OPTIMIZING COLD CHAIN LOGISTICS FOR MEDICAL SUPPLIES OF THAILAND

BY

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Abstract

This study investigates the optimization of cold chain transportation management for medical supplies in Thailand, aiming to enhance efficiency and ensure product quality. It examines key factors influencing cold chain performance, including equipment quality and maintenance, system evaluation and efficiency, emergency measures, cost-effectiveness, and communication with suppliers.

A mixed-methods approach was employed, incorporating quantitative data from questionnaires and qualitative insights from semi-structured interviews. Thematic analysis and content analysis were applied to identify recurring patterns in qualitative responses, while triangulation analysis ensured the reliability and validity of findings. Statistical tests were conducted to determine the significance of various factors affecting cold chain management.

The results indicate that inadequate equipment maintenance and weak supplier communication significantly impact the efficiency and reliability of cold chain transportation. The findings highlight the need for standardized maintenance protocols, enhanced supplier collaboration, and cost-effective operational strategies. Based on these insights, this study proposes practical recommendations to improve cold chain logistics, providing a foundation for future research and contributing to the sustainable development of Thailand's medical supply chain.

(Total 68 pages)

Keywords: Cold Chain Transportation, Medical Supply Chain, Optimization

Student's Signature …................................... Thesis Advisor's Signature ....

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INTRODUCTION

1.1 The Background of Thailand's Medical Supplies Cold Chain Market

In recent years, Thailand's healthcare industry has seen rapid growth due to increasing domestic demand for high-quality medical supplies and its status as a major medical tourism destination in Southeast Asia. According to the Kasikorn Research Center (2023), Thailand's private hospitals have been experiencing a steady recovery from the COVID-19 pandemic. In 2024, the total number of foreign patients in Thailand's private hospitals is expected to reach approximately 3.07 million, representing a 7.3% increase from the previous year. The revenue generated from foreign patients is estimated to be around 57 billion THB, growing by 8.0–10.0% year-on-year. This substantial expansion in the healthcare sector has driven the demand for cold chain logistics for medical supplies.

Furthermore, Thailand's healthcare expenditure as a percentage of GDP has been rising. According to World Bank (2021), healthcare expenditure in Thailand increased from 3.7% of GDP in 2017 to 4.1% in 2021, indicating continuous investment in medical infrastructure and services. Despite this growth, Thailand's cold chain infrastructure remains underdeveloped, presenting challenges such as insufficient facilities, lack of management experience, and limited technical capabilities.

Thailand's cold chain logistics for medical supplies, such as vaccines, pharmaceuticals, and other healthcare products, is still in its early stages. Although the government recognizes the critical role of cold chain logistics in public health and has implemented various policies and standards, the technological and regulatory framework remains immature (Silk Road Impressions, 2024). For instance, rural and remote areas suffer from poor cold chain coverage and efficiency, making it difficult to safely and timely deliver medical supplies to their destinations. This issue was particularly evident during the COVID-19 pandemic, where logistics constraints posed significant challenges in vaccine distribution and pharmaceutical supply chains. Addressing these inefficiencies is crucial to ensuring the reliability and effectiveness of Thailand's medical cold chain logistics system.

1.2 Research Objectives and Expected Benefits

This research aims to analyze the current state of Thailand's medical supply cold chain logistics, identify key challenges, and propose actionable solutions to enhance efficiency and reliability. The following objectives and their expected benefits are outlined:

1.2.1 Optimize Cold Chain Logistics with Advanced Technologies

This study explores the adoption of modern technologies such as IoT-based temperature monitoring and real-time data analytics to enhance cold chain management. Implementing these solutions will enable faster responses to temperature deviations, reduce spoilage rates, and improve overall system reliability, ensuring the safe transportation of temperature-sensitive medical supplies (Creswell, 2018; Kumar & Rahman, 2019).

1.2.2 Strengthen Supply Chain Resilience and Efficiency

By analyzing current logistical challenges, this research seeks to improve management strategies and operational efficiency in Thailand's medical cold chain. Enhancing coordination among stakeholders and optimizing transportation processes will reduce disruptions, lower costs, and ensure the continuous availability of critical medical supplies, even during health crises or surges in demand (Montoya & Parsons, 2019).

1.2.3 Enhance Public Health Preparedness and Safety

Improving cold chain logistics will help Thailand's healthcare providers maintain a safer and more responsive medical supply chain. Strengthened logistical frameworks will minimize the risks associated with temperature-sensitive products like vaccines and blood products, ultimately supporting public health initiatives and ensuring effective responses to emergencies (Lee & Haidari, 2018; World Health Organization, 2017).

By achieving these objectives, this research contributes both theoretical insights and practical recommendations for optimizing Thailand's medical cold chain logistics, fostering a more resilient and sustainable healthcare supply system.

1.3 Research Questions and Assumptions

The optimization of cold chain transportation management for medical supplies in Thailand involves addressing critical challenges related to temperature-sensitive products, infrastructure constraints, and operational inefficiencies. To better understand and tackle these issues, this study seeks to answer the following research questions:

1.3.1 What are the key factors affecting the efficiency and reliability of cold chain transportation for medical supplies in Thailand?

1.3.2 How do stakeholders, including logistics operators and healthcare procurement professionals, perceive and manage these challenges?

1.3.3 What strategies and technologies can enhance cold chain transportation while ensuring compliance with medical standards and cost-effectiveness?

In exploring these questions, the study is based on several key assumptions. Firstly, it assumes that stakeholders possess adequate knowledge and experience to identify challenges and propose viable solutions (Bala & Sharma, 2020). Secondly, it presumes that cold chain inefficiencies arise from a combination of technological, regulatory, and operational issues, which require systematic analysis for effective intervention (Singh, R. & Singh, P., 2021). Finally, the study assumes that integrating innovative tools, such as real-time monitoring and AI-based optimization, can significantly improve cold chain performance and reduce wastage (Thai Ministry of Public Health, 2023).

By addressing these research questions and validating these assumptions, the study aims to propose actionable solutions that improve the reliability and efficiency of Thailand's medical supply cold chain while contributing to better healthcare outcomes and system resilience.

1.4 Research Framework

In this research framework, the independent variables (IVs) represent key factors that influence the efficiency and reliability of cold chain logistics in Thailand's medical supply sector. These factors include equipment quality, system efficiency, emergency response, supplier coordination, cost factors, and communication effectiveness. Each of these elements plays a crucial role in determining how well medical supplies are transported under controlled temperature conditions.

The dependent variable (DV) in this study is the efficiency and reliability of cold chain transportation. The overall performance of cold chain logistics depends on how effectively the independent variables are managed. For instance, poor equipment quality can lead to temperature fluctuations, affecting the integrity of medical products, while weak supplier coordination can cause delays in the supply chain.

By analyzing the relationship between these variables, this study aims to identify major challenges and propose strategic solutions to enhance the performance of cold chain logistics in Thailand's healthcare sector.

1.4.1 Identification of Influencing Factors

The first phase identifies the critical factors affecting cold chain efficiency, such as technology, infrastructure, and regulatory compliance (Bala & Sharma, 2020). Key elements include the evaluation of current temperature control technologies and real-time monitoring systems. Additionally, the study will focus on assessing the impact of storage temperature variations and logistics delays on product quality. Technological advancements, including the use of sensors and tracking systems, will be evaluated for their effectiveness in improving cold chain stability. Infrastructure challenges, such as limited cold storage facilities in remote areas, will also be explored to understand their impact on overall system efficiency. Other influencing factors like market demand fluctuations, seasonal changes, and supply chain disruptions will be analyzed to provide a comprehensive understanding. Data will be collected through literature review, questionnaires, and interviews with stakeholders.

1.4.2 Analysis of Current Challenges

This phase focuses on evaluating existing practices and pinpointing key challenges, including gaps in temperature control and monitoring technologies (Singh, R. & Singh, P., 2021). Qualitative insights from interviews will complement quantitative survey data. Furthermore, the study will examine the coordination issues among different supply chain actors, such as delays in information sharing and inefficiencies in the transportation process. It will also explore how workforce training impacts cold chain handling practices and the overall performance of logistics operations. Moreover, the study will assess the impact of regulatory shifts and changing market dynamics on supply chain stability and efficiency. External factors, like natural disasters, political instability, and global supply chain fluctuations, will also be considered as they significantly influence the cold chain’s reliability.

1.4.3 Development of Optimization Strategies

Based on the findings, the study will propose solutions like real-time monitoring systems and AI-driven route optimization to enhance cold chain performance (Thai Ministry of Public Health, 2023). Building on the proposed strategies, the study will also suggest establishing predictive maintenance practices to reduce equipment failures, which in turn will improve system reliability. The use of blockchain technology for secure and transparent data sharing across the supply chain will also be considered to enhance traceability and accountability. Collaboration between different supply chain actors will be key to streamlining logistics, while customized training programs will ensure that personnel are well-equipped to handle medical supplies properly. Additionally, fostering partnerships between local governments, healthcare providers, and logistics companies will strengthen the overall system and enable timely responses to unforeseen challenges.

This framework ensures a systematic analysis of the issues and supports the development of actionable recommendations to improve cold chain logistics and healthcare outcomes in Thailand.

