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Leveraging blockchain for enhancing electronic data interoperability in Thailand's port community system: Barriers and strategic enablers

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ABSTRACT

Thailand's port logistics sector faces significant challenges in achieving secure and interoperable electronic data exchange across stakeholders. Although a standardized Port Community System (PCS) has been promoted, persistent issues-including fragmented digital platforms, security vulnerabilities, and institutional mistrust-impede Electronic Data Interchange (EDI) effectiveness. This study investigates the key barriers (BAR) to EDI implementation and examines how blockchain technology can be a foundational solution to overcome (OVB) them. A structured survey of 350 PCS service users and providers was administered. The data were examined using Confirmatory Factor Analysis (CFA) to check the different parts of the study and Canonical Correlation Analysis (CCA) to look at the relationships between seven identified barrier factors (like infrastructure, legal issues, and budget) and seven strategies to overcome them (such as technology acceptance, organizational readiness, and management support). The first canonical function showed a strong relationship, with a correlation coefficient of 0.652 ($p < 0.01$), meaning that certain organizational actions are closely linked to reducing important barriers. This research is the first empirical study in Thailand to apply multivariate statistical modeling to blockchain-enabled PCS adoption. It contributes methodological rigor through validated measurement models, structural analysis, and practical insight for policymakers, port administrators, and logistics managers. The findings suggest blockchain can enhance transparency, trust, and secure data integration in national logistics infrastructures.

Keywords: Canonical-Correlation Analysis, Maritime NSW, National Single Window (NSW), Port Community System (PCS), Thailand

INTRODUCTION

Thailand's port logistics system is fundamental to its trade competitiveness. While projects such as the Port Community System (PCS) [1], Electronic Data Interchange (EDI) [2, 3], and National Single Window (NSW) have been implemented globally for the better part of the past few decades [4] to improve efficiency in cargo handling processes and reduce paperwork, it is clear from the state of the current port operations that Thailand has many disparate digital platforms in use [5]. User complaints include repetitive manual entry requirements, limited system integration, and delays from multiple operations among the various port authorities, government agencies, and port service providers [6].

Thailand is not unique in this. Most countries around the Asia-Pacific have attempted reforms along these lines with varying degrees of success [7]. While countries like Singapore have developed advanced NSW systems that make it easier to do business [8], others are wrestling with uneven implementation, regulatory loopholes, and a lack of trust among stakeholders. These problems are slowing Thailand's efforts to create a smooth, paperless trade system, even though the government is stressing the need to improve PCS operations and connect with regional platforms like the ASEAN Single Window.

One of the technologies frequently proposed to address such challenges is blockchain. Its decentralized and immutable structure offers promising solutions to long-standing trust, duplication, and inefficiency issues in PCS and NSW platforms [3, 12, 13]. Empirical studies from Japan, Croatia, and the Asia-Pacific further support blockchain's ability to enhance data integrity and streamline cross-agency logistics operations [7, 14]. The distributed, tamper-proof nature of blockchain is naturally well-suited to environments where multiple organizations must share data [13] and simultaneously access it without depending on a central reference point of control [12]. In port logistics, blockchain technology would enable the automatic execution of transactions, reduce fraud, increase trust and transparency [12, 15], and support real-time visibility throughout the process. In Thailand, however, the practical use of

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blockchain in PCS environments has been marginally explored, and its feasibility in practical use is still unclear.

While blockchain technical models have been proposed in global contexts [3, 7, 12-16], there is little empirical work about what conditions need to be in place for the blockchain-enabled EDI to succeed-especially in a country such as Thailand in which organizational, legal, and infrastructure barriers remain considerable. Much of the conversation remains conceptual or technical, failing to consider the barriers service users and providers face on the ground. This diagnostic study aims to identify the socio-organizational preconditions for blockchain adoption in PCS rather than to design a technical solution.

Therefore, this study addresses that gap. Rather than establishing a technical architecture, we identify the organizational and system-level challenges of EDI interoperability in Thailand's PCS (EDI-PCS) and assess how blockchain could best help overcome those challenges. Using a survey of 350 logistics and port stakeholders, we identify key barriers-infrastructure limitations, management resistance, legal uncertainty, and lack of coordination and then rank which strategies are most likely to overcome those barriers [17].

Utilizing Confirmatory Factor Analysis (CFA) [18]. Additionally, using Canonical Correlation Analysis (CCA) [19], we examine these obstacles and suggest ways to overcome them, pointing out specific factors (like support from top management, readiness of the organization, and acceptance of technology) that are statistically linked to better success in implementation.

This research contributes practical insights for decision-makers in Thailand's logistics ecosystem by clarifying the socio-organizational conditions necessary for blockchain adoption. It also lays the groundwork for future technical implementations, offering a roadmap for what must be in place before blockchain can improve port interoperability.

