

Analysis of Barriers Affecting Performance of Port Logistics in Industry 4.0

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Abstract

Port logistics is a complex process involving numerous interconnected activities. Port logistics are inherently volatile, uncertain, complex, and ambiguous (VUCA). Due to VUCA, it is necessary to enhance port logistics performance in order to remain competitive on the market. Recently, the digital revolution has facilitated process improvement across all industries. In the age of Industry 4.0, this study also seeks to identify and analyze the barriers affecting the performance of port logistics. The research offers a novel strategy for developing an analytic hierarchical model for analyzing and ranking the barriers. Reviewing existing literature and conducting semi-structured interviews with port managers during the field visit helped to identify barriers. Further, Fuzzy Set Theory (FST), Stakeholders Theory, and Analytical Hierarchy Process were utilized in this study to rank the identified barriers. The framework categorizes the barriers as strategic, tactical, and operational. In addition, it assists managers in understanding the barriers, making informed decisions, and addressing the barriers that require immediate attention.

Keywords

Barriers, Fuzzy- Analytical Hierarchy Process, Industry 4.0, Port Logistics, Stakeholder Theory

1. Introduction

Seaports have an impact on virtually every aspect of people's daily lives. It is evident by the fact that approximately 90 percent of the world's goods are transported by sea. Using bulk carriers, container ships, and tankers, more than 8 million tons of goods are transported by sea. The Marine Transportation System is comprised of six components: navigable waterways, terminals, vessels intermodal connections, and ports and shipping networks (Sarkar et al. 2022). Figure 1 depicts a maritime transportation system with an interface between land and water. The fourth Industrial Revolution can increase port logistics' overall throughput. Simulation, autonomous robots, cybersecurity, 3D printing, the Internet of Things, big data, cloud computing, system integration, and augmented reality are the nine pillars of Industry 4.0. Numerous European nations have begun integrating their ports with Industry 4.0 (Sarkar and Shankar, 2021). Due to the existing system's barriers, port industries are confronted with numerous problems and obstacles. Thus, it becomes vital to address the barriers which hinder the performance of port logistics in Industry 4.0 by categorizing and ranking it. The study develops a model to identify, rank, and categorize port logistics barriers in the era of Industry 4.0.

Port logistic barriers are responsible for disrupting the entire process and incurring enormous losses for port authorities, shipping companies, 3PL providers, etc. Due to its significance, the paper attempts to investigate the barrier and ranks them hierarchically. The research creates a framework to assist managers and port operators in overcoming the identified obstacles. The purpose of this study is to identify the barriers facing port logistics in the age of Industry 4.0. Multiple Stakeholders theory has been incorporated into the process of identifying barriers. Using the

Fuzzy-AHP method, a hierarchy of port logistic barriers has been developed based on their severity. The final objective is to categorize the obstacles according to their decision-making properties.

The remainder of the paper is organized as follows: Section 2 provides a concise literature review. The third section explains how the stakeholder theory has been incorporated into the Fuzzy-AHP method to model the barriers. In Section 4, results and discussions are presented, followed by a discussion of the conclusions and future scope.