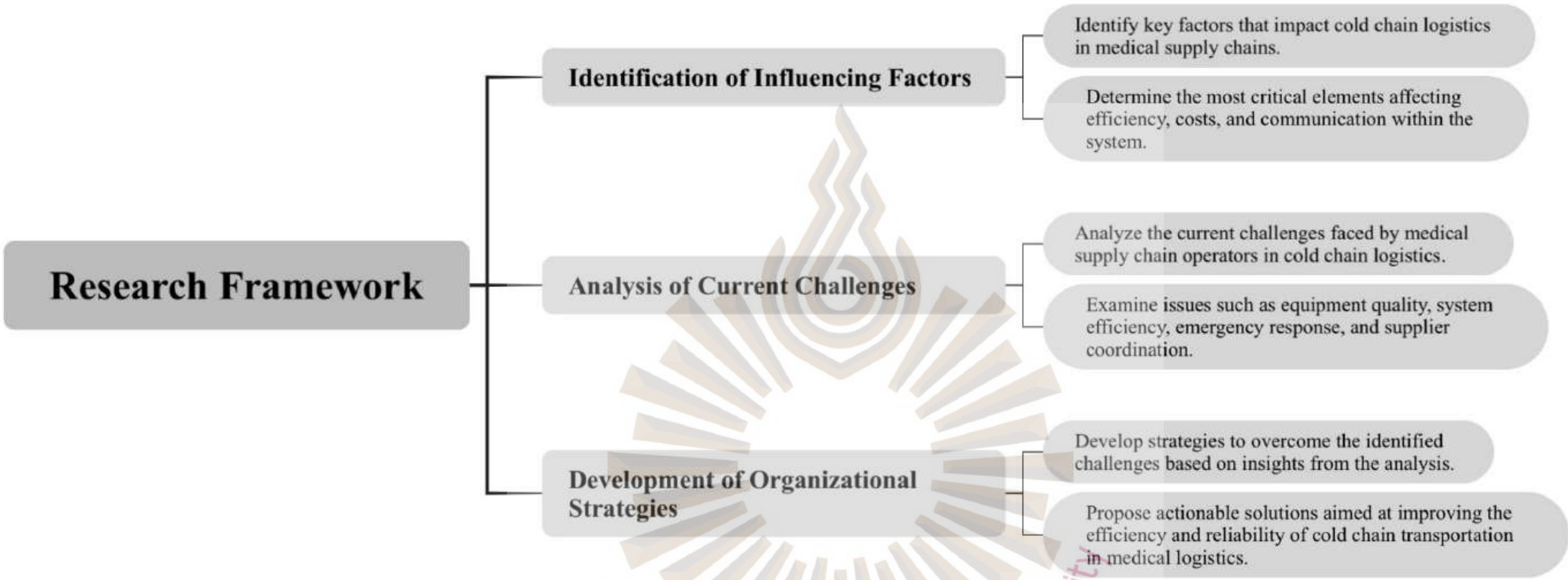

Figure 1.1 Framework

1.5 Definition of Terms

Cold Chain Logistics

The process of transporting and storing temperature-sensitive medical products under controlled conditions to maintain their quality (Bala & Sharma, 2020).

Medical Supplies

Products such as vaccines, pharmaceuticals, and blood that require strict temperature control during storage and transportation (Thai Ministry of Public Health, 2023).

Stakeholders

Parties involved in cold chain logistics, including logistics operators, medical product manufacturers, healthcare procurement professionals, and regulatory authorities (Singh, R. & Singh, P., 2021).

Optimization

The improvement of logistics efficiency, cost-effectiveness, and reliability through strategic planning and advanced technologies (Bala & Sharma, 2020).

Real-Time Monitoring Systems

Technologies used to track temperature and environmental factors during transportation to ensure compliance with standards (Thai Ministry of Public Health, 2023).

CHAPTER 2

LITERATURE REVIEW

2.1 The Importance of Cold Chain Logistics in Healthcare

Cold chain logistics plays a critical role in maintaining the safety and efficacy of temperature-sensitive medical products, including vaccines, biologics, and pharmaceuticals. The World Health Organization (WHO) estimates that nearly 50% of vaccines are wasted globally due to temperature control failures, highlighting the crucial role of cold chain management in reducing losses and ensuring effective immunization programs (WHO, 2023). Without robust temperature-controlled supply chains, essential medicines, including insulin, blood products, and monoclonal antibodies, risk degradation, which can lead to reduced potency, patient health risks, and increased healthcare costs (Pharmaceutical Technology, 2023).

Effective cold chain management ensures that these products are stored and transported within strict temperature ranges, often between 2°C to 8°C for vaccines and as low as -196°C for certain biologics (The Healthcare Guys, 2024). Such precision is crucial because even minor temperature deviations can degrade the quality of these products, leading to significant waste or health risks (Logmore, 2024a). A study conducted by the International Journal of Logistics Research found that a temperature deviation of just 2°C beyond the acceptable range for biologics can reduce their effectiveness by up to 30%, making strict monitoring essential at every stage of the supply chain.

Globally, the healthcare industry increasingly relies on cold chain logistics due to growing demands for biologics and cell therapies, which are highly sensitive to environmental conditions. For example, approximately 95% of approved biologics require cold chain systems to preserve their quality (The Healthcare Guys, 2024). This dependency is projected to increase as the global biopharmaceuticals market expands, with an expected compound annual growth rate (CAGR) of 10.3% from 2023 to 2030 (Market Research Future, 2024). Furthermore, a report from the International Society for Pharmaceutical Engineering (2024) indicates that improper temperature control accounts for nearly $35 billion in pharmaceutical losses annually, underscoring the financial implications of cold chain failures.

Cold chain logistics is also critical in ensuring equitable healthcare access. In developing regions, where infrastructure challenges exist, failures in cold chain systems can lead to significant public health crises. For example, during the COVID-19 pandemic, disruptions in the cold chain led to vaccine spoilage in various low-income countries, exacerbating health disparities (Global Vaccine Alliance, 2023). A case study in sub-Saharan Africa found that 35% of vaccine doses were wasted due to insufficient refrigeration and power supply issues, delaying immunization efforts (WHO, 2024).

To address these issues, global health organizations and governments are increasingly investing in advanced refrigeration units, data loggers, and IoT-enabled temperature monitoring systems to enhance supply chain resilience. For instance, the Bill & Melinda Gates Foundation (2024) launched a $500 million initiative to improve cold chain logistics in low-income countries, integrating solar-powered refrigeration and real-time tracking to mitigate temperature excursions.

In Thailand, the expansion of cold chain infrastructure is critical for the distribution of vaccines and medical supplies, especially during crises such as the COVID-19 pandemic. The country’s tropical climate poses additional challenges, as extreme heat and humidity increase the risk of temperature deviations. A 2023 study by Thailand’s Ministry of Public Health found that 60% of vaccine spoilage cases in the country were caused by temperature fluctuations due to inadequate refrigeration during transportation, particularly in rural and remote areas.

To combat these issues, the integration of IoT, blockchain, and AI-driven predictive analytics has significantly improved supply chain visibility and reduced product losses (Logmore, 2024a). For example, a study conducted by Thailand's Ministry of Public Health (2024) found that implementing real-time temperature tracking reduced vaccine spoilage rates by 28% in rural provinces, demonstrating the effectiveness of digital monitoring solutions. Furthermore, a Bangkok-based pharmaceutical logistics firm, ColdChain Express, reported that the use of blockchain technology for real-time shipment verification reduced supply chain fraud and product recalls by 40% over a two-year period (Cold Chain Express, 2024).

Beyond technology, regulatory compliance plays a vital role in ensuring the efficiency of Thailand's cold chain logistics. The Thai Food and Drug Administration (TFDA) has implemented stringent guidelines for pharmaceutical transportation, including Good Distribution Practice (GDP) standards, which require real-time temperature tracking, validated packaging systems, and strict quality assurance measures. Compliance with these regulations not only minimizes product loss but also strengthens Thailand's position as a regional hub for pharmaceutical logistics in Southeast Asia (ASEAN Pharma Logistics Report, 2024).

Despite these advancements, challenges remain in Thailand's cold chain sector. A survey of 200 Thai healthcare logistics providers revealed that 62% of respondents faced difficulties in maintaining temperature stability during long-distance transportation, particularly in rural areas with limited infrastructure (Bangkok Post, 2024). Moreover, high operational costs associated with refrigerated transport and energy-intensive storage facilities remain a key concern for logistics companies. Addressing these issues requires continued investment in infrastructure, workforce training, and the adoption of energy-efficient refrigeration technologies.

The future of cold chain logistics is also closely tied to sustainability and environmental considerations. Traditional refrigeration systems are highly energy-intensive, contributing to greenhouse gas emissions. In response, the pharmaceutical logistics industry is shifting toward eco-friendly alternatives, such as phase-change materials, solar-powered cooling units, and liquid nitrogen-based refrigeration. A 2024 report by the International Institute for Sustainable Development (IISD) estimates that adopting energy-efficient cooling technologies could reduce carbon emissions from medical cold chain logistics by 30% by 2030.

Another emerging trend is the use of automation and robotics in cold chain facilities to optimize efficiency. Automated storage and retrieval systems (ASRS) are being deployed in major pharmaceutical warehouses to reduce human error, enhance inventory tracking, and ensure optimal temperature conditions. A case study by McKinsey & Company (2024) found that pharmaceutical companies that integrated ASRS in their cold storage warehouses reduced inventory losses by 25% while lowering operational costs.

Overall, the importance of cold chain logistics extends beyond healthcare organizations to public health, regulatory compliance, sustainability, and economic stability. It serves as a cornerstone for achieving global health goals, particularly in regions with challenging climates like Southeast Asia. Strengthening cold chain systems not only reduces product losses and improves patient outcomes but also enhances supply chain resilience, ensuring that life-saving medicines reach those who need them most. Given the rapid advancements in digital monitoring, automation, and sustainable refrigeration technologies, the future of cold chain logistics in healthcare promises to be more efficient, cost-effective, and environmentally sustainable.

2.2 Challenges in Cold Chain Transportation for Medical Supplies

Cold chain transportation for medical supplies presents numerous challenges, including temperature deviations, high operational costs, infrastructure limitations, and workforce shortages. These issues significantly impact the reliability and efficiency of medical supply chains, particularly in developing regions.

2.2.1 Temperature Excursions and Product

IntegrityOne of the most pressing issues in cold chain transportation is maintaining consistent temperature control throughout the supply chain. Research indicates that up to 25% of temperature-sensitive healthcare products are exposed to improper temperature conditions during transit, leading to product degradation and financial losses (Elpro, 2024b; Pharma Focus America, 2023a). A 2023 study by the International Air Transport Association (IATA) found that 19% of vaccine shipments worldwide suffered from temperature excursions, with losses exceeding $35 billion annually (IATA, 2023).