Literature review

As nations modernize their trade and logistics systems, integrating digital technologies like Electronic Data Interchange and Port Community Systems (EDI-PCS) and blockchain has become essential. However, despite global momentum, many countries-particularly in developing regions-continue to face persistent barriers to full system interoperability. This literature review examines the evolution of PCS and EDI platforms, identifies recurring obstacles to their adoption, explores strategies for overcoming these barriers, and evaluates the potential role of blockchain in enhancing transparency and trust. By critically engaging with global and regional studies, this section establishes the empirical and conceptual foundation for the present research and identifies the gaps it seeks to address.

Evolution of PCS, EDI, and NSW systems

Ever since the 1980s, EDI-PCS systems have been at the heart of digital trade reform, with first-generation PCS platforms designed to improve communication and automate documentation between customs, ports, shipping lines, and freight companies [1, 7, 20]. As a result, port communities become more competitive [21]. Thailand followed this global trend by launching a management information system (MIS) in 1998 and EDI-based customs clearance in 2000 [3, 4].

Introducing Thailand's National Single Window (NSW) in 2005 was a significant step toward integrating various government and private-sector systems. Similar systems were deployed across the Asia-Pacific to streamline data exchange and reduce clearance times [10, 11], with Singapore's TradeNet beginning in 1989, followed by Hong Kong's TradeLink in 1997, Japan's Nippon Automated Cargo and Port Consolidated System (NACCS) and South Korea's u-Trade platform in 2003, Indonesia's NSW in 2007, and Malaysia' NSW in 2009 [11].

At the same time, Thailand's National Single Window (THAI NSW) has evolved but still faces operational fragmentation. While paperless customs have reduced processing costs, stakeholder systems often remain disconnected, resulting in duplicated inputs, delays, and inefficiencies.

The development of the Single Window system has been categorized into five progressive levels [11], as illustrated in Figure 1.

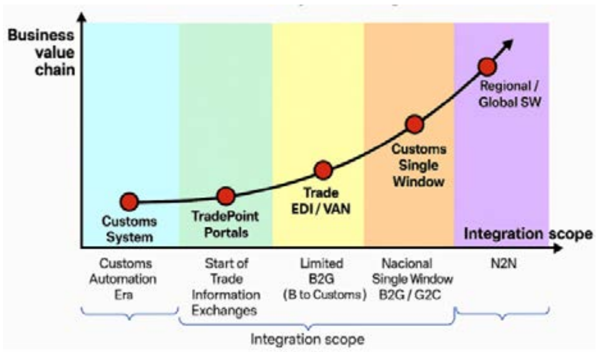

Figure 1 Level of development of integrated government electronic services system (Single Window) [11] (with author enhancements).

Globally, NSW platforms have multiplied. A 2022 UNECE report noted that 74% of Asia-Pacific countries were developing or operating NSWs. The Organization of Islamic Cooperation reported 40% adoption across its members by 2016, attributing progress to improved ICT infrastructure and falling software costs [22].

Thailand's logistics costs reached an estimated USD 70.2 billion in 2023 (14.1% of GDP), suggesting that continued digital reform could yield significant gains [5, 23]. Meanwhile, countries like Singapore (TRADENET), Ghana, and Senegal have served as early benchmarks, setting expectations for faster, more coordinated digital customs ecosystems [8].

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Common barriers (BAR) to EDI integration in Port Community Systems (EDI-PCS)

Despite digital infrastructure investments, many nations-Thailand included-struggle to realize the full potential of EDI-PCS platforms. Common challenges include technological mismatches between systems, lack of interoperability, and outdated infrastructure [20, 24]. Organizational barriers, such as resistance to change, low digital literacy, and weak interagency coordination, further complicate integration [25].

Legal and institutional gaps also persist. Trade policies still lack alignment with digital practices, creating uncertainty, particularly in cross-border transactions. In Pakistan, stakeholders reported that while interest in blockchain exists, issues like skills shortages, immature infrastructure, and a lack of government incentives hinder rollout [5]. Corruption and a fear of losing control over opaque processes were also noted as deterrents to full-scale system adoption.

In Montenegro, Peynirci [26] argued that maritime systems favor technical over human-centered design, limiting broader stakeholder buy-in. These structural and cultural challenges are critical to understanding why digital port systems underperform, even when supported by national plans.

Strategies for overcoming (OVB) digital trade barriers

Recognizing these challenges, many governments have issued national logistics development plans. Thailand's Third Logistics Development Plan calls for a unified NSW authority, improved PCS-to-airport integration, and greater use of EDI between government-to-government (G2G) and government-to-business (G2B) actors [27-28].

Strategic interventions include:

- Enhancing top management support to drive system reforms;
- Increasing organizational readiness via training and process reengineering;
- Strengthening infrastructure and legal frameworks for data security and privacy;
- Supporting cross-agency coordination and inter-ministerial integration [9].

