

## A Case Study in Integrating Digital Solutions for Improving Vaccine Supply Chain Efficiency

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### ABSTRACT

Thailand's vaccine supply chain faces persistent challenges in logistics, limited cold chain capacity, and weak coordination among stakeholders, resulting in inefficiencies and higher vaccine wastage. This study examines how integrating digital technologies, specifically IoT, blockchain, and AI, could help overcome these issues. Based on primary and secondary data, this study employs a qualitative research design with semi-structured interviews with policymakers, healthcare workers, logistics professionals, and technology providers. Thematic analysis will be conducted to identify key themes, including inadequate infrastructure, gaps in real-time data sharing, and scalability constraints in rural areas. This study will propose a practical roadmap for integrating digital solutions into Thailand's vaccine supply chain. It is expected that enhanced traceability, real-time monitoring, and data-driven demand forecasting will not only reduce wastage but also improve vaccine distribution to both central and rural areas. Moreover, collaboration between public and private organisations will be essential to ensure that digital integration aligns with existing policies and operational practices. These efforts will be consistent with the World Health Organization's Effective Vaccine Management (EVM) guidelines. This paper will highlight the potential for creating a more efficient and resilient vaccine supply chain. Finally, the findings will provide decision-makers with practical guidance to navigate the complexities of digital transformation in healthcare, offering a pathway toward vaccine supply chain efficiency at both national and regional levels in Thailand and other Low- and Middle-Income Countries.

**Keywords:** Digital solutions, digital integration, public health, cold chain management, technology adoption frameworks, vaccine supply chain.

### INTRODUCTION

Thailand's vaccine supply chain plays a critical role in achieving national public health goals, particularly through the Expanded Programme on Immunisation (EPI), established since 1977. Initially, the EPI focused on providing vaccines for diseases such as tuberculosis, diphtheria, tetanus, pertussis, polio, and hepatitis B later expanding to cover measles, mumps, rubella, and Japanese encephalitis (PATH *et al.*, 2011). Despite these expansions, the vaccine supply chain continues to face critical challenges, including inefficiencies in cold chain logistics, inadequate storage facilities, and insufficient collaboration among stakeholders. These issues affect vaccine quality and accessibility, particularly in rural areas, where delays and stockouts occur more often (PATH *et al.*, 2011). Some studies highlight the dynamic impact of introducing new vaccines, such as rotavirus and pneumococcal, on the supply chain. Computational modelling using the Highly Extensible Resource for Modelling Event-Driven Simulations (HERMES) found that these vaccines could overwhelm existing storage and transport capacities at various levels, from provincial to sub-district (Lee *et al.*, 2011). For example, an additional storage capacity of up to 1,151 litres per month was needed at the provincial level, significant increases in transport capacity were necessary to maintain vaccine availability (Lee *et al.*, 2011). These findings emphasise the importance of adapting supply chain infrastructure to support new vaccine introductions effectively. Thailand's efforts to address these challenges have included transitioning to a Vendor Managed Inventory (VMI) system in 2009, managed by the Government Pharmaceutical Organization (GPO) (Riewpaiboon *et al.*, 2015). The VMI system reduced logistical complexity and cut vaccine wastage by about 20 per cent in its first year (PATH *et al.*, 2011). However, continuing challenges such as limited data integration, lack of real-time monitoring, and weak stakeholder collaboration highlight the need for further studies, particularly through digital solutions (World Bank [WB], 2021). Transparency and efficiency are pivotal in ensuring the timely and equitable distribution of vaccines. According to the U.S. Centers for Disease Control and Prevention (CDC), around 35 per cent of vaccines worldwide are wasted because of inadequate cold chain management and logistical inefficiencies (Rusnack, 2021). In Thailand, vaccine wastage rates and delays in delivery in rural areas continue to threaten immunisation programs. This leads to disease outbreaks (PATH *et al.*, 2011). Studies emphasise that improper storage and transportation not only degrade vaccine efficacy but also increase operational costs, making immunisation programs less sustainable (World Health Organization [WHO] & United Nations Children's Fund [UNICEF], 2018). There is a global framework, such as the WHO's Effective Vaccine Management (EVM) initiative, which offers actionable guidelines for improving supply chain performance. The EVM framework identifies critical areas, including leadership, cold chain equipment optimisation, and data-driven decision-making,

