IMPROVING COLD CHAIN LOGISTICS FOR MEDICAL SUPPLIES OF THAILAND

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Received: 19 February 2025 / Revised: 31 May 2025 / Accepted: 28 June 2025

ABSTRACT

Purpose – This study aims to improve cold chain transportation management for medical supplies in Thailand by identifying the key factors that influence operational efficiency and the preservation of product quality.
Methodology – A mixed-methods approach was employed, integrating quantitative data from 200 structured questionnaire responses with qualitative insights obtained through semi-structured interviews with 10 industry experts. Quantitative data were analyzed using descriptive statistics, independent-samples t-tests, and one-way ANOVA via SPSS, while thematic content analysis was used for the qualitative data.
Results – The findings reveal that inadequate equipment maintenance and poor communication with suppliers significantly reduce the reliability of cold chain systems. Furthermore, deficiencies in emergency response protocols and inconsistent cost-efficiency strategies contribute to systemic inefficiencies.
Implications – The results provide actionable insights for healthcare logistics stakeholders in Thailand, emphasizing the need for standardized maintenance practices, stronger supplier collaboration, and the adoption of cost-effective logistics strategies to enhance cold chain performance.
Originality/Value – This research offers a comprehensive and practical analysis of Thailand's medical cold chain logistics using a mixed-methods approach. It addresses a critical gap in the existing literature and provides a foundation for future improvements and studies in the field.

Keywords: Cold chain transportation, Medical supply chain, Optimization

Paper Type: Research Article

INTRODUCTION

Thailand's healthcare sector has experienced remarkable growth in recent years, driven by increasing domestic healthcare demand and the expanding medical tourism industry. It is projected that more than 3.07 million foreign patients will generate over 57 billion THB in 2024 (Kasikorn Research Center, 2023). This expansion has intensified the need for an efficient and reliable medical logistics system, especially for the cold chain, which plays a vital role in maintaining the integrity of vaccines, specialty pharmaceuticals, and biological products. However, Thailand's cold chain infrastructure continues to face challenges in rural accessibility, equipment maintenance, and real-time temperature monitoring (Global Cold Chain Alliance, 2022; PATH, 2011). These limitations threaten product quality and patient safety, particularly in remote healthcare settings. Consequently, strengthening the cold chain system is crucial to support Thailand's healthcare expansion, minimize losses from temperature deviations, and ensure the delivery of safe and effective medical supplies nationwide. Addressing these challenges will enhance the resilience of Thailand's healthcare logistics and reinforce its competitiveness as a regional healthcare hub.

Citation:
Chen, H., & Deechongkit, S. (2025). Improving Cold Chain Logistics for Medical Supplies of Thailand. *RMUTT Global Business Accounting and Finance Review, 9*(2), 27-37. https://doi.org/10.60101/gbafr.2025.279157

Despite continuous investment in healthcare logistics, the COVID-19 pandemic exposed significant weaknesses in Thailand's cold chain system, particularly in vaccine distribution. Issues such as delayed delivery, inconsistent temperature control, and fragmented coordination among stakeholders highlighted systemic inefficiencies (PATH, 2011). These problems stem from a lack of integrated technology and limited information sharing across supply chain actors. The absence of real-time temperature tracking systems, data-driven decision-making tools, and standardized operating protocols further weakens supply reliability (Chermala et al., 2025). In addition, rural areas face shortages in skilled personnel and technical capacity, increasing the risk of product spoilage and public health impacts. Such challenges underscore the need for a comprehensive investigation into Thailand's cold chain management practices. A focused study on technological adoption, operational optimization, and stakeholder collaboration can reveal improvement opportunities and strategic approaches to building a more efficient and resilient medical cold chain system that meets international standards.

Based on the above significance, the researcher aims to identify improvement opportunities in technology adoption, operational processes, and stakeholder collaboration within Thailand's cold chain logistics for medical supplies. The study seeks to propose strategic measures that enhance the efficiency, reliability, and sustainability of the medical cold chain system. The expected outcomes include practical recommendations for integrating advanced technologies, optimizing operations, and fostering multi-stakeholder partnerships. Ultimately, this research will contribute to strengthening Thailand's healthcare logistics capacity and supporting its long-term vision of becoming a leading medical service and logistics hub in the ASEAN region (TechSci Research, 2025; Kasikorn Research Center, 2023).

