Journal of South Asian Logistics and Transport
Volume 6 Issue 1 March 2026
JSALT 6.1.5: pp. 109-139
DOI: https://doi.org/10.4038/jsalt.v6i1.137

ASSESSING THE BARRIERS AND READINESS FOR THE INTEGRATION OF MULTIMODAL TRANSPORTATION IN THE MARITIME LOGISTICS SECTOR OF SRI LANKA

C H P W M R G Katupitiya [*] ***and C A Kavirathna***

Department of Industrial Management, University of Kelaniya, Sri Lanka

[*] Correspondence should be addressed to gayathrikatu@gmail.com

ABSTRACT

Although multimodal transportation (MMT) is being promoted as a sustainable solution to enhance freight efficiency and port hinterland connectivity, many developing economies still have limited integration of MMT. This study examines the key barriers and current readiness of Sri Lanka's maritime logistics industry for MMT integration. A survey-based approach was employed to capture industry stakeholders' perceptions, targeting maritime and logistics professionals in Sri Lanka, following the snowball sampling method, and the data were analysed using Partial Least Squares Structural Equation Modelling (PLS-SEM) to evaluate the impact of five pre-identified barrier categories on MMT integration. A readiness assessment covering seven readiness dimensions was conducted concurrently, adopting a Balanced Readiness Level (BRL) framework. The findings indicate that market and economic, technological, and infrastructure barriers had the most significant detrimental impact on MMT integration, whereas readiness analysis revealed initial preparedness as an overall of seven considered dimensions. The findings provide useful insights for setting priorities for phased investments and policy interventions.

Keywords: *Multimodal transportation, maritime logistics, barriers to integration, readiness assessment, Sri Lanka*

1. INTRODUCTION

Multimodal transportation (MMT) can be defined as the involvement of two or more transport modes under a single contract, which has become essential for modern freight logistics, facilitating global trade to improve supply chain efficiency, shorten transit times, and boost sustainability through integrated modal connections. Many developed and emerging economies have advanced their multimodal systems by investing in digital technologies, creating regulatory frameworks, and building intermodal infrastructure [1].

With the Port of Colombo serving as a major regional transshipment hub and Sri Lanka located along major East-West maritime routes, the country has enormous opportunities for multimodal freight development. Nevertheless, the country's logistics sector remains heavily dependent on unimodal road transport. Weak rail freight utilisation, absence of well-developed inland terminals, fragmented stakeholder coordination, and inconsistent technological integration collectively hinder the progress of MMT integration [2]. Existing scholarly work from Sri Lanka and other emerging economies tends to focus on port operations or individual modes, offering limited insight into multimodal integration as a systemic challenge.

Although there is a considerable amount of literature on the development of multimodal transport worldwide, most of it focuses on optimisation methods, terminal operations, or simulation-based network design [3], [4]. However, developing countries such as Sri Lanka frequently lack the fundamental evaluations required to comprehend their current capacities, institutional constraints, and stakeholder alignment. Therefore, rather than reproducing simulation-focused studies, this research aims to provide a diagnostic study of the practical limits and preparation elements in the Sri Lankan setting.

The main problem identified is the lack of a clear understanding of the barriers to integrating MMT and whether Sri Lanka's maritime logistics system is ready for this integration. Unlike countries that have successfully adopted MMT by recognising key constraints and gaps in their institutions, Sri Lanka lacks studies that focus on these areas. As a result, important stakeholders, such as legislators, port officials, and logistics operators, lack the knowledge necessary to create coordinated plans for multimodal deployment.

An integrated understanding of the barriers to multimodal transport integration, as well as the readiness of the maritime logistics industry to implement such systems, is necessary to close the identified gaps. Accordingly, this study evaluates the influence of infrastructural, technological, operational-human resource, market-economic, and institutional-regulatory barriers using Partial Least Squares Structural Equation

Modelling (PLS-SEM). In addition, the study uses a Balanced Readiness Level (BRL) framework to evaluate readiness in a selection of areas. Through this combined assessment, the study provides new empirical insights into the practical limitations affecting multimodal transport integration in Sri Lanka and identifies the enabling factors required to support future implementation, following the objectives of this study.

i. To identify the key features of MMT and outline potential barriers through a systematic literature review.
ii. To evaluate the critical barriers affecting multimodal transport integration in Sri Lanka's maritime logistics sector.
iii. To assess the current readiness of the sector using a multidimensional readiness framework.
iv. To propose strategic recommendations to enhance multimodal transport integration and improve freight movement efficiency.

2. LITERATURE REVIEW

2.1. Global Evolution of Multimodal Transportation

Maritime logistics refers to the process of ensuring the effective, affordable, and sustainable movement of goods using ports, shipping lines, hinterland transportation techniques, and supporting infrastructure [1].

Sixty-nine scholarly publications were systematically reviewed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to provide a comprehensive and transparent foundation for understanding global developments in multimodal transport. Accordingly, scholarly interest in multimodal transport integration has evolved, as evidenced by the distribution of studies by year of publication. As shown in Figure 1, there are fewer studies on MMT integration in the early years, and it has gained increasing recognition as a strategic logistics approach over time.

There is a growing awareness of the potential of MMT to address challenges, such as port congestion, hinterland connectivity, and sustainability goals. The need for integrated solutions and the growing complexity of global logistics networks has been highlighted by the increasing amount of research conducted in the last ten years.

According to the review, Asia and Europe are the most common regions in multimodal transport research, accounting for a significant portion of the studies. Europe follows, with advanced multimodal systems in countries such as the Netherlands, Germany, and the United Kingdom, where policies, infrastructure, and technological integration for multimodal systems are well-established [5]. South

America and Africa are relatively under-represented because of institutional barriers, lack of infrastructure, and low rates of technology adoption.

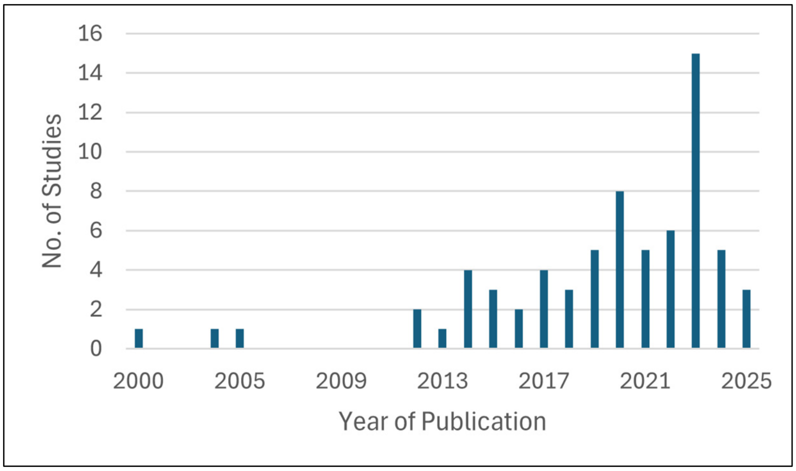

Figure 1: Variation of studies by year of publication

Figure 2 shows that developed economies have significantly higher values, representing 55 studies focused on developed regions. Owing to demanding laws, regulations, and technological integration, MMT networks are well-established in North America, Europe, and developed Asian nations such as South Korea and Japan, where many of these studies are centred [6]. By emphasising digital innovation, policy frameworks, and port-hinterland connectivity, these regions demonstrate their commitment to efficiency, sustainability, and the adoption of the latest technologies.

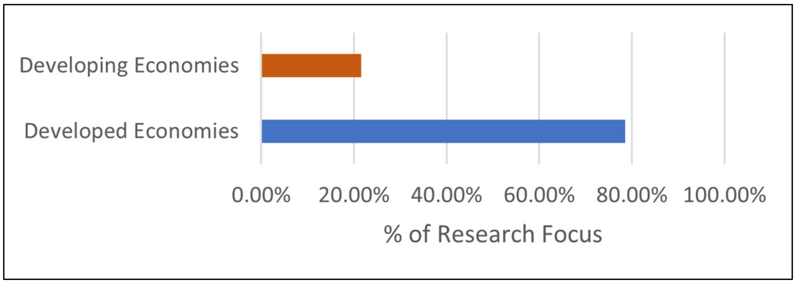

Figure 2: Research focus - Developing vs. developed countries

The representation of developing economies is much smaller, while some studies have addressed regions such as Sri Lanka, India, Bangladesh, South America, Africa, and the Caspian Sea regions [7]. In these regions, the successful integration of multimodal transport systems is hindered by institutional barriers, technological gaps, and inadequate infrastructure. Despite their growing significance in international trade, there has been little research on emerging economies.

