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The Role of Indian Ports in International Trade

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ABSTRACT

Ports of India play an essential role in international trade of India because ports provide essential link and movement of imports and exports for Indian domestic market to the world market. In this study, the importance of Indian ports in international trade is examined by emphasizing infrastructure, cargo-handling process, connectivity, efficiency, logistics, digitalization, contribution to the economy, and the most significant problems affecting ports in playing an important role in international trade. The study employs a quantitative and descriptive approach based on a structured questionnaire with 100 responses. Percentage analysis is employed in summing up the characteristics of the responses and the views about the contribution of ports in India and their effectiveness. It is found that there are convincing perceptions that ports play a definite role in international trade. Overall, 88% of respondents strongly agree or agree that Indian ports contribute to international trade, while 84% express this view about support for import and export activities. A number of factors such as infrastructure, cargo handling, connectivity, technology, and investment affect port efficiency and trade performance, while congestion, delays in cargo handling, and high logistics costs remain major issues for Indian ports. It could be reasonably acknowledged from the results of the study that efficient Indian ports actively participate in smooth international trade, reduce logistics costs, impact economic growth, contribute to international competitiveness, and help in reaching the desired goal of sustainable development of maritime trade through various measures.

Keywords: Indian ports, international trade, port infrastructure, cargo handling, logistics, connectivity, port efficiency

1. Introduction

International trade is an important part of India's economic development, and ports provide a major connection between the domestic economy and international markets. Indian ports handle the movement of goods required for imports and exports and therefore influence the speed, cost and reliability of international trade. The effectiveness of ports depends on factors such as infrastructure, cargo-handling facilities, connectivity, capacity, technology and operational efficiency.

Previous studies have examined Indian ports from different perspectives, including port infrastructure, port efficiency, logistics costs, containerization, transshipment and individual port performance. The literature suggests that efficient ports can reduce maritime transport costs, improve cargo movement and support greater export activity. However, Indian ports also face challenges such as congestion, capacity constraints, inadequate infrastructure, high operational costs and connectivity limitations.

Against this background, the present study examines the overall role of Indian ports in international trade. It considers how infrastructure and facilities affect trade efficiency, evaluates operational performance, identifies major challenges and assesses the contribution of ports to India's international trade growth and competitiveness.

2. Review of Literature

Ghosh and De (2001)

Ghosh and De (2001), in their study "Indian Ports and Globalisation: Grounding Economics in Geography," examined the relationship between Indian ports, overseas traffic and economic development. The study highlighted the importance of port performance and connectivity in supporting India's growing international trade. The authors emphasized that improvements in port infrastructure and transport networks are essential for strengthening India's position in global trade.

Sharma and Sha (2008)

Sharma and Sha (2008), in “Analysis of Port Operations and Planning for the Development of an Integrated Container Shipping Model for Indian Ports,” examined Indian port operations in the context of increasing containerized international trade. The study emphasized the importance of container-handling facilities, port infrastructure and efficient operations for export and import activities. It suggested that improvements in port capacity and operations are necessary to handle the growing volume of international cargo.

World Bank (2013)

The World Bank (2013), in its report “Reforming the Indian Ports Sector,” examined the infrastructure, efficiency, connectivity and regulatory environment of Indian ports. The report identified challenges such as congestion, inadequate infrastructure, limited connectivity and operational inefficiencies. It highlighted that efficient and competitive ports are essential for reducing trade costs and improving India’s participation in international trade.

Pal (2013)

Pal (2013), in “Pattern of International Trade through West Bengal: Some Evidence from Port-Level Data,” analysed international trade using port-level data. The study examined the role of ports in facilitating trade and highlighted the importance of geographical location, hinterland connectivity and port performance. The findings showed that improvements in port facilities and connectivity could help Indian ports benefit more effectively from growing international trade.

Onkarnath and Pradhan (2014)

Onkarnath and Pradhan (2014), in “Port Sector in India – Key Issues and Challenges Faced,” examined the major challenges affecting India’s port sector. The study identified infrastructure limitations, capacity constraints, cargo-handling problems, low productivity and high operational costs as important issues. These challenges can reduce the competitiveness of Indian ports and affect their ability to efficiently support international trade.