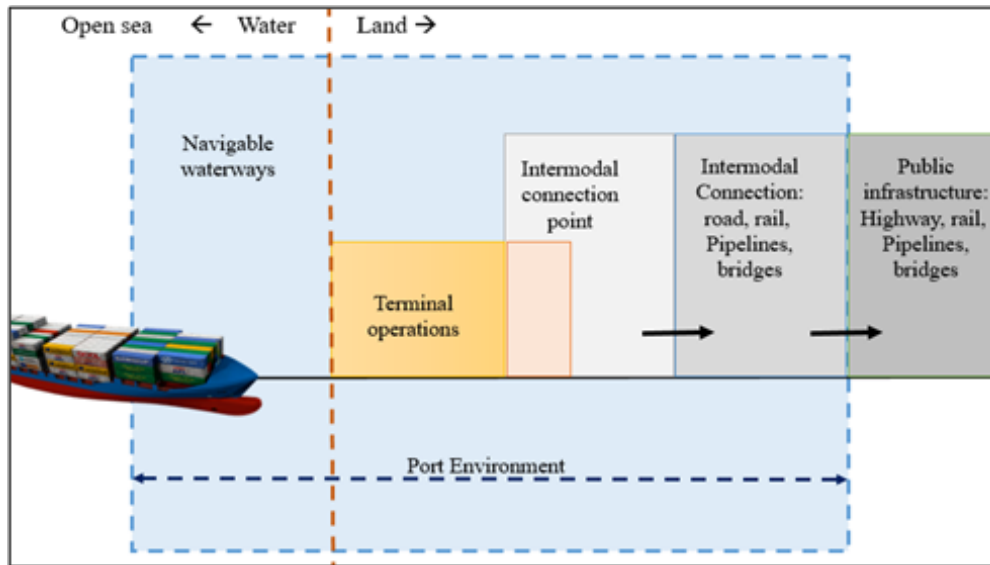


Figure 1. Sea-land Interface of Marine Transportation

2. Literature Review

2.1. Port Logistics

Port logistics encompasses a vast array of operations, including loading/unloading, customs paperwork, warehousing, etc. It contributes to the economic growth of the nation. Industry 4.0 has the potential to enhance the efficiency of ports (Douaioui, et al., 2021). Countries such as China, Germany, Spain, the United States, etc. have recently implemented Industry 4.0 in their ports. Table 1 displays a brief literature review on port logistics for Industry 4.0.

Table 1. Selected Literature in the Context of Port Logistics

Author	Description
Douaioui et al. (2018)	Explain smart logistics. The framework that helps logistic operators with smart ports.
Muhammad et al., (2018)	Developed a model with automation and robotics. Enhances the port operation in Industry 4.0.
Sarkar et al., (2021)	A scenario-based interval-input output model to analyze the risk of COVID-19 pandemic in port logistics.
Ramirez et al (2020)	Connect various Industry 4.0 technologies with the supply chain. Studies green, lean, resilient, and agile shipbuilding supply chain.
Gonzalez et al., (2019)	Digitization of maritime logistics.
Sarkar & Shankar, (2021)	Identify the barriers in port logistics. Develops a model for understanding the barriers.
Andriani et al., (2019)	Identify risks associated with occupational safety in ports and develops risk mitigation strategies.
Lee, et al., (2018)	Framework for Fifth Generation Ports.

2.2. Barriers related to Port Logistics

Barriers play a crucial role in the operation of port logistics, as they diminish its effectiveness. It increases turnaround time, waiting time, equipment failure, etc., resulting in a decrease in port throughput. As shown in Table 2, this study identifies port logistics barriers in the era of Industry 4.0. Section 3 discusses the steps involved in identifying and finalizing port logistics barriers.

Table 2. Key Barriers of Port Logistics in Industry 4.0

Barriers	Description	Sources
Lack of coordination (B1)	Coordination among shipping companies, 3PL providers, port operators, etc. is required.	(Ozcan, Eliiyi, & Reinhardt, 2020)
Terminal congestion (B2)	Inadequate planning and poor forecasting lead to congestion in terminals.	(Loh, Zhou, Thai, Wong, & Yuen, 2017)
Inadequate use of data in decision making (B3)	Managing and processing a huge amount of data is a difficult task.	(Chauhan, Agarwal, & Kar, 2016)
Lack of employee incentives (B4)	Fewer incentives lead to higher corruption, insecurity between economic agents, agency problems, etc.	(Dwivedi et al., 2019)
Deficit number of domain experts and training (B5)	Learning and unlearning new methods is a difficult task.	(Lam & Bai, 2016)
Port strikes (B6)	Disagreement among port authorities, managers, workers leads to port strikes.	(DePillis, 2015)
Container imbalance problem (B7)	The mismatch between supply and demand leads to CIP	(Kuzmicz & Pesch, 2019)
Lack in Research & Development (B8)	Governments are providing fewer funds for research and development.	(Chen, Wei, & Peng, 2018)
Regulatory issues (B9)	Inadequacy in custom works. Different rules for national and international vessels carriers.	(Venkatesh et al., 2017)
Inadequate infrastructure (B10)	It increases the overall waiting time of ships and degrades the efficiency of port logistics.	(Kuznetsov, Dinwoodie, Gibbs, Sansom, & Knowles, 2015)
Agency problems (B11)	The conflict between an individual, group, port authorities.	(Shermin, 2017)
Less RoI (B12)	Generating profit from ports is a time taking process.	(Styhre & Winnes, 2019)
Less number of Stakeholders involvement (B13)	The disagreement between stakeholders to have a common goal is a difficult task.	(Almutairi et al., 2019)
Stacking problem (B14)	Inefficient positioning of containers for loading and unloading to trucks/ships.	(Maldonado, González-Ramírez, Quijada, & Ramírez-Nafarrate, 2019)
Mismatch in operating standards (B15)	Mismatch of technologies, infrastructure, and management between local and international ports.	(Mdlankomo, 2017)
Technology mapping issues (B16)	Use of proper algorithm is necessary for determining turn around time, waiting time, stacking the containers, etc.	(Bierwirth & Meisel, 2015)
Lack in trust (B17)	Lack of information sharing, profit sharing, experience, transparency, etc. leads to a lack of trust.	(Bag, Gupta, & Telukdarie, 2018)
Unsatisfied customers (B18)	Due to delay in delivery, prolonged custom works, lack of coordination, lack in customer services, etc.	(Ferretti, Parmentola, Parola, & Risitano, 2017)