2.2. Barriers to Multimodal Transport Integration

Currently, MMT is becoming more widely acknowledged as an effective and sustainable way to improve international freight transport, and several countries are actively planning to increase its adoption. For example, the European Union has set ambitious targets to shift freight from roads to more ecologically friendly options, such as rail and inland waterways [6]. Similarly, China is attempting to link port systems with rail and road networks to enhance the multimodal transport network [8]. In Indonesia, integrating rail and maritime transport on Java Island has been a key strategy to lower transportation costs and enhance regional logistics operations [9].

Despite these efforts, several barriers impeding the widespread adoption of MMT, particularly in developing nations. One significant barrier is infrastructure constraints. Additionally, regulatory discrepancies between different transport modes and the high capital investment required to develop integrated infrastructure are key obstacles to the expansion of MMT networks [10]. Delays in cargo movement are caused by capacity constraints, ineffective terminal operations, and antiquated handling machinery. The environmental impact of the maritime logistics industry has also drawn increased attention as people's awareness of climate change has increased. Almost all worldwide greenhouse gas emissions are attributable to this industry, especially heavy-duty shipping vessels that burn fossil fuels [11]. Simultaneously, the absence of intermodal terminals is a considerable barrier to MMT adoption [6, 10]. Bottlenecks are caused by massive cargo volumes and inefficient terminal operations [1]. The growing size of container ships is causing congestion in many major ports, making it more difficult to effectively handle MMT [11]. The absence of government support for the development of MMT infrastructure also acts as a considerable barrier. Many governments have not prioritised multimodal systems in their transportation plans. Instead, they have focused solely on road transportation. This focus limits the possibility of developing integrated transport networks [9].

In Sri Lanka, most freight movements occur by road, and there is minimal integration between maritime and other transport modes. This situation restricts the efficiency of hinterland connectivity [12]. Local logistics systems that support these operations face issues such as road congestion, slow container turnaround times, and low rail freight usage [13]. Although the railway system historically played an important role in moving freight, its current use for container transport remains low and scattered. This is largely limited to a few bulk goods and industrial cargo streams [2]. Additionally, national spatial planning documents, such as the National Physical Plan 2050, show how land use and transportation development can be combined. However, fragmented governance and a lack of sectoral cooperation continue to impede progress [2].

Through thorough thematic coding of the selected publications, 22 barriers to the integration of MMT were identified and compiled, as shown in Table 1, which can be described under five main categories.

Table 1: Categorisation of identified barriers for the integration

Barrier Categories	Barriers	References
Infrastructure-related barriers	Insufficient intermodal terminals, lack of hinterland connections, low rail-road connectivity at ports, low quality and capacity of existing transport infrastructure	[6], [10], [14], [15], [16], [17], [18], [19], [20]
Operational and human resource barriers	Irregular service frequency, lack of service reliability, lack of cargo handling efficiency, lack of skilled workforce in logistics management, poor competence in managing complex multimodal transport systems	[6], [10], [11], [16], [19]
Institutional, policy, and regulatory barriers	Regulatory misalignment, lack of coordination between transport agencies, customs inefficiency and delays, poor supportive government policies for multimodal transport adoption, and poor stakeholder engagement in decision-making processes	[7], [10], [11], [16], [19], [21]
Technological barriers	Slow adoption of modern digital platforms, limited automation in ports, lack of Io systems, and real-time data sharing	[4], [6], [10], [11], [16], [22]
Market & economic barriers	High transition costs, lack of sufficient financial incentives for companies adopting multimodal transport, poor analysis of the cost efficiency of multimodal solutions, and lack of long-term funding mechanisms	[6], [10], [11], [12], [20], [23]

2.3. Readiness Assessment Criteria for the Integration of MMT

Furthermore, 42 readiness assessment criteria were identified through a systematic review process. These criteria were extracted from the selected studies and subjected to a thorough thematic coding procedure that eliminated duplication by combining conceptually related items. The finalised criteria were categorised into seven identified primary dimensions: institutional capacity, infrastructure, technology, human resources, financial readiness, and environmental considerations.

The availability of multimodal facilities, the level of terminal connectivity, the standard of port-hinterland access, and the overall strength of modal linkages all influence infrastructure readiness [10], [18], [19], [24]. The degree of digitalisation and ICT system deployment, the use of integrated digital workflows, the accessibility of real-time data and tracking capabilities, and the degree of digital awareness among stakeholders are indicators of technological readiness [25], [26], [27]. In the institutional and policy domains, readiness is impacted by the existence of a supportive institutional ecosystem, clear multimodal policies and legal provisions, and alignment with national transport strategies [7], [19].

The use of standardised operating procedures, the availability of a skilled workforce, the presence of continuous learning mechanisms, and exposure to MMT principles are all components of operational and human resource readiness [10], [16], [19]. The financial dimension encompasses the role of public-private partnerships in promoting multimodal development, the availability of funding and incentive mechanisms, and investment programs [11], [14], [28]. Environmental readiness is reflected through compliance with environmental regulations, active monitoring systems, and the incorporation of sustainability or green logistics practices [11], [17], [29]. Additionally, the degree of cooperation and coordination among important players, participation in cooperative projects, and the existence of multistakeholder platforms that support co-development initiatives all influence stakeholder cooperation readiness [6], [10], [19]. Together, these criteria form a comprehensive structure for assessing the readiness of a logistics ecosystem to adopt and sustain multimodal transport solutions.

In conclusion, despite the global evolution of MMT, the literature specific to Sri Lanka remains scarce. Existing studies largely examine maritime operations or the conceptual feasibility of inland freight options, but do not investigate interconnected multimodal systems. There is minimal empirical evidence explaining how maritime and inland networks interact in practice, and limited research has incorporated stakeholder perspectives. Furthermore, no prior studies have examined both barriers and readiness together or applied a structured framework to evaluate Sri Lanka’s preparedness for MMT integration. These limitations underscore the need for the present study.

3. METHODOLOGY

To investigate the barriers and prepare for the integration of multimodal transport within Sri Lanka's maritime logistics industry, a quantitative research design was used, as shown in Figure 3. A comprehensive literature review, the creation and validation of a conceptual framework for barriers, and the evaluation of sectoral readiness were the three successive stages of the research process.

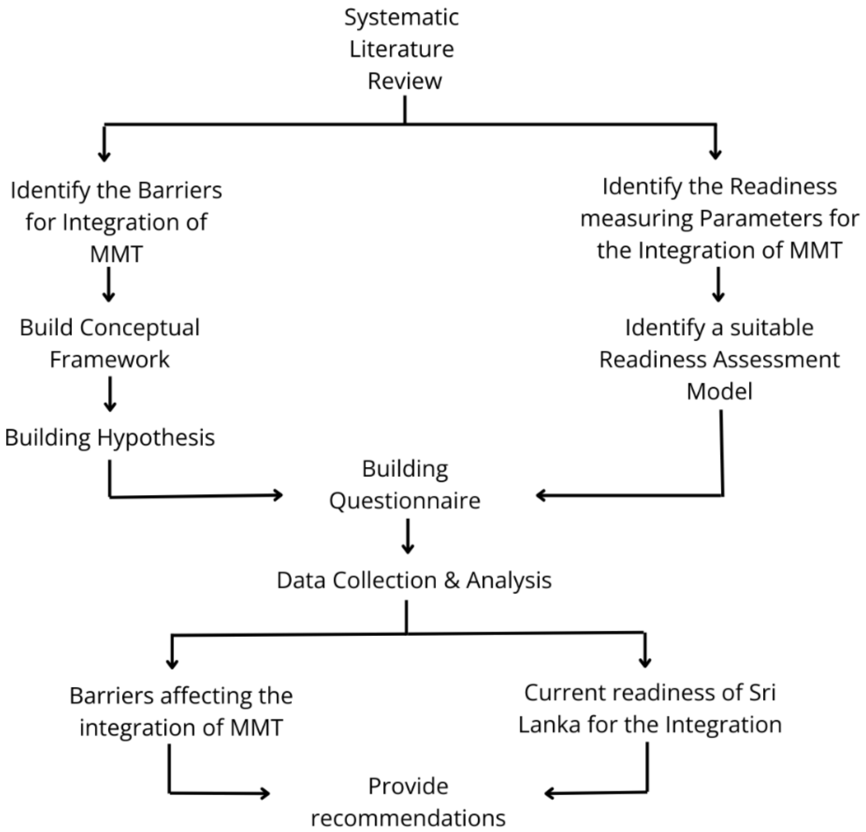

Figure 3: Research design

To identify MMT concerns in the marine industry and major obstacles that have been shown to impede the integration of MMT in various global and regional contexts, a systematic literature review was conducted in the first phase. Concurrently, a pertinent set of readiness variables and readiness assessment dimensions was identified from previous research and modified to fit the Sri Lankan marine industry. The results of the literature review were combined to create a conceptual framework in which barriers were divided into five primary groups: institutional, policy and regulatory, technological, market and economic, operational and human resource, and infrastructure.