to strengthen vaccine supply chain systems and improve vaccine accessibility (World Health Organization [WHO], 2021). Leveraging these global frameworks while incorporating innovative digital technologies could help Thailand address systemic inefficiencies (Kritchanchai *et al.*, 2021). However, while Thailand has begun to implement digital technologies in the healthcare system, the integration of information systems in the vaccine supply chain remains limited and has not fully resolved existing issues (WB, 2021). In particular, insufficient real-time data sharing between organisations and relevant partners continues to cause delays and inefficiencies in vaccine stock management (Jarrett *et al.*, 2020). Moreover, the disconnected information systems hinder vaccine monitoring and compromise vaccine quality (Radanliev & De Roure, 2023).

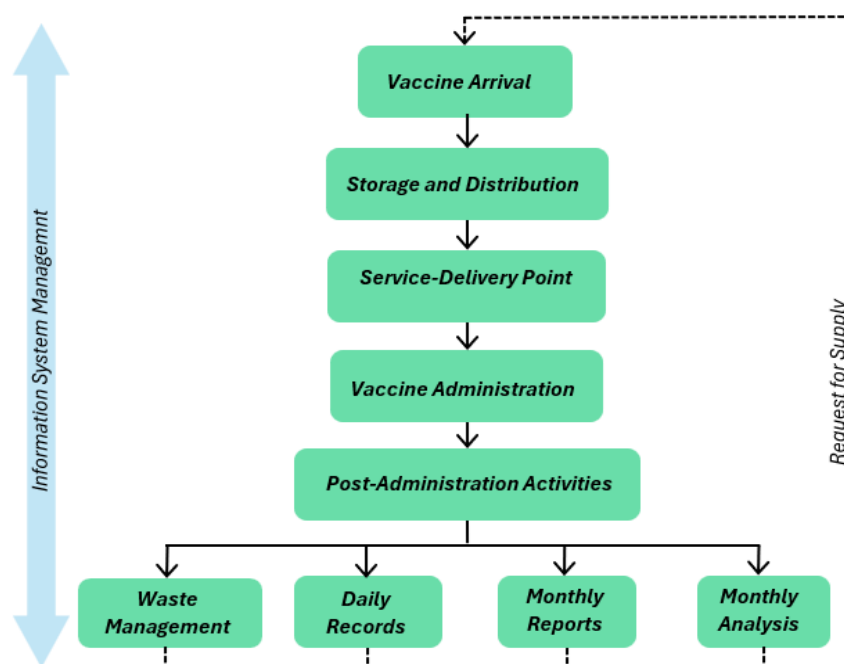
Innovative digital technologies offer significant potential to bridge these gaps. For example, blockchain technology can enhance supply chain traceability, reducing the risks of counterfeit vaccines, while Artificial Intelligence (AI) and the Internet of Things (IoT) can support real-time temperature monitoring and demand forecasting (Radanliev & De Roure, 2023). For example, India implemented a system called the Electronic Vaccine Intelligence Network (eVIN), Indonesia developed the SMILE platform to strengthen the immunisation supply chain system, and Laos adopted a Cold Chain Information System (CCIS) to report vaccine stock by SMS (Anderson *et al.*, 2014). These have demonstrated the transformative impact of digital solutions, but Thailand has yet to fully implement and manage these technologies. Therefore, this study will focus on the integration of digital solutions into Thailand's vaccine supply chain to overcome data limitations and improve vaccine management efficiency. The study will present a roadmap to support relevant public and private organisations in strategic decision-making to enhance the efficiency of the vaccine supply chain and the public needs (Prosser *et al.*, 2021; WHO & UNICEF, 2018).