Croatia's PCS rollout, for instance, was tied directly to national port competitiveness, while Turkey's system emphasized harmonizing ship-clearance procedures in compliance with IMO standards [24, 26].

Blockchain as a solution to EDI challenges

In response to trust and transparency issues-especially in developing economies-blockchain has emerged as a promising technology. First popularized after the 2008 financial crisis, blockchain offers a decentralized ledger system where transactions are secure, transparent, and immutable [29-31] (Figure 2).

Blockchain's core features-distributed architecture, smart contracts, peer-to-peer transactions, consensus mechanisms, and encryption-make it attractive for supply chains involving multiple stakeholders [3, 32]. When integrated with PCS platforms, blockchain could reduce manual duplication, automate document sharing, and enhance accountability. However, blockchain is not a plug-and-play solution. It requires political will, technical expertise, and readiness at multiple levels. Studies in Pakistan and Turkey underscore that successful deployment hinges on much more than just the technology itself-it depends on governance structures, stakeholder trust, and digital literacy [5, 33].

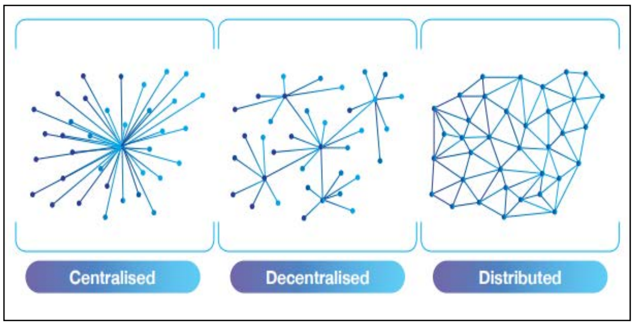

Figure 2 Centralized, decentralized, and distributed systems [31].

Identified gap and study contribution

Although there are many case studies and ideas about integrating PCS, NSW, and blockchain, there are not many large-scale studies that look at the specific challenges and strategies that influence how ready organizations in Southeast Asia are for blockchain-based EDI. Most studies are either theoretical or narrowly scoped to technical implementation.

This study addresses that gap by:

- Surveying 350 stakeholders across Thailand's PCS ecosystem;
- Identifying seven major categories of barriers and seven overcoming strategies;
- Applying CFA to validate these constructs [18];
- Using Canonical Correlation Analysis (CCA) to explore multivariate relationships between barriers and strategies [19].

In doing so, this research provides a grounded, stakeholder-driven perspective on the conditions that must be in place for blockchain adoption in PCS settings to succeed.

The researcher created a research framework, shown in Figure 3, based on the literature review about challenges in connecting electronic information of freight community systems at ports with blockchain technology (BAR) and addressing issues in PCS EDI using blockchain technology (OVB).

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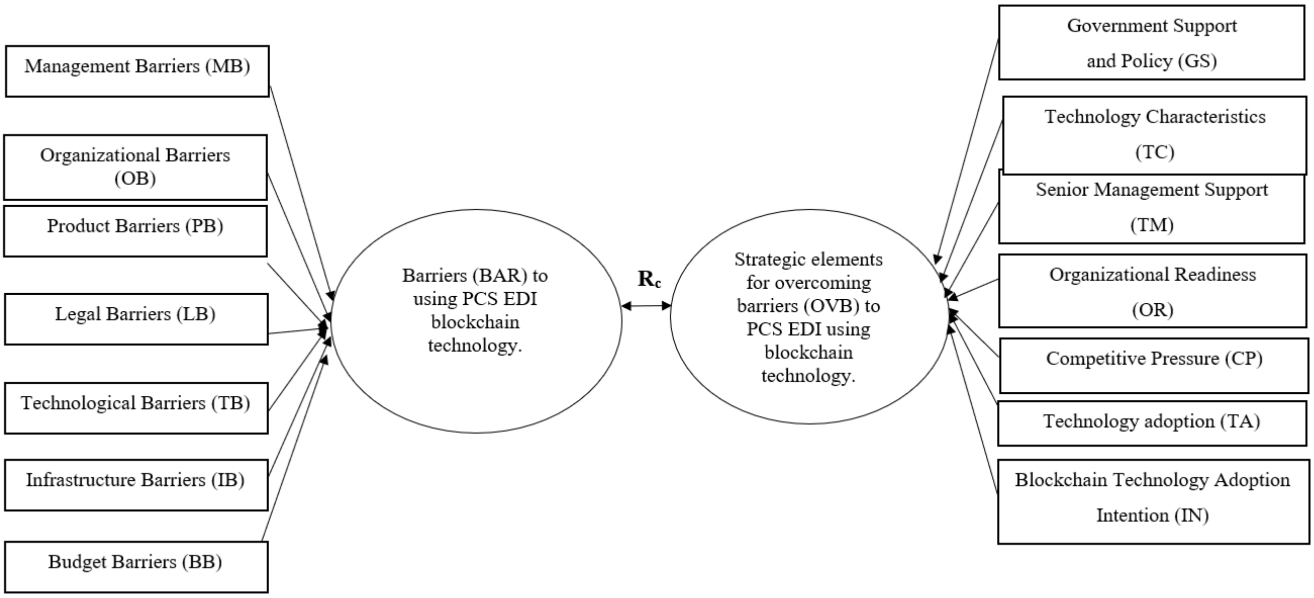

Figure 3 Research framework.