Based on this framework, hypotheses were formulated to investigate the influence of each type of barrier on the successful integration of MMT. Investigating the complex relationships between different latent constructs and with a small-to-medium sample size, PLS-SEM analysis was selected as the analysis method for the assessment of barriers. A structured questionnaire with measurement components gathered from reliable literature was developed for data collection. Port authorities, shipping lines, freight forwarders, logistics service providers, inland transport operators, terminal operators, and Sri Lankan customs involved in multimodal freight operations and maritime logistics in Sri Lanka were among the target population. The questionnaire was distributed electronically, and data were collected over a period of four months. The objectives of the data analysis were to determine the explanatory capacity of the suggested framework, evaluate the validity and reliability of the constructions, and validate the conceptual model.

A customised readiness assessment model, which was developed from multidimensional frameworks found during a comprehensive literature analysis of earlier related studies, was used to evaluate the sector's current readiness status.

To reduce integration barriers and improve the overall readiness of Sri Lanka's maritime logistics industry for MMT adoption while considering identified contemporary global issues, the study's findings were utilised to develop strategic recommendations for pertinent stakeholders and policymakers.

A conceptual framework was developed using the 22 indicators identified during the systematic review (see Table 2). The indicators were categorised into five major barrier categories and modelled against the dependent variable, the success of MMT integration in the maritime logistics sector of Sri Lanka.

Table 2: Variable identification

Variable	Indicator ID	Indicator
Infrastructure Barriers	(IB 01)	Availability of multimodal terminals
	(IB 02)	Railroad connectivity at ports
	(IB 03)	Quality and capacity of existing transport infrastructure
	(IB 04)	Development of dry ports and inland logistics centres
	(IB 05)	Alignment of inland port capacities
Operational and Human Resource Barriers	(OHB 01)	Service frequency
	(OHB 02)	Service reliability
	(OHB 03)	Cargo handling efficiency
	(OHB 04)	Availability of a skilled workforce in logistics management
	(OHB 05)	Competence in managing complex multimodal transport systems
	(OHB 06)	Continuous training and capacity-building programs for logistics professionals
Institutional, Policy, and Regulatory Barriers	(IPRB 01)	Existence of regulations to facilitate coordination among transport modes
	(IPRB 02)	Supportive government policies for multimodal transport adoption
	(IPRB 03)	Stakeholder engagement in decision-making processes
	(IPRB 04)	Policy stability

Variable	Indicator ID	Indicator
Technological Barriers	(TB 01)	Adoption of ICT tools
	(TB 02)	Automation in port operations
	(TB 03)	Integration of digital platforms across transport modes
	(TB 04)	Availability of real-time data for decision-making
Market and Economic Barriers	(MEB 01)	Availability of financial resources for infrastructure development
	(MEB 02)	Availability of long-term funding mechanisms for freight logistics development
	(MEB 03)	Availability of financial incentives for companies adopting multimodal transport

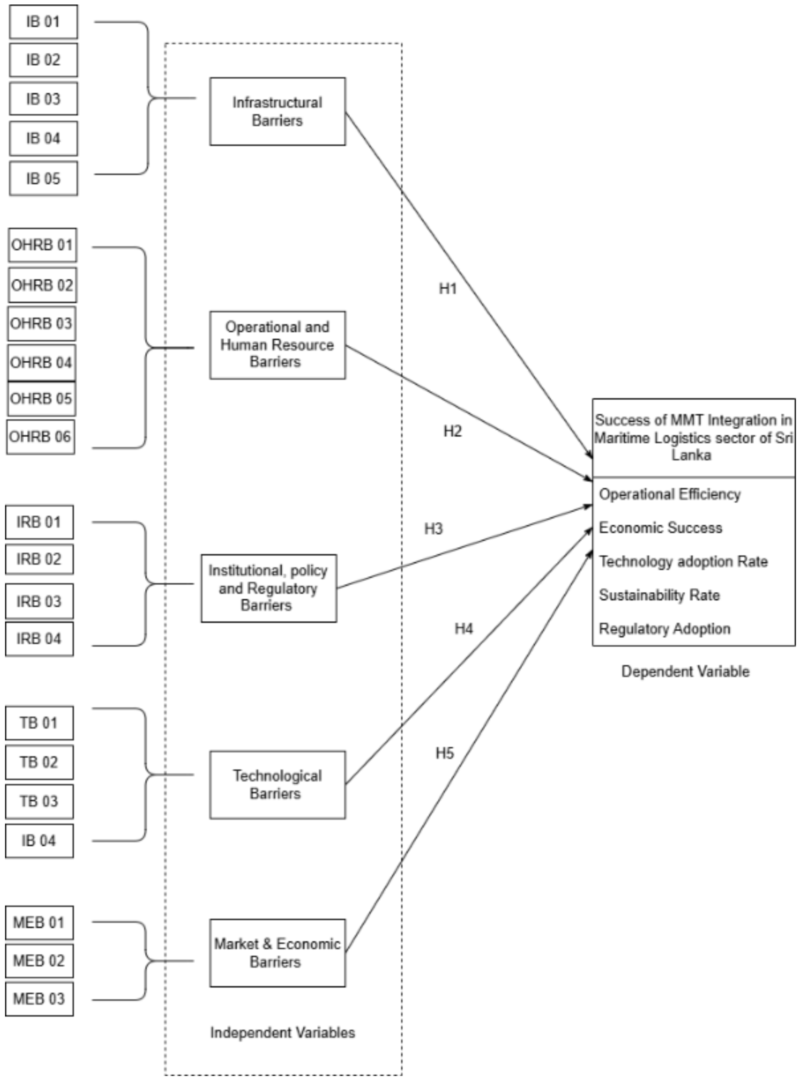

Figure 4: Conceptual model

Based on the conceptual framework, five hypotheses were formulated to examine the effect of each barrier category on the success of MMT integration in Sri Lanka's maritime logistics sector, as shown in Table 3.

Table 3: Hypothesis development

H1	Infrastructural barriers significantly impact the success of MMT integration into maritime logistics.
H2	Operational and human resource barriers significantly impact MMT integration.
H3	Institutional, policy, and regulatory barriers significantly affected MMT integration success.
H4	Technological barriers significantly affect the success of MMT integration in maritime logistics.
H5	Market and economic barriers significantly affect the success of MMT integration.

The Balanced Readiness Level Assessment (BRLa) framework proposed by Vik et al. [30] served as the basis for the readiness assessment in this study. The BRLa model provides a comprehensive framework for evaluating the readiness of emerging technologies across multiple dimensions, extending beyond the traditional Technology Readiness Level (TRL) approach. In the original study, the framework was developed to assess the adoption of emerging agricultural technologies in Norway by integrating five readiness dimensions: technological, market, regulatory, organisational, and acceptance.

The model evaluates readiness using a nine-level scale, where each dimension is assessed individually and then visualised to illustrate the overall balance of readiness across the system. Unlike purely numerical assessment tools, the BRLa framework adopts a descriptive and diagnostic approach, enabling a more comprehensive understanding of readiness that considers institutional, social, and regulatory factors alongside technological maturity.