Herrera Dappe, Jooste and Suárez-Alemán (2017)

Herrera Dappe, Jooste and Suárez-Alemán (2017), in “How Does Port Efficiency Affect Maritime Transport Costs and Trade? Evidence from Indian and Western Pacific Ocean Countries,” investigated the relationship between port efficiency, maritime transport costs and trade. The study found that improving port efficiency can reduce maritime transport costs and support greater export activity. The research provides evidence that efficient ports contribute positively to international trade.

Karthik and Dubey (2024)

Karthik and Dubey (2024), in “The Impact of Port Infrastructure on International Trade – A Study on Indian Ports,” examined the relationship between Indian port infrastructure and international trade. The study focused on infrastructure, port efficiency, logistics and initiatives such as the Sagarmala Project. It concluded that better port infrastructure and logistics facilities can improve India’s export competitiveness and strengthen international trade.

Kumar, Nishanthi, Sam.E and Sheeba (2025)

Kumar, Nishanthi, Sam.E and Sheeba (2025), in “Mumbai Port as a Strategic Hub in India’s Maritime Trade Network: A Comparative Study of Import and Export Efficiency,” studied the role of Mumbai Port in India’s maritime trade network. The research examined import and export efficiency, cargo handling, digital infrastructure and connectivity. The study highlighted the strategic importance of Mumbai Port while suggesting that further improvements in digitalization and operational efficiency can strengthen India’s international trade performance.

Guhan and Devi (2026)

Guhan and Devi (2026), in “Reducing Dependence on Foreign through the Development of Domestic Infrastructure: Vizhinjam Port as India’s Future Trans-Shipments Hub,” examined the potential of Vizhinjam Port as an important transshipment hub for India. The study discussed India’s dependence on foreign transshipment ports and its impact on logistics costs and delivery time. It concluded that developing domestic transshipment infrastructure could reduce costs, improve supply-chain efficiency and strengthen India’s position in international maritime trade.

Mittal

Mittal, in “Indian Ocean Ports and the Australia-India Trade Relationship,” examined the role of Indian Ocean ports in supporting India’s trade relationship with Australia. The study emphasized the importance of port infrastructure, maritime connectivity and efficient logistics in facilitating international trade. It highlighted that strengthening Indian ports can improve India’s connectivity with international markets and support the expansion of its global trade relationships.

3. Research Problem Statement

Indian ports are essential for the movement of imports and exports, but their contribution to international trade depends on infrastructure, cargo-handling efficiency, connectivity, technology, logistics and operational performance. Congestion, delays, inadequate facilities and high logistics costs can reduce

trade efficiency. The study therefore examines how Indian ports contribute to international trade and identifies the factors and challenges associated with their performance.

4. Research Gap

The reviewed literature demonstrates that Indian ports are an important component of India's international trade through their contribution to exports, imports, container movement, maritime connectivity, logistics and transshipment. However, existing studies generally focus on individual aspects such as infrastructure, efficiency, specific ports or particular trade routes. There is therefore a need for a comprehensive study that examines the overall role of Indian ports in international trade, considering infrastructure, cargo movement, connectivity, efficiency, logistics and recent developments in the Indian maritime sector.

5. Conceptual Background

Indian ports form a key link between domestic production and international markets because they handle the movement of imports and exports. In the present study, port performance is considered through infrastructure and facilities, cargo-handling efficiency, connectivity and operational efficiency. These dimensions are viewed as important for smoother cargo movement, stronger global-market connections and improved international trade performance.

6. Conceptual Framework

The conceptual framework of the study is based on the assumption that the performance of Indian ports is influenced by infrastructure and facilities, cargo-handling efficiency, connectivity, operational efficiency and logistics support. These factors affect the smooth movement of imports and exports and, consequently, international trade performance.