LITERATURE REVIEW

Cold chain logistics is critical for maintaining the efficacy of temperature-sensitive medical products such as vaccines and biologics, with the World Health Organization estimating that nearly 50% of global vaccine wastage occurs due to temperature control failures. This issue is particularly severe in Thailand, where the tropical climate and uneven rural infrastructure significantly intensify distribution risks, especially for vaccines and pharmaceutical products (Aung & Chang, 2014; Kuo & Chen, 2010). Key challenges in cold chain transportation include frequent temperature excursions affecting approximately 25% of shipments, while operational costs are 30–50% higher than conventional logistics systems. Moreover, rural and remote regions experience additional obstacles such as unstable electricity supply and inadequate transportation networks, which further compromise cold chain integrity and threaten public health outcomes.

To address these challenges, technological innovations such as IoT-based temperature monitoring and blockchain-enabled tracking systems have demonstrated strong potential for reducing spoilage and improving transparency. Evidence from pilot projects in Thailand indicates that these technologies can reduce vaccine losses by up to 28%. However, despite these benefits, high investment costs, complex system requirements, and limited technical capacity restrict widespread adoption, particularly in resource-constrained healthcare environments (Bottani et al., 2022; Pajic et al., 2024). Consequently, Thailand's cold chain infrastructure remains fragmented; approximately 30% of cold storage equipment fails to meet required standards, and nearly 40% of facilities lack effective monitoring and evaluation systems (Lu & Zhang, 2021). Furthermore, weak communication between logistics stakeholders and insufficient emergency response protocols continue to undermine consistent temperature-controlled distribution nationwide (Emigh et al., 2023; Feng, 2024).

Several advanced economies provide valuable models for strengthening Thailand's cold chain system. The United States emphasizes stringent regulatory oversight combined with extensive IoT integration, Germany promotes public–private incentive frameworks, and Japan leads in automation and standardized logistics operations. Together, these approaches highlight the importance of technological investment, institutional collaboration, and comprehensive regulatory frameworks in reducing spoilage and improving operational efficiency. By selectively adapting these international best practices, Thailand can significantly enhance the resilience and reliability of its cold chain logistics network.

Thailand's government has already initiated key measures to improve cold chain performance through policies such as the Smart Logistics Development Program, expanded public–private partnership (PPP) investments, and strengthened Food and Drug Administration regulations (National Economic and Social Development Council, 2022; PATH, 2011). These interventions have contributed to improved distribution efficiency, reduced vaccine spoilage, and increased Thailand's competitiveness in pharmaceutical and food exports (Global Cold Chain Alliance, 2022). Moving forward, sustained government commitment combined with deeper private-sector collaboration will be essential for building a robust, sustainable, and globally competitive cold chain ecosystem.

METHODOLOGY

Population and Samples

The study targets stakeholders in Thailand's cold chain logistics and medical supply sectors, including logistics operators, manufacturers, and healthcare professionals. Based on Cochran's formula (Cochran, 1977), the required sample size was calculated to be 196. A total of 200 valid responses were ultimately collected through structured surveys and semi-structured interviews. This ensures representative insights into cold chain optimization challenges.

Demographic Data

The sample included 200 professionals directly involved in Thailand's cold chain logistics, exceeding the calculated minimum (196) for statistical reliability. Respondents provided diverse perspectives through structured surveys and in-depth interviews.

Research Instruments

The study used questionnaires (200 responses) and semi-structured interviews (10 experts) to assess cold chain logistics across five key dimensions. Quantitative data was analyzed via SPSS (ANOVA, t-tests), while qualitative insights were thematically coded for deeper context.

Data Collection

A mixed-methods approach gathered data from 200 stakeholders, exceeding Cochran's minimum sample size (196). Surveys provided statistical insights, while interviews enriched findings with expert perspectives, ensuring a balanced analysis of Thailand's cold chain challenges.