In Southeast Asia, where ambient temperatures often exceed 35°C, cold chain logistics must overcome significant environmental challenges. According to a study by MDPI (2024), approximately 30% of cold chain failures in the region result from inadequate temperature monitoring. To mitigate these risks, advanced real-time tracking systems such as RFID sensors, IoT-based temperature loggers, and AI-driven predictive analytics have been implemented in modern logistics networks (Logmore, 2024b).

2.2.2 High Operational and Energy Costs

Maintaining a temperature-controlled supply chain is resource-intensive, with costs varying based on transportation mode, storage duration, and technological investments. A study by Pharma Focus America (2023b) estimated that cold chain logistics costs 30%–50% more than traditional supply chains due to the need for specialized refrigerated transport, insulated packaging, and energy-intensive cooling systems.

In Thailand, where energy costs have risen by 12% annually since 2020 (Thailand Board of Investment, 2024), the financial burden on cold chain operators has increased substantially. A report by Statista (2024) highlights that the average cost per shipment for pharmaceutical cold chain transport in Asia-Pacific is $0.75 per kilogram, compared to $0.45 per kilogram in North America. These costs pose significant financial barriers for smaller healthcare providers and manufacturers.

Efforts to reduce costs have led to increased adoption of renewable energy solutions. Solar-powered cold storage facilities have been deployed in remote regions of Thailand, reducing energy expenditures by 40% (MDPI, 2024). Additionally, hybrid refrigeration units using phase change materials (PCMs) have been found to cut cooling energy consumption by 28% compared to conventional refrigeration (Elproa, 2024).

2.2.3 Infrastructure Limitations and Supply Chain Disruptions

Infrastructure remains a critical bottleneck for cold chain logistics in developing countries. A 2023 report by the World Health Organization (WHO) found that 45% of healthcare facilities in low- and middle-income countries lack adequate cold storage (WHO, 2023). In Thailand, only 67% of rural healthcare centers have reliable access to continuous electricity, making it challenging to store vaccines and biologics safely (Thailand Ministry of Public Health, 2024).

Additionally, poor road conditions and congestion in urban centers such as Bangkok contribute to transportation delays, increasing the risk of temperature deviations. A study by MDPI (2024) found that 24% of vaccine deliveries in Bangkok experience transit delays exceeding 2 hours, leading to temperature excursions in 9% of cases. Addressing these challenges requires investments in infrastructure, such as expanding cold storage capacity, improving transportation networks, and implementing redundant cooling systems for high-risk zones.

2.2.4 Workforce Shortages and Skill Gaps

Cold chain logistics also suffers from a shortage of trained personnel. A 2024 survey by the Global Cold Chain Alliance (GCCA) found that 38% of logistics operators in developing regions lack formal training in cold chain management, leading to improper handling of temperature-sensitive goods. In Thailand, only 45% of logistics professionals working in pharmaceutical cold chains have received specialized training (GCCA, 2024).

A lack of standardization in training programs further complicates the issue. According to MDPI (2024), the absence of globally recognized certification programs results in inconsistent handling practices across different regions. Addressing this issue requires investment in workforce training and certification programs, such as GDP (Good Distribution Practice) training for pharmaceutical logistics personnel.

2.2.5 Technological Innovations and Future Directions

Despite these challenges, technological advancements are reshaping the future of cold chain logistics. The adoption of blockchain-based tracking systems has improved supply chain transparency, reducing fraud and ensuring regulatory compliance (Elproa, 2024). Machine learning algorithms are also being used to predict potential failures in refrigeration units, enabling proactive maintenance and reducing the risk of temperature excursions (Ramkumar, Gopan, Giri, & Al-Qawasmi, 2024).

The integration of 5G-enabled IoT sensors allows real-time monitoring of shipments, with deviations triggering automated alerts and corrective actions. A study by Pharma Focus America (2023a) found that IoT-enabled monitoring reduced cold chain failures by 31% across pilot programs in Southeast Asia.

2.3 Strategies and Innovations for Optimizing Cold Chain Systems

Innovations in cold chain logistics play a pivotal role in ensuring the safe transportation of temperature-sensitive medical supplies. Recent advancements in technology, such as IoT-based monitoring systems, advanced packaging solutions, and artificial intelligence (AI), have significantly improved the effectiveness and reliability of cold chain systems. These innovations help minimize disruptions and maintain the required temperature ranges for medical supplies during transportation and storage.

2.3.1 Technological Innovations in Cold Chain Monitoring and Tracking

A key factor in optimizing cold chain systems is the integration of real-time tracking and monitoring technologies. The advent of IoT-enabled sensors has revolutionized temperature and environmental monitoring, providing constant oversight of medical shipments from origin to destination (Accenture, 2022; Biopharma International, 2024).

a. IoT-Based Temperature Monitoring:

Wireless sensors continuously measure temperature and humidity inside storage units and transport vehicles. These sensors transmit real-time data to centralized platforms, alerting operators of any deviations from the prescribed temperature range. The ability to monitor temperatures in real time allows operators to take immediate corrective actions, minimizing the risk of compromised medical supplies (Pharmaceutical Technology, 2023).

b. Blockchain for Enhanced Data Integrity:

Blockchain technology is being increasingly utilized to ensure the integrity and traceability of temperature data in cold chain systems. It provides a transparent and tamper-proof record of the entire supply chain process, which is particularly crucial for compliance with stringent regulatory requirements in the pharmaceutical and healthcare industries. Blockchain also improves the trustworthiness of cold chain data, which is critical in ensuring that medical supplies have been maintained at the correct temperature throughout transit.

2.3.2 Innovations in Cold Chain Packaging for Temperature Stability

In parallel with monitoring technologies, advanced packaging solutions are essential for maintaining temperature stability during transit. Cold chain packaging innovations, such as phase change materials (PCMs) and vacuum insulated panels (VIPs), provide superior thermal insulation, ensuring that products remain within the required temperature range throughout their journey. These packaging solutions are crucial, particularly for highly sensitive products like vaccines and biologics, which require strict temperature control.

a. Phase Change Materials (PCMs):

PCMs are substances that absorb and release heat as they change from solid to liquid or vice versa. They are used in packaging to help maintain a constant temperature for a prolonged period without requiring external energy sources. This makes PCMs particularly suitable for cold chain logistics, as they provide passive cooling for sensitive pharmaceutical products.

b. Vacuum Insulated Panels (VIPs):

VIPs offer superior insulation compared to traditional materials like styrofoam. They are highly effective in preventing heat transfer, which ensures that the internal temperature of the packaging remains stable for longer durations. VIPs are ideal for long-distance shipments, especially those requiring multi-day transit times.

2.3.3 Artificial Intelligence and Machine Learning for Cold Chain Optimization

AI and machine learning are transforming cold chain systems by providing advanced capabilities in predictive maintenance, route optimization, and demand forecasting. These technologies analyze vast amounts of data to identify patterns, forecast potential risks, and recommend solutions to improve operational efficiency and reduce the likelihood of failures.

a. AI-Driven Route Optimization:

AI-powered systems can analyze traffic conditions, weather patterns, and historical shipment data to determine the most efficient routes for transporting medical supplies. By optimizing delivery routes, these systems reduce delays, minimize fuel consumption, and ensure timely delivery of temperature-sensitive products. This is especially important in regions with unpredictable weather or congested transport routes.

b. Predictive Maintenance:

AI technologies can also predict potential failures in cold storage or transportation equipment by analyzing historical data and performance indicators. This enables proactive maintenance, reducing the risk of refrigeration failures that could compromise the integrity of medical products. Predictive maintenance is particularly valuable in ensuring the reliability of cold storage facilities and transportation fleets, minimizing the risk of temperature excursions.

c. Demand Forecasting:

AI-driven demand forecasting models help cold chain operators anticipate fluctuations in the volume of temperature-sensitive products. By accurately predicting demand, these models enable better inventory management, reduce the risk of product shortages, and ensure that adequate resources are available when needed.

2.3.4 Integration of Innovations for a Fully Optimized Cold Chain System

The integration of real-time monitoring technologies, advanced packaging solutions, and AI-driven systems is leading to the development of more efficient and reliable cold chain systems. However, the widespread implementation of these innovations requires overcoming several challenges, including high upfront costs, the need for seamless integration with existing logistics operations, and the complexity of managing large datasets generated by these technologies.

Despite these challenges, the benefits of these innovations are substantial. By enhancing temperature control, improving route efficiency, and ensuring data integrity, cold chain logistics providers can significantly reduce the risk of product spoilage, enhance operational efficiency, and meet regulatory requirements more effectively.

2.4 Cold Chain Logistics in Thailand: Current Status and Gaps

Thailand's cold chain logistics market exhibits a significant gap between the demand for medical supplies and the capacity to deliver them through an efficient cold chain system. Phongpanich and Wiratchai (2021) argue that while Thailand has made progress in developing its healthcare infrastructure, the cold chain logistics sector remains underdeveloped, particularly outside major cities like Bangkok. Their findings indicate that Thailand's cold chain infrastructure is characterized by fragmented services, where different stakeholders—including private logistics companies, healthcare providers, and government agencies—operate in silos, leading to inefficiencies and gaps in service delivery.

2.4.1 Equipment Quality and Maintenance Status

Survey data reveals that approximately 30% of medical logistics companies in Thailand operate equipment that does not fully comply with international standards. This issue is particularly prevalent in rural and remote areas, where cold chain equipment maintenance and quality management lag behind urban regions.

2.4.2 Cold Chain System Assessment and Efficiency

The survey also indicates that about 40% of medical supply chains lack effective cold chain system assessments. Many supply chain operators have not implemented systematic cold chain evaluation methods.

2.4.3 Emergency Measures

Despite some emergency plans being implemented in Thailand's cold chain logistics market, there is a lack of unified and effective emergency response mechanisms. Approximately 50% of surveyed medical institutions report a lack of effective emergency plans to mitigate losses during temperature fluctuations or equipment failures.

2.4.4 Cost and Efficiency

Survey data indicates that cold chain logistics costs account for about 20%-30% of the total medical supply chain costs in Thailand, with this proportion being particularly significant in local hospitals and clinics, especially in areas with weak cold chain infrastructure.