Independent Variables: Port infrastructure and facilities; cargo-handling efficiency; port connectivity; operational efficiency; logistics and digital facilities.

Intervening/Challenge Factors: Congestion, capacity constraints, delays, inadequate facilities and high operational costs.

Dependent Variable: International trade performance, reflected through efficient import and export movement, reduced trade costs, improved logistics performance, trade growth and competitiveness.

Figure 1. Conceptual Framework of the Study

INDEPENDENT VARIABLES Port infrastructure and facilities • Cargo-handling efficiency • Port connectivity • Operational efficiency • Logistics and digital facilities
INTERVENING / CHALLENGE FACTORS Congestion • Capacity constraints • Delays • Inadequate facilities • High operating costs
DEPENDENT VARIABLE International trade performance: efficient import/export movement, lower trade costs, logistics performance, trade growth and competitiveness

7. Objectives of the Study

1. To examine the role of Indian ports in facilitating international trade through the movement of imports and exports.
2. To analyse the impact of port infrastructure and facilities on the efficiency of international trade.
3. To evaluate the efficiency and operational performance of Indian ports in handling international cargo and vessels.
4. To identify the major challenges faced by Indian ports in supporting and improving international trade.
5. To assess the contribution of Indian ports to the growth and competitiveness of India's international trade.

8. Research Question and Hypothesis

Research question: What is the role of Indian ports in facilitating and improving international trade?

H₀ (Null Hypothesis): There is no significant relationship between the performance of Indian ports and international trade.

H₁ (Alternative Hypothesis): There is a significant relationship between the performance of Indian ports and international trade.

The supplied study materials define these hypotheses, while the supplied results are presented as percentage analysis. Therefore, the descriptive results are used to discuss the direction of respondents' perceptions; statistical significance is not claimed without an inferential test.

9. Research Methodology

Research Design

The study uses a quantitative and descriptive research design based on a structured questionnaire. Data were collected from 100 responses and summarized using frequency and percentage analysis. The questionnaire includes demographic questions and statements covering the role, infrastructure, efficiency, economic contribution, challenges and future development of Indian ports.

Population and Sample

The analysis is based on 100 completed responses. The respondent profile includes students, private employees, port/logistics professionals, business owners, importers/exporters, government employees and other respondents. The supplied research materials do not specify a probability sampling method; therefore, no sampling method is assumed in this paper.

Instrument and Measures

A structured questionnaire was used. Part A collected demographic information, including gender, age, occupation, educational qualification and income level, while the questionnaire also included marital status. Part B contained 20 statements measured using a five-point Likert scale from Strongly Agree to Strongly Disagree. The statements were organized around five study objectives: the role of ports in international trade; infrastructure and efficiency; economic growth; challenges; and future development.

Data Analysis

Frequency and percentage analysis were used to summarize the 100 responses. The supplied coded dataset also uses a five-point Likert coding scheme, allowing descriptive mean values to be calculated for the 20 research statements. No causal relationship or statistical significance is claimed from percentage analysis alone.

Ethical Considerations

The study materials describe the questionnaire as an academic research instrument and report 100 completed responses. The supplied materials do not provide detailed documentation of formal ethics approval, informed-consent procedures, or a separate privacy protocol. Accordingly, no additional ethical procedures are claimed beyond what is documented in the supplied study materials.

10. Results

Table 1. Respondent Profile (N = 100)

Characteristic	Category	n	%
Gender	Male	72	72.0%
	Female	27	27.0%
	Other	1	1.0%
Age	20–30 years	62	62.0%
	31–40 years	20	20.0%
	41–50 years	12	12.0%
	51–60 years	6	6.0%
Occupation	Student	33	33.0%
	Private Employee	22	22.0%
	Port/Logistics Professional	13	13.0%

Characteristic	Category	n	%
	Business Owner	11	11.0%
	Importer/Exporter	11	11.0%
	Government Employee	8	8.0%
	Other	2	2.0%
Education	Undergraduate	46	46.0%
	Postgraduate	37	37.0%
	Diploma	14	14.0%
	Other	3	3.0%
Income	No Income	19	19.0%
	Below ₹20,000	20	20.0%
	₹20,001–40,000	22	22.0%
	₹40,001–60,000	16	16.0%
	Above ₹60,000	23	23.0%

Note. Marital status was included in the questionnaire but is not included in the supplied 100-response percentage-analysis output.