3. Methods

The methodology offers an algorithm that combines Stakeholder's Theory (ST), Fuzzy Set Theory (FST), and Analytical Hierarchy Process (AHP). In the age of Industry 4.0, this study develops a fuzzy analytical hierarchical

framework for port logistic barriers. Figure 2 depicts the flowchart for the developed methodology. Presented below are the steps involved in the methodology for identifying and ranking the barriers.

- Step 1. Identifying the port logistics barriers in the era of Industry 4.0.
- Step 2. Apply stakeholders' theory to finalize the port logistics barriers.
- Step 3. Formulating the pair-wise comparison matrix to capture experts' linguistic terms in the form of Triangular Fuzzy Numbers (TFNs)
- Step 4. Applying the geometric mean technique
- Step 5. Defuzzification of the geometric mean values
- Step 6. To validate the matrices
 - Step 6.1: To check the matrices consistency
 - Step 6.2: if Consistency Ratio (CR) is less than 0.10, acceptable else start again from step 3.
- Step 7: Calculate the final ranking of barriers.

3.1. Identification of Barriers of Port Logistics using Stakeholder Theory

Freeman (1984) was the first to define stakeholder theory. It states that "a company's stakeholders include any individual, group, or community affected by the company's success." The stakeholders in port logistics include shipping companies, 3PL providers, non-profit organizations, and others. As shown in Table 3, Lam & Yap (2019) compiled a list of the various stakeholders involved in port-related activities.

The study identifies various barriers by conducting a field visit to one of India's major container handling ports and by conducting a literature review. In addition, a workshop was held to gather the opinions of the involved parties regarding the obstacles. Experts were asked to define the obstacles in the workshop based on their knowledge and experience. Stakeholders are from concerned sectors: two were government officials, one was a supply chain partner, one was from the port community, and one was an academic who helped finalize the Industry 4.0 port logistics barriers presented in Table 2 of section 2.2.

Table 3. Stakeholders involved in Port Logistics Decision Making

Stakeholders Type	Stakeholders	Decision Makers
Internal	Minority shareholders, Port employees	No
	Port managers, Board members	Yes
	Ports owners	Yes
Public Sector	Port authority; port state control	Yes
	Ministries-in-concern e.g., Labour unions, Urban development authorities, Environment Ministry, Finance Ministry, Transport Ministry	Yes
Corporate bodies/ Market Players	Inland and Sea transport operators, Stevedoring companies, logistics companies, shipping, and transport companies,	Yes
Community; Interest Groups	Non-profit organisations (NGOs) e.g., press, media, environmental groups	No
	Taxpayers and customers	No