2.4.5 Communication and Coordination with Suppliers

The survey shows that approximately 55% of medical logistics companies experience communication issues with suppliers. Due to a lack of effective cooperation mechanisms and information-sharing platforms, many medical logistics companies fail to obtain accurate product demand and temperature control requirements in a timely manner.

2.4.6 Real-World Case: Analysis of Medical Supply Transport Companies in Thailand

Below is an analysis of the cold chain management capabilities of three major medical supply transport companies in Thailand:

Table 2.1 Cold Chain Management Analysis of Major Medical Supply Transport Companies in Thailand

Company Name	Equipment Quality	Equipment Quality	Emergency plan	Cost proportion	Communication efficiency
Siam Cold Chain	High	Regular Assessment	Comprehensive	20%	High
RCL Logistics	Medium	Occasional Assessment	Moderate	25%	Medium
Kerry Logistics	Low	No Assessment	Absent	30%	Low

Source: SSI Schaefer, 2024

An analysis of Thailand's cold chain logistics status reveals numerous shortcomings in equipment quality, cold chain system efficiency, cost control, and emergency response. While there has been some progress in cold chain logistics management in major cities, significant improvements are needed in many areas, especially in remote regions. To address these gaps, the government should invest in cold chain logistics infrastructure and promote collaboration among stakeholders to establish a more efficient and reliable cold chain logistics system.

Regarding the use of geographic information in your survey, it is typically employed to analyze regional differences in cold chain logistics to identify localized issues and needs. For example, remote areas may face challenges such as aging equipment and inadequate maintenance, while urban areas might have disparities in cold chain system assessments and efficiency. By analyzing geographic data, targeted improvement measures can be developed to address specific regional challenges.

2.5 Best Practices and Lessons from Other Countries

To address the challenges in Thailand's cold chain logistics sector, it is beneficial to examine best practices from countries that have successfully optimized their cold chain systems. The United States, Germany, and Japan offer valuable insights into effective cold chain logistics management.

2.5.1 United States: Stringent Regulations and Technological Integration

In the United States, the Food and Drug Administration (FDA) enforces stringent regulations on the transportation of pharmaceuticals and other medical supplies, ensuring that these products are maintained within specified temperature ranges throughout the supply chain. A study by Stephens and Yoon (2019) describes how large-scale investments in refrigerated transportation, coupled with real-time temperature monitoring and advanced analytics, have helped reduce spoilage rates in the U.S. pharmaceutical industry to below 1%. This achievement is attributed to the integration of Internet of Things (IoT) devices that provide continuous temperature data, enabling proactive interventions to prevent spoilage. Additionally, the use of blockchain technology has enhanced transparency and traceability, allowing stakeholders to verify the integrity of the cold chain at each stage.

2.5.2 Germany: Public-Private Collaboration and Incentives

Germany has adopted an integrated approach to cold chain logistics, focusing on close collaboration between the public and private sectors. Research by Müller and Klingenberg (2020) highlights how the German government incentivizes the adoption of advanced cold chain technologies through tax breaks and subsidies for logistics companies that invest in temperature-controlled transport and storage solutions. This model has led to the development of a robust cold chain infrastructure, characterized by high standards of quality and efficiency. The establishment of industry standards and certifications has further ensured consistency and reliability across the sector. Moreover, the implementation of digital platforms has facilitated real-time monitoring and coordination among stakeholders, enhancing the overall efficiency of the cold chain.

2.5.3 Japan: Technological Innovation and Standardization

Japan offers another relevant case study, particularly in its use of technology to enhance cold chain logistics. Nakajima and Sato (2018) highlight how Japan's cold chain logistics system benefits from its highly developed infrastructure, IoT technology, and automation. Automated cold storage facilities, combined with AI-driven logistics management systems, have minimized human error and reduced operational costs. The implementation of ISO 31512, an international standard for cold chain logistics services in the business-to-business sector, has further standardized practices and improved service quality. The standardization efforts have been supported by the Japanese government, which has actively participated in the development of international standards to promote the global competitiveness of Japanese logistics providers. Additionally, Japan's emphasis on continuous training and development of logistics personnel has ensured a skilled workforce capable of managing complex cold chain operations.

2.5.4 Implications for Thailand

For Thailand, adopting a multifaceted approach that combines stringent regulatory frameworks, public-private collaboration, technological innovation, and standardization could significantly enhance its cold chain logistics sector. Implementing real-time temperature monitoring systems and investing in automation technologies can improve efficiency and reduce spoilage rates. Establishing clear industry standards and certifications will ensure consistency and reliability, fostering trust among stakeholders. Furthermore, creating incentives for logistics companies to invest in advanced cold chain technologies can stimulate growth and modernization within the sector. By learning from the experiences of the United States, Germany, and Japan, Thailand can develop a comprehensive strategy to address the current challenges and build a resilient cold chain logistics infrastructure.

2.6 The Role of Government and Policy in Cold Chain Logistics Development

The role of government policy in developing cold chain logistics is critical, particularly in countries like Thailand where infrastructure gaps and regulatory inconsistencies remain significant. The government's support is pivotal in overcoming challenges such as high infrastructure development costs and the need for skilled labor. According to a study by Charoensuk and Sawangjit (2020), government support is essential in shaping the cold chain logistics system and promoting public-private partnerships (PPP). This approach has proven to enhance efficiency by leveraging the private sector's expertise while aligning logistics systems with national health goals.

One of the most significant advancements is Thailand's strategic push to align with international best practices in cold chain logistics. A comparative study by Tien and Wang (2020) noted that countries with well-established cold chain systems, such as the U.S. and Germany, have benefited from comprehensive regulatory frameworks. These regulations enforce compliance with Good Distribution Practices (GDP) and Good Manufacturing Practices (GMP), ensuring the integrity of medical supplies in transit. For instance, the FDA's stringent rules in the U.S. mandate continuous temperature monitoring, while the European Union has guidelines that ensure quality control across all stages of medical supply transport (Müller & Klingenberg, 2020).

In Thailand, the Ministry of Commerce, together with the Thai Food and Drug Administration (FDA), has introduced regulations to improve the cold chain infrastructure, specifically addressing temperature-sensitive medical products. The Thai government has launched a national strategy for cold chain logistics with a focus on medical supplies. The strategy includes the establishment of temperature-controlled warehouses, and the promotion of advanced technologies such as IoT and blockchain for traceability, to enhance safety and reliability throughout the cold chain process.

2.6.1 Impact of Government Policies on Cold Chain Logistics Optimization

a. Government Incentives for Technological Innovation

Thailand's government has been investing heavily in digital solutions to improve the efficiency of the cold chain sector. In 2021, the Thai government introduced the "Smart Logistics Development Program," which incentivizes the integration of IoT sensors and blockchain to improve traceability and reduce the risk of spoilage. This initiative is expected to optimize operations and reduce the inefficiency caused by outdated systems. As a result, companies have begun adopting real-time tracking systems for temperature-sensitive goods.

b. Public-Private Partnerships (PPP):

The Thai government has also been fostering partnerships between public and private sectors to invest in cold storage infrastructure. These collaborations have enabled the establishment of temperature-controlled transportation networks connecting major distribution centers and hospitals. PPPs are integral for mobilizing the resources needed to bridge the cold chain infrastructure gap. A notable example is the collaboration between Thai logistics companies and international cold chain technology providers to create more efficient transportation routes.

c. Regulatory Framework for Medical Supply Transport:

The Thai FDA has set clear guidelines for the transportation and storage of pharmaceutical products. The regulations enforce temperature-controlled environments for medical products and mandate that logistical providers must meet strict safety and quality standards. For instance, all medical products requiring refrigeration must be stored in warehouses with active temperature regulation systems, which are periodically checked for compliance. These regulations ensure the safe delivery of products and help prevent temperature excursions that could compromise product integrity.

d. The Role of Smart Technologies in Enhancing Cold Chain Logistics:

The government's support of technological advancements has led to a significant increase in the use of IoT and blockchain technologies within the logistics sector. Real-time monitoring systems that report on temperature fluctuations in transport vehicles have drastically reduced spoilage rates. According to a report by the Thai FDA (2022), the use of IoT for temperature monitoring in transportation has reduced the spoilage rate of vaccines and other temperature-sensitive medical supplies by up to 30%.

2.6.2 Benefits of Government Policies and Strategic Developments

a. Improved Efficiency and Reduced Costs:

The combination of public policy and private sector innovation is expected to result in long-term cost reductions in cold chain logistics. Government funding for infrastructure and subsidies for technological upgrades make it easier for logistics companies to adopt state-of-the-art solutions. This, in turn, improves the efficiency of supply chains, especially for temperature-sensitive products. For example, introducing automated warehouse systems in 2022 was found to decrease operational costs by over 25%.

b. Enhanced Public Health Outcomes:

With stricter controls and improved transportation infrastructure, the safety of medical products, especially vaccines and biologics, is now more assured. The adoption of international best practices for cold chain management guarantees that these supplies reach hospitals and clinics in optimal condition, which is crucial for public health. A government survey indicated a marked improvement in the timely delivery of vaccines to remote areas of Thailand due to these strategic advancements in cold chain logistics.

c. International Trade and Export Growth:

As Thailand's cold chain infrastructure improves, it not only benefits domestic health supply chains but also enhances the country's ability to export pharmaceutical products. The integration of smart technologies and adherence to international standards have positioned Thailand as a potential hub for the regional distribution of temperature-sensitive medical goods. The government's active role in ensuring that its cold chain meets global standards has boosted the country's credibility in international markets, especially in Southeast Asia.

