An Assessment of Vaccine Supply Chain and Logistics Systems in Thailand

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PATH, World Health Organization, Health Systems Research Institute, and Mahidol University

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- Provincial health offices (Angthong, Saraburi, Trad, Kanjanaburi, Surin, Loei, Ubonratchathani, Uthaithani, Phitsanulok, Lumphun, Phang Nga, Trung).
- District health offices (Muaklek, Saiyok, Trakanpuetpol, Wangtong, Kapong, and Muang District of Angthong, Saraburi, Trad, Kanjanaburi, Surin, Loei, Ubonratchathani, Uthaithani, Phitsanulok, Lumphun, Phang Nga, and Trung Provinces).
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Abbreviations

AIDS	Acquired immune deficiency syndrome
CONV	Conventional system
DDC	Department of Disease Control
DTP	Diphtheria-tetanus-pertussis
EPI	Expanded Programme on Immunization
GPO	Government Pharmaceutical Organization
HepB	Hepatitis B
HIV	Human immunodeficiency virus
IT	Information technology
JE	Japanese encephalitis
KPI	Key performance indicator
MoPH	Ministry of Public Health
NHSO	National Health Security Office
OPV	Oral polio vaccine
PCU	Primary care unit
THB	Thai baht
TT	Tetanus toxoid
VMI	Vendor-managed inventory system
WHO	World Health Organization

Executive summary

Improper storage and transportation can put vaccine products at risk of degradation. Therefore, an effective vaccine supply chain and logistics system is essential to ensure product quality. Since the conventional vaccine supply chain and logistics system was inefficient, resulting in wasted and expired vaccine products, inventory control issues, and high costs, in 2009, the government of Thailand launched a pilot project to outsource vaccine supply management and distribution to the Government Pharmaceutical Organization (GPO), which in turn introduced and managed a vendor-managed inventory system (VMI) and subcontracted with a private logistics company to distribute vaccine products in 28 of 76 provinces. The system gradually expanded nationwide by late 2010. The goal of VMI is to streamline supply chain operations for suppliers and their customers, increasing management efficiency and reducing vaccine wastage.

The Health Systems Research Institute, in collaboration with PATH and the World Health Organization, commissioned a study led by the Faculty of Pharmacy, Mahidol University, to better understand the vaccine supply chain system in Thailand and the challenges of implementing the streamlined VMI system. Specifically, the study aimed to evaluate the overall performance of VMI compared to the conventional system that was implemented prior to 2009 and the associated vaccine logistics costs, as well as to provide recommendations to improve the vaccine supply chain and logistics system in Thailand. The study was conducted in 12 provinces (Angthong, Saraburi, Trad, Kanjanaburi, Surin, Loei, Ubonratchathani, Uthaithani, Phitsanulok, Lumphun, Phang Nga, and Trung) from March 2010 to July 2011. The study employed a combination of methodologies, including document review, interviews with representatives of implementing agencies, surveys of health officials, and an economic analysis.

The findings revealed that the VMI system has been implemented successfully in Thailand. The transition from the conventional vaccine distribution system to the VMI system was viewed positively by staff and implementers. Problems encountered in the early stages of VMI system implementation were adequately resolved. The information technology (IT) used in the current VMI system, although satisfactory, could be further developed to gain even greater efficiency.

An economic analysis comparing the two systems found that the VMI system saved nearly one-fifth of the total cost of vaccine procurement and distribution in its first year through more efficient use of resources, lower logistics costs, and a smaller number of vaccines procured and distributed.

Our findings suggest that multiple factors contributed to the success of the transition to the VMI system in Thailand. The transition was driven by problems with the conventional system, the earlier successful distribution of AIDS drugs by the GPO through the VMI system, a viable existing health care infrastructure and IT, and strong political will and commitment to address the problems of the vaccine supply chain and logistics. The VMI system has streamlined the supply chain, improved communication, built on existing infrastructure, and increased staff IT capacity.

Despite the successes, challenges remain. Feedback from implementing agencies identified two major pitfalls to the VMI system. The first involves a shortage of GPO-manufactured vaccine. The GPO, which serves as both the vaccine procurement agent and the local manufacturer of

Japanese encephalitis vaccine, has been reluctant to procure vaccines from other companies for fear of losing market revenue. This has led to repeated vaccine shortages. In retrospect, since the GPO is also the contractor to the National Health Security Office (NHSO) on vaccine distribution, assigning vaccine procurement activities to another agency not involved in vaccine production could prevent this conflict of interest. Another option would be to implement a penalty for failing to meet the procurement timeline. In addition, the national safety stock level of vaccines has not been clearly stated in the contract between the NHSO and the GPO and should be set to achieve a balance between the benefits of holding reduced inventory and the need to store enough vaccine to serve as a buffer against possible vaccine shortages.

The second pitfall is related to the roles and responsibilities of each party involved in the National Immunization Program. Staff members indicated they were not clear whose job it is under the VMI system to provide technical support on supply chain management, vaccines, and vaccination. In the VMI system, the NHSO is responsible for vaccine procurement and distribution, whereas issues regarding immunization policy and practices are the responsibility of the national Department of Disease Control (DDC). However, when there are vaccine-related problems, systematic responses are not yet in place. For instance, it is not clear whether the DDC or the NHSO is responsible for managing events such as a cold chain breakdown, a change in the dose or strain of a vaccine, or the response to a serious adverse event following immunization. In order to mitigate these problems, terms of reference, working guidelines, standard operating procedures, and workflows for each activity among stakeholders should be developed.

The results of this study have led to the following recommendations:

- Increase the efficiency of the VMI system by improving IT systems (i.e., the VMI web presence, the improvement of vaccine inventory software, and the reliability and speed of Internet connections). The benefit of extending the VMI vaccine distribution system to the health center level should also be explored.
- Improve the quality of vaccine distribution services between the GPO and the district warehouses. The system should impose quality control measures such as a systematic quality monitoring system and the Good Distribution Practice guidelines.
- Increase the quality of vaccine management at district warehouses and health centers through training, supervision, and monitoring.
- Extend the IT system to health centers to improve efficiency.
- Improve the system at the central level to better manage the vaccine supply chain, clinical services, and technical support. Clear roles and responsibilities of the three major stakeholders need to be established, with the DDC as immunization manager, the NHSO responsible for vaccine procurement and distribution, and the GPO as a contractor for the NHSO on vaccine distribution and procurement.

Introduction

Importance of the vaccine supply chain and logistics

Immunization has been widely accepted as one of the most cost-effective public health interventions for disease prevention. Despite high immunization coverage rates and vaccine effectiveness, there are still a number of reported outbreaks, some of which could be prevented by better vaccine management practices. For example, measles and polio outbreaks have been observed in several countries where measles and polio were previously under control, including in Italy, Japan, Laos, and Namibia.[1–8]

The continuing number of reports of vaccine-preventable disease outbreaks raises concerns about vaccine quality.[9] Vaccines are biological products that can be damaged by high temperatures, freezing temperatures, and excessive light. They are generally effective for a limited period of time at room temperature. Inappropriate transportation and improper storage of vaccines might lead to a decrease in vaccine effectiveness.[9–12] For example, according to the product information sheets,[13] inactivated polio vaccine, diphtheria-tetanus-pertussis vaccine (DTP), diphtheria and tetanus toxoids vaccine, hepatitis B vaccine (HepB), and tetanus toxoid vaccine (TT) are seriously damaged at temperatures less than 0°C. HepB vaccine freezes at temperatures less than -0.5°C. Once potency has been lost through exposure to excessive heat or freezing temperatures, returning the vaccine to the correct storage temperature will not cause the vaccine to regain its potency. If potency is lost through heat exposure, the vaccine's appearance will not change. Without performing a laboratory test, it is not possible to know whether a vaccine has lost its potency.

Association between vaccine quality and proper transport/storage

There have been a number of reports demonstrating an association between vaccine quality and appropriate vaccine transport and storage. In Nigeria, the potency of oral polio vaccine (OPV) as well as vaccines for measles and yellow fever was found to decrease below international standards when they were transported from the national warehouse to health facilities. The rate of the decrease in the potency of measles vaccine was greater than in OPV and yellow fever vaccine. The potency loss was most likely due to several factors, including repeated cycles of vaccine freezing and thawing caused by deficiencies in cold storage equipment, inconsistent electrical distribution systems, a lack of backup electricity, and improper vaccine storage.[10] A study in Australia reported that improper vaccine storage may have been associated with an outbreak of diphtheria from 1993 to 1996.[8] One localized measles outbreak in the United States in 1970 was associated with the storage of vaccine in the door shelf of a refrigerator rather than in its central core.[14] There was also a report of poor vaccine effectiveness and an outbreak of 180 measles cases in one province of Thailand. Two villages of that province that had the highest morbidity rates (9.57% and 6.99%) had vaccine coverage rates of 71.7% and 50.9% and low vaccine efficacy rates of 35.2% and 39.9%, respectively.[15]

Problems in the vaccine supply chain and logistics

The transport and storage of vaccines at temperatures higher than 8°C (the optimum temperature range for vaccine storage is 2°C to 8°C) have been reported in the United States and Australia.[16,17] Vaccine freezing has been reported in many countries.[9,11,12,18–25] A study in Indonesia that monitored the temperature of HepB vaccine shipped from the manufacturer to the

provider found that 75% of vaccine shipments were being frozen. The highest rates of freezing occurred during transport from provincial to district warehouses.[22] A study in Bolivia that monitored the temperature of DTP-HepB-*Haemophilus influenza* type b vaccine throughout its transportation from the national warehouse to 11 communities in 3 provinces reported that the proportion of time that the temperature fell to less than 0°C ranged from 2% to 50%. Vaccine freezing occurred at all levels of the cold chain, especially from the district warehouse to health centers. In addition, 7 of the 11 routes from provincial to district warehouses had a temperature higher than 8°C.[21] A study in Papua New Guinea recorded vaccine temperatures during transportation from the national warehouse to health centers and detected frozen vaccine vials caused by insulation between the vaccines and the icepacks that was not sufficient to protect the vaccines from direct contact with the icepacks.[25]

In the United States, a temperature study was conducted of refrigerators used to store vaccines in medical clinics. Thermometers were used to measure the minimum and maximum temperatures for a 24-hour period. The results indicated that only 2 of the 21 clinics studied had refrigerator temperatures that fell within the acceptable range. About 63% of the samples had temperatures that fell below the acceptable range, 59% reached temperatures higher than the acceptable range, and 93% were both higher and lower than the acceptable range.[17] Since the study measured only the minimum and maximum temperatures, it is impossible to know how long the temperatures remained outside the acceptable range. During a three-day monitoring period, a study in New South Wales used data loggers to measure the temperature of 53 vaccine refrigerators in pharmacies and found that only 19% of the refrigerators studied had temperatures that fell within the acceptable range, while 23% of the refrigerators had temperatures that fell to less than 0°C and 29% had temperatures higher than 8°C.[23]

The vaccine supply chain and logistics in Thailand

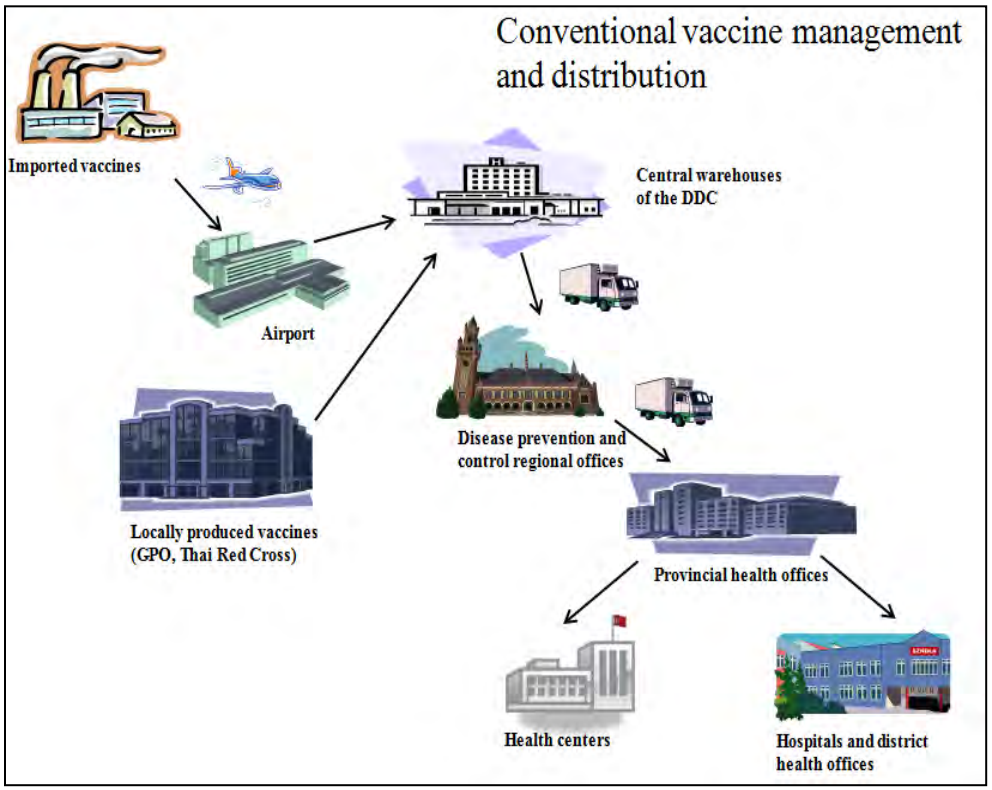
Thailand has supported immunization activities since 1838. The Expanded Programme on Immunization (EPI), supported by the World Health Organization (WHO), was implemented in 1977 with Bacille Calmette Guérin vaccine for tuberculosis, DTP, OPV for children younger than one year in Bangkok, and TT for pregnant women. To date, the National Immunization Program covers the whole country and offers eight vaccines against ten diseases (diphtheria, pertussis, tetanus, HepB, Japanese encephalitis [JE], measles, mumps, rubella, poliomyelitis, and tuberculosis).[26]