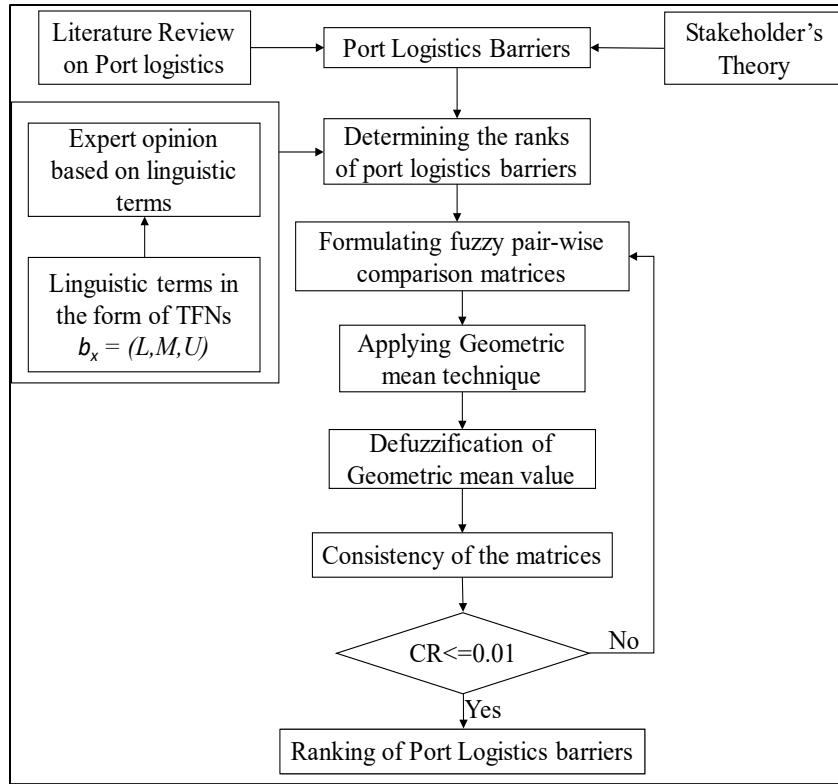


Figure 2. Methodological Flowchart

3.2. Implementing Fuzzy-AHP

AHP is a decision-making technique that organizes judgments, emotions, memories, and perceptions into a multilevel structure (Satty, 1996). Fuzzy-AHP is an advanced form of AHP that incorporates fuzziness because it is simpler to provide fuzzy judgments than crisp ones. Chang's extent analysis is the most frequently used Fuzzy-AHP method in the literature. Fuzzy-AHP is used in this study to rank the identified Industry 4.0 port logistics obstacles. The following are the symbols used in this study:

- b_x = Triangular Fuzzy Numbers (L, M, U),
- L = lower value,
- M = middle value,
- U = upper value,
- b_{ij} = relative importance when events are compared,
- $n * n$ = matrix order,
- k = number of experts
- e_{ij}^k = expert's judgment in TFN format (Table 4)
- $b_{i,n}$ = comparison value of the matrix.

$$b_x = (L, M, U) \quad \dots (1)$$

$$b_{ij} = (1/n) \otimes (e_{ij}^1 \oplus e_{ij}^2 \oplus e_{ij}^3 \oplus e_{ij}^4) \quad \dots (2)$$

$$b_{ji} = (1/ b_{ij}) \quad \dots (3)$$

$$b = \begin{pmatrix} b_{11} & b_{12} & \dots & b_{1n} \\ b_{21} & b_{22} & \dots & b_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ b_{n1} & b_{n2} & \dots & b_{nn} \end{pmatrix} \quad \dots (4)$$

g_i = geometric mean of the i^{th} row in the matrix

$$g_i = (b_{ij} \otimes b_{ij} \otimes \dots b_{ij})^{1/n} \quad \dots (5)$$

r_i = fuzzy rank of i^{th} criteria

$$r_i = g_i \otimes (g_1 \oplus g_2 \dots \oplus g_n)^{-1} \quad \dots (6)$$

r_i^l, r_i^m, r_i^u = fuzzy rank (lower, middle, upper) of i^{th} criteria.

Now,

Defuzzification is carried out to locate the Best Non-fuzzy Performance value (BNP).

$DF(r_i)$ = de-fuzzified mean for r_i^l, r_i^m, r_i^u .

$$DF(r_i) = \frac{r_i^l + r_i^m + r_i^u}{3} \quad \dots (7)$$

$$r_i = \frac{DF(r_i)}{\sum DF(r_i)} \quad \dots (8)$$

CR was employed to assess the consistency of the pairwise comparison. If the value of CR for the comparison matrix is less than 0.10, it is acceptable. In this investigation, the value of RI was determined to be 1.6181 (Alonso & Lamata, 2006).

Where,

CI = consistency index.

RI = average random index.