Table 2. Percentage Analysis of Research Statements (N = 100)

Research statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Ports Facilitate International Trade	55.0%	33.0%	8.0%	3.0%	1.0%
Ports Support Import & Export Activities	57.0%	27.0%	13.0%	3.0%	0.0%
Efficient Port Operations & Cargo Movement	47.0%	41.0%	10.0%	2.0%	0.0%
Global Market Connectivity	53.0%	29.0%	13.0%	5.0%	0.0%
Modern Infrastructure & Port Efficiency	43.0%	43.0%	10.0%	3.0%	1.0%
Advanced Cargo Handling & Time Reduction	41.0%	43.0%	12.0%	3.0%	1.0%
Road & Rail Connectivity & Trade	45.0%	39.0%	11.0%	5.0%	0.0%
Port Infrastructure Investment & Trade	46.0%	37.0%	12.0%	4.0%	1.0%
Ports & Economic Growth	45.0%	37.0%	13.0%	5.0%	0.0%
Port Activities & Employment	48.0%	34.0%	11.0%	7.0%	0.0%
Ports & Trade-Related Industries	49.0%	31.0%	16.0%	3.0%	1.0%
Efficient Ports & Logistics Costs	43.0%	47.0%	9.0%	1.0%	0.0%
Port Congestion as a Trade Challenge	44.0%	37.0%	16.0%	3.0%	0.0%

Research statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Cargo Handling Delays & Trade	49.0%	38.0%	7.0%	5.0%	1.0%
Advanced Technology & Port Efficiency	46.0%	35.0%	19.0%	0.0%	0.0%
High Logistics Costs as a Challenge	52.0%	30.0%	13.0%	5.0%	0.0%
Digitalization & Port Efficiency	48.0%	32.0%	16.0%	2.0%	2.0%
Infrastructure Investment for Future Trade	47.0%	37.0%	14.0%	2.0%	0.0%
Advanced Technology & Global Competitiveness	49.0%	33.0%	14.0%	3.0%	1.0%
Further Port Development & Trade Position	38.0%	47.0%	11.0%	3.0%	1.0%

Note. Percentages are calculated from the supplied 100-response percentage analysis.

Table 3. Descriptive Mean Scores for Research Statements

Research statement	Mean (1–5)
Ports Facilitate International Trade	4.38
Ports Support Import & Export Activities	4.38
Efficient Port Operations & Cargo Movement	4.33
Global Market Connectivity	4.30
Modern Infrastructure & Port Efficiency	4.24
Advanced Cargo Handling & Time Reduction	4.20
Road & Rail Connectivity & Trade	4.24
Port Infrastructure Investment & Trade	4.23
Ports & Economic Growth	4.22
Port Activities & Employment	4.23
Ports & Trade-Related Industries	4.24
Efficient Ports & Logistics Costs	4.32
Port Congestion as a Trade Challenge	4.22
Cargo Handling Delays & Trade	4.29
Advanced Technology & Port Efficiency	4.27
High Logistics Costs as a Challenge	4.29
Digitalization & Port Efficiency	4.22
Infrastructure Investment for Future Trade	4.29
Advanced Technology & Global Competitiveness	4.26

Research statement	Mean (1–5)
Further Port Development & Trade Position	4.18

Note. Means were calculated from the supplied coded 100-response dataset using 1 = Strongly Disagree through 5 = Strongly Agree.

11. Interpretation

The respondent profile shows that 72% of respondents were male and 27% were female, while 1% selected other. The largest age group was 20–30 years (62%). Students formed the largest occupation category (33%), followed by private employees (22%). Undergraduates represented 46% of respondents and postgraduates 37%. Income categories were distributed across the sample, with 23% reporting income above ₹60,000 and 19% reporting no income.