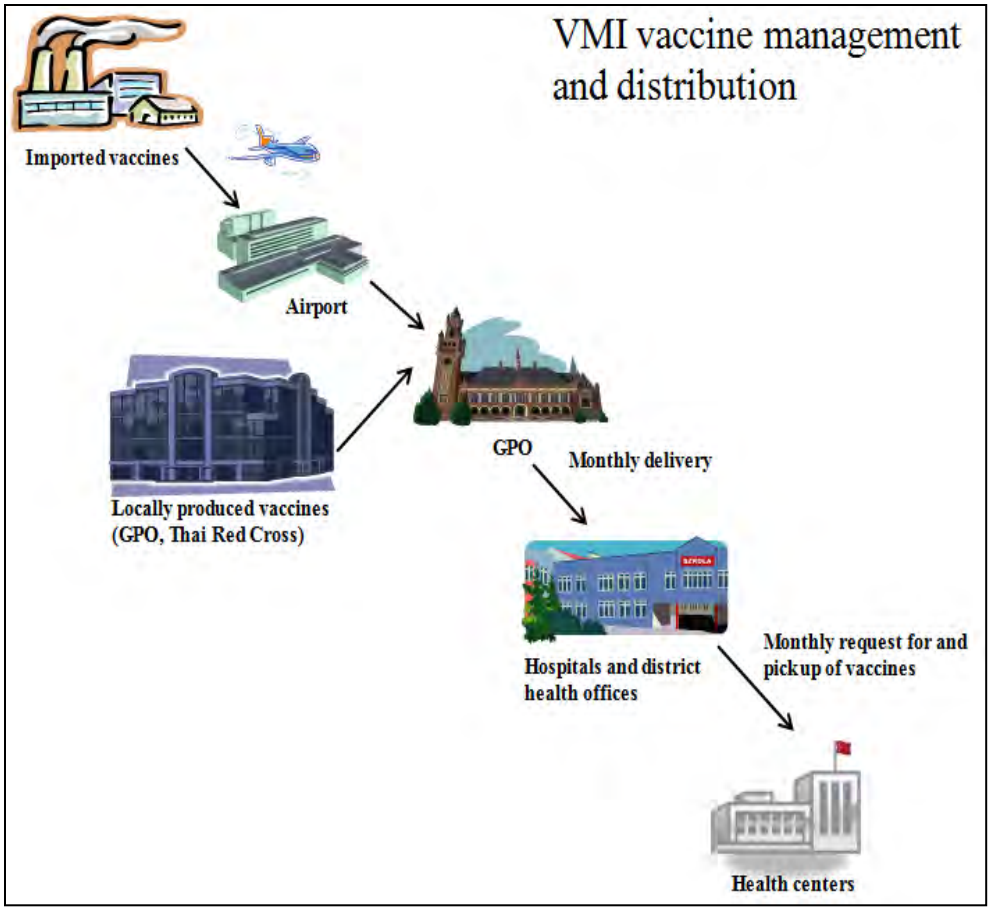
Until 2009, the procurement and distribution of EPI vaccines was the responsibility of the national Department of Disease Control (DDC), formally known as the Department of Communicable Disease Control, within the Bureau of General Communicable Diseases, Ministry of Public Health (MoPH). Prior to 2002, to procure vaccines, the Pharmacy unit of the Bureau of General Communicable Diseases made a budget request to the MoPH and purchased vaccines through a tender process from producers or distributors, including the Government Pharmaceutical Organization (GPO), a parastatal organization under the MoPH responsible for procuring vaccines and medicines and distributing medicines for the MoPH. Following health care reform in 2002, the budget for EPI vaccines was based on the capitation payment under the universal health coverage scheme managed by the National Health Security Office (NHSO). The NHSO was established under the National Health Security Act of 2002 to manage the provision of universal health care to Thai citizens as well as the National Health Security Fund. It is a

public, autonomous organization governed by the National Health Security Board and chaired by the minister of public health. Since 2002, the NHSO has been responsible for managing EPI financing of vaccines, and the budget request for EPI vaccines was made to the NHSO from 2002 to 2008.

The vaccine supply chain and logistics system was managed by the DDC under this system. The cold chain started with the delivery of vaccines from the producer/importer to the central warehouse of the Pharmacy unit, located in the MoPH. Vaccines were transported to 12 disease prevention and control regional offices, then to 76 provincial health offices, and finally to some 10,000 health facilities (including hospitals and health centers). The system comprised several distribution steps that were considered unnecessary, likely to result in vaccine wastage and expired vaccine, and that led to overstocks at some distribution points. In addition, inventory control and vaccine wastage were not traceable due to the lack of a reporting system. Replacement and maintenance costs for existing cold chain equipment were also high. To streamline the vaccine supply and logistics system and improve information flow, the NHSO and DDC launched a pilot project in 2009 to outsource vaccine supply management to the GPO. The GPO introduced and managed a vendor-managed inventory (VMI) system and subcontracted with a private logistics company to distribute vaccine products in 28 of 76 provinces. During the pilot phase, vaccines procured by the DDC were directly distributed from the central warehouse of the GPO to the pharmacy department at provincial/district hospitals and to the primary care units (PCUs) in local health centers (Figure 1).[27] Since 2010, the NHSO has been in charge of procuring and distributing EPI vaccine and has outsourced its procurement and distribution functions to the GPO. The VMI system was then expanded to the whole country in late 2010.

Figure 1. Comparison of Thailand's conventional and VMI supply chain systems.





In the VMI system, the vaccine supply chain starts at the GPO warehouse and goes directly to district warehouses (provincial and district hospitals). It then goes from the district warehouses to the PCUs (health centers or hospital immunization clinics). In the conventional system, the system starts at the central warehouse of the Pharmacy unit of the DDC and goes from the regional warehouses (regional offices for disease prevention and control) to the provincial warehouses (provincial health offices) and continues to the district warehouses (district health offices and hospitals), ending at the PCUs.

VMI is a streamlined approach to inventory management and order fulfillment. VMI involves collaboration among suppliers and customers (e.g., the distributor, retailer, original equipment manufacturer, or product end-user) that changes the traditional procurement and distribution processes. Instead of sending purchase orders, customers electronically send daily demand information to the supplier. The supplier generates replenishment orders for the customer based on demand. The process is guided by mutually agreed objectives for the customer's inventory levels, fill rates, and transaction costs. The goal of VMI is to align business objectives and streamline supply chain operations for both suppliers and their customers. The business value is a direct result of increased information flow.

The advantages of VMI at the lower end of the supply chain, usually a large retailer, have been well documented.[28] The main advantages of VMI are reduced costs and improved customer service.[28] VMI greatly reduces inventory carrying costs and stockout problems while also

offering the ability to synchronize both inventory and transportation decisions.[29] Williams reiterated these same benefits and added the benefits of improved customer retention and reduced reliance on forecasting.[30] A case study on the continuous replenishment program at Johnson & Johnson revealed that advantages of VMI included improved customer service, reduced demand uncertainty, reduced inventory requirements, and reduced costs.[31] Fox stated that Black & Decker decreased returned goods from one of its retail customers from $1 million to $75,000 and that Schering-Plough increased service levels to 99% while decreasing inventory levels by 25% as a result of VMI implementation.[32] Anecdotal evidence suggests that VMI may offer more management efficiency for the vaccine supply chain system and is expected to reduce unopened vaccine wastage. However, there is no empirical evidence in support of the claim of VMI benefits for vaccine products in the public sector, including in Thailand.

Economic studies of vaccination programs

Economic analyses of vaccination programs are being used increasingly as a tool to support health policy decision-making.[33,34] The cost of vaccination programs at minimum includes the acquisition cost of the vaccine, the cost of administration, and the cost of delivery or logistics.[35] A sufficient and regular supply of vaccines (or an adequate logistics and supply chain) affects the costs and outcomes of vaccination programs. However, few empirical studies have focused on the cost of vaccine logistics. A recent study in Thailand[36] estimated the cost of logistics of the EPI vaccines from the central to provincial levels under the conventional system. Another Thailand study focused on the cost of logistics of EPI vaccines between district warehouses and health centers.[37] Two studies estimated the costs of the vaccination program. One study looked at HIV vaccine and the other at DTP-HepB vaccine.[38,39] Studies conducted outside Thailand include analysis of the costs of introducing a malaria vaccine through EPI in Tanzania,[40] the costs of integrating HepB vaccine into the national immunization program in Ethiopia,[41] and the costs of implementing the EPI in Vietnam.[42]

Study objectives

Given the lack of empirical evidence to support the benefits of VMI or the benefits of outsourcing vaccine distribution to the GPO, the Health Systems Research Institute, in collaboration with PATH and WHO, commissioned a study led by the Faculty of Pharmacy, Mahidol University, to better understand the vaccine supply chain system in Thailand and the challenges of implementing the VMI system. The overall objective of the study was to assess the EPI vaccine supply chain and logistics system in Thailand.

Specific objectives were to:

- Document the EPI vaccine logistics systems (conventional and VMI), their evolution, and the decision-making processes surrounding the transition to VMI.
- Assess the performance of both the conventional vaccine logistics system and the VMI system.
- Estimate the logistics costs from the provider (government) perspective.
- Provide recommendations to develop and implement an effective VMI system in the EPI vaccine supply chain.

Methods

Conceptual framework

In this study, supply chain management and logistics are defined as follows:[43]

> Supply chain management *is the art and science of integrating the flows of products, information, and financials through the entire supply pipeline from the supplier's supplier to the customer's customer.*
>
> Logistics *is the process of anticipating customer needs and wants; acquiring the capital, materials, people, technologies, and the information necessary to meet those needs and wants; optimizing the goods- or service-producing network to fulfill customer requests; and utilizing the network to fulfill customer requests in a timely manner.*

The study was designed as a retrospective, quasi-experimental study comparing performance and logistics costs of the conventional and VMI systems. A formal evaluation of the conventional and VMI systems was conducted using the Context, Input, Process, and Product model,[44] a systems model, to provide a comprehensive assessment of the performance of the logistics systems.

The study estimated the direct logistics costs to the providers (NHSO and DDC) of both supply chain systems using a microcosting approach. Cost items included labor,[i] materials,[ii] and capital.[iii] An economic analysis of capital costs of refrigerators, computers, and printers used a 3% discount rate. The indirect costs from supporting units, the hidden costs of inventory, and the start-up costs were not included in the analysis. Quantities of vaccine supplied from the central warehouse were collected for the whole year period. The time period for the analysis was 2009 and 2010 for the conventional and VMI systems, respectively. All costs presented were adjusted to 2010 prices using the consumer price index.

A meeting with implementing agencies in the vaccine supply chain and logistics system was also conducted to present and receive feedback on preliminary findings.

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[i] Labor cost was estimated using two methods. The first method was based on actual time spent on each activity in terms of man-minute per activity per month. Cost per man-hour was calculated from average monthly salary adjusted by 22 working days per month and 6 productive hours per day. General activities of vaccine logistics management included estimating target quantities, preparing and submitting request forms, taking or receiving vaccines, completing inventory registration, storing vaccines, and monitoring temperature. The second method used salary adjusted by the proportion of total working time spent on each activity.

[ii] Material costs included office supplies, transportation, electricity costs of the cold chain, and transportation. Transportation cost was either the outsourcing fee (in the VMI system) or the estimation of distance and reference cost per kilometer (in the conventional system). Outsourced logistics costs of the VMI system were 5% of the vaccine product's cost. Reference costs for motorcycles and cars were 2 Thai baht (THB) and 4 THB per kilometer, respectively. Electricity costs were estimated from electricity units (kilowatt-hour) and cost per electricity unit. Electricity units were calculated from the multiplication of watt of compressor and estimated running compressor time of eight hours per day. The cost of electricity unit was estimated at 2.89 THB per unit.

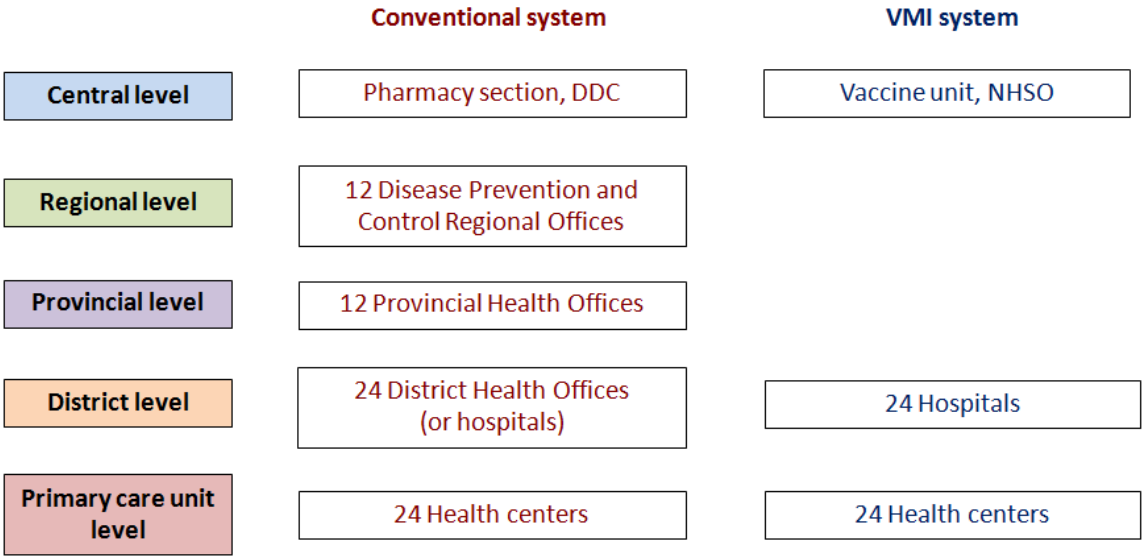
[iii] Equivalent annual capital cost = current price/annuity factor.
Current price (in the year of analysis) = original price * inflation adjustment factor.
Inflation adjustment factor = customer price index of the current year/customer price index of the year of first using the annuity factor = $[1-(1+r)^{-n}]/r$, where n = length of working years or useful years and r = discount rate or real interest rate (3%).
Purchasing prices of capital items were based on reference prices. Costs of capital shared by other activities were allocated based on the proportion of utilization.

Study sites and data sources

This study focused on vaccines provided by the National Immunization Program (i.e., EPI vaccines). The scope of the supply chain was from the provider (NHSO/DDC) to the PCU. The study covered 12 health management regions of Thailand. Bangkok, the capital of Thailand, is not part of the 12 health management regions and was excluded from the study because it has a different system.

In each of the 12 health management regions, one province, one provincial hospital, one district hospital, and two health centers were randomly selected for data collection activities. Twelve provinces (Angthong, Saraburi, Trad, Kanjanaburi, Surin, Loei, Ubonratchathani, Uthaithani, Phitsanulok, Lumphun, Phang Nga, and Trung) representing 12 health management regions were purposely selected. The selected provinces were the same as those in the Thailand vaccine and cold chain system survey conducted in 2004[45,46] to enable a comparison of the temperatures of vaccine shipments. Additional data were also collected at the central level (Pharmacy unit of the Bureau of General Communicable Diseases, DDC, and the Vaccine unit of the NHSO), 12 disease prevention and control regional offices, and 12 provincial health offices (Figure 2).

Figure 2. Sampling frame for data collection.



Data were collected through literature reviews, face-to-face interviews with health staff, and observation sessions at health facilities between March 2010 and January 2011. Questionnaires were developed for each level and type of facility. The questionnaires explored the following topics: key activities and work flow, resources used, costing information for each type of resource, quantities of vaccine requested and received, vaccine stock levels (JE vaccine stock was used as a proxy for vaccine stock), status of the information technology (IT) system, staff satisfaction with the system, cold chain management, and quality of vaccine and vaccine-related services. Questionnaires were tested for content validity and field-tested prior to use. Costing data from regional levels to health centers were collected for a period of four months for both systems. Data from hard copies and electronic reports were collected as appropriate.