MATERIALS AND METHODS

Population and sample

The study's population is service users and service providers who use EDI systems to transport goods within Thailand's port community system (PCS). The sample group is service users and providers using EDI systems to transport goods within Thailand's port community (PCS) have stated that there is no shortage of recommendations regarding sample sizes using factor analysis. However, various studies have suggested that a ratio method can be used and suggested 10 to 20 questionnaires for each observed variable. Other studies have indicated that for CFA/SEM research, a sample size of 200 or more is sufficient, depending on the model complexity.

Therefore, the study identified 14 observed variables. Using a multiple of 20 to ensure better statistical validity, and when multiplied by 14, the researchers obtained a requirement for 280 questionnaires. However, an effort was made to achieve a higher number, which, after the received questionnaires were audited for usability, was 350.

Research tools

A three-part questionnaire was used as the research tool, which contained items concerning the barriers (BAR) and overcoming barriers (OVB) to EDI within Thailand's PCS using blockchain technology.

Part 1 consisted of a checklist of general information about the respondent's gender, age, education level, and position.

Part 2 and Part 3 included questions about each person's views on the obstacles to EDI (Electronic Data Interoperability), called BAR, and ways to overcome those obstacles, known as OVB, in Thailand's PCS using blockchain technology.

Part 2 and Part 3 consisted of items concerning each individual's opinions about barriers (BAR) and overcoming barriers (OVB) to EDI of Thailand's PCS using blockchain technology, divided into 21 items for BAR and 30 for OVB (51 total).

Opinion measurement

The questionnaire used a 5-level opinion scale that used '5' to indicate the 'highest level' of agreement (4.51-5.00), '4' to indicate a 'high level' of agreement (3.51-4.50), 3' to indicate a 'moderate level' of agreement (2.51-3.50), '2' to indicate a 'low level' of agreement (1.51-2.50), and '1' to indicate the 'lowest level' of agreement (1.00-1.50).

Questionnaire content validity

Five experts participated in the questionnaire's content validity process. [6] Commonly, the index of item-objective congruency (IOC) is suggested for this process [42], with studies suggesting that values of ≤ .50 should be revised or deleted. [36] After completing this process, the authors determined that the final questionnaire had IOC values of 0.60-1.00.

Questionnaire content reliability

After the experts' content validity check, the revised questionnaire was used to try out 30 service users and EDI service providers within Thailand's PCS (Table 1) who did not participate in the final survey. Content reliability is commonly assessed using a Cronbach's alpha coefficient. After the numbers were tallied, the tryout reliability was assessed to have an average value of 0.90. According to [28], α values ≥ .9 are excellent.

Sample questionnaire items

Table 1 shows sample items from the final questionnaire.

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Journal of Applied Research on Science and Technology

Table 1 Sample items for questionnaire constructs.

Construct	Sample Item (English Translation)
Management Barriers (MB)	Executives lack systematic planning for blockchain implementation.
Organizational Barriers (OB)	Our organization lacks a suitable structure to support blockchain technology.
Legal Barriers (LB)	There is no clear regulatory support for blockchain use.
Technological Barriers (TB)	There is a lack of adequate ICT infrastructure to support blockchain applications.
Infrastructure Barriers (IB)	The organization lacks sufficient facilities and systems to support blockchain integration.
Budget Barriers (BB)	The implementation of blockchain faces budget constraints and requires high investment.
Technology Adoption (TA)	Blockchain improves operational efficiency compared to existing systems.
Technology Characteristics (TC)	Blockchain increases data security and reliability for port logistics systems.
Top Management Support (TM)	Executives should participate in blockchain-related policy and decision-making.
Organizational Readiness (OR)	Our organization has sufficient resources and infrastructure to implement blockchain.
Competitive Pressure (CP)	International trade organizations are encouraging the use of blockchain.
Government Support (GS)	Government policy development encourages the adoption of blockchain.
Adoption Intention (IN)	I plan to use blockchain to improve the transparency of information sharing in our logistics system.

Analysis tools

Data analysis tools included descriptive statistics (mean, standard deviation, skewness, and kurtosis) and inferential statistics.