The research statements show strong agreement with the role of Indian ports in international trade. For the statement that ports facilitate international trade, 55% strongly agreed and 33% agreed, giving 88% combined agreement. For support of import and export activities, 57% strongly agreed and 27% agreed, giving 84% combined agreement. Efficient port operations and global-market connectivity also received 88% and 82% combined agreement respectively.

Infrastructure, cargo handling, road and rail connectivity, and infrastructure investment were also viewed positively. Modern infrastructure received 86% combined agreement, advanced cargo handling 84%, road and rail connectivity 84%, and infrastructure investment 83%. The results therefore show a consistent perception that infrastructure and operational factors are important to trade performance.

Challenge-related statements also received substantial agreement. Congestion was identified as a challenge by 81% of respondents through combined strong agreement and agreement. Cargo-handling delays received 87%, lack of advanced technology 81%, and high logistics costs 82% combined agreement. Future-oriented measures also received high agreement, including digitalization (80%), further infrastructure investment (84%), advanced technology for global competitiveness (82%), and further port development (85%).

12. Discussion

The descriptive results indicate a generally positive perception of the role of Indian ports in international trade. Respondents associate port effectiveness with infrastructure, cargo handling, connectivity, investment and technology. At the same time, congestion, cargo-handling delays and logistics costs are perceived as continuing challenges. These observations are consistent with the study framework, while the descriptive design does not establish causal or statistically significant relationships.

13. Findings and Suggestions

1. A large majority of respondents perceive Indian ports as important facilitators of international trade.
2. Respondents associate efficient port operations with smoother cargo movement and stronger global-market connectivity.
3. Modern infrastructure, cargo-handling facilities, road and rail connectivity, and investment are consistently viewed as important for port efficiency and trade.
4. Congestion, cargo-handling delays, lack of advanced technology, and high logistics costs are identified as major challenges.
5. Digitalization, additional infrastructure investment, advanced technology and further port development are strongly supported as future measures.
6. Port development should continue to focus on operational efficiency, connectivity, cargo-handling capacity and technology-enabled services.
7. Further research can use larger samples, inferential statistical tests and port-specific comparisons to examine the relationships stated in the hypotheses.

14. Practical Implications

The findings have practical relevance for port authorities, logistics stakeholders and policymakers. The positive responses toward infrastructure, cargo-handling facilities, road and rail connectivity, digitalization and technology indicate areas that respondents associate with improved port performance. The identified challenges of congestion, delays and logistics costs also point to areas where operational improvements and investment may be useful.

15. Theoretical Implications

The study provides a descriptive conceptual view linking port infrastructure, cargo-handling efficiency, connectivity and operational performance with international trade performance, while recognizing challenge factors such as congestion, delays, capacity constraints and high costs. Because the analysis is descriptive, the framework should be treated as a basis for further empirical testing rather than as evidence of causal relationships.

16. Conclusion

Indian ports play an important role in connecting India with global markets and supporting the movement of imports and exports. The 100-response survey indicates strong positive perceptions of the contribution of ports to international trade, infrastructure development, economic growth, logistics performance and global competitiveness. At the same time, respondents recognize congestion, delays, technology limitations and logistics costs as important challenges. The results indicate that continued investment in infrastructure, connectivity, cargo-handling facilities, digitalization and advanced technology is relevant to the future development of Indian ports. The study therefore concludes, based on the descriptive survey evidence, that port efficiency and development are closely associated in respondents' perceptions with stronger international trade performance. The hypothesis describes a relationship between port performance and international trade; however, the supplied analysis is descriptive and does not establish statistical significance or causation.

17. Limitations

The study is based on 100 responses and uses descriptive percentage analysis as the principal reported analysis. The supplied materials do not document a probability sampling method, so the findings should not be generalized beyond the respondents without further evidence. The study also relies on perceptions collected through a questionnaire. The supplied percentage analysis does not include marital-status results, although marital status appears in the questionnaire. Finally, no inferential test result is supplied, so the hypotheses cannot be accepted or rejected on the basis of statistical significance in this version of the paper.