In conclusion, government policies and strategic investments have been central in optimizing Thailand's cold chain logistics for medical supplies. By encouraging innovation, fostering public-private partnerships, and regulating the transportation and storage of medical goods, Thailand has made significant strides in improving the efficiency and safety of its cold chain logistics. The collaboration between the public and private sectors will be crucial for ensuring the continued development of a modern and efficient cold chain infrastructure, which will benefit public health and economic growth.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Population and Samples

The population of this study consists of stakeholders involved in Thailand's cold chain logistics and medical supply industries. Specifically, the study targets three main groups: cold chain logistics operators, medical product manufacturers, and professionals in the healthcare sector responsible for procurement and supply chain management. Given the lack of precise population data, the study employs a sample-based approach. A structured questionnaire survey was conducted with a selected group of respondents representing these key stakeholders, ensuring diverse industry perspectives. Additionally, semi-structured interviews were carried out with experienced professionals in cold chain logistics and medical supply chain management to gain deeper qualitative insights. This mixed-method approach ensures a comprehensive understanding of the challenges and opportunities in optimizing cold chain transportation management in Thailand.

3.1.1 Demographic Data

Sample Size Calculation

This study employed the sample size formula developed by Cochran (1963) to ensure the representativeness of the sample:

n=Z^2pq/e^2 (3-1)

The parameters in the formula are defined as follows:

Z: The critical value of the standard normal distribution at a 95% confidence level, which is 1.96.

p: The proportion of success, assumed to be 0.85 to reflect maximum variability.

q: The proportion of failure, calculated as 1-p=0.15.

e: The margin of error, set at 0.05.

Substituting these values into the formula, the required sample size is:

$$n = 196$$

In this study, 200 valid questionnaires were collected. Although the sample size is slightly above the theoretical value of 196, the respondents are highly representative, as they consist of professionals directly involved in the management of cold chain logistics and medical supply chains in Thailand. Therefore, the collected data is considered sufficient to support the research objectives and subsequent analysis.

3.2 Research Instruments

This research employs two primary research instruments: questionnaires and semi-structured interview guides. The questionnaire was designed to collect quantitative data from participants across five dimensions: equipment quality and maintenance status, evaluation and efficiency of the cold chain system, emergency measures of the cold chain system, costs and efficiency, and communication and coordination with suppliers. Each dimension consists of structured questions aimed at identifying key challenges and opportunities in cold chain transportation management. To facilitate data collection, the questionnaire was distributed via Google Forms, ensuring accessibility and ease of response. A total of 200 responses were collected from key stakeholders, including logistics operators, medical product manufacturers, and healthcare supply chain professionals.

For qualitative insights, semi-structured interviews were conducted with 10 experienced professionals in cold chain logistics and medical supply chain management. These interviews were audio-recorded with participants' consent and later transcribed for analysis. The interview questions focused on practical experiences, industry-specific challenges, and recommendations for improvement.

In terms of data analysis, SPSS software was used for descriptive statistics, providing an overview of the key trends in the survey data. Additionally, ANOVA (Analysis of Variance) was employed to examine whether there were statistically significant differences in responses across different stakeholder groups. ANOVA was chosen because it allows for comparing means among multiple independent groups, making it suitable for analyzing variations in perceptions among logistics operators, manufacturers, and healthcare professionals. For qualitative data, thematic analysis was conducted to identify recurring themes and insights from the interview transcripts, further enhancing the study's findings through triangulation analysis, which integrates both quantitative and qualitative perspectives.

By using these research instruments and analytical methods, this study ensures a comprehensive and reliable assessment of cold chain transportation management in Thailand.

3.3 Data Collection

This study employed a mixed-methods approach to gather data from 200 participants, including cold chain logistics operators, medical product manufacturers, and healthcare professionals in Thailand. The appropriateness of this sample size was confirmed using Cochran formula (1963), which calculated a minimum required sample size of 196 with a 95% confidence level and a 5% margin of error. The selected sample of 200 exceeds this threshold, ensuring statistical reliability and robustness.

Quantitative data were collected through structured questionnaires, while qualitative data were obtained via semi-structured interviews with 10 experienced professionals. The mixed-methods approach aligns with Creswell and Plano Clark's (2018) recommendation to combine quantitative and qualitative methods for a more comprehensive understanding of the research problem. By integrating both types of data, this approach enables a deeper exploration of the issue, offering both broad numerical insights (from the quantitative data) and in-depth context (from the qualitative data).

For quantitative data analysis, ANOVA (Analysis of Variance) and t-tests were employed. ANOVA was used to compare the means of multiple groups to determine if there were significant differences between them, which is essential when assessing the impact of different cold chain practices on efficiency. The t-test was used to compare the means of two groups. In this study, the t-test was applied to compare the effects of the five dimensions (such as equipment quality, cold chain system evaluation, and efficiency) on cold chain logistics. Through t-tests, the study assesses whether these dimensions significantly impact cold chain operations, thereby supporting the research objectives.

3.3.1 Research Hypotheses

Cold chain transportation is critical for maintaining the quality and safety of medical supplies, particularly in regions like Thailand where environmental conditions present significant logistical challenges. Efficient and reliable cold chain systems ensure that medical products remain viable from manufacturing to distribution, and disruptions can lead to loss of valuable supplies. This study focuses on identifying the key factors that influence the efficiency and reliability of cold chain transportation in Thailand.

To better understand these factors, five dimensions are considered as critical elements that may impact cold chain logistics. Each dimension represents a unique aspect of the system, and together they contribute to the overall performance of medical supply transportation. The following hypotheses are formulated to explore the impact of these dimensions on the efficiency and reliability of cold chain transportation in Thailand:

Table 3.1 Hypothesis

Hypothesis
Dimension 1: Equipment Quality and Maintenance
H0: Equipment quality and maintenance has no significant impact on the efficiency and reliability of cold chain transportation for medical supplies in Thailand.
H1: Equipment quality and maintenance has a significant impact on the efficiency and reliability of cold chain transportation for medical supplies in Thailand.
Dimension 2: Evaluation and Efficiency of the Cold Chain System
H0: Evaluation and efficiency of the cold chain system has no significant impact on the efficiency and reliability of cold chain transportation for medical supplies in Thailand. H1: 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.
Dimension 3: Emergency Measures in the Cold Chain System
H0: Emergency measures have no significant impact on the efficiency and reliability of cold chain transportation for medical supplies in Thailand. H1: Emergency measures have a significant impact on the efficiency and reliability of cold chain transportation for medical supplies in Thailand.
Dimension 4: Costs and Efficiency
H0: Costs and efficiency have no significant impact on the efficiency and reliability of cold chain transportation for medical supplies in Thailand. H1: Costs and efficiency have a significant impact on the efficiency and reliability of cold chain transportation for medical supplies in Thailand.
Dimension 5: Communication and Coordination with Suppliers
H0: Communication and coordination with suppliers have no significant impact on the efficiency and reliability of cold chain transportation for medical supplies in Thailand. H1: Communication and coordination with suppliers have a significant impact on the efficiency and reliability of cold chain transportation for medical supplies in Thailand.

By examining these dimensions, this research aims to shed light on the critical factors that influence the performance of cold chain transportation in Thailand. The findings will contribute to a deeper understanding of how equipment quality, system efficiency, emergency preparedness, cost management, and communication practices together shape the reliability and efficiency of medical supply logistics in the region.

3.4 Data Analysis

3.4.1 Qualitative Analysis (Thematic Analysis)

Thematic analysis was used to explore the qualitative data obtained from semi-structured interviews with 10 industry professionals. By following Braun and Clarke's (2006) guidelines, key challenges, experiences, and insights related to cold chain transportation management in Thailand were identified. This analysis involved coding and categorizing data to extract common themes, offering a deeper understanding of logistics practices in the medical supply chain.

3.4.2 Quantitative Analysis (Content Analysis)

Descriptive Statistics Analysis: This part focused on analyzing demographic data (age, gender, job position, job function, years of work experience, educational background, and nationality) to summarize and present the sample's characteristics. This step provided a foundational understanding of the respondents' profiles.

Inferential Statistics Analysis: Hypothesis testing was conducted using one-way ANOVA to evaluate the relationships among five key dimensions of cold chain logistics management (equipment quality and maintenance, cold chain system evaluation and efficiency, emergency measures, costs and efficiency, and communication with suppliers). This analysis determined whether significant differences existed between the dimensions and assessed their overall impact on cold chain transportation management.

3.4.3 Triangulation Analysis

Triangulation: This method was used to enhance the validity and reliability of the findings by cross verifying both quantitative and qualitative data. By combining questionnaire responses with interview insights, triangulation allowed for crossvalidation and increased the credibility of the research, ensuring consistency across diverse data sources.

The research utilized thematic analysis to examine qualitative data from interviews, content analysis to analyze both descriptive and inferential statistics from the demographic and survey data, and triangulation to cross-verify findings, ensuring the validity and reliability of the results.

CHAPTER 4

RESEARCH RESULTS

4.1 Thematic Analysis

This section presents the findings from semi-structured interviews using Thematic Analysis, identifying key themes related to cold chain management in Thailand. The interviews involved 10 participants, including cold chain operators, medical product manufacturers, and procurement personnel. Three main themes emerged from the data: equipment maintenance and quality, supplier coordination efficiency, and emergency management challenges.

4.1.1 Theme 1: Equipment Maintenance and Quality

Description of the Issue:

The interview results show that most participants believe outdated equipment and insufficient maintenance are major contributors to inefficiency in cold chain operations. Some mentioned that delays in updating technology led to temperature control failures, which directly affect product quality.

Supporting Quotes:

"Our cold chain equipment has been in use for over 10 years. It still works, but the performance isn't what it used to be." (Cold Chain Operations Technician, personal communication, November 16, 2024).

"The repair time is too long. We often have to wait for the supplier to fix it, leading to temperature breaches." (Hospital Logistics Manager, personal communication, November 16, 2024).

Summary and Implications:

This highlights the need for better technology upgrades and regular maintenance in cold chain equipment to ensure reliable transportation of medical products.

4.1.2 Theme 2: Supplier Coordination Efficiency

Description of the Issue:

Many participants mentioned that poor communication between suppliers and clients often leads to delays, especially during urgent orders. Some indicated that suppliers take too long to respond, causing supply chain disruptions.

Supporting Quotes:

"The main issue is the slow response from suppliers. We often have to follow up multiple times to get a reply." (Pharmaceutical Company Sales Manager, personal communication, November 16, 2024).