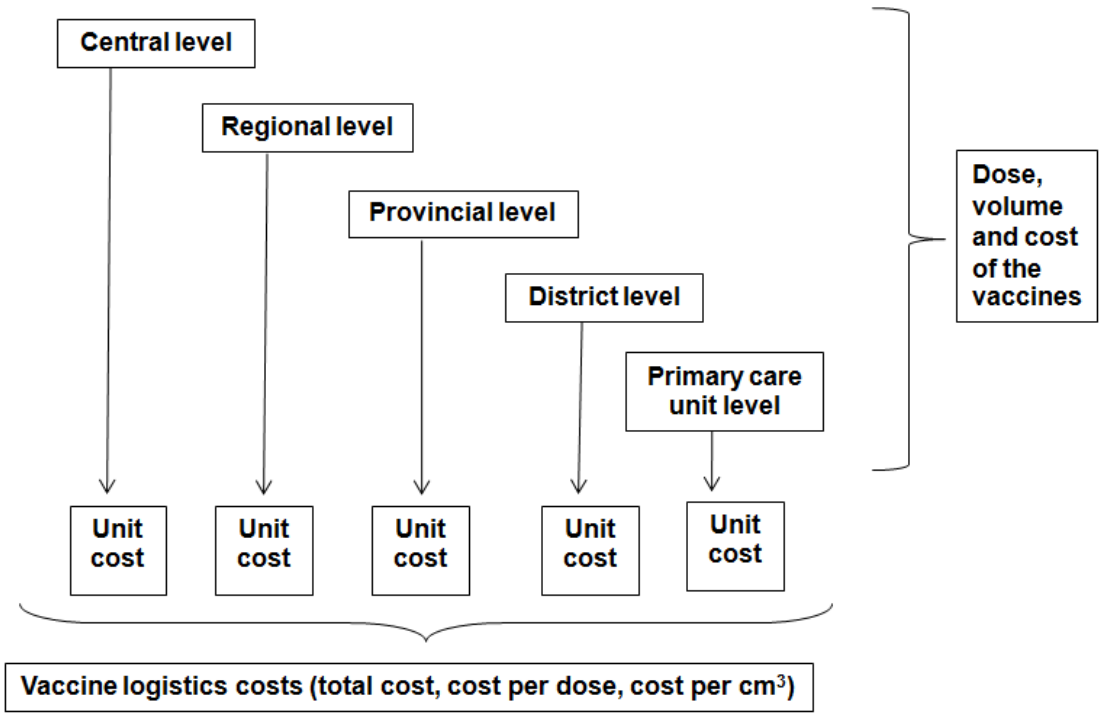
To monitor the vaccine temperatures during transport to selected hospitals, the NHSO and GPO were asked to place computerized data loggers inside the vaccine boxes on each vaccine shipment between August and December 2010.

Quantitative data were entered and analyzed using Microsoft Excel. Variability among sites was checked by comparing the data from each site to the mean. Data were rechecked and validated for sites with a high deviation from the mean. Data analysis covered both qualitative and quantitative approaches. Both descriptive and inferential statistics (paired samples t-test) were employed for a comparison of the quantitative responses between the conventional and VMI systems. An Excel spreadsheet was developed for the cost analysis. The unit cost and percentage of the logistics cost compared to vaccine costs were computed. Unit cost analysis included cost per dose and cost per cm^3 of vaccine. The unit cost of each facility level was calculated and aggregated to the overall unit cost (Figure 3).

The temperatures monitored by the data loggers were read at the GPO, and data files were sent to the study team in PDF format. Data were re-entered in Excel for analysis.

The data collected through interviews were reviewed, transcribed to Excel, and grouped by supply chain level. All responses were reviewed at researcher meetings for verification and were then summarized.

Figure 3. Costing methods for overall unit cost.



Results

Comparison of EPI vaccine logistics systems

Context

One important aspect of the transition from the conventional system to the VMI system was the outsourcing of the vaccine distribution function to an entrepreneurial agency. Under the conventional system, the DDC, together with the regional, provincial, and district health offices, was in charge of the EPI vaccine supply chain from the central level to the PCUs or health centers (Figure 4). In October 2009, the NHSO outsourced vaccine supply management to the GPO, which introduced and carried out VMI (Figure 5). The outsourcing and contract mechanisms were designed to allow the payer (NHSO) to control the quality of services performed by the contractor (GPO). The GPO's introduction of the VMI system simultaneously streamlined the vaccine supply chain.

Figure 4. Conventional vaccine supply chain distribution system.

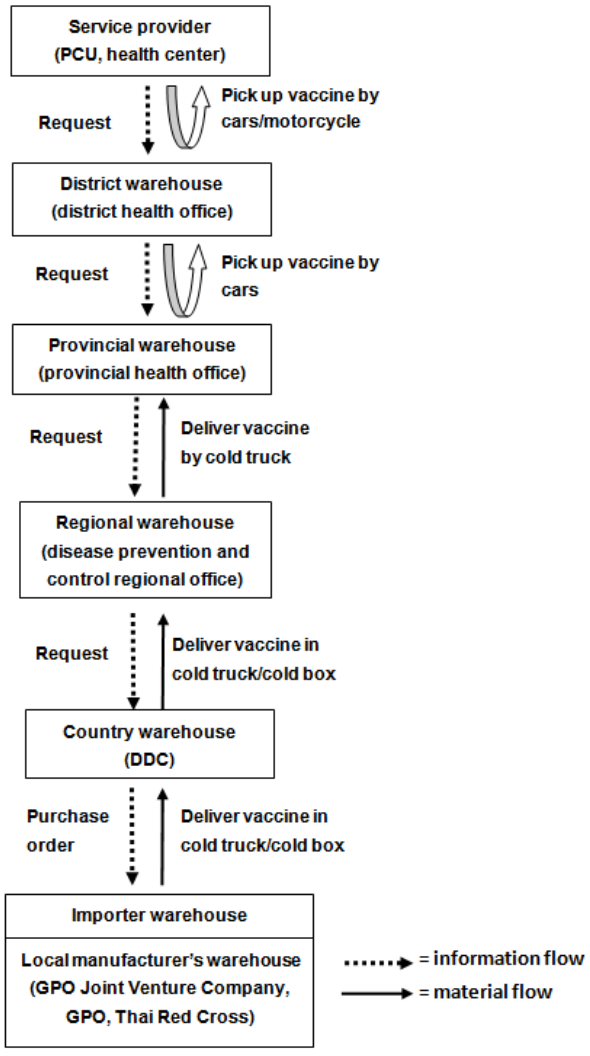
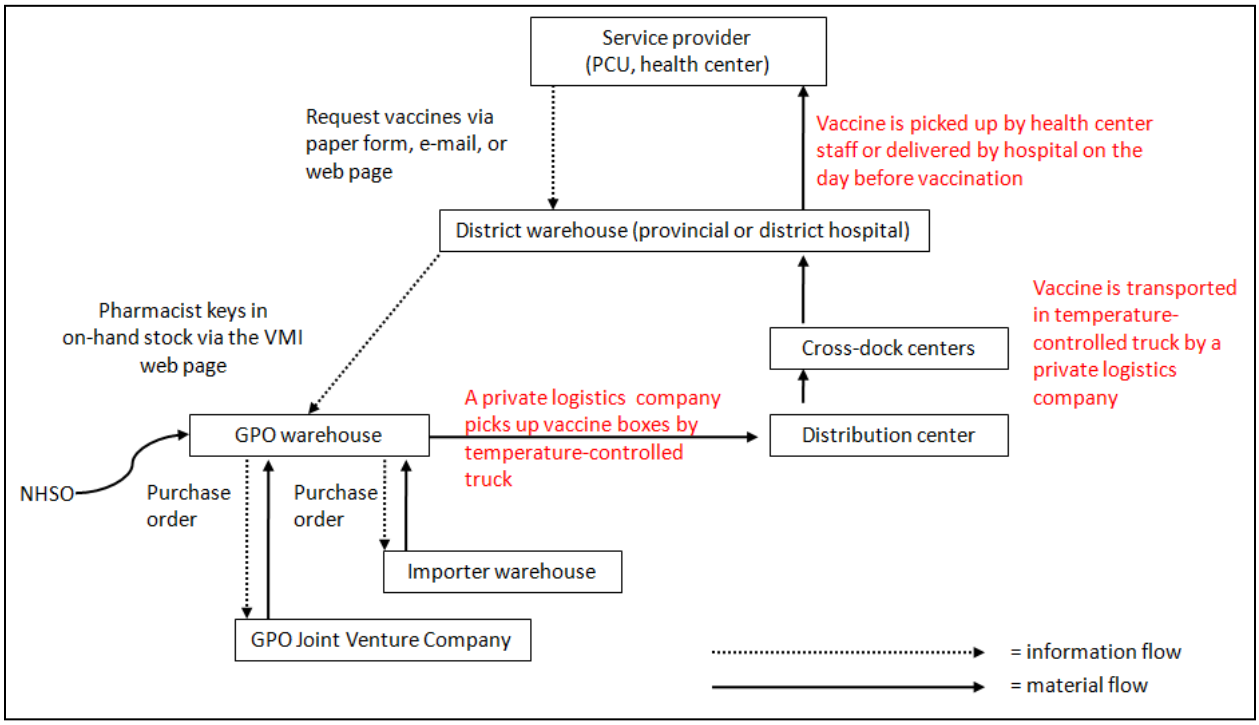


Figure 5. VMI vaccine supply chain distribution system.



Problems in the conventional system

Research previously conducted in Thailand revealed problems in vaccine transportation and storage that may have affected vaccine quality. In 2004, a study used data loggers to track the transportation and storage of HepB and measles vaccines from the national level through the provincial and district levels to 43 health centers. The study showed that vaccines were stored at a temperature lower than 0°C on 32 out of 43 routes. This mainly occurred during transport from the provincial to the district level. Three cases resulted from faulty refrigerators and power failures, and two cases were caused by the carelessness of local health officers who did not notice the abnormal temperature. Besides freeze exposure, vaccines also were exposed to temperatures greater than 8°C on 43 out of 43 transport routes and greater than 22°C on 5 of the 43 routes.[24] A vaccine cold chain system survey found that 5% of health centers did not store OPV in a freezer, 11% did not have an emergency plan in case of a power outage, and 28% did not have a circuit breaker or tape to ensure the tightness of the refrigerator's seal.[46] The Office of Disease Prevention and Control in Region 6 evaluated its cold chain system at 50 health facilities in 7 provinces. Major problems reported were that the refrigerator temperature was not in the range of 2°C to 8°C (22%), thermometers were not calibrated and ready for use (40%), and there were no emergency plans in case of a power failure (84%). In addition, vaccine freezing was detected at the provincial level (50%), the district level (29%), and health centers (28%).[47]

A 2008 survey assessed the cold storage conditions for drugs and vaccines during transportation and delivery to 84 general hospitals and 155 district hospitals. The survey found that OPV was delivered at temperatures higher than 8°C or with ice melting in the box in 12.7% and 35% of shipments to provincial and district hospitals, respectively. Standard practice is to store OPV in the freezer at -20°C. Concerns about vaccine quality from improper transportation and storage practices led to a survey that evaluated the quality of OPV and DTP vaccines in 1993. A random

sample of 85 OPV and 140 DTP vaccines was collected from health centers throughout the country to examine vaccine potency. The results revealed substandard potency in 11.8% (10/85) of OPV and 3.6% (5/140) of DTP samples. [48]

Interviews with the NHSO reflected strong concerns about the efficiency of the conventional system. In addition to problems with the quality of vaccine storage and transportation described above, there was a concern that the inventory control system was weak and that the unopened vial wastage rate was high (i.e., vaccine expired at warehouses before use). These incidents often went unreported due to staff fears that there would be a financial penalty or criticism. Interviews of DDC warehouse staff reflected similar concerns. The DDC staff also mentioned that maintenance and replacement costs of old cold chain equipment were expensive. A reduction in the number of public health officers in addition to an increase in their job responsibilities also caused problems. After the 2002 health system reform, the number of public health officers at district health offices, where district warehouses are normally located, was markedly reduced due to a government hiring freeze. The remaining officers were responsible for several duties, such as health education, providing services for mother and well-baby clinics, and home visits, and they were frequently called away from the office for field service, meetings, and trainings. Vaccines stored at the district warehouses were often left unattended and accessed freely (the refrigerator was not locked), and inventory was not up to date.

The transition to VMI

Since 2002, the NHSO, by law, has held budgets for the National Health Promotion and Prevention programs, which were previously responsible under the DDC for vaccine management. There had been several discussions on how to improve the DDC's existing vaccine management system over the years, but no progress was made due to the bureaucracy of the system and a lack of planning and budget authority. The idea of outsourcing vaccine distribution to the GPO occurred when the NHSO and DDC recognized the benefits of the VMI system during the distribution of AIDS drugs organized by the GPO. In October 2008, the GPO was contracted by the NHSO for a pilot trial of influenza vaccine distribution through the VMI system. In another pilot project, the NHSO outsourced EPI vaccine distribution activities to the GPO in 28 provinces via the VMI system. From October 2009, the VMI system for EPI vaccines expanded gradually through outsourcing to the GPO until it reached nationwide coverage in late 2010.

In October 2009, the NHSO also contracted with the GPO to procure EPI vaccines at a fixed annual price. The fee was inclusive of distribution costs via the VMI system and vaccine damage costs. Under this contract, the NHSO provides annual vaccine demand projections to the GPO based on DDC statistical records. The GPO then launches a call for tenders among vaccine vendors, except local producers (GPO Joint Venture Company, Thai Red Cross, and the GPO itself), and negotiates prices. The vendors' delivery plan is submitted to the NHSO for approval.

The NHSO sets key performance indicators (KPIs) for the GPO regarding quantity and quality levels of vaccines at delivery. The GPO procures vaccines from either local or overseas manufacturers. These vendors deliver vaccines to the GPO warehouse according to the GPO purchase order. During the time of the study, the GPO hired a private logistics company to distribute vaccines from the GPO warehouse to their final destinations (provincial and district hospitals).

The MoPH also accepted a suggestion by the DDC to transfer responsibilities for vaccine management from the district health offices to provincial and district hospitals. The hospitals function as district warehouses, and hospital pharmacists with expertise in drug inventory management are assigned the duty of vaccine management. The NHSO welcomed this change and provided financial support to hospitals to improve cold chain equipment, including the procurement of refrigerators.

Vaccine management policies and activities

Interview respondents at all levels agreed that their office administrators valued their role as vaccine managers under both the conventional system and the VMI system. In the conventional system, staff were supported with regular budgets and resources (mainly for vaccine transportation and workshop attendance, not cold chain equipment). Because vaccine management was usually seen as a routine job function—not as part of the organization's KPIs—the vaccine quality control and improvement plan normally relied solely on the intentions of staff members. When respondents were asked about the potential impact that a reshuffling of the head of the unit might cause, responses were unanimous that there would be no change in the policy and practices aforementioned because vaccine management is considered a routine part of prevention activities.