18. Recommendations

Future research may examine Indian ports using larger and more diverse samples and compare perceptions across port locations, occupations or stakeholder groups. Inferential methods could be used to test the hypotheses formally. Further studies could also examine specific dimensions such as congestion, digitalization, transshipment, hinterland connectivity, logistics costs and port-specific operational efficiency. Longitudinal research could help assess how infrastructure and technology improvements affect international trade performance over time.

19. Future Research Directions

Future studies can extend the present work by using larger and more diverse samples, comparing perceptions across individual ports or stakeholder groups, and applying inferential statistical methods to test the hypotheses stated in the study. Port-specific comparisons and longitudinal research could also provide a stronger basis for examining how infrastructure, connectivity, technology and operational efficiency relate to international trade performance.

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Appendix A – Questionnaire

Part A: Demographic Profile

1. Name of the Respondent: _____

2. Gender: Male / Female / Other
3. Age: 20–30 years / 31–40 years / 41–50 years / 51–60 years
4. Occupation: Student / Private Employee / Port/Logistics Professional / Business Owner / Importer/Exporter / Government Employee / Other
5. Educational Qualification: Undergraduate / Postgraduate / Diploma / Other
6. Income Level: No Income / Below ₹20,000 / ₹20,001–40,000 / ₹40,001–60,000 / Above ₹60,000
7. Marital Status: Single / Married / Other

Part B: Research Statements

1. Indian ports play an important role in facilitating international trade. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
2. Indian ports significantly support India's import and export activities. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
3. Efficient port operations help in the smooth movement of goods internationally. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
4. Indian ports strengthen India's connection with global markets. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
5. Modern infrastructure improves the efficiency of Indian ports. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
6. Advanced cargo-handling facilities reduce the time required to handle goods. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
7. Better road and rail connectivity to ports improves international trade. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
8. Investment in port infrastructure can increase India's international trade. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
9. Indian ports contribute significantly to India's economic growth. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
10. Port activities create employment opportunities in India. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
11. Indian ports support the growth of industries involved in international trade. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
12. Efficient ports help reduce transportation and logistics costs. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
13. Port congestion is a major challenge affecting international trade. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
14. Delays in cargo handling negatively affect international trade. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
15. Lack of advanced technology reduces the efficiency of Indian ports. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
16. High logistics and transportation costs are a major challenge for Indian ports. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
17. Digitalization can improve the efficiency of Indian ports. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
18. Greater investment in port infrastructure is necessary for future trade growth. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
19. Advanced technology can make Indian ports more competitive globally. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree
20. Further development of Indian ports will strengthen India's position in international trade. Response: Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree

Appendix B – Data Coding and Analysis Summary

1. Sample size: 100 valid responses were used for the descriptive analysis.

2. Likert scale coding: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, and 5 = Strongly Agree.
3. Demographic variables analyzed: gender, age, occupation, educational qualification, income level, and marital status where data were available.
4. The research statements were analyzed using frequencies, percentages, and descriptive mean scores.
5. Percentage analysis was used to summarize respondents' perceptions of Indian ports and their role in international trade.
6. Mean scores were calculated from the five-point Likert responses for the 20 research statements.
7. The overall mean across the 20 research statements was 4.27, indicating generally positive responses toward the role and development of Indian ports.
8. The highest mean score was 4.38 for the statements that Indian ports facilitate international trade and support import and export activities.
9. The findings identify infrastructure, connectivity, cargo handling, technology, digitalization, logistics costs, and investment as important areas related to port performance.
10. Congestion, cargo-handling delays, lack of advanced technology, and high logistics costs were treated as challenges based on respondents' perceptions.
11. The analysis is descriptive; therefore, the study does not claim statistical significance, causation, or population-wide generalization from the percentage and mean results alone.
12. The coded response dataset and questionnaire form the basis for the results presented in the main research paper.