Moreover, a CFA was employed to assess and confirm the construct validity of the hypothesized barrier (BAR) and overcoming-barrier (OVB) constructs. The reason for using CFA is that it can check how accurately the observed variables reflect the hidden constructs suggested in the theoretical framework based on existing research. Since there are known theoretical aspects of the challenges and solutions in blockchain adoption, CFA checks if measuring these fits with the data we have gathered.

A Canonical Correlation Analysis (CCA) was also conducted to examine the multivariate relationships between the two sets of variables-BAR and OVB. CCA is particularly appropriate for this study because it allows us to identify which barriers are most strongly associated with overcoming strategies in blockchain-based EDI systems. This insight is crucial for practical implementation in port community systems, where multiple interdependent factors interact across technical, organizational, and policy domains.

RESULTS AND DISCUSSION

1. Results

1.1 Research framework

Table 2 presents the demographic characteristics of the 350 respondents and their level of understanding of blockchain technology. A notable finding is that over 74% of respondents rated their knowledge of blockchain as moderate to high, indicating a strong foundational awareness that could support adoption initiatives. Furthermore, the relatively balanced gender participation (55% men, 45% women) reflects inclusive engagement across organizational roles. Significantly, 59% of participants were 40 or younger, suggesting that technology adoption efforts may benefit from a workforce that is both adaptive and poised for long-term integration. The high level of education (90% holding a bachelor's degree or higher) reinforces the capability of the target population to understand and implement EDI systems using blockchain.

Table 3 reveals that BAR and strategies for overcoming OVB were rated at a high level, with mean scores ranging from 3.54 to 3.71. Among the barrier categories, Organizational Barriers (OB) were the most significant, likely reflecting internal challenges in

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adapting organizational culture and procedures. Infrastructure and Management Barriers (MB) were rated the lowest, perhaps due to ICT access or institutional readiness improvements. On the other hand, Technology Adoption (TA) and Organizational Readiness (OR) received the highest OVB ratings, suggesting that stakeholders perceive internal preparedness and adaptability as critical levers for success. These insights highlight where targeted interventions as leadership buy-in or infrastructure modernization-could yield the most significant returns.

Table 4 shows the CFA results, which indicate strong and important factor loadings (all $p < 0.01$), confirming the strength of both BAR and OVB concepts. The R^2 values show that Competitive Pressure (CP) ($R^2 = 0.83$) and Organizational Readiness (OR) ($R^2 = 0.70$) are very strong indicators in the OVB construct. Similarly, Management Barriers (MB) ($R^2 = 0.75$) and Technology Barriers (TB) ($R^2 = 0.56$) contribute substantially to the BAR construct. These findings support the structural validity of the model and indicate where strategic resources should be focused in implementation planning.

Table 5 shows the results of the canonical correlation analysis (CCA) that looks at the relationships between the barrier (BAR) and overcoming-barrier (OVB) concepts. Out of the seven main functions identified, only the first one was statistically significant (Wilk's Lambda = 0.520, $\chi^2 = 88.186$, $p < .01$), showing a canonical correlation of 0.652, which means there is a shared variance (R^2) of 0.425.

Table 2 Respondents' information (*n* = 350).

Item		*n*	%
Blockchain Technology Knowledge Levels			
5 = The most level		33	9.40
4 = High level		123	35.20
3 = Moderate level		138	39.40
2 = Low level		56	16.00
1 = Lowest level		-	-
	Summation	350	100.00
Gender			
Men		191	54.60
Women		159	45.40
	Summation	350	100.00
Age			
25-30 years		51	14.60
31-35 years		70	20.00
36-40 years		84	24.00
41-45 years		38	10.90
46-50 years		66	18.80
Over 51		41	11.70
	Summation	350	100
Education			
No university degree		34	9.70
Bachelor's degree		226	64.60
Postgraduate		90	25.70
	Summation	350	100

Table 3 Descriptive statistics for BAR and OVB constructs.

Latent Variable	Observable Variables	Mean	SD	Skew.	Kurt.
BAR	MB-Management Barriers	3.54	0.78	-0.15	1.20
BAR	OB-Organization Barriers	3.69	0.59	-0.52	1.38
BAR	PB-Product Barriers	3.64	0.82	-2.07	1.07
BAR	LB-Legal Barriers	3.60	0.89	-2.17	0.74
BAR	TB-Technology Barriers	3.62	0.82	-1.46	0.92
BAR	IB-Infrastructure Barriers	3.54	0.61	-2.45	0.02
BAR	BB-Budget Barriers	3.58	0.70	-2.85	1.11
OVB	TA-Technology Adoption	3.70	0.60	-0.05	1.24
OVB	TC-Technology Characteristics	3.60	0.60	-0.46	0.60
OVB	TM-Senior Management Support	3.56	0.52	-2.80	0.71
OVB	OR-Organizational Readiness	3.71	0.68	-0.42	2.52
OVB	CP-Competitive Pressure	3.61	0.66	-1.39	1.08
OVB	GS-Government Support and Policies	3.62	0.71	-0.18	1.25
OVB	IN-Intention	3.65	0.69	-0.11	0.98

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Journal of Applied Research on Science and Technology

Table 4 CFA results for BAR and OVB constructs.