All surveyed respondents at warehouses and health centers reported that there are staff members responsible for vaccine management activities, although assignments may not be in writing. In the conventional system, the key activities of health center staff include monthly vaccine target planning, vaccine requisitioning, vaccine collection, and inventory control. At the higher levels (district and provincial warehouses), activities include compiling and verifying vaccine targets requested by the lower levels, requesting vaccine, collecting and/or distributing vaccine, managing inventory control, and monitoring lower-level facilities on vaccine management. According to provincial policy, vaccination days are the same for the whole province, and the vaccine distribution schedule is set according to that date. For example, if the vaccination day is scheduled on the 15th of the month, vaccines may be distributed from the provincial warehouse on the first of each month during the provincial monthly meeting. Staff from the district warehouses are at the provincial health office, so it is convenient to collect the vaccines. Responsible health personnel from health centers then go to the district warehouses to collect vaccines on the 13th or 14th of the month. Staff at health centers and district warehouses reported no involvement in setting the annual vaccine target. Interviews with DDC staff revealed that the annual vaccine target is set by DDC staff using historical data and population data referenced from the office of the National Economic and Social Development Board. Each province then verifies and negotiates the number of vaccines needed at the beginning of the fiscal year (October 1 to September 30).

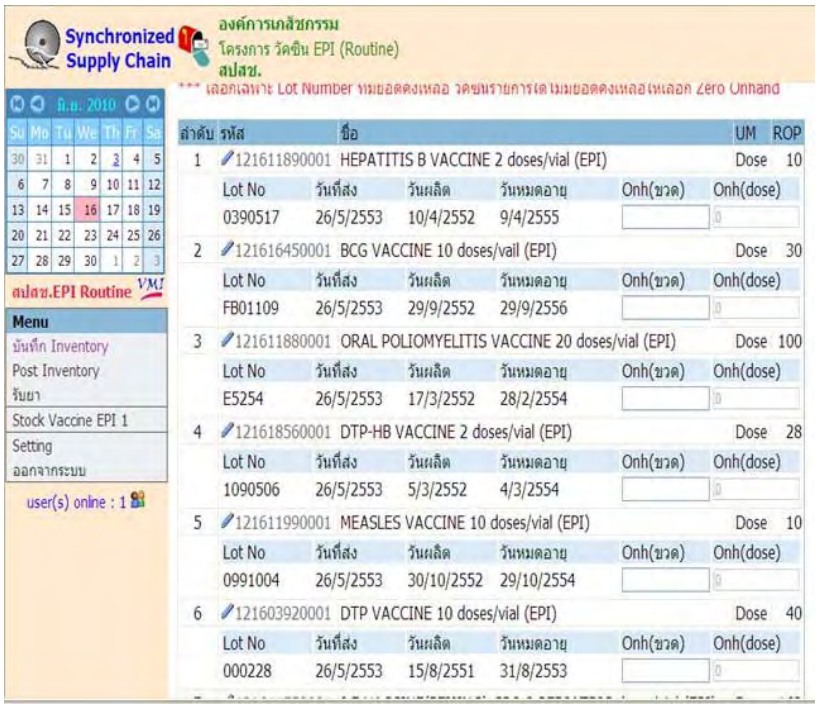
When the VMI system was introduced, the policy of having a staff member responsible for vaccine management activities and workflow remained the same at the health center level. That is, each month, health staff submit vaccine request forms to a pharmacist at the district or provincial hospital in their supply chain, and they either go collect the vaccines on the set date or have the hospital deliver the vaccines to them. At the district level, once the monthly vaccine distribution is completed, hospital pharmacists enter the number of vaccines on hand into the GPO/VMI web page. If the amount of vaccine on hand is less than a set level, the GPO then arranges for a new supply of vaccines to be delivered. Other vaccine management duties for

pharmacists include maintaining vaccine inventories and managing vaccine distribution. In the conventional system, the monitoring of vaccine management activities at the PCU level, such as checking vaccines in the refrigerator and checking stock records, was not always done systematically. Under the VMI system, respondents reported that pharmacists from the hospitals regularly visit and are responsible for monitoring vaccine management activities at the PCUs.

In conclusion, the VMI system has a streamlined vaccine supply chain. Under the conventional system, there were six warehouses between the importer, the local producer's warehouse, and the service providers (Figure 4). In the VMI system, there are five warehouses or centers (Figure 5). The information flow from the end-user to the government supplier is also more streamlined under VMI (two steps for VMI versus five for the conventional system), making for more precise inventory management. In addition, the GPO has set up a VMI web page for hospitals to access information about vaccines, including on-hand inventory and warnings about upcoming expiration dates (Figure 6).

Figure 6. GPO/VMI web page.

This VMI home page allows for entry of a user name and password in order to view a list of drugs and vaccines under the VMI program, and to view some VMI-related forms.



Once logged in, you can do several things, including viewing warnings for expired vaccine, viewing delivery dates, and running reports. The image directly above shows the on-hand amount of each vaccine by lot number.

Inputs

Human resources

In 14 out of 24 districts surveyed, hospitals were used as district warehouses under the conventional system but were managed by public health officers, not pharmacists. Under both the conventional and VMI systems, a specific staff member is responsible for vaccine management. However, in practice, activities are actually carried out not only by that staff member but also by colleagues if that staff member is unavailable.

At the district warehouse level, 81% of responsible public health staff in the conventional system reported taking cold chain management training. After VMI implementation, 95% of pharmacists at district and provincial hospitals reported receiving training. The data also showed an increase in risk management planning for vaccine shortages at district warehouses under the VMI system (87% under VMI versus 79% under the conventional system). However, at the health center level, there was no change in human resource inputs after VMI implementation (Table 1).

Table 1. Comparison of human resource inputs between the conventional and VMI systems at different levels.

Human resource input	Health center		District		Province	Region
	CONV (n=24)	VMI (n=24)	CONV (n=24)	VMI (n=24)	CONV (n=12)	CONV (n=12)
Trained on cold chain management	79.2%	79.2%	75.0%	95.8%	91.7%	83.3%
Prepared a risk management plan for vaccine shortage	91.7%	91.7%	79.2%	87.5%	100%	83.3%

CONV = conventional system; VMI = vendor-managed inventory system.

Materials

Under the conventional system, cold trucks and other vehicles used for collecting and distributing vaccines down to the district level belonged to the health offices, and thus fuel was reimbursable. Staff who made overnight vaccine distribution trips were paid per diem and for accommodations. However, at the health center level, staff vehicles and sometimes motorcycles were used, and fuel costs were often not reimbursable. Under the VMI system, temperature-controlled vehicles were used by the private logistics company contracted by the GPO to deliver vaccine to district warehouses. Practices at the health centers remained the same after the transition to the VMI system in most surveyed sites. In some districts, hospitals arranged for a monthly vaccine delivery service to health centers (4 of 24 surveyed hospitals [17%]).

Data on refrigerators are shown in Table 2. At the health center level, 100% of refrigerators met the standard size requirement of 5 cubic feet, but only 13% to 17% had an automatic defrost system. At the district warehouses, more than half of the refrigerators were smaller than 18 cubic feet, the recommended capacity at this level. The number of district warehouses that used less than standard size refrigerators decreased from 71% to 58% after implementation of the VMI system. However, all refrigerators larger than 18 cubic feet had an automatic defrost system (as recommended by the DDC). The proportion of district warehouses using refrigerators without an automatic defrost system decreased from 17% to 13%, and those using an automatic defrost system increased from 13% to 29%. This improvement was made because the NHSO gave funding to health facilities to buy new refrigerators. The availability of thermometers in refrigerators was not investigated in this study.

Table 2. Comparison of refrigerators between the conventional and the VMI systems at different levels.

Type of refrigerator	Health center		District		Province	Region
	CONV (n=24)	VMI (n=24)	CONV (n=24)	VMI (n=24)	CONV (n=11)	CONV (n=12)
Refrigerator, smaller than standard size[a]	0	0	70.8%	58.3%	54.5%	0
Refrigerator, standard size,[a] without defrost system	87.5%	83.3%	16.7%	12.5%	9.1%	0

Type of refrigerator	Health center		District		Province	Region
	CONV (n=24)	VMI (n=24)	CONV (n=24)	VMI (n=24)	CONV (n=11)	CONV (n=12)
Refrigerator, standard size,[a] with automatic defrost system	12.5%	16.7%	12.5%	29.2%	36.4%	100%

CONV = conventional system; VMI = vendor-managed inventory system.

[a] Standard sizes for refrigerators are greater than 18 feet^3 for hospitals and greater than 5 feet^{3}for health centers.

Information system

Three aspects of the information system were evaluated: the availability of information to estimate the vaccine quantity target; the status of inventory software; and the capacity of current IT systems to support the development of full VMI systems in the future. A successful VMI system depends on the utilization of existing information to analyze and estimate customer demand for products. The availability of information is, therefore, the top requirement. The next requirement is the degree of precision by vendors in estimating vaccine needs. This in turn depends on the accuracy of information received from the customer using inventory software. Survey data showed that the information necessary to estimate vaccine quantities needed, such as monthly target population, past vaccination rate, and vaccine wastage rate, is available to all health center staff. Health center staff estimated the number of the monthly target population for the next month and the number of missed eligible children in the previous month based on either previous services data or demographic and program data (birth rate, number of children in each age group, target vaccination, past vaccination rate, and wastage rate). Pharmacists reported that 100% of the data they used to verify requests received from health centers were available to them. Only 78% of district warehouse staff under the conventional system reported being able to access these data (p-value = 0.05). At the provincial and regional levels, estimating vaccine quantity targets relied solely on the vaccine quantity requests sent from the lower levels.

The process has remained the same since VMI system implementation, except that information goes from the district level to the central level. Under both systems, after monthly target populations were estimated, health center staff calculated the amount of vaccine needed and checked vaccine left in inventory, then sent request forms to the district warehouses. The request forms should have been verified at the district warehouse, but it was reported that only 78% of district staff in the conventional system were able to verify the data.

In both systems, vaccine inventory management was done either manually or by using software. The responsible staff has to report the amount of vaccine on hand in order to request vaccine. Utilization of software facilitates inventory management and efficiency. The availability of inventory management software at district warehouses (Table 3) increased from 33% to 71% (p-value = 0.02) after VMI implementation. This may imply that pharmacists have a higher skill level with computers compared to public health officers. The use of inventory management software at the health center level showed a small increase (46% versus 33%). During the transition to the VMI system, some pharmacists at the district warehouses developed an Excel-based request form and encouraged health center staff to use it.

Table 3. Comparison of information and IT inputs between the conventional and VMI systems at different levels.

Information and IT inputs	Health center		District		Province	Region
	CONV	VMI	CONV	VMI	CONV	CONV
Data for estimating the requested vaccine quantity	100% n=24	100% n=24	78.3%[a] n=23	100%[a] n=19	83.3% n=12	100% n=10
Inventory management software	33.3% n=24	45.8% n=24	33.3%[b] n=24	70.8%[b] n=24	25% n=12	16.7% n=12

CONV = conventional system; IT = information technology; VMI = vendor-managed inventory system.

Note: There are missing data at the district and regional levels.

[a] p-value = 0.05; [b] p-value = 0.02.

The availability of IT at provincial hospitals, district hospitals, and health centers was assessed. Table 4 shows that all provincial and district hospitals and 96% of health centers had Internet access. Utilization of software for vaccine inventory management at provincial hospitals, district hospitals, and health centers was 75%, 50%, and 41%, respectively. For those who used vaccine inventory software, about 56% of provincial hospitals and 43% of district hospitals had to pay for the software, while the software used at health centers was available free of charge (mostly Excel).

All surveyed district hospitals were able to regularly update and customize the vaccine inventory software and generate reports on vaccines and lot numbers that would expire within three months. Survey data showed lower capacity in this area at the provincial hospital and health center levels: 75% of provincial hospitals and 71% of health centers can regularly update the software; 71% and 50% of provincial hospitals and health centers, respectively, can customize the software; and 57% and 40% can generate reports on vaccines and lot numbers to expire in three months. Technical problems related to the inventory software were mostly found at district hospitals (43%), followed by 38% at provincial hospitals, and 11% at health centers. About 71% of district hospitals had inventory software that could directly connect to the supplier's computer system. All provincial and district hospitals could access data through the GPO/VMI web page to see the number of vaccines kept in GPO stock.

Table 4. Current IT availability at provincial hospitals, district hospitals, and health centers.

Item	n	Percent "yes" response		
		Provincial hospital	District hospital	Health center
1. Availability of the Internet at your office.	46	100.0	100.0	95.5
2. Utilization of the software for inventory management.	46	75.0	50.0	40.9
3. Payment for the software.	23	55.6	42.9	0.0
4. Ability to regularly update the software.	22	75.0	100.0	71.4

Item	n	Percent "yes" response		
		Provincial hospital	District hospital	Health center
5. Availability in both Thai and English languages.	24	87.5	57.1	88.9
6. The software operation manual was provided.	21	71.4	50.0	75.0
7. Ability to customize the software.	20	71.4	100.0	50,0
8. Problems with the inventory software.	24	37.5	42.9	11.1
9. The software can generate reports on items and on the lot number of vaccines that will expire in the next three months.	19	57.1	100.0	40.0
10. The software can directly connect to the computer system of the next-higher-level distributor.	25	22.2	71.4	11.1
11. Ability to access inventory data of the next-higher-level distributor via the Internet.	48	100.0	100.0	0.0
12. Ability to access the inventory data of the next-lower-level facility via the Internet.	48	0.0	25.0	N/A

Regarding the quality of the Internet in terms of connection and speed, once connected, 36% of provincial hospitals, 50% of district hospitals, and 50% of health centers reported having a "good" connection and speed (Table 5). About 33%, 43%, and 0% of respondents at provincial hospitals, district hospitals, and health centers, respectively, perceived that their software was capable of compatibility with new technology (e.g., barcode technology) (Table 6). About 33%, 29%, and 22% of respondents at provincial hospitals, district hospitals, and health centers, respectively, believed that their software was capable of generating information on inventory levels that could be manually shared with the supplier (Table 7).

Table 5. The quality (connection and speed) of the Internet.

Facility	n	Good	Fair	Poor	N/A	Total[a]
Provincial hospital	11	36.4%	27.3%	36.4%	0.0%	100%
District hospital	12	50.0%	41.7%	8.3%	0.0%	100%
Health center	22	50.0%	31.8%	13.6%	4.5%	100%

[a] the total may not add up exact due to rounding.

Table 6. Capability of software to be compatible with new technology.