This study aims to investigate how digital technologies can address inefficiencies in Thailand's vaccine supply chain. The objectives are (i) to identify current logistical and structural inefficiencies in Thailand's vaccine logistics and distribution systems, (ii) to evaluate the potential of digital tools such as blockchain, AI, and IoT to improve transparency, monitoring, and decision-making, and (iii) to develop a roadmap for integrating digital technologies to enhance vaccine supply chain resilience and equity. The proposed research questions are (i) What are the primary logistic challenges in Thailand's vaccine supply chain? (ii) How can digital technologies address these challenges effectively? (iii) What are stakeholders' experiences with digital tools in vaccine logistics? The expected research contribution is to expand a body of knowledge on vaccine supply chain management in Low- and Middle-Income Countries (LMICs) (Prosser *et al.*, 2021), focusing on Thailand as a case study. This study aims to support policymakers, healthcare providers, and logistics stakeholders by identifying inefficiencies and proposing actionable, technology-driven solutions to strengthen vaccine distribution systems. Furthermore, these findings will provide a reference framework for other LMICs seeking to integrate digital solutions into their immunisation programs (Guignard *et al.*, 2019). The study aligns with global health initiatives such as the WHO's Effective Vaccine Management (EVM) framework and the Sustainable Development Goals (SDGs) - Goal 3, ensure healthy lives and promote well-being for all at all ages (WHO & UNICEF, 2018).

## LITERATURE REVIEW

### Vaccine Supply Chain Management

WHO developed a vaccine supply chain framework that outlines a functional, end-to-end supply chain process (Figure 1). These systems encompass storing, distributing, handling, and managing vaccines effectively. This ensuring strict temperature control in the cold chain and using logistics management information systems to enhance system performance. The main goal is to guarantee a steady supply of high-quality vaccines from the manufacturer to the end service delivery points. Vaccine supply chains face global challenges, particularly in ensuring cold chain integrity, timely delivery, and equitable distribution. These issues are especially prevalent in Low- and Middle-Income Countries (LMICs), where infrastructure limitations, resource constraints, and inadequate staff training hinder effective immunisation supply chains (WHO & UNICEF, 2018). For example, insufficient cold chain systems often result in vaccine degradation, wastage, and inequitable access to immunisation services. Recent studies show that up to 35 per cent of vaccines globally are wasted due to improper storage and handling (Rusnack, 2021).



Source: Adapted from Vaccine supply chain framework (World Health Organization).  
Figure 1: The Vaccine Supply Chain Process.

To address these issues, many countries have adopted innovative strategies to streamline vaccine logistics. India implemented the Electronic Vaccine Intelligence Network (eVIN), a cloud-based system that enables real-time monitoring of vaccine stocks, storage conditions, and supply levels, significantly reducing vaccine wastage and enhancing decision-making (United Nations Development Programme [UNDP], 2022). Similarly, Indonesia developed the SMILE platform, which enhances vaccine distribution efficiency by applying digital tools to improve logistics operations, allowing greater transparency and accountability (UNDP, 2022). Additionally, Laos used a Cold Chain Information System (CCIS), built on the District Health Information System (DHIS2) platform, and utilises a manual and automatic SMS alert to report vaccine stock visibility and equipment performance, especially in rural areas (Anderson *et al.*, 2014).

In Thailand, a new system has been introduced to tackle similar challenges. Previously, vaccine procurement and distribution were centralised under the Department of Disease Control (DDC), but inefficiencies such as cold chain breakdowns and frequent stockouts persisted (PATH *et al.*, 2011). The Vendor Managed Inventory (VMI) system was introduced in 2009, governed by the Government Pharmaceutical Organization (GPO). This system reduced a logistic process, minimised vaccine wastage, and achieved cost savings streamlined logistics, reduced vaccine wastage, and delivered cost savings of nearly 20 per cent in the first year (PATH *et al.*, 2011). Recent computational modelling studies, such as those studied by Lee *et al.* (2011), highlighted the challenges posed by new vaccine introductions, including rotavirus and pneumococcal vaccines. These studies revealed that additional storage capacities of up to 1,151 litres per month at the provincial level and significant transport enhancements were necessary to maintain vaccine availability. Furthermore, Thailand has a regional vaccine production hub supported by the Government Pharmaceutical Organization (GPO) and private firms such as BioNet Asia, contributing to domestic and regional vaccine manufacturing capabilities (Postigo, 2023). These efforts reflect the country's growing role in enhancing regional vaccine security. Thailand's COVID-19 vaccination rollout further underscored the importance of preparation and adaptability in immunisation programs. A comprehensive health infrastructure with collaborative policy structures enables Thailand to address the logistical complexities of the largest vaccination campaign (Limwattanayingyong *et al.*, 2021). The key measurements include cold chain assessments, investments in storage equipment, and the use of digital dashboards for real-time tracking and reporting. Additionally, multi-organisation collaboration through the National Vaccine Deployment Sub-Committee ensured efficient vaccine distribution and prioritisation of high-risk groups in line with WHO guidelines. These strategies represent the integration of evidence-informed policies and advanced logistics systems to support vaccine supply chain improvement. However, gaps remain, particularly in integrating advanced digital tools to enhance system resilience and efficiency (Radanliev & De Roure, 2023; PATH *et al.*, 2011).