Observed Variables	b_{sc}	SE.	T	R^2
	BAR Variables			
MB	0.68**	0.08	8.89	0.75
OB	0.41**	0.04	11.34	0.48
PB	0.45**	0.05	9.11	0.30
LB	0.56**	0.05	11.19	0.39
TB	0.62**	0.05	12.85	0.56
IB	0.40**	0.03	11.77	0.43
BB	0.44**	0.05	8.21	0.39
	OVB Variables			
TC	0.31**	0.03	9.34	0.26
TM	0.33**	0.03	12.86	0.40
OR	0.57**	0.03	19.23	0.70
CP	0.60**	0.03	21.61	0.83
GS	0.59**	0.03	18.34	0.69
IN	0.54**	0.03	17.21	0.61
TA	0.32**	0.03	9.61	0.28

Note: ** $p < 0.01$

Table 5 Canonical Correlation Analysis (CCA) results between BAR and OVB constructs.

CF	CC	Canonical R^2	Wilk's Lambda	χ^2	*p*-value
1	0.652**	0.425	0.520	88.186	0.000
2	0.225	0.051	0.907	6.398	0.596
3	0.153	0.023	0.955	2.853	0.931
4	0.117	0.013	0.978	1.671	0.966
5	0.688	0.004	0.992	0.552	0.979
6	0.051	0.002	0.997	0.319	0.913
7	0.013	0.001	0.999	0.022	0.800

Note. **Statistically significant at 0.01 level, CF = canonical correlation, CC = Canonical Correlation.

This result suggests a moderately strong multivariate association between the perceived barriers and mitigation strategies. The first function's strength and importance show that one main factor explains how organizations match their views on challenges with their strategic responses.

The non-significance of subsequent functions ($p > 0.05$) indicates that additional canonical dimensions do not contribute meaningful explanatory power. This highlights the key role of the main canonical relationship, where factors like technological readiness (TA), leadership support (TM), and organizational preparedness (OR) are important in overcoming challenges related to technology, infrastructure, and management.

These findings support the idea that a company's internal skills and flexible leadership are closely connected to how people see both outside and inside challenges, giving a solid basis for focused strategic planning.

Table 6 shows the main weights, loadings, cross-loadings, and shared variance (R^2) for Function 1, which is the only important canonical dimension found in earlier analysis. This breakdown reveals how each variable contributes to the multivariate relationship between barriers (BAR) and overcoming barriers (OVB) constructs.

On the independent side (BAR), the most influential contributors are Management Barriers (MB), with a canonical loading of -0.908 (R^2 = 33.46%) and Infrastructure Barriers (IB) (-0.876, R^2 = 32.38%). These high loadings suggest that internal organizational and technical challenges are perceived as dominant constraints to EDI-PCS implementation.

On the dependent side (OVB), Technology Adoption (TA) exhibited an exceptionally high canonical weight (0.867), with a canonical loading of 0.991 and R^2 = 56.54%. This underscores its role as the central success lever, mediating the relationship between internal barriers and strategic outcomes. Other key contributors include Senior Management

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Support (TM) and Organizational Readiness (OR), which exceed R^2 thresholds of 40%.

The cross-loadings show that there is a significant overlap between the two ideas, especially for TA and MB, indicating that trying to address internal challenges with adaptive technologies and active leadership matches well with the obstacles people see. These results strongly support prioritizing technology-oriented interventions and internal capacity building in policy design and implementation roadmaps.

Table 6 Canonical weights (CW), canonical loadings (CL), canonical cross-loading (CCL), and shared variance (R^2) for Function 1 between BAR and OVB variables.

	CW	CL	CCL	R^2
Independent Variables (BAR)				
MB	-0.417	-0.908	-0.570	33.46
OB	-0.228	-0.903	-0.568	31.25
PB	-0.170	-0.863	-0.544	30.39
LB	-0.096	-0.844	-0.529	27.98
TB	-0.148	-0.710	-0.446	19.85
IB	-0.349	-0.876	-0.552	32.38
BB	-0.021	-0.822	-0.518	26.79
Dependent Variables (OVB)				
TA	0.867	0.991	0.623	56.54
TC	0.189	0.545	0.312	29.25
TM	0.542	0.741	0.464	46.78
OR	0.521	0.736	0.398	44.22
CP	0.312	0.622	0.344	37.21
GS	0.224	0.597	0.300	29.97
IN	0.147	0.494	0.290	28.74

Figure 4 shows the standard correlation model that represents the complex relationship between BAR and OVB variables in using a blockchain-based Electronic Data Interchange Port Community System (EDI-PCS).