Building on this framework, the current study assessed Sri Lanka's maritime logistics industry's readiness for MMT integration by implementing and expanding the BRLa matrix. This study adapted the model to the logistics and infrastructure context, whereas the original framework concentrated on the deployment of agricultural technologies. Consequently, a thorough literature review and thematic analysis were conducted to identify seven contextual dimensions that were added to the five original BRLa dimensions:

i. Infrastructure readiness: Availability and connectivity of multimodal terminals, dry ports, and transport corridors.
ii. Technological readiness: Level of ICT adoption, automation, and real-time data integration in port and logistics operations.

iii. Institutional and policy readiness: Degree of coordination among ministries, agencies, and public–private institutions.
iv. Operational and human resource readiness: Workforce competence, intermodal service efficiency, and process standardisation.
v. Financial readiness: Availability of funding, investment incentives, and public–private partnership frameworks supporting multimodal infrastructure.
vi. Environmental readiness: Integration of sustainable logistics practices and compliance with environmental regulations.
vii. Stakeholder cooperation readiness: Extent of collaboration, communication, and shared strategic vision among key logistics actors.

Table 4: Derived readiness assessment framework

Dimension/ Readiness Level	1 (Not Ready)	2 (Initial Stage)	3 (Developing)	4 (Moderate Readiness)	5 (Fully Ready)
Infrastructure Readiness	No multimodal infrastructure exists, the terminals are disconnected, and there are severe capacity issues.	Isolated facilities in place; initial feasibility studies or plans exist	Partial infrastructure exists (e.g., inland ports, dry ports); upgrades are ongoing	Major facilities upgraded or under expansion; good modal connectivity	Fully integrated multimodal hubs operational; seamless port-hinterland access
Technological Readiness	No ICT systems; digitalisation absent; manual processes dominate	Some awareness and plans for tech integration; systems under discussion	Pilot ICT tools; partial digital workflows; basic tracking tools used	Integrated digital platforms in place for operations and planning	Advanced digital systems across the chain; real-time data and optimisation are used
Institutional & Policy Readiness	No clear policies or legal provisions for MMT	Initial policy drafts or informal guidelines are emerging	Supporting regulations under development; moderate institutional support	Policies exist and are moderately enforced; aligned with national plans	Fully aligned national policies; supportive legal and institutional ecosystem
Operational & HR Readiness	No trained staff; siloed operations; low intermodal knowledge	Basic staff awareness; minimal exposure to MMT principles	Training programs initiated; some role specialisation evident	Most operational teams are trained; SOPs are available; intermodal functions are working	Highly skilled workforce; efficient intermodal coordination; continuous learning

Dimension/ Readiness Level	**1 (Not Ready)**	**2 (Initial Stage)**	**3 (Developing)**	**4 (Moderate Readiness)**	**5 (Fully Ready)**
Financial Readiness	No funding or planning for investment in MMT	Early-stage budget discussions; limited external support	Investment programs initiated; partial funding mechanisms active	Adequate funds available; support from public-private partnerships	Sustained funding, incentives, and investment; resilient financial support
Environmental Readiness	Environmental impact not considered; no green practices	Some green initiatives were introduced with low enforcement	Environmentally focused infrastructure is emerging (e.g., cleaner trucks)	Compliance with most environmental regulations; monitoring active	Environmental sustainability embedded in operations; emissions monitored
Stakeholder Cooperation Readiness	No engagement or coordination between actors	Limited, ad hoc partnerships; weak collaboration structures	Stakeholder dialogues initiated; some joint projects exist	Multistakeholder governance platforms exist; collaboration is formalised	Strong, continuous cooperation among actors; co-developed strategies in place

The derived readiness level framework in Table 4 describes the qualitative features of each dimension, including policy development, digital maturity, and institutional collaboration. These dimensions and was established with five progressive levels (1–5) ranging from "Not Ready" to "Fully Ready."

A structured Likert scale questionnaire created from the literature-derived indicators of the seven readiness dimensions and the five barrier categories was used to gather data for the study. Freight forwarders, shipping agents, port-related employees, and operators involved in inland logistics operations were the focus of the survey. The inclusion and exclusion criteria were at least five years of experience and a minimum education level of an advanced diploma or equivalent. After a total of 140 responses were screened for data consistency and preliminary data analysis using SPSS, with an emphasis on outliers and normality, 135 valid responses were retained for analysis. These responses met the minimum sample requirements recommended by Cohen (1992).

The assumed relationships between the five barrier categories for MMT integration were tested using PLS-SEM. The analysis was conducted using the conventional two-stage method, in which the inner model was evaluated to ascertain the significance and strength of the structural relationships after the outer model was evaluated to confirm indicator reliability and construct validity.

The data gathered for the seven readiness dimensions through the questionnaire were mapped onto the adapted BRL framework for the readiness assessment. According to the criteria derived from the systematic review, the mean score value method was used to align each respondent's scores with the five readiness levels. The overall readiness position of Sri Lanka's maritime logistics sector was ascertained by performing an aggregated interpretation following the determination of dimension-wise readiness levels.

4. ANALYSIS AND FINDINGS

Preliminary data analysis was conducted to ensure data quality and reliability. This process involves screening for missing values using mandatory fields, removing responses exhibiting suspicious or inconsistent patterns, and eliminating statistical outliers. Normality was assessed using skewness and kurtosis. Initially, 140 responses were collected. Following the preliminary analysis, 135 valid responses were retained for the main analysis.

4.1. Demographic Analysis

According to the respondent profile, the survey primarily captured opinions from experienced professionals. Approximately 60% of the respondents held senior executive or managerial positions, indicating strong representation from the sector's decision-making levels. Significant exposure to maritime and logistics operations was indicated by the fact that 65.2% of the participants reported having more than five years of industry experience. In terms of occupational background, most respondents were from logistics service providers (25.9%), freight forwarding companies (16.3%), and transport operations (15.6%), alongside over 15 other maritime and logistics-related occupations.

4.2. Measurement Model for Analysis of Barriers

The two main components of the conceptual framework in PLS-SEM are the measurement model and the structural model. The measurement model illustrates how each latent or composite variable is operationalised through its perceived indicators, thereby illustrating the relationship between constructs and their corresponding measurement items. However, because the structural model captures the suggested relationships between the latent variables, path analysis can be used to assess dependencies and causal associations. The measurement model focuses on evaluating internal consistency and validity, convergent validity, and discriminant validity.

4.2.1. Measuring internal consistency reliability

Consistency within reliability refers to how well the indicators of a certain construct consistently measure the same concealed principle. In the PLS-SEM framework, this reliability is typically assessed using Cronbach's alpha (α) and composite reliability. Cronbach's alpha assumes that all indicators contribute equally, whereas composite reliability provides a more accurate estimate by considering the different loadings of each indicator.

Initially, all constructs except Infrastructure Barriers (IB) recorded Cronbach's alpha (α) and composite reliability values above the recommended threshold of 0.7 [31], confirming adequate internal consistency reliability. The IB construct had slightly lower reliability values (α = 0.660; CR = 0.784), which were slightly below the optimal Cronbach's alpha threshold. This indicates that one or more indicators within the IB construct may not align strongly with the underlying latent factor. Therefore, the model was slightly revised by reviewing and potentially removing the indicators, IB_04, and IB_05, to enhance the reliability and representativeness of this construct [31]. Table 5 presents the revised and finalised Cronbach's alpha (α) and composite reliability values.

Table 5: Cronbach's alpha and composite reliability values

	Cronbach's alpha	Composite reliability
D	0.831	0.836
IB	0.701	0.700
IPRB	0.764	0.768
MEB	0.745	0.745
OHB	0.818	0.828
TB	0.700	0.710

4.2.2. Measuring convergent validity

The measurement of convergent validity checks the extent to which various indicators measuring one construct are related and jointly signify the underlying latent variable. In other words, the question is whether the indicators developed to measure a construct converge on some common theoretical construct. In the PLS-SEM modelling framework, convergent validity is often measured using the Average Variance Extracted (AVE) and indicator loadings.

Outer Loadings

Typically, individual indicator loadings would be preferably higher than 0.7, meaning each item has an appreciable contribution to its latent construct. Convergent validity is thus confirmed before the test of discriminant validity, as each construct is guaranteed to be theoretically significant and internally consistent.