CR = consistency ratio

$$CR = CI/RI \quad \dots (9)$$

β_{\max} = maximum value of $n \times n$ matrix

$$\beta_{\max} = \frac{\sum_{j=1}^n \sum_{k=1}^n (r_k \frac{b_{jk}}{r_j})}{n} \quad \dots (10)$$

$$CI = (\beta_{\max} - n) / (n - 1) \quad \dots (11)$$

Table 4. Linguistic Terms used in the study

Sl. No	Importance Level	(TFNs)
1	Equal Importance	(1,1,2)
2	Between equal and weak importance	(1,2,3)
3	Weak importance	(2,3,4)
4	Between strong and weak importance	(3,4,5)
5	Strong Importance	(4,5,6)
6	Between strong and very strong importance	(5,6,7)
7	Very strong importance	(6,7,8)
8	Between very strong and absolute importance	(7,8,9)
9	Absolute importance	(8,9,9)

4. Results and Discussions

As shown in Table 5, Fuzzy-AHP analysis was used to determine the rankings of port logistics barriers in the era of Industry 4.0. It displays the non-normalized value, the normalized value, and their overall contribution percentage. It is evident from Table 5 that the regulatory issues barrier (B9) is at the top of the hierarchy of barriers, contributing 18.56 percent, followed by inadequate infrastructure (B10) with 13.52 percent and lack of research & development

(B8) with 13.32 percent. Bottom of the hierarchy are obstacles such as agency problems (B11), dissatisfied customers (B18), and lower return on investment (B12), with 0.97 percent, 0.88 percent, and 0.79 percent, respectively.

Figure 3 depicts the normalized percentage value of eighteen barriers. According to the pie chart, regulatory issues (B9), inadequate infrastructure (B10), a lack of research & development (B8), a small number of stakeholders' participation (B13), a mismatch in operating standards (B15), and technology mapping issues (B16) account for approximately 70 percent of the total. These are considered to be unstable barriers. Therefore, in order to improve the overall process of port logistics, decision-makers must address the obstacles immediately.

Table 5. Ranking of the Barriers of Port Logistics in Industry 4.0

Barriers	Non-Normalized value	Normalized value	Percentage contribution (%)
B1	0.049401	0.0472	4.72
B2	0.018618	0.0178	1.78
B3	0.031482	0.0300	3.00
B4	0.012456	0.0119	1.19
B5	0.043656	0.0417	4.17
B6	0.027036	0.0258	2.58
B7	0.029931	0.0286	2.86
B8	0.139523	0.1332	13.32
B9	0.194497	0.1856	18.56
B10	0.141685	0.1352	13.52
B11	0.010207	0.0097	0.97
B12	0.00832	0.0079	0.79
B13	0.087063	0.0831	8.31
B14	0.018269	0.0174	1.74
B15	0.079449	0.0758	7.58
B16	0.086786	0.0828	8.28
B17	0.060065	0.0573	5.73
B18	0.00925	0.0088	0.88
Total	1.047696	1.0000	100