Research Hypotheses

Based on the qualitative findings and relevant literature, the performance of Thailand's cold chain logistics system for medical supplies is influenced by multiple interrelated organizational and operational factors. Deficiencies in equipment quality and maintenance increase the likelihood of temperature deviations, which directly threaten product integrity. Inadequate system evaluation mechanisms limit the ability of organizations to detect failures and improve operational efficiency. Weak emergency preparedness further amplifies the consequences of system breakdowns, while high operational costs constrain the sustainability of logistics operations. In addition, ineffective communication and coordination with suppliers disrupt service continuity and responsiveness. These interconnected challenges collectively affect the efficiency and reliability of cold chain transportation, which is a critical determinant of healthcare service quality and patient safety. Therefore, this study proposes that improvements in these key factors will significantly enhance cold chain performance. Accordingly, this study examines five key factors affecting Thailand's cold chain logistics efficiency for medical supplies, including equipment quality, system evaluation, emergency measures, cost efficiency, and supplier coordination, leading to the formulation of the following research hypotheses.

H1: Equipment quality and maintenance has a significant impact on the efficiency and reliability of cold chain transportation for medical supplies in Thailand.

H2: Evaluation and efficiency of the cold chain system has a significant impact on the efficiency and reliability of cold chain transportation for medical supplies in Thailand.

H3: Emergency measures have a significant impact on the efficiency and reliability of cold chain transportation for medical supplies in Thailand.

H4: Costs and efficiency have a significant impact on the efficiency and reliability of cold chain transportation for medical supplies in Thailand.

H5: Communication and coordination with suppliers have a significant impact on the efficiency and reliability of cold chain transportation for medical supplies in Thailand.

Data Analysis

This study employed a mixed-methods data analysis approach to ensure comprehensive and robust findings. First, qualitative analysis was conducted through thematic analysis of in-depth interviews with ten experts to identify key challenges and best practices in Thailand's cold chain logistics system. Second, quantitative analysis involved the use of descriptive statistics and inferential statistics, specifically analysis of variance (ANOVA), to examine five dimensions of cold chain performance based on survey responses from 200 participants. Finally, triangulation analysis was applied to integrate and validate the qualitative and quantitative findings by systematically cross-referencing interview insights with survey results, thereby enhancing the credibility, reliability, and overall rigor of the research conclusions.

RESULTS

The thematic analysis findings from the expert interviews revealed three critical issues affecting cold chain performance. First, outdated equipment and poor maintenance were identified as major causes of temperature control failures, as aging infrastructure and delayed repairs increase the risk of product quality degradation. Second, weak supplier coordination was frequently reported, where slow responses and rigid operating procedures disrupt the timely delivery of urgent medical supplies. Third, the experts emphasized the presence of an ineffective emergency response plan, noting that system breakdowns exposed serious gaps in contingency measures, leading to preventable losses. Together, these themes reflect fundamental structural and managerial weaknesses within the healthcare cold chain system. The following figure presents the professional composition of the ten experts who provided the qualitative data supporting these findings.

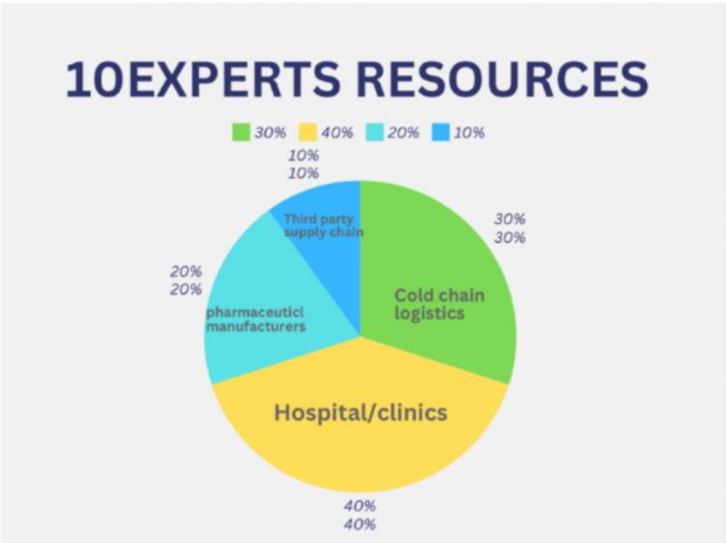

Figure 1. 10 interviewees in this study

The content analysis of the ten experts further supports these findings and strengthens their credibility. As illustrated in Figure 1, the expert panel consisted of professionals from hospitals and clinics (40%), cold chain logistics providers (30%), pharmaceutical manufacturers (20%), and third-party supply chain organizations (10%). Despite their diverse professional backgrounds, all groups consistently highlighted similar concerns regarding equipment deterioration, insufficient maintenance systems, ineffective inter-organizational coordination, and the lack of reliable emergency preparedness. This convergence of perspectives across stakeholder groups underscores the urgency of strengthening infrastructure investment, collaborative management practices, and systematic risk management to enhance the resilience and reliability of healthcare cold chain operations.