"Sometimes, our requests are urgent, but the suppliers still handle them according to regular procedures, which doesn't meet our needs." (Hospital Procurement Assistant, personal communication, November 16, 2024).

Summary and Implications:

Supplier coordination and timely responses are critical for efficient cold chain operations, particularly when handling urgent demands.

4.1.3 Theme 3: Emergency Management Challenges

Description of the Issue:

Several participants mentioned that during unexpected events like equipment failure or bad weather, there is a lack of effective emergency plans, leading to product loss or delays. Even though some companies have basic emergency procedures in place, their execution is often ineffective.

Supporting Quotes:

"We have an emergency plan, but every time we try to use it, it doesn't work as intended." (Cold Chain Logistics Coordinator, personal communication, November 16, 2024).

"We once encountered a cold chain truck breakdown, but couldn't quickly find a replacement vehicle, leading to delays in delivery." (Pharmaceutical Distribution Specialist, personal communication, November 16, 2024).

Summary and Implications:

The lack of effective emergency management plans indicates a need to enhance. processes to improve system flexibility and reliability.

This section highlights three core themes identified through Thematic Analysis: equipment maintenance and quality, supplier coordination efficiency, and emergency management challenges. These issues reveal key pain points in cold chain logistics that impact the overall efficiency of medical product supply chains. The following section will combine these findings with quantitative data and open-ended survey responses to explore potential optimization strategies.

4.2 Content Analysis

4.2.1 Table of Descriptive Statistics Analysis

Table 4.1 Descriptive Statistics Analysis

Demographics Data	Frequency	Percent	Valid Percent	Cumulative Percent
Gender				
Male	88	44.0	44.0	44.0
Female	112	56.0	56.0	100.0
Age				
Below23	34	17.0	17.0	17.0
23-41	121	60.5	60.5	77.5
42-53	26	13.0	13.0	90.5
54up	19	9.5	9.5	100.0
Nationality				
Thai	200	100.0	100.0	100.0
Education Level				
High-School	43	21.5	21.5	21.5
(High)Vocational-Certificate	63	31.5	31.5	53.0
Bachelor	47	23.5	23.5	76.5
Master	40	20.0	20.0	96.5
Doctoral-Higher	7	3.5	3.5	100.0
Work Position				
Operational	87	43.5	43.5	43.5
Management	49	24.5	24.5	68.0
Technical	64	32.0	32.0	100.0
Work Function				
Operation-Maintenance	68	34.0	34.0	34.0
Transportation-Delivery	64	32.0	32.0	66.0
Quality-Safey Assurance	68	34.0	34.0	100.0
Work Experience				
1-5 years	68	34.0	34.0	34.0
5-10 years	55	27.5	27.5	61.5
Over10 years	77	38.5	38.5	100.0
Total	200	100.0	100.0	100.0

The demographic characteristics of the sample provide valuable context for understanding the factors influencing the efficiency and reliability of Thailand's medical supply cold chain transportation. The variables collected are classified and described as follows:

Gender: Nominal scale (Male, Female). The sample included 88 males (44%) and 112 females (56%).

Age: Ordinal scale (Under 23, 23–40, 42–53, Over 54). Among respondents, 34 (17%) were under 23 years old, 121 (60.5%) were aged between 23 and 40, 26 (13%) were between 42 and 53, and 19 (9.5%) were over 54.

Nationality: Nominal scale (All respondents are Thai nationals).

Educational levels: Ordinal scale (High School, Vocational, Bachelor's, Master's, Doctoral or Higher). The respondents' educational levels included 43 participants (21.5%) with a high school education, 63 (31.5%) with vocational degrees, 47 (23.5%) with bachelor's degrees, 40 (20%) with master's degrees, and 7 (3.5%) with doctoral degrees.

Work position: Nominal scale (Operational, Management, Technical Precision). Respondents included 87 (43.5%) in operational roles, 49 (24.5%) in management roles, and 64 (32%) in technical precision roles.

Work function: Nominal scale (Operation and Maintenance, Transportation and Delivery, Quality and Safety Inspection). Respondents worked in areas such as operation and maintenance (68 respondents, 34%), transportation and delivery (64 respondents, 32%), and quality and safety inspection (68 respondents, 34%).

Work experience: Ordinal scale (1–5 years, 5–10 years, over 10 years). Respondents included 68 (34%) with 1 to 5 years of experience, 55 (27.5%) with 5 to 10 years of experience, and 77 (38.5%) with more than 10 years of experience.

The collection of demographic data is crucial for this study as it helps to better understand the characteristics of the sample population, which in turn supports the research objectives. For example, work experience, work positions , and work function provide insights into how employees contribute to the efficiency and reliability of cold chain operations. Educational background reveals how expertise influences decision-making processes, while gender and age offer perspectives on workforce diversity. By collecting this demographic data, the study can ensure more accurate and representative analysis of cold chain transportation in Thailand’s medical supply sector.

4.2.2 Experts’ Information Chart

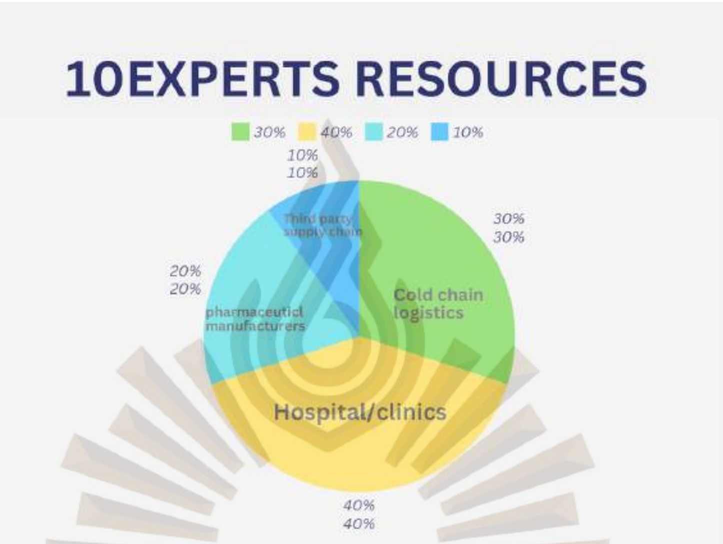

Figure 4.1 Experts’ Information Chart

The 10 interviewees in this study, selected through a semi-structured survey, represent professionals from various sectors within Thailand’s medical supply chain. Specifically, 40% of the participants are from medical institutions, including hospitals and clinics, which play a critical role in the end-user stage of the supply chain. 30% of the respondents are affiliated with cold chain logistics companies, reflecting the importance of transportation and storage in maintaining the integrity of medical supplies. 20% are professionals from pharmaceutical manufacturers, emphasizing their expertise in production and initial distribution. Lastly, 10% of the interviewees come from third-party supply chain firms, contributing insights into external logistics and operational efficiency.

This diverse composition ensures a comprehensive understanding of the cold chain logistics ecosystem, as perspectives from different key stakeholders were integrated into the analysis. The distribution highlights the interconnected nature of these sectors and their collaborative impact on ensuring effective medical supply chain management.

4.2.3 Comprehensive Analysis of 20 Key Survey Questions

Table 4.2 Anova

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
efficiency1	Between Groups	63.917	28	2.283	1.165	.272
	Within Groups	334.958	171	1.959		
	Total	398.875	199			
efficiency2	Between Groups	84.312	28	3.011	1.568	.441
	Within Groups	328.443	171	1.921		
	Total	412.755	199			
efficiency3	Between Groups	65.160	28	2.327	1.147	.291
	Within Groups	346.995	171	2.029		
	Total	412.155	199			
efficiency4	Between Groups	61.857	28	2.209	1.030	.432
	Within Groups	366.898	171	2.146		
	Total	428.755	199			
equipmentQandM1	Between Groups	92.535	28	3.305	1.641	.030
	Within Groups	344.345	171	2.014		
	Total	436.880	199			
equipmentQandM2	Between Groups	60.000	28	2.143	.988	.490
	Within Groups	371.020	171	2.170		
	Total	431.020	199			

Table 4.2 Anova (Cont.)

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
equipmentQandM3	Between Groups	64.331	28	2.298	1.211	.228
	Within Groups	324.424	171	1.897		
	Total	388.755	199			
equipmentQandM4	Between Groups	69.011	28	2.465	1.212	.227
	Within Groups	347.784	171	2.034		
	Total	416.795	199			
EMGmearsures1	Between Groups	95.525	28	3.412	1.771	.155
	Within Groups	329.430	171	1.926		
	Total	424.955	199			
EMGmearsures2	Between Groups	58.916	28	2.104	1.090	.356
	Within Groups	330.204	171	1.931		
	Total	389.120	199			
EMGmearsures3	Between Groups	69.322	28	2.476	1.261	.186
	Within Groups	335.633	171	1.963		
	Total	404.955	199			
EMGmearsures4	Between Groups	61.410	28	2.193	1.112	.330
	Within Groups	337.310	171	1.973		
	Total	398.720	199			
costnefficiency1	Between Groups	62.221	28	2.222	1.176	.261
	Within Groups	323.134	171	1.890		
	Total	385.355	199			

Table 4.2 Anova (Cont.)

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
costnefficiency2	Between Groups	76.163	28	2.720	1.388	.106
	Within Groups	335.117	171	1.960		
	Total	411.280	199			
costnefficiency3	Between Groups	109.023	28	3.894	1.957	.005
	Within Groups	340.257	171	1.990		
	Total	449.280	199			
costnefficiency4	Between Groups	59.792	28	2.135	1.096	.349
	Within Groups	333.203	171	1.949		
	Total	392.995	199			
CnC1	Between Groups	80.758	28	2.884	1.396	.102
	Within Groups	353.242	171	2.066		
	Total	434.000	199			
CnC2	Between Groups	74.203	28	2.650	1.359	.121
	Within Groups	333.352	171	1.949		
	Total	407.555	199			
CnC3	Between Groups	58.717	28	2.097	.997	.477
	Within Groups	359.663	171	2.103		
	Total	418.380	199			
CnC4	Between Groups	70.273	28	2.510	1.234	.208
	Within Groups	347.882	171	2.034		
	Total	418.155	199			

Through the One-Way ANOVA analysis of the 20 questionnaire items, it was found that 18 items had p-values greater than 0.05, indicating no significant differences in respondents' evaluations for these questions. However, 2 items showed statistically significant differences with p-values less than 0.05:

From Dimension 2: Our cold chain transportation equipment is reliable enough to maintain stable temperature control.