### Challenges and Opportunities

Vaccine supply chains in LMICs encounter significant challenges, including inadequate cold chain infrastructure, lack of demand forecasting, and financial constraints. These limitations lead to vaccine stock running out, delays in immunisation, and unequal vaccine access (Jarrett *et al.*, 2020; WHO & UNICEF, 2018). In Thailand, logistical constraints increase inequalities, especially in rural areas, where maintaining cold chain integrity is particularly difficult. Barriers such as insufficient digital literacy among health workers, high implementation costs, and fragmented policy frameworks also obstruct the adoption of scalable digital solutions (UNDP, 2022). However, LMICs also have significant opportunities to strengthen vaccine supply

chains through targeted digital tools. Advanced packaging technologies, such as temperature-sensitive labels, can help ensure vaccine quality during transportation and storage (Jarrett *et al.*, 2020). Public and private partnerships, such as Thailand's collaboration with SK Bioscience, demonstrate the potential to enhance local vaccine manufacturing capabilities, reduce reliance on imports, and improve supply chain resilience (SK Bioscience, 2023). Thailand has participated in ASEAN initiatives and partnerships with global pharmaceutical companies, including the development of mRNA vaccines. These further strengthen the capability to address both domestic and regional vaccine needs (Postigo, 2023). Moreover, increasing investments in healthcare staff training and policy alignment could enable LMICs to integrate digital solutions and enhance overall vaccine supply system efficiency (WHO & UNICEF, 2018).

### **Digital Technologies in Supply Chain Management**

Digital technologies are transforming supply chain management by improving transparency, traceability, and operational efficiency. Blockchain technology, for example, enables secure and recorded unchangeable information, reducing the risk of counterfeit vaccines and enhances accountability (Radanliev & De Roure, 2023). IoT provides real-time monitoring of cold chain conditions, ensuring that vaccines remain within optimal temperatures throughout the supply chain process. Similarly, AI supports demand forecasting, route optimisation, and proactive inventory management (UNDP, 2022). In Thailand, the adoption of digital technologies in vaccine supply chain management remains limited. The SmartMedSupply platform and the National Medicinal Product Catalogue Database (NMPCD) provide centralised data for decision-making, but their scalability and integration with other logistics platforms pose significant challenges. However, these platforms are not specifically focused on vaccination products (Kritchanchai *et al.*, 2021). Barriers such as high initial investment costs, inadequate infrastructure in rural areas, and the absence of a clear policy for digital health hinder the implementation. (PATH *et al.*, 2011; UNDP, 2022). Addressing these issues through improved training programs, increased investment, and improved cooperation between the public and private sectors could significantly enhance digital transformation in Thailand's vaccine supply chain. The lessons learned from successful implementations like eVIN in India, SMILE in Indonesia, and CCIS in Laos highlight the potential for Thailand to adopt similar approaches. These systems demonstrate how digitised information can improve inventory management, reduce wastage, and enhance the overall healthcare system. By aligning digital adoption strategies with global best practices and addressing local barriers, Thailand can position itself to ensure an equitable and efficient vaccine supply chain (UNDP, 2022; WHO & UNICEF, 2018).