Table 1. Descriptive Statistics Analysis

Demographics data	Frequency	Percent
Gender		
Male	88	44
Female	112	56
Age		
Below23	34	17
23-41	121	60.5
42-53	26	13
54up	19	9.5
Nationality		
Thai	200	100
Education level		
High-school	43	21.5
(High)vocational certificate	63	31.5
Bachelor	47	23.5
Master	40	20
Doctoral-higher	7	3.5
Work position		
Operational	87	43.5
Management	49	24.5
Technical	64	32
Work function		
Operation-maintenance	68	34
Transportation-delivery	64	32
Quality-safety assurance	68	34
Work experience		
1-5 years	68	34
5-10 years	55	27.5
Over10 years	77	38.5
Total	200	100

From Table 1, the demographic data of the 200 respondents show that 56% were female and 44% were male. Most respondents were aged 23–41 years (60.5%), followed by those aged below 23 (17%), 42–53 years (13%), and 54 years and above (9.5%). All respondents were Thai nationals (100%). Regarding education level, 31.5% held a high vocational certificate, 23.5% held a bachelor's degree, 21.5% completed high school, 20% obtained a master's degree, and 3.5% held doctoral or higher qualifications. In terms of work position, 43.5% were in operational roles, 32% in technical positions, and 24.5% in management. The respondents' work functions were distributed among operation and maintenance (34%), quality and safety assurance (34%), and transportation and delivery (32%). Concerning work experience, 38.5% had over 10 years of experience, 34% had 1–5 years, and 27.5% had 5–10 years of experience.

Table 2. Anova

Variables		Sum of Squares	df	Mean Square	F	Sig.
efficiency1	Between Groups	63.917	28	2.283	1.165	0.272
	Within Groups	334.958	171	1.959		
	Total	398.875	199			
efficiency2	Between Groups	84.312	28	3.011	1.568	0.441
	Within Groups	328.443	171	1.921		
	Total	412.755	199			
efficiency3	Between Groups	65.16	28	2.327	1.147	0.291
	Within Groups	346.995	171	2.029		
	Total	412.155	199			
efficiency4	Between Groups	61.857	28	2.209	1.03	0.432
	Within Groups	366.898	171	2.146		
	Total	428.755	199			
equipmentQandM1	Between Groups	92.535	28	3.305	1.641	0.03
	Within Groups	344.345	171	2.014		
	Total	436.88	199			
equipmentQandM2	Between Groups	60	28	2.143	0.988	0.49
	Within Groups	371.02	171	2.17		
	Total	431.02	199			
equipmentQandM3	Between Groups	64.331	28	2.298	1.211	0.228
	Within Groups	324.424	171	1.897		
	Total	388.755	199			
equipmentQandM4	Between Groups	69.011	28	2.465	1.212	0.227
	Within Groups	347.784	171	2.034		
	Total	416.795	199			
EMGmearsures1	Between Groups	95.525	28	3.412	1.771	0.155
	Within Groups	329.43	171	1.926		
	Total	424.955	199			
EMGmearsures2	Between Groups	58.916	28	2.104	1.09	0.356
	Within Groups	330.204	171	1.931		
	Total	389.12	199			
EMGmearsures3	Between Groups	69.322	28	2.476	1.261	0.186
	Within Groups	335.633	171	1.963		
	Total	404.955	199			
EMGmearsures4	Between Groups	61.41	28	2.193	1.112	0.33
	Within Groups	337.31	171	1.973		
	Total	398.72	199			
costnefficiency1	Between Groups	62.221	28	2.222	1.176	0.261
	Within Groups	323.134	171	1.89		
	Total	385.355	199			
costnefficiency2	Between Groups	76.163	28	2.72	1.388	0.106
	Within Groups	335.117	171	1.96		
	Total	411.28	199			
costnefficiency3	Between Groups	109.023	28	3.894	1.957	0.005
	Within Groups	340.257	171	1.99		
	Total	449.28	199			

Table 2. (Cont.)