Facility	n	Yes	No	Unknown	Total[a]
Provincial hospital	9	33.3%	22.2%	44.4%	100%
District hospital	7	42.9%	14.3%	42.9%	100%
Health center	9	0.0%	77.8%	22.2%	100%

[a] the total may not add up exact due to rounding.

Table 7. Capability of software to generate inventory-level information that could be manually shared with the supplier.

Facility	n	Yes	No	Unknown	Total[a]
Provincial hospital	9	33.3%	22.2%	44.4%	100%
District hospital	7	28.6%	57.1%	14.3%	100%
Health center	9	22.2%	66.7%	11.1%	100%

[a] the total may not add up exact due to rounding.

Table 8 shows that all surveyed provincial hospitals and district hospitals were able to submit their vaccine request forms via the Internet, either by logging in to the next-higher-level distributor's web page or by emailing their form as an attachment (when the web-based system was down). Health centers submitted their vaccine request forms via email attachments (41%) and by logging in to the next-higher-level distributor's web page (18%) using the program provided by the provincial office.

Table 8. Submission methods for request forms.

Facility	n	Via the Internet as an attached file	Via the Internet by log-in to the supplier's web page	Not via Internet	Total
Provincial hospital	12	8.3%	91.7%	0%	100%
District hospital	12	16.7%	83.3%	0%	100%
Health center	22	40.9%	18.2%	40.9%	100%

Process

General work process

The general work process at the health center level includes preparing a monthly request form, receiving the vaccine, and completing inventory records. The monthly request form used by health centers under both the conventional and VMI systems is the same. The form is divided into two parts. The first part is for reporting the number of children and type of vaccine received, the number of vaccines used, and the calculated wastage rate for each vaccine. The second part is for requesting vaccine for the coming month. Health centers report the expected number of children for the coming months, the expected number of vaccines to be used, including wastage, the number of vaccines left in stock, and the amount of vaccine needed. Prior to submission of the request form, health staff have to obtain an official reference running number from an authority at the next higher level in the health system. There are many ways to send the request forms, including by fax, by hand, through the provincial website, and by email.

When the request form is received at the district level, the number of vaccine requests sent by each health center is verified against the number of children expected to receive vaccine in that month or against previous data. In the conventional system, a summary of monthly targeted vaccine quantity from the district level was sent to the higher tier, where all the requests were compiled and verified against past requests. Some staff at the provincial and regional levels reported adding another 5% to 20% more vaccine quantity to the original request to avoid vaccine shortage.

The survey revealed that not every step in this general work process was followed. For example, the estimates did not take the stock and wastage rates into account, and some facilities did not calculate the actual number of vaccines needed, instead relying on previous data. A common problem was that request forms from the health centers often were not received on time. As a result, staff at the district level used the requested quantity of vaccines from the last period's order. This practice created a shortage in some places and a surplus in others.

Changing to the VMI system did not reduce the paperwork at the health center level, but the process is more convenient because there are more ways to send the request forms to the hospitals. Pharmacists do not need to prepare request forms. They simply enter the amount of stock they have on hand into the GPO/VMI web page. The system automatically assigns the number of vaccines to be delivered. If the number of vaccines estimated by the GPO is less than that requested by the health centers, pharmacists send a fax to the GPO to request additional vaccines or ask the GPO to update the database to reflect the number of vaccines to be delivered. The GPO requires two weeks to change the preset database. Some survey respondents reported problems with this process, including failure of the Internet system and slow web page responsiveness.

The process of receiving vaccines is the same in both systems. When receiving vaccines from the distributor, health staff check the type, amount, lot number, expiration date, and condition of packages and vaccines. Vaccine temperature is not usually monitored. Health center staff reported that pharmacists are more concerned with the condition of the vaccine carriers and icepacks than are the district health officers.

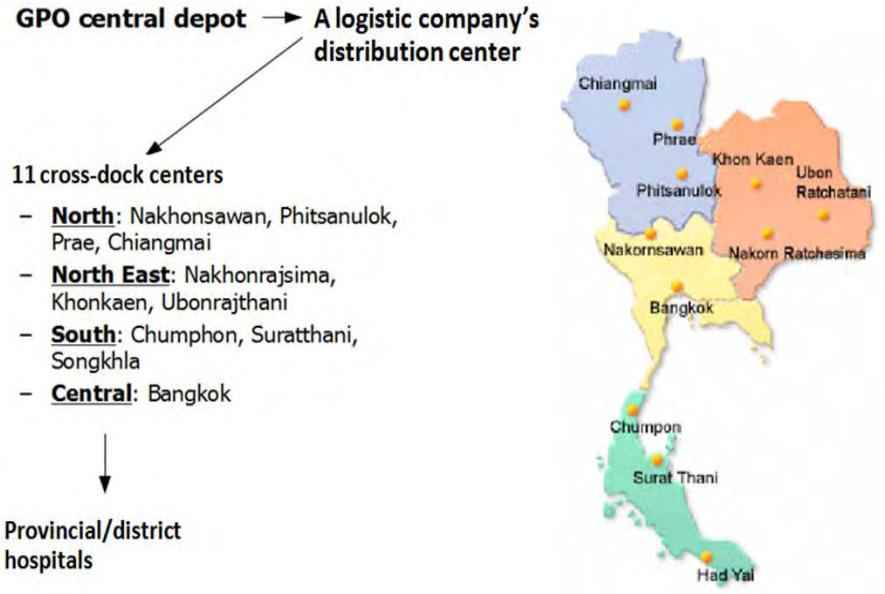
The inventory registration system differs between the conventional and VMI systems. Although there was a standard inventory guideline in place under the conventional system, practices were varied. In some places, there was no vaccine inventory system, while inventory registration systems varied widely between regional, provincial, and district warehouses. These included inventory log books, stock cards, hospital drug inventory programs, invoice slips, and stand-alone vaccine inventory programs that were not connected to hospital drug inventory programs (mostly in Excel). Under the VMI system, the vaccine inventory control system is consistent but more labor intensive for the pharmacist. The pharmacist must document the inventory two times—once through the hospital inventory control program and once through the VMI web page in order to report the vaccine on hand to the GPO. This is because the data entered in the hospital inventory management system cannot be automatically linked to the GPO/VMI system, effectively doubling the pharmacist's workload.

Cold chain management

An interview with GPO representatives revealed that in the VMI system, vaccines in each shipment are packed at the GPO central warehouse in Bangkok (where there are two storage rooms, one at 2°C to 8°C and one at -20°C). After packing, the private logistics contractor picks up the vaccine using a ten-wheeled, 25°C temperature-controlled truck and delivers it to its distribution center in Bangkok. From the distribution center, the private contractor transfers the vaccine to its 11 cross-dock centers located in the central, north, northeast, and south regions of Thailand (Figure 7) using a ten-wheeled, 25°C temperature-controlled truck.[49] From the cross-dock centers to the hospitals, vaccines are transported in a four-wheeled, 25°C temperature-controlled pickup truck. Trucks and pickup trucks may carry the vaccines together with other

medical supplies, which are dropped at different destinations along the way. The vaccines can be stored for hours at the cross-dock or distribution centers while waiting for their transport to be scheduled, but the vaccines must reach their final destinations within 48 hours of being packed at the GPO warehouse. There is no repacking in the transportation process. squiggly

Figure 7. Transportation process of vaccines in the VMI system.



According to DDC staff, the VMI transportation process is more streamlined than the transportation process under the conventional system (see Figures 4 and 5). In the conventional system, vaccines were transported in cold trucks from the DDC central warehouse to 12 regional warehouses. At the regional warehouses, vaccines were stored for about one month before being transported via cold trucks to 76 provincial health offices (provincial warehouses), where they were then stored for a few weeks. From the provincial health offices, vaccines destined for provincial hospitals and other health centers in a city were transported in vaccine carriers. In areas outside of cities, vaccines were transported to district warehouses in cold boxes and may have been stored for a few weeks while waiting for hospitals and health centers to pick them up using vaccine carriers. Vehicles used during transportation from the provincial level to lower levels were not temperature controlled.

Vaccine packaging also is different between the two systems. Under the VMI system, the GPO packs the vaccines in polystyrene foam boxes using several validated techniques to maintain vaccines at their proper temperatures and protect them from sunlight. There are three sizes of polystyrene foam boxes (15 kg, 20 kg, and 30 kg). At first, ice cubes are sealed inside a plastic bag and placed at the bottom of the boxes, followed by bubble wrap and a base board. The vaccines and data loggers (if applicable) are placed together on top of the base board, then covered by more bubble wrap and a plastic board. Then a layer of frozen icepacks is placed on top. Lastly, the lid is sealed, and the boxes are labeled with their intended destination as well as their latest acceptable time of arrival. The number of ice cubes and frozen icepacks used depends on the box size. All vaccines except OPV are packed in 2°C to 8°C boxes. OPV is packed in -20°C boxes. These packing techniques are validated to maintain a constant temperature within

the 2°C to 8°C range for at least 48 hours. In practice, once packed, the vaccine boxes must arrive at destination hospitals no later than 4 pm the following day.

Under the conventional system, DDC staff reported that vaccines transported from the central warehouse via regional warehouses to the provincial health office were simply placed in airy plastic trays in refrigerated trucks. Vaccines transported from the provincial health office to the district level were packed in cold boxes together with icepacks using various invalidated techniques.

Table 9 shows a comparison of cold chain management practices between the conventional and VMI systems. The transportation of vaccines by vehicles equipped with air conditioning units increased at health centers from 67% to 70% after the introduction of VMI. Likewise, the transportation of vaccines by vehicles with air conditioning at the district warehouse level increased from 52% to 75%. However, at the health center level, 22% of vehicles used did not have air conditioning or roofs (motorcycles). In the VMI system, 100% of the vaccines transported to district warehouses were packed in a polystyrene foam box using combined cooling sources (icepacks and ice cubes). In the conventional system, about half of the vaccines delivered to district warehouses came in a cool box, and the other half came in vaccine carriers. In both systems, less than half of the vaccines delivered to health centers used proper conditioning icepacks (defined as icepacks that can be kept at room temperature for a period of time after coming out of the freezer to allow ice at the core to rise to 0°C). After the VMI implementation, the amount of vaccine delivered to district warehouses that used proper conditioning icepacks increased from 50% to 78%, and temperature monitoring during vaccine transportation increased from 13% to 21% at the district level. Practices on refrigerator temperature monitoring varied, but there was a statistically significant decrease in the number of respondents stating that there was “no temperature monitoring of refrigerators” under the VMI system. This is true at both the health center (not statistically significant) and district warehouse levels. The improvement may be because, at the health center level, pharmacists conduct monitoring of the cold chain, and at the district level, pharmacists have taken over that responsibility from public health staff.

Table 9. Comparison of cold chain management practices between the conventional and VMI systems at different levels.

Cold chain management	Health center		District		Province	Region
	CONV	VMI	CONV	VMI	CONV	CONV
1. Vehicle to transport to your office						
n	24	23	23	24	12	12
No air conditioning, no roof	29.2%	21.7%	13.0%	0.0%	0.0%	0.0%
No air conditioning, with roof	4.2%	8.7%	34.8%	25.0%	0.0%	0.0%
With air conditioning	66.7%	69.6%	52.2%	75.0%	100.0%	100.0%
2. Container to transport to your office						
n	24	24	23	24	N/A	N/A

Cold chain management	Health center		District		Province	Region
	CONV	VMI	CONV	VMI	CONV	CONV
No container	0.0%	0.0%	0.0%	0.0%	N/A	N/A
Cooler box or foam box with icepack	0.0%	4.2%	56.5%	100.0%	N/A	N/A
Standard vaccine carrier or equivalent	100.0%	95.8%	43.5%	0.0%	N/A	N/A
3. Cooling source during vaccine transport to your office						
n	23	23	22	23	N/A	N/A
Ice	8.7%	4.3%	13.6%	4.3%	N/A	N/A
Solid icepack	47.8%	52.2%	36.4%	17.4%	N/A	N/A
Conditioning icepack/ice gel	43.5%	43.5%	50%	78.3%	N/A	N/A
4. Monitor temperature of vaccines during transport to your office						
n	22	21	23	19	10	9
No	59.1%	52.4%	73.9%[a]	36.8%[a]	70.0%	33.3%
Yes, sometimes	27.3%	28.6%	13.0%[a]	42.1%[a]	10.0%	33.3%
Yes, every time	13.6%	19.0%	13.0%[a]	21.1%[a]	20.0%	33.3%
5. Monitor temperature of refrigerators						
n	24	24	24	24	12	11
No	0.0%	0.0%	4.2%	0.0%	0.0%	9.1%
Yes, sometimes	25.0%	25.0%	66.7%	41.7%	83.3%	54.5%
Yes, twice a day, including holidays	75.0%	75.0%	29.2%	58.3%	16.7%	36.4%

CONV = conventional system; N/A = not applicable; VMI = vendor-managed inventory system.

[a] p-value less than 0.05.

Information management

As part of the vaccine request process (at all levels of the supply chain and under both systems), 100% of the vaccine inventory data were provided to the next-higher-level distributor manually, via email, or through the GPO web page. However, none of the inventory data were provided by an automatic electronic data transfer system.

Being able to track the delivery of urgent vaccine requests would be helpful for health staff. But neither system is able to track the location of vaccine during transport. Information on whether vaccines were released from the warehouse is available and can be obtained by telephone only.

At the national level, having information on vaccine use, coverage rate, and wastage is important. A vaccine distribution system with an online database that can provide this kind of information should be established to support prompt management in case of vaccine quality problems. Under the VMI system, the GPO cannot track which vaccine lot number is

administered to a particular child. Each distributor in the vaccine supply chain records the vaccine lot numbers delivered to the next level. That is, the GPO records the lot numbers sent to hospitals, and some hospitals record the lot numbers sent to the health centers. Only the service level (PCU), the last level of the supply chain, has records of the names of children and the vaccine lot numbers received. In case of a vaccine shortage, a health worker will contact other health offices by telephone to ask for vaccines. The sharing of information on vaccine lots among warehouses via an online database is not currently possible.

Outputs

Emergency request response rates

The ability of the VMI system to respond to emergency requests is not as good as that of the conventional system. The proportion of district warehouses receiving vaccines within a 24-hour period after an emergency request decreased from 72.2% to 22.2% under the VMI system, while the proportion of district warehouses receiving vaccines after 24 hours increased from 16.7% to 72.2% (Table 10).

Table 10. Comparison of response rates to emergency vaccine requests between the conventional and VMI systems at different levels.

Output	Health center		District		Province	Region
	CONV n=10	VMI n=10	CONV n=18	VMI n=18	CONV n=11	CONV n=10
Requests for vaccines in emergency shortage situations						
Not received	10.0%	10.0%	11.1%	5.6%	0.0%	0.0%
Received, but it took longer than 24 hours	10.0%	10.0%	16.7%	72.2%	18.2%	40.0%
Received within a 24-hour period	80.0%	80.0%	72.2%	22.2%	81.8%	60.0%

CONV = conventional system; VMI = vendor-managed inventory system.