The model visually confirms the statistically significant inverse relationship between the two variable sets identified in the CCA (canonical function 1, $R^2 = 0.425$, $p < .01$). Barrier variables, such as Management Barriers (MB) and Infrastructure Barriers (IB), are shown on the left side of the model and are negatively correlated with OVB factors, such as Technology Adoption (TA), Organizational Readiness (OR), and Leadership Support (TM), displayed on the right.

The moderate-to-strong negative canonical loadings indicate that when people feel there are more barriers-especially those related to internal structure and technical infrastructure tend to think that strategies for overcoming these barriers are less effective, and the opposite is also true. Technology Adoption (TA) emerges as the most critical OVB dimension, given its substantial canonical weight and loading observed in Table 5.

This figure is important because it visually confirms the structural alignment and compensatory dynamics between organizational challenges and strategic enablers. Investment in internal capabilities (like digital readiness, leadership engagement, and infrastructure modernization) is reactive and potentially predictive of success in overcoming adoption hurdles.

The CCA model shown here is a useful tool that helps in planning by allowing stakeholders to see which barriers need the most attention and which supports can provide the best benefits for using EDI-PCS with blockchain.

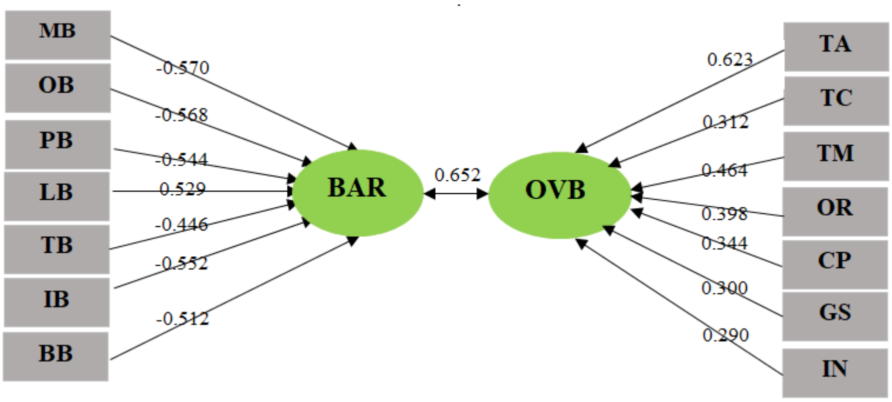

Figure 4 Canonical Correlation Model depicting the relationship between Barrier (BAR) and Overcoming-Barrier (OVB) constructs in implementing a blockchain-based EDI PCS.

2. *Discussion*

2.1 Barriers (BAR)

The model that explains the obstacles (BAR) to using a blockchain-based Electronic Data Interchange Port Community System (EDI PCS) includes seven main types of barriers: Management Barriers (MB), Organizational Barriers (OB), Product Barriers (PB), Legal Barriers (LB), Technological Barriers (TB), Infrastructure Barriers (IB), and Budget Barriers (BB). These categories highlight challenges like leaders' resistance, inflexible structures, complicated regulations, and technical issues that make using new technologies in port systems hard.

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2.2 Overcoming barriers (OVB)

The OVB model points out seven key factors that help with strategy: Technology Adoption (TA), Technology Characteristics (TC), Senior Management Support (TM), Organizational Readiness (OR), Competitive Pressure (CP), Government Support and Policies (GS), and Blockchain Adoption Intention (IN). These factors are a mix of what a company can do internally and outside influences that affect how well blockchain is adopted in PCS [8, 35].

Results from the CCA revealed significant pairings between specific barriers and overcoming variables:

1. Management Barriers (MB) and Technology Adoption (TA) - Canonical loadings of 0.570 for MB and 0.623 for TA suggest that strong technological competencies significantly mitigate managerial resistance. This reinforces the importance of promoting technical literacy and digital confidence among organizational leaders [36].

2. Organizational Barriers (OB) and Government Support (GS) - The combination of OB (0.568) and GS (0.593) shows that having supportive policies and clear rules can significantly lower pushback against change, particularly in organizations with strict structures.

3. Product Barriers (PB) and Blockchain Adoption Intention (IN) - With scores of 0.544 and 0.548, this relationship indicates that a strong intention to use blockchain helps reduce worries about product issues like how well the system works with other systems and its reliability.

4. Technology Barriers (TB) and Senior Management Support (TM) - Canonical loadings of 0.552 for TB and 0.471 for TM highlight the role of engaged leadership in addressing technical complexity. Leaders who actively champion innovation help foster a culture of openness to new technologies [37].