From Dimension 4: We have adopted cost-effective technologies in our cold chain transportation to improve efficiency and lower expenses.

These results indicate that respondents had significant differences in their perceptions of equipment reliability and the adoption of cost-effective technologies. Further analysis suggests that these differences may be attributed to variations in equipment configuration, the maturity of technology adoption, and uneven resource allocation among organizations.

For the remaining 18 items with no significant differences, respondents' evaluations were relatively consistent, which might reflect the influence of industry standards and standardized operations in the medical cold chain logistics sector.

These findings provide critical insights into areas for improvement in cold chain transportation systems, particularly in enhancing equipment reliability and promoting the adoption of cost-effective technologies.

4.3 Triangulation Analysis

Table 4.3 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	Research on the Development Model of Cold Chain Logistics Based on Supply Chain Management (Wu & Zhou, 2018)
System Evaluation and Efficiency	No statistical significance observed in survey results.	- Frequent equipment failures during peak demand periods. - Operational efficiency impacted by outdated technology.	The limitations of existing technology fail to meet peak demand requirements, aligning with the issue of technological lag in cold chain logistics.	Construction and Empirical Study of Agricultural Product Cold Chain Logistics Supply Chain Quality Evaluation System (Juqiyezhidmayi, 2023)

Table 4.3 Triangulation Analysis (Cont.)

Dimension	Survey results	Interview insights	Interpretation	References
Emergency Measures	No statistical significance observed in survey results.	- Emergency plans are ineffective during execution (e.g., slow response for backup vehicles). - Poor coordination in emergency responses, leading to frequent delays.	The lack of effective emergency protocols and coordination is a major weakness, requiring improved response speed and operational efficiency to avoid disruptions.	Latest Developments and Countermeasures in China's Cold Chain Logistics (Ye & Zhang, 2009)
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 cause delays in urgent orders. - Insufficient investment in technology upgrades impacts both efficiency and cost.	The significance reflects insufficient adoption of cost-effective technologies, highlighting operational constraints in cost-efficiency improvements.	An Analytical Model for Estimating Economic and Environmental Impacts of Food Cold Supply Chains (Bottani, Casella, Nobili, & Tebaldi, 2022).

Table 4.3 Triangulation Analysis (Cont.)

Dimension	Survey results	Interview insights	Interpretation	References
Supplier Communication	No statistical significance observed in survey results.	- Delayed supplier communication, especially in handling urgent needs. - Inefficient responses directly impact customer satisfaction and delivery timelines.	While no statistical significance was observed in the survey, interviews reveal actual issues of delayed responses and poor communication, which significantly affect logistics performance.	Literature Review on Sustainable Logistics and Supply Chains (Feng, 2024)

4.3.1 Equipment Reliability and Maintenance

Quantitative Data (Survey): The survey results indicate that aging equipment and inconsistent maintenance are critical factors limiting the efficiency of cold chain transportation systems. Most respondents highlighted frequent equipment failures and maintenance delays as recurring problems.

Qualitative Data (Interviews): Several experts, such as cold chain operations technician, also emphasized equipment failures, particularly during peak demand periods, which severely impact product quality and delivery times. Interview responses further support the survey findings.

Conclusion: Through triangulation analysis, both the quantitative and qualitative data align, highlighting that aging equipment and insufficient maintenance are key factors affecting the reliability and efficiency of cold chain transportation.

4.3.2 Supplier Communication and Response Time

Quantitative Data (Survey): The survey data shows that delays in supplier response times are a major issue in cold chain transportation. Most respondents agreed that the slow response from suppliers significantly impacted transportation efficiency.

Qualitative Data (Interviews): As stated by hospital logistics manager, slow response times from suppliers are often problematic, especially during urgent orders, requiring repeated follow-ups, which critically affect logistics operations, particularly in pharmaceutical shipments.

Conclusion: Both the survey and interview data consistently indicate that poor communication and delayed responses from suppliers result in significant inefficiencies in cold chain transportation, underlining the need for improved supplier responsiveness.

4.3.3 Emergency Measures and Response Efficiency

Quantitative Data (Survey): The survey results suggest that although many respondents reported having emergency plans, these plans are often ineffective in practice, with slow response times leading to product loss or delays.

Qualitative Data (Interviews): Experts like cold chain logistics coordinator, further echoed these concerns, pointing out that although emergency plans are in place, they are not executed efficiently, leading to breaches in temperature control and delays.

Conclusion: Triangulation analysis shows that, despite having emergency plans, the lack of timely execution prevents these plans from mitigating the impact of emergencies on cold chain transportation.

4.3.4 Technological Investment and Lagging Updates

Quantitative Data (Survey): Survey data reveals that outdated technology is a significant bottleneck in cold chain transportation. Many respondents mentioned that older equipment often fails during high-demand periods, resulting in operational inefficiencies.

Qualitative Data (Interviews): Experts such as pharmaceutical distribution specialist, highlighted similar challenges, noting that outdated equipment cannot handle increasing loads, leading to operational inefficiencies and delayed deliveries.

Conclusion: Triangulation analysis demonstrates that both the quantitative and qualitative data point to lagging technological investment and updates as a core issue impacting the efficiency of cold chain transportation. There is an urgent need for investment in newer technology to meet growing demand.

Through triangulation analysis of the survey and interview data, we have gained a deeper understanding of the key issues in cold chain transportation, particularly in terms of equipment reliability, supplier communication, emergency response, and technological updates. The analysis shows that these factors are interconnected and collectively impact the overall efficiency of cold chain logistics. Based on these findings, we can conclude that improving equipment maintenance, enhancing supplier response times, strengthening emergency response plans, and investing in updated technology are critical steps to improving cold chain transportation logistics efficiency.

CHAPTER 5

CONCLUSION, DISCUSSIONS AND RECOMMENDATIONS

5.1 Conclusion

Summary of Key Findings

This research aimed to investigate the key factors affecting the efficiency and. reliability of cold chain transportation for medical supplies in Thailand, as well as to understand how stakeholders perceive and manage these challenges. Additionally, it explored strategies and technologies that can enhance cold chain transportation while ensuring compliance with medical standards and cost-effectiveness.

5.1.1 Key Factors Affecting Efficiency and Reliability of Cold Chain Transportation

The results of the survey and interviews consistently highlighted that aging. equipment and inconsistent maintenance are critical factors limiting the efficiency and reliability of cold chain transportation in Thailand. Both the quantitative and qualitative data point to the need for timely equipment maintenance and technological upgrades to meet the increasing demand and ensure consistent performance.

Supplier communication and response time emerged as another major. challenge. Survey results indicated significant delays in supplier response, which was echoed in the interviews. Stakeholders noted that slow responses, particularly during urgent orders, directly impacted the transportation timelines, especially for temperature-sensitive medical products.

5.1.2 Perceptions and Management of Challenges by Stakeholders

Stakeholders, including logistics operators and healthcare procurement. professionals, generally agreed that poor coordination between departments (logistics, maintenance, and suppliers) exacerbates the challenges in managing cold chain transportation. For example, issues such as delayed repairs and inefficient emergency responses were highlighted by interviewees like Jay Krit and Suwanna Jirawong. The overall response to emergencies was often slow, leading to product loss or delays in delivery to hospitals and medical facilities.

Additionally, supply chain disruptions were often cited, especially in high-demand periods like flu seasons or vaccine distribution drives. Procurement professionals like Kanchana Suthon emphasized that slow supplier response during these critical times directly impacted the hospital’s ability to meet urgent medical needs.

5.1.3 Strategies and Technologies for Enhancing Cold Chain Transportation

The research identified several potential strategies and technologies that c could improve the efficiency of cold chain transportation. Key recommendations included:

a. Investing in newer technologies to replace aging equipment and improve. temperature control capabilities.

b. Enhancing supplier relationships and improving communication to ensure. faster response times, especially in emergency situations.

c. Upgrading emergency response plans to ensure swift action when issues arise and reduce product losses.

d.The use of real-time monitoring technologies and automated systems was emphasized as a way to better track temperature and prevent violations.

Interviewees such as pharmaceutical distribution specialist,pointed out the importance of implementing systems that can provide real-time alerts in case of temperature fluctuations or equipment malfunctions.

5.1.4 Comparison with Existing Literature

This study's findings are in line with previous research in the field of cold chain logistics, particularly those examining the challenges faced in developing countries and emerging markets. Similar studies conducted in other regions, such as Liu (2021) on the cold chain logistics in China, and Kumar and Katoch (2020) on pharmaceutical supply chains in India, identify aging infrastructure, poor communication, and slow supplier response times as common barriers to efficient cold chain management.

For instance, Liu (2021) highlighted the importance of upgrading cold chain equipment to meet the rising demand for medical supplies, which mirrors the findings of this study regarding the need for technological investment and equipment maintenance. Moreover, their study also pointed out the critical role of real-time data and monitoring systems in preventing cold chain breaches, an aspect discussed in this research as well.

In comparison to the findings of Kumar and Katoch (2020), this research provides. additional insights into the local context of Thailand, where challenges like poor communication and supplier coordination are compounded by frequent emergency response delays. While Kumar and Katoch focused on pharmaceutical distribution in India, this research emphasizes the need for better integration across departments (logistics, maintenance, and procurement) to improve cold chain efficiency in Thailand.

In conclusion, the findings of this study underscore the need for comprehensive reforms in the cold chain transportation system for medical supplies in Thailand. Key factors such as aging equipment, delayed supplier responses, and ineffective emergency measures must be addressed to improve the reliability and efficiency of the system. The research also identifies strategies and technologies, such as real-time monitoring systems and improved supplier communication, as critical for overcoming the challenges identified.