Customer service KPIs

At the health center level, the VMI system performed better than the conventional system on five customer service KPIs, although the improvement was not statistically significant. The proportion of health centers receiving more than 90% of their vaccine shipments on time improved from 92% to 96%. Based on invoice records, the percentage of health centers that always received the correct quantity of vaccines improved from 92% to 96%. The percentage of health centers that received more than 70% of their emergency request orders increased from 88% to 100%. The percentage of expired vaccines found at least once in refrigerators decreased from 38% to 17%. On the other hand, two customer service-related KPIs worsened. The percentage of vaccines received without any mistakes, according to the orders, decreased from 96% to 88%. Health centers that kept more than the recommended buffer stock of JE vaccine after immunization sessions increased from 19% to 29%. The percentage of health centers that always received the correct type of vaccines and always received vaccines in good condition remained high (100% and 96%).

At the district level, two customer service KPIs showed small improvements under the VMI system. The percentage of hospitals receiving vaccines for more than 70% of their emergency

request orders changed from 91% to 93%. Also, the number of expired vaccines found in refrigerators at least once decreased from 38% to 22%. Four other KPIs deteriorated. The proportion of facilities receiving more than 90% of vaccine shipments on time decreased from 92% to 88%. The proportion of facilities that always received vaccines according to the request decreased from 71% to 67%; the proportion that always received the correct type of vaccines decreased from 100% to 92%; and the proportion that always received vaccine in good condition decreased significantly, from 96% to 58%, due to the delivery of broken OPV vials. The damage was caused by dry ice that made the temperature inside the vaccine boxes too cold. In the conventional system, OPV was delivered at 2°C to 8°C along with other vaccines, and the problem of broken vials did not occur. In the VMI system, in order to meet the Good Distribution Practice guidelines, the GPO insisted on delivering OPV at -20°C as stated on the manufacturer's vaccine insert. The other two KPIs were unchanged. The percentage of facilities that always received the right quantity of vaccines according to invoice stayed at about 88%, and the proportion of facilities that had more than the required buffer stock level of JE vaccine was 88% (Table 11).

Table 11. Comparison of customer service KPIs between the conventional and VMI systems at different levels.

Customer service KPI	Health center		District		Province	Region
	CONV	VMI	CONV	VMI	CONV	CONV
1. Received vaccines on time						
n	24	24	24	24	12	12
Up to 50%	4.2%	4.2%	0.0%	4.2%	8.3%	0.0%
51% through 70%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
71% through 90%	4.2%	0.0%	8.3%	8.3%	8.3%	0.0%
Greater than 90%	91.7%	95.8%	91.7%	87.5%	83.3%	100.0%
2. Received vaccines according to request						
n	24	24	24	24	12	11
Was edited by the distributor at least one time	4.2%	12.5%	29.2%	33.3%	16.7%	27.3%
No mistake	95.8%	87.5%	70.8%	66.7%	83.3%	72.7%
3. Received correct types of vaccines according to invoice						
n	24	24	24	24	12	12
Incorrect, at least once	0.0%	0.0%	0.0%	8.3%	8.3%	8.3%
No mistake	100.0%	100.0%	100.0%	91.7%	91.7%	91.7%
4. Received correct quantity of vaccines according to invoice						
n	24	24	24	24	12	12
Incorrect, at least once	8.3%	4.2%	12.5%	12.5%	33.3%	16.7%

Customer service KPI	Health center		District		Province	Region
	CONV	VMI	CONV	VMI	CONV	CONV
No mistake	91.7%	95.8%	87.5%	87.5%	66.7%	83.3%
5. Received vaccines in good condition						
n	24	24	24	24	12	12
Incorrect, at least once	4.2%	4.2%	4.2%[a]	41.7%[a]	8.3%	0.0%
Good condition with no mistake	95.8%	95.8%	95.8%[a]	58.3%[a]	91.7%	100.0%
6. Percentage of vaccines received according to emergency requests						
n	8	8	11	15	6	8
Up to 50%	12.5%	0.0%	9.1%	6.7%	16.7%	0.0%
51% through 70%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
71% through 100%	87.5%	100.0%	90.9%	93.3%	83.3%	100.0%
7. Monthly stock of JE vaccine after injection to children or dispersing vaccine						
n	16	17	7	16	7	10
Over the required buffer stock	18.8%	29.4%	14.3%	12.5%	28.6%	20.0%
Equal to or less than the required buffer stock	81.3%	70.6%	85.7%	87.5%	71.4%	80.0%
8. Number of times expired vaccines were found in the refrigerator						
n	24	24	24	23	12	12
At least once	37.5%	16.7%	37.5%	21.7%	33.3%	41.7%
Not at all	62.5%	83.3%	62.5%	78.3%	66.7%	58.3%

CONV = conventional system; VMI = vendor-managed inventory system.

[a] p-value less than 0.05.

A four-month survey of the number of doses of JE vaccine left in stock each month before and after changing to the VMI system was conducted at health centers and district warehouses. Table 12 shows that at the health center level, the amount of JE vaccine in stock was the same between the two systems. However, the amount of vaccine in stock at district hospitals significantly increased following implementation of the VMI system. This is probably because during the transition, leftover vaccines were transferred to district hospitals.

Table 12. Comparison of the number of JE vaccine doses in stock under the conventional and VMI systems at health centers and district warehouses.

Level	Average JE vaccine stock level (dose)	
	CONV	VMI
Health center	134 (n=18)	134 (n=22)
District warehouse	1,214 (n=16)	7,044 (n=21)

CONV = conventional system; JE = Japanese encephalitis vaccine; VMI = vendor-managed inventory system.

Health center staff satisfaction

Our survey showed that health center staff preferred collecting vaccines at hospitals under the VMI system. They believed that the risk of making a mistake was lower under the VMI system and were more confident about vaccine quality because of strict processes at hospitals and a shorter supply chain. Health center staff were asked to rate their satisfaction using a 10-point score (0 = absolutely unsatisfied and 10 = very satisfied). The mean score of satisfaction of health center staff for the conventional system and VMI system was 6.14 and 7.96, respectively (Table 13). The level of satisfaction among health center staff for the VMI system may help sustain the system.

Table 13. Comparing the level of satisfaction of health center staff between the conventional and VMI systems.

Mean ± SD (n=86)		p-value
Conventional system	VMI system	
6.14 ± 1.88	7.96 ± 1.47	0.063

SD = standard deviation; VMI = vendor-managed inventory.

Quality of cold chain management

While there were several steps to vaccine transport and storage in the conventional system, the VMI system does not store vaccines when vaccine boxes are delivered to the distribution center, cross-dock centers, and hospitals. In the conventional system, each trip was dedicated to only one destination; thus, the total transport time in the conventional system was shorter than that in the VMI system (Table 14). Both systems took less than 30 hours (between 4 and 18 hours in the conventional system and between 19.5 and 27.5 in the VMI system). However, the total time required to deliver (transport and store) vaccines in the conventional system from the beginning of the supply chain to the PCU took longer because vaccines were stored at warehouses at each level before being transferred to the next level.

In the VMI system, the technique of packing vaccines in polystyrene foam boxes and transporting vaccine packages in 25°C temperature-controlled trucks provided better temperature control than the technique used in the conventional system. Although the transport time in the VMI system was longer than that of the conventional system, the packaging method provided good temperature control. Unlike in the conventional system, the vaccine is not stored at each warehouse level in the VMI system. Thus, the total delivery time (time to transport plus storage time at warehouses) to reach the lowest level of facility is shorter.

Table 14. Transportation time (hours) from central depots to 24 district-level study sites in the conventional and VMI systems.

Hospital/District warehouse	CONV	VMI	Hospital/District warehouse	CONV	VMI
1	4	23.5	13	10	26
2	5	22.5	14	11	24.5
3	5	21	15	7	26
4	6	23.5	16	8	23.5
5	10	22.5	17	9	19.5
6	13	24	18	10	19.5
7	4	22	19	11	26.5
8	5	23.5	20	12	26
9	11	24	21	15	26.5
10	13	25	22	16	27
11	12	23	23	17	23
12	14	23	24	18	27.5

CONV = conventional system; VMI = vendor-managed inventory system.

During August and December 2010, computerized data loggers were placed in vaccine shipments from the GPO warehouse to the 24 study sites. The results showed that the VMI system's temperature control during transportation was relatively better than that of the conventional system, as reported in 2004.[46]

Of the 24 shipments monitored, no temperatures of less than 0°C were detected. Temperatures less than 2°C were recorded in nine shipments (37.5%), ranging from 1°C to 1.9°C. Four out of nine shipments had temperatures of less than 2°C for more than 15 hours (30 record points). Temperatures higher than 8°C were recorded in six shipments (25%). However, the temperature violations were mild, ranging from 8.5°C to 9.1°C, and all of them were either on the first record point on the route (five shipments) or the two last record points on the route (one shipment). Detailed data are shown in Table 15.

Table 15. Number of shipments outside the 2°C to 8°C range in the VMI system.

Data logger no.	Number of recorded points	Number of recorded points <2°C	Lowest temperature	Number of recorded points >8°C	Highest temperature
1	47	0	N/A	1	8.6°C[a]
2	45	0	N/A	0	N/A
3	42	0	N/A	1	9.0°C[a]
4	47	0	N/A	1	8.5°C[a]
5	45	0	N/A	0	N/A
6	48	0	N/A	0	N/A

Data logger no.	Number of recorded points	Number of recorded points <2°C	Lowest temperature	Number of recorded points >8°C	Highest temperature
7	44	0	N/A	0	N/A
8	47	0	N/A	0	N/A
9	48	1	1.9°C	2	8.8°C[b]
10	50	11	1.5°C	1	9.1°C[a]
11	46	0	N/A	0	N/A
12	46	0	N/A	0	N/A
13	52	1	1.9°C	0	N/A
14	49	2	1.9°C	0	N/A
15	52	0	N/A	0	N/A
16	47	0	N/A	0	N/A
17	39	0	N/A	0	N/A
18	39	0	N/A	0	N/A
19	53	47	1°C	0	N/A
20	52	18	1.1°C	1	8.5°C[a]
21	53	33	1°C	0	N/A
22	54	23	1.1°C	0	N/A
23	46	0	N/A	0	N/A
24	55	2	1.8°C	0	N/A

Note: Data logger recorded every 30 minutes. First record point started at 30 minutes after operation.

[a] At first record point; [b] At last record point.

A direct comparison of the data logger results between the two systems cannot be achieved because of their different transportation processes. Data from the conventional system collected in 2004 showed that there were problems even during transportation from the central depot to the regional depots (Annex 1). Four out of 24 shipments (17%) had temperatures of less than 2°C, and one shipment had a temperature as low as -0.9°C. Thirteen shipments (54%) had temperatures greater than 8°C, with a maximum temperature of 18.6°C. During transportation from the regional depots to the provincial health offices, the data showed that 16 shipments (67%) had temperatures higher than 8°C, with a maximum temperature of 16.5°C. No temperatures less than 2°C were found. During the transportation between provincial health offices and district depots, 14 shipments (58%) were found to be less than 2°C, and 11 shipments (46%) were found to be less than 0°C, with a minimum temperature of -5.6°C. Temperatures higher than 8°C were found in five shipments (20.8%), with a maximum temperature of 18.6°C (Annex 1). Apart from the temperature violations during transportation, the data also revealed major temperature violations while vaccines were stored in the provincial health offices under the conventional system. At 9 out of the 12 provinces studied, vaccines were stored at the provincial depots at temperatures less than 0°C to as low as -3.7°C.[46]

Cost analysis

A total of 26.6 million doses of vaccines were supplied by the conventional system in 2009, and 20.6 million doses of vaccines were supplied by the VMI system in 2010. The average unit cost for each level of facility was estimated from the data collected at each level of facility included in the study sites. A sum of the unit cost at all levels, from the central level to the PCU, was multiplied by the number of facilities in the vaccine supply chain in each system to derive the total logistics costs for the whole EPI system. The total warehouse logistics costs at each level included cost of purchasing, cost of storage and inventory management (vaccine storage), and cost of transportation (vaccine distribution). For the VMI system, the logistics costs also included the outsourcing cost of 5% of the cost of procured vaccine (28,608,786 Thai Baht [THB]). The total costs of vaccines procured (728,128,057 THB in the conventional system and 572,175,722 THB in the VMI system) were calculated using the prices of vaccines procured in the VMI system. To estimate the number of doses delivered (stored and distributed), the number of vaccines in stock was estimated based on the number of doses procured and the recommended buffer stock at each warehouse level because data on vaccine stock were not available. In the conventional system, recommended buffer stocks were, on average, 6, 2.5, and 1.5 months, or 13,306,692, 5,544,455, and 3,326,673 doses for central, regional, and provincial warehouses, respectively. Adding the stock level to the number of doses procured, the estimated total doses delivered was 48,791,202 in 2009. For the VMI system, the buffer stocks were equal to 6 and 1.5 months, or 10,278,199 and 2,569,550 doses for central and district warehouses, respectively. The estimated total doses delivered in the VMI system was 33,404,147 in 2010.

Table 16 reports the total and average logistics costs of the conventional system and the VMI system. The VMI unit cost was slightly higher than that of the conventional system. The total logistics costs of the VMI system were 52 million THB less than those of the conventional system. The VMI system resulted in an annual savings of approximately 208 million THB.

Table 16. Total and average logistics costs of the conventional and VMI systems (THB at 2010 prices).

Indicator	CONV	VMI
Total logistics costs	408,854,040	356,965,460[a]
Total doses of vaccine procured	26,613,383	20,556,398
Total doses of vaccine delivered	48,791,202	33,404,147
Total maximum packed volume (cm^3)	109,552,124	71,727,775
Cost per dose procured	15.36	17.36
Cost per dose delivered	8.38	10.68
Cost per cm^3 of vaccine	3.73	4.97
% value of vaccine	30.62	38.39

CONV = conventional system; VMI = vendor-managed inventory system.

[a] Including outsourcing costs at 5% of vaccine cost (28,608,786 THB).

Labor costs were a major component of logistics costs at health centers and district warehouses, ranging from 66% to 68% (Tables 17 and 18). The cost per dose delivered at health centers was

also the highest compared to other facility levels. However, the proportion of VMI system labor costs to the total VMI system logistics costs was slightly less than that of the conventional system. The fact that the total logistics costs of the VMI system at the health center and district levels were also higher than those of the conventional system may be due to an investment in new refrigerators during the transition.

Table 17. Logistics costs by facility level for the conventional system (THB at 2010 prices).