### **Theoretical Framework**

There are two theoretical frameworks that support this research. First, the Technology-Organization-Environment (TOE) Framework categorises factors into three domains (i) Technological readiness, such as infrastructure and compatibility, (ii) Organisational support, such as leadership and resources, and (iii) Environmental, such as regulations and market competition (Tornatzky *et al.*, 1990). This approach helps identify various factors affecting the adoption of digital technology to improve the efficiency of the vaccine supply chain in Thailand. Specifically, in the area of technology readiness, the focus is on the level of readiness of the existing technological infrastructure within the Thailand healthcare system (Prosser *et al.*, 2021). While the organisational support aspect addresses resource management, personnel readiness, and support from organisational leaders (Jarrett *et al.*, 2020), while the environmental factors emphasise external contexts such as regulations, government policies that may influence the adoption of digital technology in Thailand's vaccine supply chain system (Kritchanchai *et al.*, 2021). Second, the Organisational Information Processing Theory (OIPT) emphasises how technology can reduce uncertainty and improve decision-making within complex environments. The OIPT framework explains the management of data and communication processes within the vaccine supply chain, which are complex and highly uncertain. The use of OIPT in this research will help to identify the capability of digital technology to reduce uncertainty by increasing data accuracy and supporting more efficient decision-making processes (Galbraith, 1974; Radanliev & De Roure, 2023). Additionally, this framework helps explain how digital technology can link and integrate data in real-time, enabling all organisations in the supply chain to manage logistics and resources more efficiently (Jarrett *et al.*, 2020). Both of these frameworks guide the interpretation of findings during the qualitative analysis. These frameworks help categorise emerging themes related to technological readiness, organisational capacities, and environmental or regulatory constraints that influence the adoption of digital solutions in the vaccine supply chain ((Tornatzky *et al.*, 1990; Galbraith, 1974).

## **RESEARCH METHODOLOGY**

This research will employ the case study methodology because it suits qualitative research, which focuses on in-depth exploration of complex issue in a specific context (Creswell, 2009). This enables an in-depth study and analysis of the factors related to the integration of digital technology in Thailand's vaccine supply chain system, while identifying the real environment and the complexities of vaccine management in a LMICs such as Thailand. Thailand is selected as the case study due to its notable characteristics in managing the healthcare system and infrastructure at an appropriate level of readiness, as well as its experience initiating the vaccine management system through Vendor Managed Inventory (VMI) in 2009 (PATH *et al.*, 2011; Riewpaiboon *et al.*, 2015). Moreover, Thailand faces several challenges, such as insufficient data system integration, disparities in vaccine access between urban and rural areas, and limitations in fully leveraging digital technology (UNDP, 2022). This makes Thailand a unique case study for exploring the problems and opportunities faced by other LMICs in their efforts to develop an efficient vaccine logistics system using digital technology (Prosser *et al.*, 2021). Additionally, studies in the context of Thailand have the potential to be applied in other countries in the Southeast Asia region with similar environments and public health contexts (Kritchanchai *et al.*, 2021).

## Data Collection and Analysis

The research data collection and analysis are structured into four key stages (Figure 2).

### Stage 1 – Primary Data Collection

Primary data will be gathered through interviews with key stakeholders in Thailand's vaccine supply chain, including government officers, logistics managers, healthcare professionals, and digital technology providers. The questions will be designed to elicit detailed insights into participants' experiences, challenges, and opportunities in using digital technology within the vaccine system (Creswell, 2009). Participants will be recruited using a purposeful sampling strategy to ensure representation across critical roles in the vaccine supply chain (Palinkas *et al.*, 2015). Inclusion criteria include (i) direct involvement in vaccine logistics or distribution or policymaking, (ii) experience with or knowledge of digital technologies in healthcare, and (iii) representation from diverse geographic regions, including urban and rural areas. Invitations will be sent via professional networks, government agencies, and healthcare institutions to identify individuals who meet these criteria through online or in-person meetings. A targeted total of 15 – 20 participant interviews is planned. Interviews will be recorded, transcribed, and anonymised to ensure ethical compliance.