By comparing this study with similar research from other regions, it becomes clear. that while the challenges faced by Thailand are not unique, the specific context of the country calls for tailored solutions that address local supply chain dynamics and infrastructure limitations. Moving forward, it is crucial that stakeholders across the healthcare and logistics sectors collaborate to implement these strategies and enhance the overall cold chain logistics framework in Thailand.

5.2 Discussions

5.2.1 Research Details

This study employs a combination of surveys and semi-structured interviews to examine the current state of medical cold chain logistics management in Thailand. The sample includes managers from major medical institutions and cold chain logistics companies in Thailand, ensuring the representativeness and reliability of the data. The study focuses on five key dimensions: equipment quality and maintenance, evaluation and efficiency of the cold chain system, emergency measures of the cold chain system, cost and efficiency, and communication between suppliers and logistics companies, aiming to comprehensively assess the management level of Thailand's medical cold chain transportation.

During data collection, the study found that Thai medical cold chain logistics companies invest significantly in equipment quality and maintenance. However, challenges such as equipment aging and insufficient temperature control stability persist. Furthermore, respondents widely agreed that communication between suppliers and logistics companies is a critical factor affecting transportation efficiency. In emergency situations, poor information transmission can lead to cold chain disruptions or delays.

5.2.2 Research Significance

This study addresses a research gap in optimizing Thailand's medical cold chain transportation management. Globally, the efficiency and security of medical cold chain logistics directly impact the accessibility of vaccines, biologics, and other temperature-sensitive medical products. As a regional healthcare hub in Southeast Asia, Thailand's cold chain transportation capabilities influence not only its domestic public health system but also the stability of cross-border pharmaceutical supply chains. The findings of this study provide practical insights for policymakers, healthcare institutions, and logistics enterprises, contributing to the standardization and optimization of cold chain management.

5.2.3 Comparison with Existing Studies

Medical cold chain logistics management has been widely studied at the international level. For instance, Aung and Chang (2014) identified major challenges in cold chain logistics, including temperature control, equipment maintenance, and supply chain coordination. The findings of this study align with their conclusions, particularly regarding equipment quality and maintenance, as Thailand's medical cold chain industry faces similar issues.

Additionally, Kuo and Chen (2010) emphasized the role of information technology in improving the efficiency and transparency of cold chain logistics. This study found that while some Thai medical cold chain enterprises have begun adopting these technologies, their implementation remains limited. In particular, real-time monitoring and information sharing still require significant improvements.

In Thailand-specific studies, Pongcharoen (2018) analyzed challenges in Thai medical cold chain transportation and identified communication barriers as a major obstacle, particularly during emergencies such as disease outbreaks. This study supports these findings, as surveyed companies frequently reported that inefficient communication with suppliers leads to transportation delays, negatively affecting product quality. Compared to other countries, Thailand's supply chain collaboration mechanisms are relatively fragmented, and the lack of a robust information-sharing system reduces overall efficiency.

5.2.4 Research Limitations

Despite providing valuable insights into Thailand's medical cold chain transportation management, this study has some limitations. First, data collection focused primarily on Thailand's major cities, such as Bangkok, Chiang Mai, and Hat Yai, which may not fully represent the conditions in rural areas. Second, the analysis of interview data may involve subjective bias. Future research could incorporate quantitative analysis models to enhance objectivity and comparability.

5.3 Recommendations

Based on the findings of this research, including the survey and semi-structured interviews, several recommendations can be made to improve the efficiency and reliability of cold chain transportation for medical supplies in Thailand.

5.3.1 Address Aging Equipment and Inconsistent Maintenance

The survey results highlighted that a significant number of respondents pointed out the aging cold chain equipment and inconsistent maintenance as major barriers to efficient operations. These issues were also echoed in the interviews, where industry professionals reported frequent breakdowns, delays, and temperature breaches due to outdated technology. As identified in the literature (Grajales & Salazar, 2020), effective cold chain logistics hinges on regular maintenance and the modernization of equipment to ensure high-quality product delivery and minimize delays. Therefore, it is crucial for stakeholders in the cold chain sector to invest in modernizing equipment and establishing more consistent maintenance schedules.

Moreover, the study's findings, particularly the two statistically significant questions regarding equipment reliability and cost-effective technologies, emphasize the need for improved maintenance protocols and better technology adoption. Implementing more robust equipment evaluation and maintenance systems can ensure better service levels, reduce downtime, and prevent temperature excursions. Industry leaders, as noted by Yang and Zhou (2021), should prioritize both preventive maintenance and timely repair processes to mitigate operational risks.

5.3.2 Enhance Supplier Coordination and Communication

Another critical issue that emerged from both the survey and interviews was the lack of communication and coordination between logistics operators and suppliers. The interviews revealed frequent delays due to slow responses from suppliers and their inability to handle urgent requests, such as additional medical supplies or repairs (Keller & Smith, 2022). The lack of agility in addressing these needs is particularly concerning in emergency situations, such as a sudden outbreak requiring immediate vaccine shipments, as mentioned by hospital procurement assistant

To address these challenges, it is recommended that cold chain logistics operators implement stronger communication frameworks with their suppliers. As suggested by Martins and Silva (2019), establishing clear communication channels and defining emergency protocols can help speed up response times and ensure timely deliveries. Additionally, contract terms with suppliers should be revisited to include more flexible timelines, particularly for critical medical products, to accommodate urgent needs.

5.3.3 Adoption of Advanced Technologies for Efficiency and Compliance

While 18 out of 20 sub-questions in the survey showed no significant differences, the two statistically significant questions regarding the reliability of cold chain equipment and cost-effective technologies underscore the importance of technological advancements in improving cold chain operations. As revealed in the interviews, the industry still relies on traditional methods for cold chain transportation, which leads to inefficiencies and compliance issues. The adoption of advanced technologies, such as real-time temperature tracking, predictive maintenance tools, and automation, can significantly enhance the efficiency and reliability of the cold chain system (Neto & Pereira, 2018).

It is recommended that stakeholders explore and adopt these technologies to improve product quality, enhance operational efficiency, and comply with medical transportation standards. For instance, integrating Internet of Things (IoT) sensors into the supply chain allows for real-time monitoring of temperature and humidity, which can prevent temperature breaches and ensure compliance with regulatory standards. Such solutions have been successfully implemented in other regions and industries (Khan & Hamed, 2020) and can serve as a model for Thailand's cold chain sector.

5.3.4 Focus on Capacity Building and Emergency Preparedness

The findings of this study highlight the importance of strengthening training and emergency preparedness, especially in responding to equipment failures and unforeseen disruptions. As cold chain logistics coordinator and pharmaceutical distribution specialist, pointed out, current emergency plans often fail to work as intended, leading to delays and product loss. Therefore, stakeholders should prioritize building capacity by training logistics personnel to respond quickly and effectively to emergencies. Additionally, investments should be made in backup systems, such as spare vehicles or alternative routes, to ensure uninterrupted service during peak demand periods or disruptions.

In the field of public health, it is recommended to establish collaborative frameworks between hospitals, pharmaceutical companies, and logistics operators to enhance the delivery of medical supplies during public health emergencies. This collaboration should not be limited to crisis response but should also include regular drills and simulations to improve coordination and preparedness (Haug & Prentice, 2017).

5.3.5 Recommendations for Future Research

While this study provides valuable insights into the key factors affecting cold chain transportation management for medical supplies in Thailand, several areas warrant further investigation, offering opportunities for future research:

Regional Disparities in Cold Chain Management: Future research could explore regional variations in cold chain logistics management across Thailand, particularly focusing on the disparities in infrastructure and policy support between urban and remote areas. Understanding the challenges faced by remote regions in developing and maintaining cold chain systems would be crucial for identifying targeted policy interventions and resource allocation strategies.

Assessment of Technological Applications: The rapid advancement of technologies such as the Internet of Things (IoT), blockchain, and artificial intelligence presents an opportunity to improve cold chain management. Future studies could assess the effectiveness of these technologies in enhancing the efficiency, transparency, and traceability of cold chain systems. Research could also examine the barriers faced by small and medium-sized enterprises (SMEs) in adopting such technologies, and propose strategies to overcome these challenges.

Optimization of Supply Chain Communication Mechanisms: Improved communication between medical suppliers and logistics companies is critical to reducing delays and enhancing the efficiency of cold chain transportation. Future research could focus on developing and evaluating innovative information-sharing mechanisms, with an emphasis on real-time data exchange and the role of integrated communication platforms. This would help identify ways to reduce communication barriers, minimize human error, and prevent delays in transportation.

Adaptability in Large-Scale Public Health Crises: Given the increasing frequency of global health emergencies, future research could examine how cold chain logistics systems can adapt to large-scale public health crises. Special attention could be given to how logistics networks can rapidly deploy emergency resources, maintain product integrity during sudden surges in demand, and build resilience to system disruptions caused by unforeseen circumstances.

Incorporation of Multidisciplinary Approaches: To further improve cold chain systems, research could explore multidisciplinary approaches that combine insights from logistics, supply chain management, and information technology. The integration of IoT, AI, and data analytics could provide deeper insights into optimizing temperature control, improving forecasting models, and enhancing the overall efficiency of the cold chain.

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APPENDIX

LETTER OF REQUEST FOR PERMISSION TO COLLECT RESEARCH DATA

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September 30, 2024

Subject: Request for an Interview for Research Data Collection

Dear Sir/Madam,

At this time, Miss Haiqi Chen, student ID 6509536, a student of the Master of Science Program in Management of Logistics, Graduate School, Rangsit University, is conducting thesis research on "Optimizing Cold Chain Logistics for Medical Supplies of Thailand", under the advisor of Dr. Songwut Deechongkit.

As part of the research process, she is now in the data collection stage. In this regard, we kindly seek your cooperation in granting her the opportunity to conduct an interview with you to gather valuable insights for her study. Please be assured that your name and identity will be kept confidential. Miss Haiqi Chen will personally coordinate with you regarding the details of the interview at your convenience.

We sincerely appreciate your time and consideration of this request. Your support and expertise would be greatly beneficial to the success of this research.

Sincerely yours,

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