The results showed that although most respondents reported sufficient loadings, a few lower indicators within OHB and TB could undermine the convergent validity of the composite model. Therefore, re-specification was considered for the low-loading items to improve construct reliability and support AVE values. Therefore, outer loadings higher than 0.7 were retained by eliminating OHB_03 and OHB_06 indicators. TB_04 was retained because its elimination resulted in no significant positive effect on the reliability of the model, as shown in Table 6.

Table 6: Outer loadings of the data set

	D	IB	IPRB	MEB	OHB	TB
D1	0.706					
D2	0.778					
D3	0.798					
D4	0.766					
D5	0.811					
IB_01		0.754				
IB_02		0.719				
IB_03		0.794				
IPRB_01			0.790			
IPRB_02			0.782			
IPRB_03			0.706			
IPRB_04			0.782			
MEB_01				0.832		
MEB_02				0.817		
MEB_03				0.791		
OHB_01					0.848	
OHB_02					0.794	
OHB_04					0.801	
OHB_05					0.722	
TB_01						0.732
TB_02						0.757
TB_03						0.786
TB_04						0.622

Average Variance Extracted (AVE)

Another method to assess convergent validity is the AVE, which reflects the proportion of the variance among the indicators explained by the related latent construct. A high AVE of 0.5 or higher reflects satisfactory convergent validity; thus, the construct explains at least half of the variance on the observed measures [32]. As shown in Table 7, all the constructs across the three models report AVE values equal to or exceeding the threshold depicted below the table; thus, each construct meets an appreciable level of convergent validity.

Table 7: AVE values

	Average variance extracted (AVE)
D	0.597
IB	0.572
IPRB	0.586
MEB	0.662
OHB	0.628
TB	0.528

4.2.3. Measuring discriminant validity

Discriminant validity assesses whether a construct is truly distinct from other constructs within the model at the statistical and conceptual levels. This guarantees that each latent variable measures a distinct concept, and the indicators measuring one construct do not significantly relate to the indicators measuring another.

Cross Loadings

The cross-loading criterion specifies that the loadings on the construct to which an indicator has been assigned should be larger than the loadings on any other construct. This aspect ensures that indicators are more related to the desired latent variable than to unrelated ones. For the model used here, as per Table 8, each indicator showed larger loadings on its construct than cross-loadings among others; thus, sufficient discriminant validity was established.

Table 8: Cross-loading values

	D	IB	IPRB	MEB	OHB	TB
D1	0.706	-0.522	-0.376	-0.461	-0.267	-0.419
D2	0.778	-0.443	-0.521	-0.503	-0.390	-0.559
D3	0.798	-0.593	-0.490	-0.565	-0.447	-0.516
D4	0.766	-0.449	-0.321	-0.548	-0.336	-0.462
D5	0.811	-0.408	-0.470	-0.510	-0.390	-0.601
IB_01	-0.481	0.754	0.338	0.409	0.489	0.540
IB_02	-0.449	0.719	0.506	0.470	0.440	0.457
IB_03	-0.488	0.794	0.489	0.471	0.518	0.511
IPRB_01	-0.416	0.429	0.790	0.497	0.607	0.528
IPRB_02	-0.491	0.423	0.782	0.465	0.522	0.514

	D	IB	IPRB	MEB	OHB	TB
IPRB_03	-0.413	0.486	0.706	0.428	0.488	0.455
IPRB_04	-0.413	0.462	0.782	0.550	0.569	0.499
MEB_01	-0.551	0.393	0.527	0.832	0.426	0.562
MEB_02	-0.550	0.571	0.548	0.817	0.521	0.531
MEB_03	-0.536	0.488	0.467	0.791	0.486	0.565
OHB_01	-0.440	0.504	0.661	0.448	0.848	0.538
OHB_02	-0.357	0.515	0.526	0.469	0.794	0.521
OHB_04	-0.326	0.463	0.567	0.428	0.801	0.517
OHB_05	-0.379	0.541	0.488	0.514	0.722	0.457
TB_01	-0.544	0.441	0.533	0.530	0.535	0.732
TB_02	-0.464	0.534	0.414	0.497	0.395	0.757
TB_03	-0.507	0.557	0.460	0.461	0.450	0.786
TB_04	-0.403	0.399	0.489	0.489	0.483	0.622

Fornell-Larcker Criterion

The Fornell–Larcker criterion checks for discriminant validity through the examination of each construct's AVE and its squared correlations with other constructs within the model. Discriminant validity is established when a construct's AVE is greater than its shared variance with any other construct to ensure that it retains more variance from its own indicators than from other variable indicators [32]. As Table 9 indicates, the Fornell–Larcker outcomes in this study indicate that all the constructs are satisfactory under this criterion and thus establish sufficient discriminant validity and support the results gained through the cross-loading test.

Table 9: Fornell-Larcker criterion

	D	IB	IPRB	MEB	OHB	TB
D	0.773					
IB	-0.626	0.756				
IPRB	-0.569	0.586	0.766			
MEB	-0.670	0.594	0.632	0.814		
OHB	-0.479	0.639	0.712	0.587	0.793	
TB	-0.665	0.666	0.652	0.679	0.642	0.727

Hetorotrait - Monotrait Ratio (HTMT)

The HTMT ratio is the third criterion used to evaluate discriminant validity between constructs. This technique checks the similarity between constructs by measuring the average correlations between different constructs and the average correlations within the same construct. If the HTMT ratio nears or exceeds 1.0, it implies the absence of discriminant validity, indicating that the constructs are not sufficiently distinct [33].

As shown in Table 10, all HTMT values are significantly lower than 1.0, confirming that each construct is empirically distinct, and the model fulfils the requirement of discriminant validity.

Table 10: HTMT values

	D	IB	IPRB	MEB	OHB	TB
D						
IB	0.868					
IPRB	0.704	0.854				
MEB	0.852	0.874	0.839			
OHB	0.574	0.901	0.906	0.760		
TB	0.863	0.987	0.892	0.944	0.856	

4.3. Structural Model for Analysis of Barriers

To answer the research questions and test the hypotheses H1 to H5, the structural model was used to calculate the effects of the independent constructs on the dependent construct directly, in accordance with the data obtained. The evaluation of these direct relationships was performed using path coefficients, 95% confidence intervals (CI), t-statistics (t), and p-values (p), as summarised in Table 11. The t-statistics were used to determine whether the estimated path coefficient significantly deviated from zero, and the corresponding p-value indicated the probability of observing such a result under the null hypothesis. A 95% confidence interval was examined to evaluate the stability and accuracy of the parameters. This section presents the results of the direct effects among the model variables, with correlations having p-values smaller than 0.05 being regarded as statistically significant. The hypotheses for the overall conceptual framework were tested using the derived structural model.

The findings show that MMT integration success was significantly impacted by infrastructural barriers (IB), market and economic barriers (MEB), operational and human resource barriers (OHB), and technological barriers (TB); however, it was not significantly affected by institutional, policy, and regulatory barriers (IPRB).

Table 11: Structural model results

Hypothesis	Path coefficient	T Value	P Value	Outcome
H1: Infrastructural barriers have a significant impact on the success of MMT integration into maritime logistics.	-0.268	2.313	0.021	Accepted

Hypothesis	Path coefficient	T Value	P Value	Outcome
H2: Operational and human resource barriers significantly impact the success of MMT integration.	0.162	2.072	0.038	Accepted
H3: Institutional, policy, and regulatory barriers have a significant impact on the success of MMT integration.	-0.139	1.559	0.119	Not Accepted
H4: Technological barriers have a significant impact on the success of MMT integration into maritime logistics.	-0.275	2.813	0.005	Accepted
H5: Market and economic barriers significantly impact the success of MMT integration.	-0.332	2.868	0.004	Accepted

The OHB construct had a marginally positive impact in the original structural model, which was theoretically in contradiction with the anticipated negative relationship. As a result, OHB was independently re-evaluated, and as Table 12 illustrates, the refined analysis verified a strong and significant negative impact on MMT integration. Similarly, the IPRB construct exhibited a statistically significant negative impact when analysed separately, despite appearing insignificant in the combined model. These revaluations confirm that, when separated from possible interactions or suppression effects in the complete structural model, both OHB and IPRB have significant inhibitory effects on the success of MMT integration.