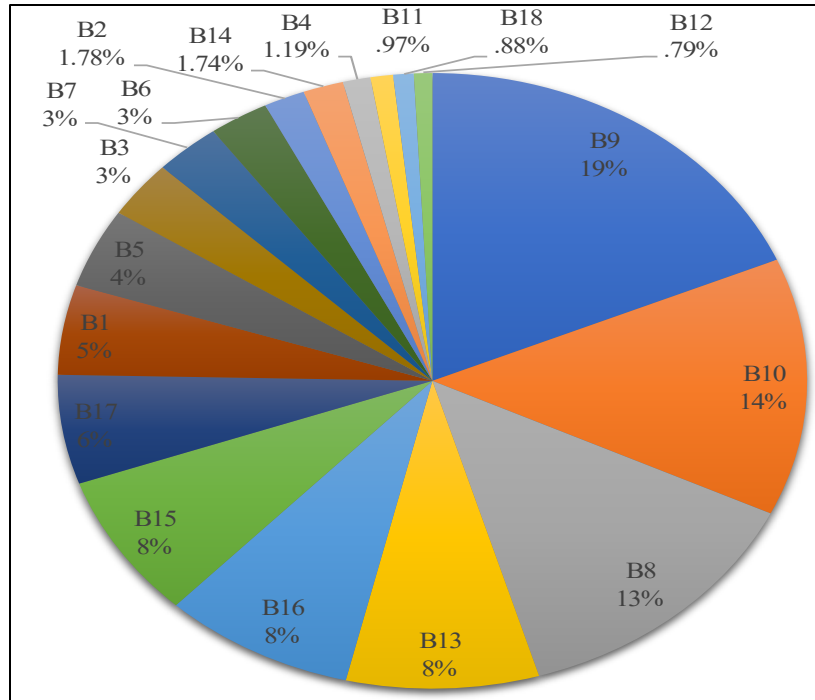


Figure 3. Pie Chart representing Normalized Percentage of Barriers

Figure 4 depicts the barrier hierarchy with their normalized value. Figure 4 helps us classify the barriers into three categories, namely strategic, tactical, and operational, based on the various types of decisions. Strategic decisions are long-term, and they facilitate the direction and control of tactical decisions. Tactical decisions are short-term decisions made to optimize routine processes. Operational decisions are daily decisions taken on detailed data. Figure depicts strategic decisions as red dotted lines, tactical decisions as orange dotted lines, and operational decisions as green dotted lines. The framework's outcomes aid decision-makers in their comprehension of the obstacles. To enhance the efficacy of port logistics, decision-makers can immediately concentrate on the strategic obstacles. Dealing with strategic barriers increases port logistics efficiency to a limited degree. To achieve a higher throughput in port logistics, decision-makers must first address tactical barriers, then operational ones.

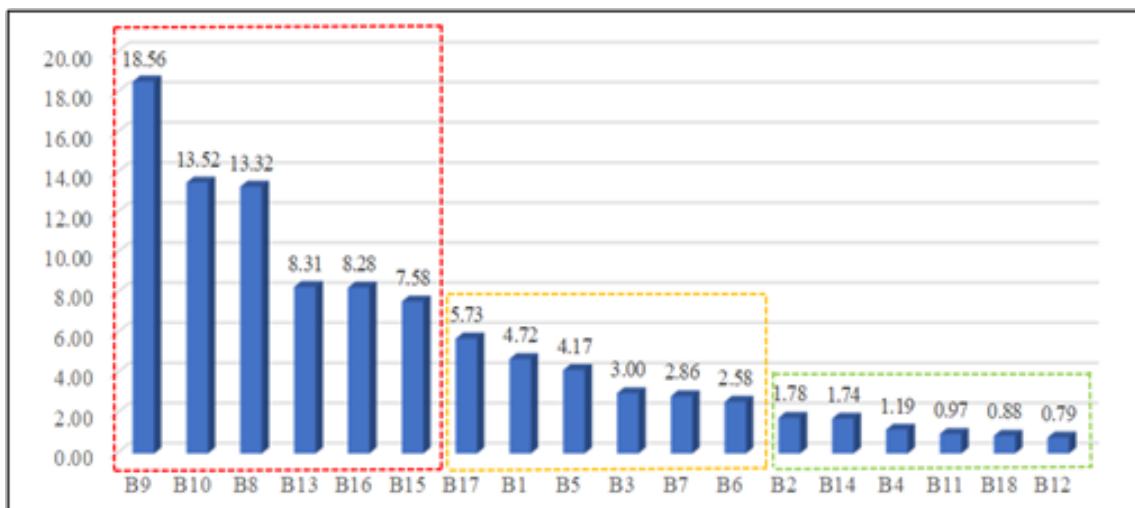


Figure 4. Classification of Port Logistics Barriers

5. Conclusion

In the global supply chain, port logistics play an important role in the transfer of goods. In the era of the fourth industrial revolution, ports are confronted with a number of obstacles during its implementation, which hinders the overall performance of port logistics. In the era of Industry 4.0, the research develops a hierarchical framework for ranking the port logistics obstacles. The study consists of two phases. In the era of Industry 4.0, the first phase entails identifying the various port logistics barriers. By conducting a field visit in one of India's major container handling ports and analyzing the available literature, barriers were identified. A workshop was held to collect the opinions of multiple port logistics stakeholders and to finalize the port logistics obstacles. In the second phase, Fuzzy-AHP was used to rank the barriers. Findings aid decision-makers in determining which obstacles require immediate attention. In addition, it facilitates the classification of barriers into three distinct categories based on their decision-making properties. In future research, subfactors of the obstacles could be identified and investigated. It is possible to conduct a sensitivity analysis of port logistics obstacles in the era of Industry 4.0.

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Biography

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