2.3 Canonical correlation analysis (CCA)

The first main function showed a strong statistical link between the barrier and overcoming factors, with a canonical correlation of 0.652 ($p < .01$) and a shared variance of 42.5% ($R^2 = 0.425$). This suggests that nearly half the variation in the barrier set can be explained by the strategic enablers in the OVB set.

These results back up the main idea, showing that certain internal challenges (like resistance from managers or old systems) can be successfully tackled with specific support measures such as leadership backing, alignment with government policies, and focused investments in technology infrastructure. As noted by Tian et al. [37], factors like perceived benefits, external pressure, and senior management trust are vital for successful digital transformation in SMEs [32, 38], an insight that translates well to the port logistics context.

3. Synthesis of findings and implications for practice

This study evaluated the strategic elements for OVB to EDI-PCS using blockchain technology. Through empirical data analysis from 350 stakeholders, we identified seven core barriers and seven corresponding overcoming strategies. Confirmatory Factor Analysis (CFA) validated the construct structure. At the same time, CCA revealed that technology adoption, organizational readiness, and senior management support are statistically and practically linked to key barrier domains such as infrastructure, management, and legal complexity. The findings underscore that blockchain adoption in PCS is not merely a technical undertaking but highly contingent upon socio-organizational readiness. This includes trust in interagency systems [32, 38], legal alignment, and institutional leadership. Our validated analytical framework can be a diagnostic tool for policymakers and logistics authorities to assess blockchain implementation feasibility. These insights are particularly relevant for developing economies where systemic barriers and institutional inertia often impede technological modernization. Addressing these preconditions is vital to unlocking the transformative potential of blockchain for secure, transparent, and interoperable logistics systems.

CONCLUSION

This study empirically analyzed the relationships between key organizational barriers and strategic enablers for Blockchain-based EDI adoption in Thailand's PCS. Using CFA and CCA, the findings highlight how management, infrastructure, and organizational issues are perceived as the most important organizational barriers to achieving sustainable Blockchain-based EDI adoption. In contrast, Technology Adoption, Organizational Readiness, and Leadership Support are strategic enablers of Blockchain-based EDI-PCS adoption.

These findings suggest that blockchain in logistics adoption is as much a socio-organizational issue as a technological one. By synchronizing internal capacity with enabling rules and leadership, Thailand will be in a stronger position to improve the efficacy and trustworthiness of its national logistical platforms.

Future research should concentrate on conducting longitudinal impact assessments, performing cost-benefit analyses, and implementing pilot programs to clarify how blockchain can impact this domain. This study presents a theoretical framework and practical roadmap for stakeholders interested in constructing interoperable and transparent port systems.

Limitations and challenges

This study provides valuable insights into the strategic enablers of blockchain technology adoption within Thailand's Port Community System (PCS) based on empirical research; however, there are a few limitations to this study. Firstly, this study is cross-

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Journal of Applied Research on Science and Technology

sectional, collecting perceptions simultaneously. Hence, we could not consider changes in respondents' organizational readiness or attitudes over time.

Second, the notable sample size (n = 350) is statistically sound but limited to Thailand stakeholders in the PCS ecosystem. Therefore, the findings may not generalize to other national contexts or port systems.

Third, since the data in the present study were gathered from self-report surveys, response bias may have emerged because the participants themselves evaluated their organizations' capabilities and awareness of blockchain.

Finally, although Canonical Correlation Analysis (CCA) offers valuable multivariate insights, it does not imply causal relationships. Future longitudinal or experimental studies should be conducted to validate these associations and causality.

Implications and future research

This study has both theoretical and practical implications. These include:

- Organizational Strategy: Blockchain implementation in port logistics is not solely a technical challenge-it requires strategic alignment, institutional agility, and stakeholder buy-in.
- Policy Recommendations: Government support is crucial. In developing economies, institutional inertia and corruption may severely hinder adoption. Policies promoting transparency, interoperability standards, and fiscal incentives can improve adoption rates.
- Managerial Action: Leaders must foster a culture of innovation, provide resources for digital upskilling, and support cross-functional integration.
- Conduct cost-benefit analyses of blockchain deployment in related systems (e.g., NSW, MNSW, secure EDI).
- Investigate the role of anti-corruption initiatives and public-private partnerships in blockchain adoption.
- Undertake longitudinal studies to monitor post-adoption performance and institutional learning trajectories.

This research provides a validated analytical framework and empirical foundation for policymakers, technology leaders, and logistics stakeholders seeking to implement blockchain in national supply chain infrastructure.

DECLARATION OF AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

The authors utilized ScholarGPT and Grammarly Premium to improve the legibility and clarity of the figures and text during the preparation of this work. The authors assume full responsibility for the publication's content, and they review and edit it as necessary after using this tool or service.

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