Variables		Sum of Squares	df	Mean Square	F	Sig.
costnefficiency4	Between Groups	59.792	28	2.135	1.096	0.349
	Within Groups	333.203	171	1.949		
	Total	392.995	199			
CnC1	Between Groups	80.758	28	2.884	1.396	0.102
	Within Groups	353.242	171	2.066		
	Total	434	199			
CnC2	Between Groups	74.203	28	2.65	1.359	0.121
	Within Groups	333.352	171	1.949		
	Total	407.555	199			
CnC3	Between Groups	58.717	28	2.097	0.997	0.477
	Within Groups	359.663	171	2.103		
	Total	418.38	199			
CnC4	Between Groups	70.273	28	2.51	1.234	0.208
	Within Groups	347.882	171	2.034		
	Total	418.155	199			

Table 2 presents the results of a one-way ANOVA conducted on 20 questionnaire items to examine differences in perceptions among respondent groups. The analysis showed that 18 items had p-values greater than 0.05, indicating no statistically significant differences among groups and suggesting a general consistency in respondents' perceptions of cold chain logistics practices. This overall similarity in responses may reflect the influence of standardized operational procedures commonly adopted across the industry.

However, two items demonstrated statistically significant differences. The first was equipmentQandM1 ($F(28, 171) = 1.641$, $p = 0.030$), which assessed perceptions of the reliability of cold chain transportation equipment in maintaining stable temperature control. The second was costnefficiency3 ($F(28, 171) = 1.957$, $p = 0.005$), which evaluated the adoption of cost-effective technologies to improve efficiency and reduce expenses. These findings indicate meaningful variations in perceptions related to equipment reliability and cost efficiency, providing empirical support for Hypotheses 2 and 4. Such differences may arise from variations in technological readiness, infrastructure quality, and resource availability across organizations and regions.

Table 3. Triangulation Analysis

Dimension	Survey results	Interview insights	Interpretation	References
Equipment Quality and Maintenance	Only one question showed statistical significance: "Our cold chain transportation equipment is reliable enough to maintain stable temperature control."	Aging equipment (over 10 years in use) with declining performance; inconsistent maintenance and lengthy repair times leading to temperature breaches and delays	Aging equipment and insufficient maintenance directly affect transportation quality, indicating the urgent need for system upgrades	Lu and Zhang (2021)

Table 3. (Cont.)

Dimension	Survey results	Interview insights	Interpretation	References
System Evaluation and Efficiency	No statistical significance observed in survey results	Frequent equipment failures during peak demand periods; operational efficiency impacted by outdated technology	Existing technological limitations fail to meet peak demand requirements, reflecting technological lag in cold chain logistics	Pajic et al. (2024)
Emergency Measures	No statistical significance observed in survey results	Emergency plans ineffective during execution (e.g., slow response for backup vehicles); poor coordination causing frequent delays	Weak emergency protocols and coordination represent a major operational vulnerability requiring improved response mechanisms	Emigh et al. (2023).
Cost and Efficiency	One question showed statistical significance: “We have adopted cost-effective technologies in our cold chain transportation to improve efficiency and lower expenses.”	Slow supplier response times; insufficient investment in technology upgrades affecting both cost and efficiency	Limited adoption of cost-effective technologies constrains operational efficiency improvements	Bottani et al. (2022)
Supplier Communication	No statistical significance observed in survey results	Delayed supplier communication in urgent situations; inefficient responses affecting service quality and delivery timelines	Despite non-significant survey results, interviews reveal communication failures that substantially impair logistics performance	Feng (2024)

From Table 3, this study employed methodological triangulation by integrating survey data and expert interviews to validate findings related to the operational efficiency of Thailand’s medical cold chain logistics. The convergence of both data sources consistently revealed four critical and interrelated challenges, namely aging equipment and inconsistent maintenance, delayed supplier response and poor communication, ineffective emergency measures, and lagging technological updates. The triangulated results indicate that equipment failures and maintenance delays remain systemic issues, particularly during peak operational periods, while supplier-side inefficiencies such as slow communication and weak responsiveness significantly disrupt logistics performance. In addition, emergency plans were found to be poorly executed, resulting in operational delays and product losses, and outdated technology continues to function as a major bottleneck, as emphasized by multiple interviewees who stressed the urgent need for innovation and modernization. These findings align with previous studies, confirming that infrastructure gaps, limited technological adoption, and fragmented coordination are persistent obstacles in cold chain systems (Aung & Chang, 2014; Kuo & Chen, 2010). Overall, triangulation strengthens the reliability of the study's conclusions and highlights the necessity for coordinated improvements in equipment systems, supplier partnerships, crisis management protocols, and digital transformation.