### Stage 2 - Secondary Data Collection

Secondary data will be collected from government reports, journal articles, and publicly available datasets to complement primary data. Key sources include the PATH assessment of Thailand's vaccine supply chain (PATH *et al.*, 2011) and the WHO's Effective Vaccine Management (EVM) Initiative reports (WHO, 2021). These secondary resources provide historical context and insights into systemic issues affecting vaccine supply chains globally, including the case of Thailand.

### Stage 3 - Thematic Analysis

Primary data collected through semi-structured interviews, along with secondary data sources, will be analysed using Thematic Analysis (Braun & Clarke, 2006), which is a widely accepted method for identifying patterns and themes in qualitative research. The analysis will focus on factors that facilitate or hinder the adoption of digital technology, the capabilities of information systems, and practical recommendations for improving the efficiency of Thailand's vaccine supply chain. Additionally, the result themes will be interpreted through the lens of TOE and OIPT frameworks to better understand how digital solutions can enhance the vaccine supply chain efficiency.

### Stage 4 - Roadmap Development

Based on the results from thematic analysis, the finding will be synthesised to develop a roadmap for the integration of digital solutions in Thailand's vaccine supply chain system. The focus will be on practical recommendations that can be implemented, such as using IoT to enhance temperature tracking accuracy, using AI for vaccine demand forecasting, or applying blockchain to increase transparency in the transportation process (Radanliev & De Roure, 2023). The development of this roadmap aims to provide policymakers and logistics managers with tools to inform future strategies.

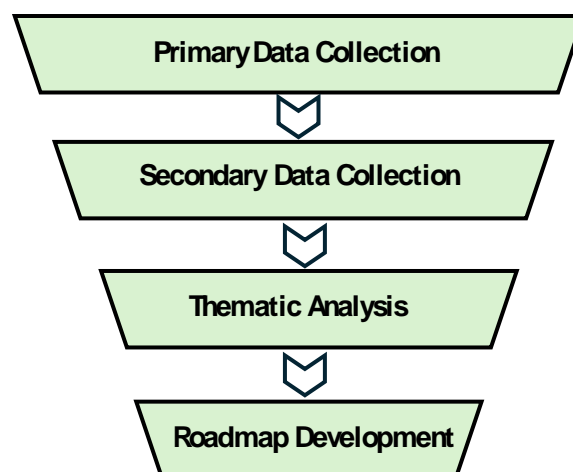


Figure 2: The stages of Data Collection and Analysis.

## EXPECTED CONTRIBUTIONS

This study is expected to contribute both practically and academically.

### Practical Contributions

The research will identify the key factors contributing to inefficiencies in Thailand's vaccine supply chain. Additionally, the study will examine how digital technologies such as blockchain, AI, and IoT can address logistical challenges, boost transparency, and reduce wastage. Finally, this study will propose a roadmap as a strategy guide for policymakers and practitioners to adopt and integrate digital tools into vaccine logistics. By grounding recommendations in global frameworks

such as the WHO's Effective Vaccine Management (EVM), this study will provide evidence-based insights to inform national vaccine supply chain policies.

### Academic Contributions

For an academic contribution, this research will extend the Technology-Organization-Environment (TOE) and Organizational Information Processing Theory (OIPT) frameworks within the context of the vaccine supply chain, specifically in LMICs. By applying these theories with qualitative data gathered from stakeholders, the study will advance theoretical understanding by illustrating how information processing capabilities shape the adoption of digital technologies in complex healthcare systems.

### CONCLUSION

This study will highlight the existing challenges in Thailand's vaccine supply chain, from infrastructural drawbacks to limited digital integration. By examining both primary and secondary data, this study will demonstrate how the strategic application of technologies such as blockchain, AI, and IoT can meaningfully address these gaps, enhancing cold chain management, reducing wastage, and boosting overall logistics performance. Importantly, the study will propose a roadmap that outlines practical steps for policymakers, healthcare providers, and technology vendors to foster a more transparent, equitable, and resilient immunisation program. The proposed roadmap will serve as a strategic tool for policymakers, logistics planners, and technology providers to support a more flexible, equitable, and responsive vaccine delivery system. The findings from this research will underscore the importance of digital transformation in Thailand's context and offer transferable insights for other LMICs seeking to strengthen their vaccine supply chains.

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