Table 12: Revised structural model results for OHB and IPRB

Hypothesis	Path coefficient	T Value	P Value	Outcome
H2: Operational and human resource barriers significantly impact the success of MMT integration.	-0.483	7.510	0.000	Accepted
H3: Institutional, policy, and regulatory barriers have a significant impact on the success of MMT integration.	-0.421	6.513	0.000	Accepted

The R^2 value of the dependent construct (D) is 0.574, indicating that the five barrier constructs, IB, IPRB, MEB, OHB, and TB, explain approximately 57.4% of the variance in the success level. The R^2 value of 0.574 provides a moderate-to-strong measure of explanatory power, in that the model explains more than half of the variation in the construct of success level. The accompanying t-statistic of 9.979 and p-value of 0.000 confirm that the value of R^2 is statistically significant, indicating that the predictors as a group contribute significantly to the explanation of the dependent variable. The finding suggests that the model provides good accuracy in prediction as well as theoretical applicability in explaining the impact of crucial barriers on the success of multimodal freight transport integration.

4.4. Readiness Assessment Model

Using the modified BRL framework, as shown in Figure 5 in the methodology chapter, the validated dataset was examined to determine the readiness of the Sri Lankan maritime sector for multimodal transport integration. Based on the mean scores of associated indicators gathered using the five-point Likert scale, each readiness dimension, namely, technological, infrastructural, institutional, policy, operational and human resources, financial, environmental, and stakeholder cooperation, was evaluated. The readiness level of each dimension was then related to the predetermined BRL framework ranges by mapping the calculated mean scores, as indicated in Table 13.

Table 13: Mean score values

Readiness Dimension	Mean Score
Operational and HR readiness	3.02
Financial readiness	2.88
Stakeholder cooperation readiness	2.87
Environmental readiness	2.78
Institutional and policy readiness	2.74
Technological readiness	2.53
Infrastructure readiness	2.38

The highest mean score was 3.02 for operational and human resource readiness, followed by 2.88 for financial readiness, 2.87 for stakeholder cooperation readiness, 2.78 for environmental readiness, and 2.74 for institutional and policy readiness. Infrastructure readiness had the lowest mean score (2.38). There was variance among the readiness dimensions evaluated, as evidenced by the overall mean scores for all seven dimensions, which ranged from 2.38 to 3.02.

A radar chart was constructed following the methodology of the BRL model [30] to show the overall readiness pattern across the evaluated dimensions. The relative strength of each readiness dimension was shown in the study by the author of the BRL model using radar visualisation in a single, well-balanced framework. Similar to that, the radar chart in this study shows the average readiness scores for each of the seven dimensions, providing a clear visual depiction of the readiness profile of the sector.

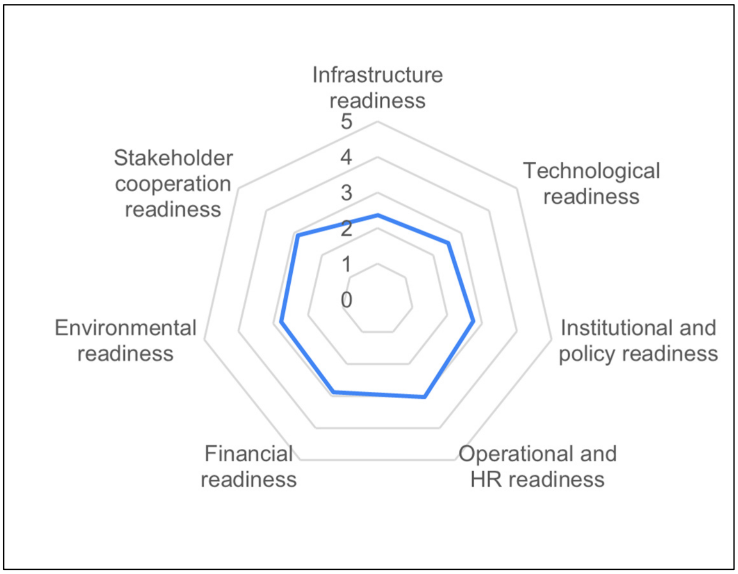

Figure 5: Radar chart for readiness dimensions

Figure 5 shows a radar chart illustrating the average readiness scores for the seven evaluated dimensions. With infrastructure readiness closest to the centre axis and operational and HR readiness at the outermost edge, the chart graphically illustrates the relative positions of each dimension based on their mean values. As indicated by the numerical distribution of the mean scores in Table 4 (See Methodology chapter), the remaining dimensions, namely, technological, institutional and policy, financial, environmental, and stakeholder cooperation readiness, form a balanced mid-level pattern around the central axis.

The results for each dimension were compared with the predetermined ranges in the derived BRL framework. This matrix was used to categorise the readiness level for each dimension, which made it possible to determine the sector's overall readiness status in a methodical and consistent way, as discussed in Table 14.

Table 14: BRL framework prediction

Readiness Dimension	BRL Framework Prediction
Infrastructure readiness	The readiness level fell within the initial stage, leaning slightly toward the developing level. This indicates that isolated facilities and basic feasibility plans were in place, and early signs of infrastructure development could also be observed.
Technological readiness	The readiness level was positioned between the initial and developing stages, suggesting that some awareness and planning for ICT integration has been initiated, with limited use of pilot systems or digital workflows.

Readiness Dimension	BRL Framework Prediction
Institutional and policy readiness	The readiness level corresponded closely with the developing stage. Supporting regulations and moderate institutional involvement were likely emerging, with initial steps taken toward formal policy alignment.
Operational and hr readiness	The readiness level slightly exceeded the development level, indicating a movement toward moderate readiness. Training programs, defined operational roles, and some intermodal coordination became more visible within the sector.
Financial readiness	The readiness level aligned with the developing level. Investment programs and partial funding mechanisms have been initiated, reflecting ongoing efforts to establish stronger financial support structures.
Environmental readiness	This dimension was placed within the developing stage, indicating that environmentally focused initiatives and compliance measures were emerging, although limited in scale.
Stakeholder cooperation readiness	The readiness level corresponded to the developing stage. Stakeholder dialogues and collaborative projects were being introduced, showing early signs of coordination among key actors.

5. DISCUSSION AND IMPLICATIONS

5.1. Analysis of Barriers for the Integration of MMT

Market and economic barriers were found to have a statistically significant and strongly negative impact on multimodal integration, acting as the most significantly negatively affecting barrier category for integration success. ($\beta = -0.332$, $p = 0.004$). This illustrates how the development of multimodal networks is significantly hindered by the unavailability of sufficient financial resources for infrastructure development, poor analysis of the cost efficiency of multimodal solutions, and a lack of sufficient financial incentives for companies adopting multimodal transport.

The negative impact suggests that unfavourable economic conditions and a lack of private sector participation may restrict investments and innovation in multimodal logistics. This result is in line with the literature, which emphasises the importance of cost competitiveness and economic stability for the long-term sustainability of integrated freight systems. Furthermore, Sri Lanka may not be prioritising financial investments in these areas, possibly due to ongoing economic struggles and limited resources for large-scale infrastructure projects.

Technological barriers were significantly correlated with the success of integrating MMT and acted as the second most significant negative barrier category ($\beta = -0.275$, p = 0.005). According to this study, deficiencies in digital infrastructure and technology adoption substantially hinder the effectiveness and integration of multimodal logistics. The negative coefficient illustrates how low adoption of ICT tools, lack of automation in port operations, lack of integration of digital platforms across transport modes, and unavailability of real-time data for decision-making hinder the success of coordinating and communicating activities in the multimodal freight transportation context. These results are consistent with previous studies that emphasise poor digitisation as a significant challenge to multimodal system performance.

The practical implications of the results demonstrate that the effective coordination of MMT and the overall success of its integration are hindered by the slow adoption of digital technologies and the absence of integrated systems, particularly in countries with limited resources, such as Sri Lanka, as stated in the literature.

The results indicate that infrastructure barriers, which are the third most negatively significant barrier category according to path coefficients, undermine the success of multimodal freight transportation integration ($\beta = -0.268$, $p = 0.021$). This means that poor infrastructure, for instance, a lack of sufficient multimodal terminals, low rail-road connectivity at ports, and low quality and capacity of existing transport infrastructure, suppresses the forces toward multimodal integration. The negative relationship confirms that as infrastructure barriers increase, integration and the efficiency of multimodal freight transportation decline.