DISCUSSION AND IMPLICATIONS

This study confirms that Thailand's medical cold chain logistics continues to face critical challenges, including aging equipment, ineffective supplier communication, fragmented coordination, and uneven adoption of cost-effective technologies. These findings are consistent with previous research emphasizing infrastructure deficiencies and coordination constraints in developing regions (Aung & Chang, 2014; Kuo & Chen, 2010). The ANOVA results revealed statistically significant differences in perceptions of equipment reliability and the adoption of cost-efficiency technologies, indicating that stakeholders experience these issues differently depending on organizational capacity, technological readiness, and resource availability. In contrast, the remaining hypotheses were not supported, suggesting a baseline level of standardized operational practices across the industry, albeit with uneven implementation.

Insights from 200 quantitative survey responses and 10 qualitative expert interviews further confirm the systemic nature of these challenges. Logistics providers and healthcare personnel consistently emphasized the lack of modern equipment, slow supplier responses—particularly during emergency situations such as vaccine distribution—and fragmented coordination between logistics teams and healthcare institutions, especially in rural and remote areas. The convergence of quantitative and qualitative evidence demonstrates that while standardized protocols exist, disparities in infrastructure investment, technology access, and organizational readiness create persistent performance gaps across Thailand's cold chain system.

From a practical and policy perspective, these findings highlight several urgent priorities. Logistics managers should accelerate the deployment of digital monitoring systems and IoT-enabled equipment to improve real-time temperature control and reduce human error, while healthcare authorities must strengthen supplier collaboration through integrated digital communication platforms to enhance responsiveness and reliability. At the policy level, targeted investment in rural cold chain infrastructure, along with the implementation of dynamic and regularly tested emergency protocols, is essential to strengthen national resilience against medical supply disruptions. Nevertheless, this study is subject to limitations related to sample scope and its focus on the Thai context. Future research should therefore examine the longitudinal impact of cold chain reforms and conduct comparative studies across ASEAN countries to improve the generalizability and policy relevance of future findings.

LIMITATIONS AND FUTURE RESEARCH POSSIBILITIES

This study acknowledges several limitations, including the concentration of data collection in urban areas and the potential for subjective bias in qualitative analysis, which may affect the generalizability of the findings. The results highlight persistent challenges in Thailand's medical cold chain logistics, particularly aging equipment requiring modernization (Suraratdecha, 2011), inadequate supplier coordination necessitating more streamlined communication protocols (Grant, 2024), and slow adoption of advanced technologies despite the demonstrated effectiveness of IoT-based solutions (Muridzi, 2024). Future research should therefore address regional disparities, systematically evaluate emerging technologies such as blockchain and artificial intelligence, and develop crisis-responsive logistics models. These efforts are essential to support infrastructure upgrades, accelerate digital transformation, and strengthen institutional capacity, ultimately enhancing Thailand's cold chain resilience for medical emergencies and aligning the national system with global standards while closing critical local operational gaps (Langkulsen & Lambonmung, 2024).

CONCLUSION

This study provides comprehensive empirical evidence that Thailand's medical cold chain logistics system continues to face substantial operational and structural challenges that directly affect the efficiency and reliability of healthcare supply distribution. Through a mixed-methods approach combining quantitative analysis of 200 stakeholders and qualitative insights from 10 experts, the research identified persistent weaknesses in equipment quality and maintenance, supplier communication, emergency preparedness, and technological adoption. The ANOVA results confirmed statistically significant differences in perceptions regarding equipment reliability and cost-efficiency technologies, reinforcing the critical role of infrastructure quality and digital investment in cold chain performance. Moreover, triangulation of findings revealed that these challenges are systemic and interrelated, with particularly severe impacts in rural and resource-constrained settings. Collectively, the findings underscore the urgent need for coordinated improvements in technological modernization, supplier collaboration, emergency response mechanisms, and policy-driven infrastructure development. By addressing these priority areas, Thailand can strengthen the resilience of its medical cold chain, enhance patient safety, reduce economic losses from temperature deviations, and reinforce its strategic position as a leading healthcare and medical logistics hub in the ASEAN region.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest found in this research.

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