	Labor costs	Material costs	Capital costs	Total logistics costs	Total doses received	Cost per dose received
Health center (n=24)						
Mean	8,441 (66%)	1,304 (10%)	3,084 (24%)	12,829 (100%)	1,344	12.28
Min	3,306	825	1,278	7,058	456	3.04
Max	15,167	2,028	6,514	21,456	4,278	29.23
SE	653	80	224	676	167	1.31
District (n=24)						
Mean	23,177 (68%)	3,546 (10%)	7,351 (22%)	34,074 (100%)	37,695	1.36
Min	7,981	1,656	2,620	15,723	8,400	0.20
Max	45,362	7,491	20,679	55,227	99,330	6.14
SE	2,143	313	1,137	2,346	5,442	0.25
Province (n=12)						
Mean	49,874 (36%)	11,104 (8%)	77,017 (56%)	137,995 (100%)	530,794	0.52
Min	6,942	7,432	15,975	35,603	63,900	0.08
Max	211,091	16,320	182,009	383,590	2,151,000	1.48
SE	16,497	853	17,746	28,057	182,417	0.13
Region (n=12)						
Mean	1,147,444 (62%)	149,549 (8%)	554,848 (30%)	1,851,842 (100%)	2,336,179	0.99
Min	261,475	44,037	189,972	930,513	909,780	0.24
Max	3,324,474	277,470	2,086,384	3,710,151	3,895,500	2.55
SE	239,111	20,770	152,200	286,963	306,407	0.19
Central (n=1)						
Mean	2,588,729 (46%)	1,072,254 (19%)	2,025,745 (36%)	5,686,728 (100%)	26,613,383	0.21

Min = minimum; max = maximum; SE = standard error.

Table 18. Logistics costs by facility level for the VMI system (THB at 2010 prices).

	Labor costs	Material costs	Capital costs	Total logistics costs	Total doses received	Cost per dose received
Health center (n=24)						
Mean	8,395 (64%)	1,314 (10%)	3,317 (25%)	13,026 (100%)	1,481	14.76
Min	3,306	756	1,278	7,058	180	2.28
Max	15,167	2,052	7,690	22,904	5,700	87.28
SE	674	85	313	741	238	3.35
District (n=24)						
Mean	22,320 (60%)	3,997 (11%)	11,182 (30%)	37,499 (100%)	41,692	1.21
Min	1,333	1,876	3,795	13,350	8,142	0.39
Max	66,194	13,202	25,895	75,533	113,430	3.32
SE	3,370	474	1,149	3,977	6,123	0.17
Central (n=1)						
Mean	128,864 (<1%)	28,661,513[a] (99.6%)	651(<1%)	28,791,027 (100%)	20,556,398	1.40

Min = minimum; max = maximum; SE = standard error.

[a] Includes outsourcing costs at 5% of the vaccine cost.

Table 19 compares the unit costs of vaccines by facility level. Costs at the health center level comprised the major cost in both systems (80% and 85% for the conventional system and VMI system, respectively). Since labor costs were a primary component of logistics costs, the effects of different methods of labor cost estimation were explored.

Table 19. Comparison of methods of working time estimation (THB at 2010 prices).

Working time method	Logistics cost per dose received					Sum of unit cost
	Health center	District	Province	Region	Central	
Conventional system						
Actual time method	12.28 (79.9%)	1.36 (8.9%)	0.52 (3.4%)	0.99 (6.4%)	0.21 (1.4%)	15.36
Proportion method	32.86 (86.6%)	2.55 (6.7%)	1.35 (3.5%)	0.99 (2.6%)	0.21 (0.6%)	37.96
VMI system						
Actual method	14.76 (85%)	1.21 (7%)	N/A	N/A	1.40 (8%)	17.37
Proportion method	37.59 (89.2%)	3.13 (7.4%)	N/A	N/A	1.42 (3.4%)	42.14

VMI = vendor-managed inventory system.

The actual time method was based on actual time spent on each activity in terms of man-minute per activity per month. Cost per man-hour was calculated from average monthly salary adjusted by 22 working days per month and 6 productive hours per day. General activities of vaccine logistics management included estimating target quantities, preparing and submitting request forms, delivering or receiving vaccines, completing inventory registration, storing vaccines, and

monitoring temperature. The proportion method used the salary adjusted by the proportion of total working time spent on each activity. Comparing costs based on the proportion method and the actual time method for each activity (base case), total costs more than doubled using the proportion method.

The capacity of refrigerators was also explored, to examine the outcome if additional vaccines were added to the VMI system. If the capacity was not enough, a refrigerator was added (Annex 2). For either one or two additional vaccines, 8.3% of health centers would require one additional refrigerator. For district warehouses, 50% and 54.2% of the warehouses would require one additional refrigerator for one and two additional vaccines, respectively. These results indicate that an additional budget of 18,275,306 THB and 19,183,522 THB should be allocated if one and two additional vaccines were added.

The GPO is not responsible for vaccine distribution from the district warehouse to the health center level. Table 20 summarizes the results if logistics of distribution between the district warehouse and the health center level were outsourced to a private logistics company. The scenario used the transport costs at the health center level as a guide to negotiate the outsourcing fee. The payer for this scenario might be the NHSO, depending on the policy. From the district warehouse to the health center, the labor costs of the health center collecting the vaccines and the transportation costs from the health centers to the district level would be offset by the outsourcing fee to the third party. In Table 20, the total logistics costs at health centers assuming no transportation cost between health centers and district warehouses was estimated. The transportation cost was at 3,242 THB per health center. The total transport cost for all health centers was estimated at 45.3 million THB, or 7.92% of the vaccine product costs. The 7.92% would serve as a guide for negotiation of a payment for a private company to perform transportation services.

Table 20. Health center logistics costs if vaccines were delivered/picked up by a third party (THB at 2010 prices).

	Labor costs	Material costs	Capital costs	Total logistics costs
Mean ± SE	5,795 ± 507	672 ± 37	3,317 ± 313	9,784 ± 611
Min	2,066	153	1,278	5,242
Max	11,646	1,205	7,690	17,121
Health centers' cost reduction	2,600	642	0	3,242
Country's cost reduction	36,348,506	8,976,444	0	45,324,950

Max = maximum; min = minimum; SE= standard error.

We also explored the impact of an immunization campaign, using an OPV campaign as an example. In the past, a total of 6,000,000 OPV vaccine doses were used over a two-month period. Therefore, the campaign required an estimated 3,000,000 doses per month. There are 1,033 district warehouses and 13,982 PCUs (mainly health centers). Therefore, each district warehouse and health center would require 2,904 and 215 doses of OPV, respectively. About 83.3% and 62.5% of district warehouses and health centers would require one additional refrigerator. The median prices of refrigerators used at district warehouses and health centers are 21,101 and 6,331 THB, respectively. This results in a total expenditure for additional

refrigerators of 73,489,653 THB. The capital costs per year for these refrigerators are 16,600,140 THB, or 2.77 THB per dose of OPV.

Feedback from respondents

Health officials were interviewed about challenges and suggestions regarding the implementation of the VMI system. The quality of cold chain management during delivery by the subcontractor was mentioned, with respondents pointing to the broken OPV vaccine vials caused by dry ice that made the temperature inside the vaccine boxes too cold. Another problem mentioned was that the expiration date of vaccines is still short under the new system, which may be because vaccine stocks were transferred from the conventional to the VMI system during the transition period.

Respondents also noted concerns regarding the VMI system's ease of use. The GPO/VMI web page uses vaccine vial to denote vaccine quantity, whereas health facilities generally use vaccine doses to indicate vaccine quantity. The GPO/VMI web page also uses different log-in information (username and password) depending on contract type (e.g., routine, campaign, school-based), which is inconvenient. For example, pharmacists need to log in twice in order to complete a vaccine request for routine and school-based programs. In addition, there is no linkage of inventory data between the VMI and the hospital inventory systems, so pharmacists have to document inventory twice, once for the hospital inventory control program and once for the VMI system. Health centers were not provided with the software for vaccine inventory management; however, some staff believed that it would be useful to have this software. It would help reduce the workload in inventory control and increase the accuracy of information.

Respondents indicated that VMI's introduction led to a communication gap between the central level and public health officers at the lower level. For example, there were no notifications to health staff of changes in dosage and presentation (e.g., number of doses per vial), vaccine administration, and vaccine strains. This led to mistakes in vaccine administration.

Pharmacists at district hospitals also requested that vaccine be delivered during business hours because there are no staff to receive vaccines at other times. Vaccines would be left overnight or over the weekend if not delivered during business hours.

Respondents suggested that the VMI system should be further developed to meet users' needs, including:

- Support for hospitals to deliver vaccines to health centers.
- Support for an online vaccine request program at health centers to link with hospitals.
- Development of a system that can link the data between the hospital inventory system and the VMI system.
- Development of a more convenient log-in system.
- Collaboration among regional and provincial health offices to assist with communication channels among health facilities as well as cold chain training and vaccine monitoring.
- Resolution of problems that occur with regard to urgent requests, requests that occur during non-business hours, and late deliveries.

- Strengthening of human resource capacity by organizing trainings for pharmacists in charge of vaccine/cold chain management on advanced vaccine knowledge.
- Provision of a budget for refrigerators, standard ice boxes (to deliver vaccines from hospitals to health centers), thermometers, and computers for use on EPI tasks.
- Development of a system to link the supply and use of vaccine lot numbers.

Feedback from implementing agencies

A meeting was organized to gather feedback from implementing agencies on the preliminary findings of this study. Overall, the findings were very well received. Participants generally agreed that the VMI system is better than the conventional system.

Participants raised issues that were not identified through the study. The first issue was regarding the JE vaccine shortage that occurred after the data collection period for this study. It was postulated that the shortage was the result of two factors:

- The GPO, which acts as the vaccine manufacturer, vaccine procurement agent, and logistics provider, was reluctant to procure vaccines from other sources even if vaccines were cheaper. Thus, vaccine shortages occurred when the GPO could not supply sufficient vaccine to the NHSO as planned.
- Under the VMI system, the NHSO does not have a policy on the national safety stock level for EPI vaccines. In the conventional system, the national safety stock level was maintained at six months.

In addition, the following issues were discussed, and it was concluded that solutions should be developed:

- *EPI management.* Under the conventional system, the Vaccine Preventable Disease unit of the Bureau of General Disease Control, Department of Disease Control, was responsible for technical and management support and served as the EPI manager. All EPI matters were resolved within the department. In the VMI system, the roles are divided between the NHSO and the DDC. However, it is not clear whose job it is to take care of overall program management.
- *Technical information system.* Technical information and technical assistance are not systematic and timely enough in the VMI system. When problems occur, staff do not know who to ask for information and suggestions. For instance, some pharmacists did not know how to adjust the reorder point for making requests in the VMI system.
- *Buffer stock.* The national safety stock level should be established, and the benefits of reduced inventory should be compared carefully to the negative consequences of vaccine shortage.

Discussion and recommendations

The VMI system was initially implemented in October 2009 and gradually expanded across Thailand by late 2010. This research assessed the overall performance and costs associated with both the conventional and VMI systems for vaccine distribution. Research findings revealed that the VMI system has been implemented successfully after a smooth transition period. Compared to the conventional system, the VMI system has resulted in a more efficient use of resources and

a more streamlined distribution system, as indicated by lower total logistics costs and lower total number of vaccines procured. However, unfavorable outputs as identified through the Context, Input, Process, and Product model raise concerns for the NHSO and the GPO.

The successful switch of Thailand's vaccine distribution system from the conventional to the VMI system was attributable to multiple factors. The change was made at the right time, coinciding with a number of fortuitous circumstances and driven by concerns about freezing and overheating of vaccines and inefficiency in the conventional system. In addition, Thailand had the proper infrastructure in place to implement the VMI system (including private logistics companies and IT systems).

Under the VMI system, pharmacists were placed in charge of vaccine inventory and distribution at the district level instead of public health officers. This factor is considered one of the key drivers of the success of the VMI system because pharmacists have long been involved in drug procurement and inventory management.

Our findings also revealed that the implementation of the VMI system was supported by public health administrators and others at every level of the system, ranging from policymakers to the heads of local offices. During interviews, a number of administrators shared details of how they support VMI both technically and financially. Financial support for purchasing new cold chain equipment, including refrigerators, and for necessary supervision and monitoring at the provincial and regional offices was provided. Most respondents reported that the cold chain equipment was in good condition and that they had a good Internet connection. In addition, a number of training workshops were provided for pharmacists responsible for district warehouses. This support at both the policy and user levels facilitated the implementation of the VMI system in Thailand.

Our findings imply that the VMI system has better cold chain management than the conventional system. Vaccines managed under the VMI system are packed using standardized techniques that maintain temperatures more consistently than the approach used in the conventional system. Temperature monitoring during transportation of vaccine shipments under the VMI system revealed that the temperature was within the proper range most of the time. In the VMI system, vaccines are packed in boxes, allowing the packing technique to be validated. This is not possible in the conventional system, as vaccines are carried in refrigerator trucks without packing. This places vaccines at risk of degradation because of exposure to extreme temperatures. Another proxy indicator of quality was derived from comments provided by local officers about pharmacists. These comments included: "They do not allow unconditioning icepacks," and, "They do not let us retrieve vaccines from their refrigerators by ourselves," and, "They do not give us vaccine if we do not bring vaccine carriers." These comments indicated that pharmacists were concerned about vaccine quality.

At the time of the study, the VMI system had not been fully implemented. The vendor (GPO) was unable to retrieve data on district warehouse inventories. Pharmacists at district warehouses had to manually transfer inventory data to the GPO/VMI web page. Appropriate vaccine inventory software is not yet available. Inventory software for drugs is not suitable for vaccines. For example, each lot number of a drug may have a different expiration date, but in the case of vaccines, several lot numbers might come with the same expiration date. Extending the VMI

system to health centers is possible. Health centers generally have good access to the Internet, and 6 out of the 24 hospitals surveyed reported their willingness to deliver vaccines to health centers. However, the impact of changes in cost, working relationships, etc., should be evaluated.

From a VMI system design perspective, savings are expected from streamlined vaccine distribution, elimination of vaccine stock at intermediate warehouses, and the resulting reduction in vaccine wastage and expired vaccines. With the use of IT and a professional logistics agency, the VMI system reduces the number of logistics operators by bypassing regional and provincial levels, resulting in lower logistics costs and more efficient use of resources. Compared to the bureaucratic conventional system, in which hundreds of people are employed and the maintenance of conventional cold chain equipment is expensive, the VMI system could result in significant cost savings. In this study, the start-up costs of the VMI system, including software development, training, and supervision during the transition, were excluded from the analysis. This is because the conventional system had been implemented for decades, making it difficult to estimate its start-up costs compared to those for the VMI system. It is essential to note that the VMI system bypasses the DDC, DDC regional offices, and the provincial health office levels. The resources and staff of the DDC and provincial health offices are now reserved for ad-hoc vaccination campaigns, such as influenza vaccination during pandemics.