This result confirms the literature that emphasises the function of efficient physical infrastructure as the foundation for multimodal transport development. The finalised set of infrastructure barriers may cause operations to be less efficient by making it more difficult to switch between modes of transportation, which leads to delays and higher operating costs. This shows how important it is to allocate resources to enhance infrastructure, transportation network connections, and transportation capacity to address these issues.

For operational and human resource barriers, the structural model had a positive path coefficient ($\beta = 0.162$, $p = 0.038$) when all the variables were analysed as a whole. However, the individual analysis revealed a negative coefficient ($\beta = -0.483$), confirming the existence of a negative relationship at the individual level when tested individually. This indicates that, although the aggregate model established a weak positive interaction, most likely due to overlapping effects, operational and human resource barriers, such as lack of service frequency, low service reliability, unavailability of a skilled workforce in logistics management, and low competence in managing complex multimodal transport systems, slightly contribute to hindering multimodal transport integration when tested individually.

Operational and human resource barriers may not be significant in countries like Sri Lanka due to processes like alternative solutions developed over time by local players, which may alleviate the challenges of service reliability, or the lack of a skilled workforce may be mitigated by reasonable training programs. Furthermore, smaller operations and more basic logistics systems may not be difficult in handling multimodal integration, as larger systems, which could account for why these barriers have less of an impact in Sri Lanka than they do according to international logistics standards.

Institutional, policy, and regulatory barriers (IPRB) did not significantly affect multimodal integration success in the overall structural model ($\beta = -0.139$, $p = 0.119$), indicating that these factors might not have a direct impact on integration outcomes when compared with more significant barriers, such as infrastructure, technology, and market-economic conditions. This could also mean that regulatory mechanisms are being adjusted without being seen as significant barriers, in contrast to operational or economic constraints, or that current policy frameworks exist but are not seen by practitioners as the most significant challenges.

The individual assessment of the IPRB construct, however, shows a strong and significant negative effect ($\beta = -0.421$, $p = 0.000$; 95% CI: –0.689 to –0.356), suggesting that, when separated from the overshadowing effects of other barriers, institutional and regulatory weaknesses have a significant impact on MMT integration. This result implies that institutional and policy factors continue to play a crucial role in determining long-term readiness and governance conditions for the development of MMT, even though they may seem less prominent during initial stages and in multi-barrier models.

5.2. Assessment of the Readiness for the Integration of MMT

The Infrastructure Readiness dimension, which has the lowest mean score (2.38), is associated with the initial stage of the framework. Given the limited number of isolated facilities and early feasibility studies, it appears that multimodal infrastructure is still limited in availability. Although preliminary initiatives and discussions are underway, the system's physical connectivity and integrated terminal operations are still under development.

Conversely, the highest score (3.02), which corresponds to the developing to moderate level, was the operational and human resource readiness. Given that training programs, clear operational structures, and intermodal coordination have begun to take shape in logistics and port operations, this suggests a relatively advanced maturity in the human capital and operational process dimensions when compared with other areas.

The dimensions of institutional and policy readiness (2.74) and technological readiness (2.53) fall within the initial and developing stages, respectively. This implies that, despite growing awareness and partial implementation of ICT-based systems, multimodal network integration is still incomplete. Similarly, as policy and regulatory frameworks evolve, institutional links and guidelines are gradually being developed to support MMT-related activities.

Stakeholder cooperation readiness (2.87), financial readiness (2.88), and environmental readiness (2.78) all represent the developing stage. These results show the existence of early stakeholder partnerships, small-scale environmental projects, and early investment programs. According to the BRL framework, this stage denotes ongoing efforts but inadequate alignment with the higher readiness levels, which are identified as comprehensive financial mechanisms, formalised multi-stakeholder platforms, and sustainability enforcement.

The radar chart visualisation confirms the results by showing an uneven but balanced spread around the mid-range levels, emphasising that while progress has been made, readiness remains partial across dimensions. Collectively, the BRL assessment demonstrates that Sri Lanka’s maritime logistics sector is transitioning from initial to developing readiness for multimodal integration, with human resource readiness leading to progress and infrastructural capacity emerging as the most critical area requiring enhancement.

6. CONCLUSION

Through a survey-based analysis that captured stakeholder perceptions, this study evaluated the barriers and current readiness for multimodal transport integration in Sri Lanka's maritime logistics sector. Infrastructure, technological, and market and economic barriers had the strongest negative impacts on MMT integration; operation and human resource barriers had less impact in the combined model, and institutional-policy barriers only had significant negative effects when present alone.

The BRL framework for the readiness assessment was derived from existing literature, and the version developed for this study offers a generalisable framework that can be used in any country and at any time during the initial phases of MMT implementation. Accordingly, the analysis of the current readiness of Sri Lanka was mainly in the initial to developing stages of readiness across most of the dimensions, with infrastructure readiness trailing at the lowest level and human resource readiness at the highest level.

When the analysis of barriers was compared with the readiness dimensions assessed, some distinct patterns and interconnections were identified. Although economic barriers were substantial, financial readiness was comparatively adequate, and infrastructure and technological factors emerged as the main challenges in both the current readiness assessment and barrier analysis. Despite demonstrating a high level of preparedness, institutional barriers had no significant effect on the barrier analysis model.

The results indicate that early-stage integration initiatives should concentrate on developing digital platforms, smart port technologies, and innovation hubs; introducing financing tools, such as green bonds and multimodal development funds, to attract both domestic and foreign investors; and enhancing port connectivity, rail-road integration, and multimodal terminals through coordinated investments and public-private partnerships. The study's limitations include its focus on the Sri Lankan context, reliance on perception-based data, and snapshot timing for assessing readiness, which may fail to recognise changes in the logistics environment in real-time. Future research should focus on comparative case studies in other developing countries, incorporate longitudinal studies to observe readiness evolution over time, and investigate emerging technologies in the industry, including smart port systems, Internet of Things (IoT), artificial intelligence (AI), and big data analytics, to evaluate their potential for enhancing multimodal integration.

REFERENCES

[1] M. Vasheghani and M. Abtahi, “Strategic planning for multimodal transportation in ports,” Maritime Policy & Management, vol. 50, no. 7, pp. 957–979, Oct. 2023, doi: 10.1080/03088839.2022.2061060.

[2] W. Mendis, “Strategic perspectives of integrating land use and transport development in Sri Lanka: a review,” J. S. Asian Logistics Transport, vol. 3, no. 1, pp. 113–127, Mar. 2023, doi: 10.4038/jsalt.v3i1.63.

[3] A. Caris, C. Macharis, and G. K. Janssens, “Decision support in intermodal transport: A new research agenda,” Computers in Industry, vol. 64, no. 2, pp. 105–112, Feb. 2013, doi: 10.1016/j.compind.2012.12.001.

[4] C. Zhou, H. Li, W. Liu, A. Stephen, L. H. Lee, and E. Peng Chew, “CHALLENGES AND OPPORTUNITIES IN INTEGRATION OF SIMULATION AND OPTIMIZATION IN MARITIME LOGISTICS,” in 2018 Winter Simulation Conference (WSC), Gothenburg, Sweden: IEEE, Dec. 2018, pp. 2897–2908. doi: 10.1109/WSC.2018.8632202.

[5] Q. Ai, J. Zhang, Q. Liu, C. Zhang, Q. Chen, and J. Yan, "Bulk Cargo Multimodal Transportation on Inland Waterways Considering Transport Wastage," IEEE Access, vol. 11, pp. 139575–139586, 2023, doi: 10.1109/ACCESS.2023.3340217.

[6] V. Paulauskas et al., "Optimizing Transportation between Sea Ports and Regions by Road Transport and Rail and Inland Waterway Transport Means Including 'Last Mile' Solutions," Applied Sciences, vol. 12, no. 20, p. 10652, Oct. 2022, doi: 10.3390/app122010652.

[7] G.-S. Kim, S.-W. Lee, Y.-J. Seo, and A.-R. Kim, "Multimodal transportation via TSR for effective Northern logistics: Perspectives of Korean logistics companies," MABR, vol. 5, no. 3, pp. 295–312, Jan. 2020, doi: 10.1108/MABR-07-2019-0029.

