZ	Coastal Regulation Zone
DEMATEL	Decision Trial and Evaluation Laboratory
GT	Gross Tonnage
IRM	Impact Relation Map
ISM	Interpretive Structural Modelling
IVHF	Interval-Valued Hesitant Fuzzy
TFN	Triangular Fuzzy Number
USD	United States Dollar
SA	Sensitivity Analysis

Appendix A

Computational Steps for Fuzzy DEMATEL

Step 1: Defining the Expert Panel and Assessment Criteria

Expert opinions are collected, and assessment criteria (barriers) are identified through the Delphi study to evaluate the Indian shipbuilding sector. A panel of $K = 20$ experts is formed to evaluate the causal interdependencies between the finalised list of ten critical barriers.

Step 2: Constructing a Pairwise Fuzzy Comparison Matrix

A pairwise comparison is conducted to develop the initial direct-relation matrix using a linguistic scale. Scores are assigned based on expert opinions: 0 = No influence, 1 = Very low influence, 2 = Low influence, 3 = High influence, and 4 = Very high influence. These judgments are converted into triangular fuzzy numbers (TFNs) (Table 3), denoted as (e_{ij}, f_{ij}, g_{ij}) , to capture uncertainty.

Step 3: Obtaining the Fuzzy Initial Direct-Relation Matrix (A)

The average fuzzy evaluation from the K experts is calculated to form the group fuzzy evaluation matrix:

$$a_{ij} = \frac{1}{K} \sum_{k=1}^K x_{ij}^k \quad (A1)$$

To proceed with matrix operations, these values are defuzzified into crisp values (z_{ij}) using the weighted average method:

$$z_{ij} = \frac{1}{6} (e_{ij} + 4f_{ij} + g_{ij}) \quad (A2)$$

Step 4: Normalising the Initial Direct-Relation Matrix (D)

The crisp matrix A is normalised using factor (m) to ensure the system is bounded:

$$m = \min \left[\frac{1}{\max_{1 \leq i \leq n} \sum_{j=1}^n a_{ij}}, \frac{1}{\max_{1 \leq j \leq n} \sum_{i=1}^n a_{ij}} \right] \quad (A3)$$

The normalised matrix is then computed as

$$D = m \times A \quad (A4)$$

Step 5: Constructing the Total-Relation Matrix (T)

The total-relation matrix (T) accounts for both direct and indirect continuous influences among barriers and is computed using the identity matrix (I):

$$T = D(I - D)^{-1} \quad (A5)$$

Step 6: Calculating the Sum of Rows (R) and Columns (C)

The values of R and C offer insights into the causal relationships. R_i represents the total influence exerted by barrier i on other barriers, while C_j reflects the total influence received by barrier j :

$$R_i = \sum_{j=1}^n t_{ij} \quad (A6)$$

$$C_j = \sum_{i=1}^n t_{ij} \quad (A7)$$

Step 7: Interpreting Prominence and Relation (R+C; R-C)

The final datasets provide the causal structure of the shipbuilding system. The

- **Prominence (R+C):** Indicates the overall significance of the barrier; high values suggest a core systemic constraint.
- **Relation (R-C):** If the value is positive, the barrier is a cause; if negative, it is an effect. Table 11 presents the application of (R+C) and (R-C).

Appendix B*Instructions for Experts*

You have received the list of 21 barriers (Table 2) and are now requested to assess how strongly one barrier influences another barrier based on your professional experience and knowledge of the Indian shipbuilding sector. Please indicate the degree of influence using the following scale:

Score	Interpretation
0	No influence
1	Very low influence
2	Low influence
3	High influence
4	Very high influence

As the next step, from the selected 10 barriers (as at Table 5), please assess the influence of each barrier (row) on the others (column) (Table A1). Diagonal elements (same barrier) should be marked 0.

Table A1. Pairwise influence evaluation matrix.

From\To	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0									
B2		0								
B3			0							
B4				0						
B5					0					
B6						0				
B7							0			
B8								0		
B9									0	
B10										0

Your expert input is essential for identifying root causes and dependent barriers in India’s shipbuilding industry.

Thank you for your valuable time and contribution.

Appendix C

Table A2. Details of participants’ profiles.

Serial No.	Affiliation/Expertise	Designation/Position #	Years of Experience
1	Academia	Professor of Maritime Economy	25
2	Academia	Professor of Logistics and Supply Chain	23
3	Government	Senior Port Planner (Major Port)	13
4	Government	Chief Port Planner (Major Port)	13
5	Maritime Consultancy & Research	Senior Port Planner (Management Consulting)	11
6	Maritime Consultancy & Research	Senior Maritime Consultant	22
7	Port & Terminal Operations	Port Officer	14
8	Port & Terminal Operations	Port Operations Manager	12
9	Procurement & Supply Chain	Procurement Head	15
10	Procurement & Supply Chain	Chief Procurement Officer	18
11	Procurement & Supply Chain	Vice President—Procurement	14
12	Shipbuilding & Ship Repair	Head of Shipyard Operations	19
13	Shipbuilding & Ship Repair	Director (Shipbuilding)	15
14	Shipbuilding & Ship Repair	Marine Engineer	15
15	Shipbuilding & Ship Repair	Naval Architect	17
16	Shipbuilding & Ship Repair	Head of Ship Repair Division	10
17	Shipping & Logistics	General Manager, Corporate Affairs	13
18	Shipping & Logistics	Head of Maritime Logistics	17
19	Shipping & Logistics	Chief Executive Officer	20
20	Shipping & Logistics	Director of Transportation	16

Verbal informed consent was obtained from all 20 experts prior to completing the questionnaire.

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