[8] C. Zhou, N. Ma, X. Cao, L. H. Lee, and E. P. Chew, "Classification and literature review on the integration of simulation and optimization in maritime logistics studies," IISE Transactions, pp. 1–39, Jan. 2021, doi: 10.1080/24725854.2020.1856981.

[9] A. S. N. Syaban, N. Fitriani, and R. Ahmad, "Implementation of Multimodal Transportation in Logistics on Java Island," JTTL, vol. 4, no. 2, pp. 121–130, Nov. 2023, doi: 10.52920/jttl.v4i2.177.

[10] A. Karam, A. J. K. Jensen, and M. Hussein, "Analysis of the barriers to multimodal freight transport and their mitigation strategies," Eur. Transp. Res. Rev., vol. 15, no. 1, p. 43, Nov. 2023, doi: 10.1186/s12544-023-00614-0.

[11] S. Okyere, J. Yang, and C. A. Adams, "Optimizing the Sustainable Multimodal Freight Transport and Logistics System Based on the Genetic Algorithm," Sustainability, vol. 14, no. 18, p. 11577, Sep. 2022, doi: 10.3390/su141811577.

[12] P. G. B. P. S. Rathnayake and C. A. Kavirathna, "Feasibility of establishing an integrated railway-based containerised cargo transport network between the Port of Colombo and free trade zones in Sri Lanka," J. S. Asian Logistics Transport, vol. 3, no. 2, pp. 103–127, Sep. 2023, doi: 10.4038/jsalt.v3i2.72.

[13] P. G. B. P. S. Rathnayake and C. A. Kavirathna, “Impacts of Integrated Railway-Based Containerized Cargo Transport Network to Connect the Port of Colombo and Free Trade Zones in Sri Lanka,” in 2023 International Research Conference on Smart Computing and Systems Engineering (SCSE), Kelaniya, Sri Lanka: IEEE, Jun. 2023, pp. 1–9. doi: 10.1109/SCSE59836.2023.10215022.

[14] D. Ambrosino and A. Sciomachen, “Investment evaluation in seaports for increasing the rail split modality in multimodal freight networks,” in 2017 IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI), Bari: IEEE, Sep. 2017, pp. 181–186. doi: 10.1109/SOLI.2017.8120991.

[15] S. Behrends, “The modal shift potential of intermodal line-trains from a haulier’s perspective: drivers and barriers in the mode choice process,” WRITR, vol. 5, no. 4, p. 369, 2015, doi: 10.1504/WRITR.2015.076925.

[16] A. Beifert and A. Moldabekova, “The Readiness of Port Logistics Services in the Caspian Sea Within the Eurasian Transport Corridor – Case Study of the Port of Aktau,” in Reliability and Statistics in Transportation and Communication, vol. 913, I. Kabashkin, I. Yatskiv, and O. Prentkovskis, Eds., in Lecture Notes in Networks and Systems, vol. 913. , Cham: Springer Nature Switzerland, 2024, pp. 233–246. doi: 10.1007/978-3-031-53598-7_21.

[17] B. Dong, M. Christiansen, K. Fagerholt, and S. Chandra, “Design of a sustainable maritime multi-modal distribution network – Case study from automotive logistics,” Transportation Research Part E: Logistics and Transportation Review, vol. 143, p. 102086, Nov. 2020, doi: 10.1016/j.tre.2020.102086.

[18] F. Indriastiwi, S. P. Hadiwardoyo, and Nahry, “Port Connectivity Model in The Perspective of Multimodal Transport: A Conceptual Framework,” IOP Conf. Ser.: Mater. Sci. Eng., vol. 1052, no. 1, p. 012008, Jan. 2021, doi: 10.1088/1757-899X/1052/1/012008.

[19] J. Lordieck and F. Corman, “Infrastructural, Decisional and Organizational Aspects to Use Mode Shift to Handle Disruptions in Freight Transport: Literature and Expert Survey,” IEEE Open J. Intell. Transp. Syst., vol. 2, pp. 37–46, 2021, doi: 10.1109/OJITS.2021.3057481.

[20] C. Yin, Z. Zhang, X. Zhang, J. Chen, X. Tao, and L. Yang, “Hub seaport multimodal freight transport network design: Perspective of regional integration development,” Ocean & Coastal Management, vol. 242, p. 106675, Aug. 2023, doi: 10.1016/j.ocecoaman.2023.106675.

[21] A. E. Coronado Mondragon, C. S. Lalwani, E. S. Coronado Mondragon, C. E. Coronado Mondragon, and K. S. Pawar, “Intelligent transport systems in multimodal logistics: A case of role and contribution through wireless vehicular networks in a sea port location,” International Journal of Production Economics, vol. 137, no. 1, pp. 165–175, May 2012, doi: 10.1016/j.ijpe.2011.11.006.

[22] I. Harris, Y. Wang, and H. Wang, “ICT in multimodal transport and technological trends: Unleashing potential for the future,” International Journal of Production Economics, vol. 159, pp. 88–103, Jan. 2015, doi: 10.1016/j.ijpe.2014.09.005.

[23] R. Bergqvist and J. Monios, “The last mile, inbound logistics and intermodal high capacity transport - the case of Jula in Sweden,” WRITR, vol. 6, no. 1, p. 74, 2016, doi: 10.1504/WRITR.2016.078157.

[24] M. Lindholm and S. Behrends, “Challenges in urban freight transport planning – a review in the Baltic Sea Region,” Journal of Transport Geography, vol. 22, pp. 129–136, May 2012, doi: 10.1016/j.jtrangeo.2012.01.001.

[25] R. Ridwan and M. A. L. Pambudi, “Singapore International Hub-Port And Its Effects On The Smooth Running Of The Sea Freight Transportation System In Indonesia,” Journal of Maritime Technology and Society, pp. 111–120, Oct. 2023, doi: 10.62012/mp.v2i3.30980.

[26] E. Surucu-Balci, Ç. Iris, and G. Balci, “Digital information in maritime supply chains with blockchain and cloud platforms: Supply chain capabilities, barriers, and research opportunities,” Technological Forecasting and Social Change, vol. 198, p. 122978, Jan. 2024, doi: 10.1016/j.techfore.2023.122978.

[27] Y.-L. Wang, “Logistics Supply Chain Management Based on Heuristic Multi-Constrained Combinatorial Optimization Method,” in 2010 International Conference on E-Business and E-Government, Guangzhou, China: IEEE, May 2010, pp. 299–302. doi: 10.1109/icee.2010.83.

[28] L. Caixia and L. Daosheng, “Comparative Review of Logistics Park Planning among China, Japan and Germany: response to territorial development in China,” in 2021 40th Chinese Control Conference (CCC), Shanghai, China: IEEE, Jul. 2021, pp. 8655–8660. doi: 10.23919/CCC52363.2021.9550448.

[29] S. Gupta and N. Gupta, “Enhancing freight logistics: overcoming barriers and driving sustainable growth with an integrated grey Delphi DEMATEL approach,” BIJ, Jan. 2025, doi: 10.1108/BIJ-03-2024-0201.

[30] J. Vik, A. M. Melås, E. P. Stræte, and R. A. Søraa, “Balanced readiness level assessment (BRLa): A tool for exploring new and emerging technologies.,” Technological Forecasting and Social Change, vol. 169, p. 120854, Aug. 2021, doi: 10.1016/j.techfore.2021.120854.

[31] J. F. Hair, C. M. Ringle, and M. Sarstedt, “PLS-SEM: Indeed a Silver Bullet,” Journal of Marketing Theory and Practice, vol. 19, no. 2, pp. 139–152, Apr. 2011, doi: 10.2753/MTP1069-6679190202.

[32] C. Fornell and D. F. Larcker, “Structural Equation Models with Unobservable Variables and Measurement Error: Algebra and Statistics,” Journal of Marketing Research, vol. 18, no. 3, p. 382, Aug. 1981, doi: 10.2307/3150980.

[33] J. Henseler, C. M. Ringle, and M. Sarstedt, “A new criterion for assessing discriminant validity in variance-based structural equation modeling,” J. of the Acad. Mark. Sci., vol. 43, no. 1, pp. 115–135, Jan. 2015, doi: 10.1007/s11747-014-0403-8.