The VMI system saves almost one-fifth of the total logistics costs of vaccines. Although the study allowed a four-month lag for collecting data for both systems (four months after VMI was introduced and four months before the transition to VMI), it is possible that the reduction in the number of vaccines procured might be due to changes in the dosage per vial as well as extra supplies of vaccines distributed from the provincial and regional warehouses to district and health center levels during the early phase of VMI system implementation. Monitoring the VMI system, especially with respect to the number of vaccine doses procured and delivered, is necessary to improve overall performance.

Regarding the benefits of the VMI system, the logistics costs per dose delivered under the VMI system were higher than those of the conventional system. However, the total logistics costs, the number of doses procured, and the number of doses delivered under the VMI system were lower than those of the conventional system (the labor time under the VMI system is less than that of the conventional system). This might be due to the use of IT for more efficient communication and management and because hospital pharmacy departments are now operating district warehouses. However, the estimated average logistics cost per vaccine is sensitive to the methods used for labor cost estimation. Both methods are notorious for their potential overestimation. However, the method using the actual time spent by activity might give a better estimate than the proportion method. For the proportion method to be reliable, it must consider all tasks to be performed by each staff member so that the proportion of time spent on each task is thoroughly recorded. The capital costs of the VMI system are higher than those of the conventional system because the VMI system invested in refrigerators and cold containers at the beginning of the transition. This resulted in higher electricity and material costs. It is also essential to note that the outsourcing of vaccine distribution through the VMI system at the current rate of 5% of the vaccine product cost is reasonable.

We examined the impact of adding new vaccines to the EPI. Only the effect of the cold chain on cost was considered for this scenario. Because of the use of IT, it was assumed that there would

be no change in labor costs. Approximately 90% of health centers had extra refrigerator capacity for additional vaccines, while approximately half of the district warehouses needed one additional refrigerator. We also explored the scenario of an immunization campaign and found that 62% of district warehouses and 83% of health centers needed additional refrigerators, based on a conservative estimate that campaigns would be conducted throughout the country. In practice, the campaign might be targeted at only high-risk areas.

Most health centers used refrigerators at less than their full capacity. Therefore, it might be more efficient to reduce the number of immunization sites or fixed site immunization sessions at some health centers if services can be effectively provided by nearby facilities.

In addition, vaccine transportation between district warehouses and health centers might be outsourced. The cost of vaccine transportation by health center staff was 45.3 million THB or 7.92% of the vaccine product cost. This 7.92% may serve as guide when negotiating costs with an outsourcing agency; however, this assumes that trips to collect vaccine are done separately from the other activities. In practice, health center staff often request or collect vaccines when they visit a district health office (for monthly meetings or other activities).

Several problems were reported during the first eight months of the VMI system. The first issue involved the broken OPV vaccine vials. Based on the survey, 41.7% of interviewees reported that they received vaccines in bad condition at least once at the district warehouses. The GPO attempted to deliver OPV at the suggested temperature of -20°C and found that the use of dry ice in polystyrene foam during transportation brought the temperature down to -60°C. The glass vials that contain the OPV cannot withstand this temperature. Attempts were made with smaller amounts of dry ice and additional icepacks. Currently, under a collaborative discussion with the NHSO and DDC, the GPO agreed to ship OPV in boxes at a temperature of less than 0°C by using dry ice together with icepacks. This has solved the problem of broken OPV vials. However, another concern raised by the NHSO, DDC, and GPO is the potential environmental hazard that dry ice poses. This latter concern is still under discussion. This incident is an example of the potential unexpected problems that can arise from the good intentions of those trying to ensure product quality. By continuing to monitor the problem incidents and through the collaborative efforts of all parties, measures have been taken to reduce the number of problem incidents to ensure the quality of vaccine products distributed.

A second concern was a report that the number of expired vaccines was still high under the VMI system (although it was lower than in the conventional system). This was counterintuitive, as it was expected that the VMI system would be very efficient in managing vaccine distribution and should have resulted in a near-zero amount of expired vaccines. The reported rate of receiving expired vaccine products was still 21.7% at hospitals and 16.7% at health centers. This may have been due to the transfer of leftover vaccines from the conventional system to the VMI system in the initial phase.

A third problem was the large number of reports indicating that it was taking a longer time for emergency vaccine requests to be filled under the VMI system than under the conventional system. The percentage of vaccines received within 24 hours dropped from 72% to 22%. This is understandable, as there are currently no warehouses near the provincial or regional levels. All emergency requests had to be handled at the central level. It would be worth exploring the

frequency and necessity of emergency requests. Also, given that the VMI system relies on a streamlined vaccine distribution chain, there is concern about what to do if a disaster were to strike (road blocks, large vaccine stocks submerged in floods, etc.). Therefore, countries should consider having a risk management plan in place (e.g., temporarily increasing stock at some hospitals in monsoon areas, planning for transportation by air, etc.).

In addition, two major pitfalls in the VMI system were discovered during the meeting with implementing agencies. The first is that the system places the GPO in the role of vaccine procurement agent without adequate controls on its procedures and timelines. This problem came to light when there were repeated problems with JE vaccine shortages. The GPO, which produces JE vaccine locally, was reluctant to buy vaccines from other companies for fear of losing annual market value, even though it ran out of in-house stock. In retrospect, this is an obvious conflict of interest that could be avoided by contracting the vaccine procurement job to another agency not involved in vaccine production or to a sales representative agency. The other option is to implement a penalty for missing the procurement timeline. In the conventional system, the DDC set the national safety stock level of vaccine at six months and used it to calculate the timeline for procurement. This six-month period has often been viewed as excessive and has led to problems such as the wastage of unopened vials and the short expiration date of vaccines at the service level. The safety stock level is not clearly stated in the VMI system contract between the NHSO and the GPO. It should be set and adjusted to balance the benefits of a reliable vaccine stock with reduced inventory and the risk of vaccine shortage. Each vaccine may have a different safety stock level according to its shelf life and market availability.

The second pitfall is the existence of gaps in the roles and responsibilities of each unit at the central and lower levels. It is not clear whose job it is to take care of the overall vaccine supply chain. Under the conventional system, the Vaccine Preventable Disease unit under the Bureau of General Disease Control's DDC was responsible for technical and management support and acted as the immunization manager. Likewise, the Pharmacy unit under the same bureau was responsible for vaccine procurement and distribution. All vaccine and immunization matters were resolved within the department. Since 2010, the NHSO has taken on vaccine procurement and distribution, while immunization policy and practices have remained the responsibility of the DDC. However, when there are vaccine-related problems, systematic responses are not yet in place. For instance, it is not clear whether the DDC or the NHSO is responsible for leading the response to a cold chain breakdown, a change in dose or strain of vaccine, or a serious adverse event following immunization. At the lower level, the impression is that the roles of staff at the provincial and regional levels in coordinating, monitoring, and supervising vaccine distribution activities have declined. Many have reduced the amount of time they spend on immunization activities in order to work on other priorities. In order to lessen these problems, terms of reference, working guidelines, standard operating procedures, and workflows for each activity should be clearly written.

Lessons learned

The findings suggest that multiple factors contributed to the success of the transition from the conventional system to the VMI system in Thailand. The transition was built on evidence (using the VMI system for drug delivery and a phased-in approach to introducing the VMI system for EPI vaccines), a viable existing health care infrastructure and IT, and strong political will and

commitment to address the problems of the vaccine supply chain and logistics. The change was driven by the payer (NHSO) and corresponded to the country's health reform approach.

Political commitment is essential. Coordination among key stakeholders, clear roles and responsibilities, and improved information flows are also fundamental to success.

Conflicts of interest and contracting practices remain a challenge. A manager is needed to provide technical and management support for the system. There were problems related to unclear roles/responsibilities of central-level staff in overall program management. When hospital and health center staff had vaccine-related problems, they did not always know where to turn. An effective technical support system to provide assistance and solve problems should be established.

A good Internet system to support the VMI system should be available across the country. Proper software is needed to manage vaccine logistics and to link data between the central office and the local health offices. Proper IT hardware at local health offices is necessary. Given that Thailand made no investments in IT in the initial phase of VMI implementation, further improvements in the VMI system will require additional financial support to strengthen IT infrastructure. Every hospital in Thailand employs a computerized system to manage drug inventory and service processes. A good system design for the vaccine supply chain is also important. Introducing the VMI system should result in a lean supply chain. The conventional system had several layers that were reduced by more than 50% under the VMI system. Strong communication channels and well-trained IT staff are highly essential.

Qualified cold chain distributors are important. Most logistics providers in developing countries have limited experience before they accept a national vaccine distribution contract. Thus, it is necessary to conduct a pilot test before VMI implementation and to closely monitor the implementation.

Outsourcing to a third-party logistics provider appears to be effective. Currently, outsourcing costs are based on a percentage of vaccine costs (5% of vaccine costs), which might be simple to manage. However, with the availability of data on the number/weight of vaccine packages delivered per year and the number and distance of customers, the NHSO should be able to calculate actual costs and make a better deal with the GPO. The expenses linked to vaccine costs might not be suitable if there is a large change in vaccine costs (e.g., adding more expensive vaccines into the system or adding a number of distribution sites). This is because logistics costs are not related to the vaccine product costs but to the volume of packaging and the distance/number of shipments. However, with limitations on cost analysis in some countries, lessons from Thailand can be used as a guide. Since the logistics costs of the VMI system are lower than those of the conventional system, assuming that vaccine costs are constant, outsourcing of vaccine logistics to a third party at a rate of 5% was considered reasonable.

Recommendations

We make the following five recommendations to improve the VMI system:

- Increase the efficiency of the VMI system.
  - The VMI web page should be improved to allow access to inventory data from the GPO and other district warehouses and to facilitate decision-making regarding vaccine stock management.
  - Vaccine inventory software should be developed and provided to hospitals. The software should be able to accommodate both the lot numbers and the expiration dates of vaccines. It should be able to link to the VMI web page and should be compatible with software currently used for drug inventory.
  - A smooth and fast Internet should be provided at all levels of health facilities. High-speed Internet from private Internet service providers is available in most areas of Thailand for less than 1,000 THB per month.
  - The GPO/VMI web page should be improved to make it more user friendly (e.g., eliminating the need for log-in for different vaccine contracts).
  - The benefits of extending the VMI vaccine distribution system to the health center level or of improving the logistics system between hospitals and health centers should be explored. Six hospitals at the district level are ready to deliver vaccines to health centers, but support is needed, including human resources and supplies (e.g., cars, gasoline, vaccine carriers/packages, data loggers, and thermometers).
- Improve the quality of services between the GPO and district warehouses to impose some quality control measures.
  - Although vaccine distribution under the VMI system is very good at temperature control during transportation, a large number of errors still occurred. The establishment of a way to systematically monitor these issues is needed.
  - The risks and benefits of transporting OPV at temperatures less than 0°C using dry ice to preserve potency and to conform with the Good Distribution Practice guidelines needs to be explored.
  - The impact of delays in responding to emergency vaccine requests in comparison to the conventional system should be further studied. If necessary, a contingency plan in case of a disaster affecting normal distribution service should be established.
- Improve vaccine management at district warehouses and health centers through training, supervision, and monitoring.
  - Although 96% of pharmacists were trained in vaccine and cold chain management at the beginning of VMI implementation, many pharmacists are still concerned that they have limited vaccine knowledge. A follow-up workshop should be provided to raise their confidence and develop their capabilities. Since staff now have experience with the system, the workshop can be focused on advanced topics or problem-solving.
  - Supervision at the regional and provincial levels should be strengthened in order to improve pharmacists' knowledge and practices and identify gaps.
  - Supervision of health centers by pharmacists should also be strengthened. Pharmacists should be trained on vaccine management at the health center level.

- Extend the IT system to health centers.
  - In the future, the VMI system could be extended to the level between the district warehouse and the health centers. There would be no need for health centers to make vaccine requests. The district warehouse would supply health centers with vaccines up to the amount needed. Each year, health centers would report the number of monthly target vaccine populations to the district warehouse. The number of vaccines required per month would be automatically updated. The health centers could adjust the number of vaccines required.
- Clarify the roles and responsibilities of key stakeholders.
  - To prevent conflicts of interest with the GPO in procuring and producing vaccines, the NHSO should amend its contracts. For example, the NHSO should establish a definitive number of vaccines to be procured and the procurement timeline. It could impose a penalty for vaccine shortages, or it could contract with other agencies to procure vaccine.
  - The NHSO should strengthen its role in monitoring and evaluation in addition to vaccine procurement and distribution.
  - The national vaccine safety stock level should be established.
  - For each stakeholder, terms of reference, guidelines, and standard operating procedures should be developed in order to define clear roles and responsibilities of each party.

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Annex 1. Study on temperature during transportation

Table A1 below shows temperature variations outside the 2°C to 8°C range for 24 shipments under the conventional system (study done in 2004).

Note: The data logger recorded information every 60 minutes. In 2004, two data loggers were placed in the same shipments destined to the same district depots. The discrepancy in the recorded temperature might be due to where the data loggers were placed in the refrigerator truck.

Province	Data logger no.	Central to regional level					Regional to provincial level					Provincial to district level				
		No. of total points	No. of points <2°C	Min temp.	No. of points >8°C	Max temp.	No. of total points	No. of points <2°C	Min temp.	No. of points >8°C	Max temp.	No. of total points	No. of points <2°C	Min temp.	No. of points >8°C	Max temp.
1	1	1	0	N/A	1	16.8	3	0	N/A	1	8.1	1	1	-0.2	0	N/A
	2	1	0	N/A	1	18.6	3	0/	N/A	0	N/A	1	1	-2.1	0	N/A
2	3	3	0	N/A	3	10.3	2	0	N/A	1	9.7	1	1	-5.6	0	N/A
	4	3	0	N/A	2	8.4	2	0	N/A	1	9	1	1	-1.8	0	N/A
3	5	4	1	0.7	0	N/A	6	0	N/A	2	11.9	3	3	0.4	0	N/A
	6	4	0	N/A	0	N/A	6	0	N/A	2	12.2	3	3	-2.7	0	N/A
4	7	3	0	N/A	0	N/A	1	0	N/A	0	N/A	1	0	N/A	0	N/A
	8	3	0	N/A	1	9	1	0	N/A	0	N/A	1	0	N/A	1	11.6
5	9	5	0	N/A	0	N/A	6	0	N/A	0	N/A	2	0	N/A	2	18.2
	10	5	0	N/A	1	8.1	6	0	N/A	3	10.3	2	0	N/A	2	18.6
6	11	9	0	N/A	9	12.2	3	0	N/A	1	10.9	2	2	-4.6	0	N/A
	12	9	0	N/A	1	8.1	3	0	N/A	1	10	2	2	-4	0	N/A

Province	Data logger no.	Central to regional level					Regional to provincial level					Provincial to district level				
		No. of total points	No. of points <2°C	Min temp.	No. of points >8°C	Max temp.	No. of total points	No. of points <2°C	Min temp.	No. of points >8°C	Max temp.	No. of total points	No. of points <2°C	Min temp.	No. of points >8°C	Max temp.
7	13	9	0	N/A	0	N/A	1	0	N/A	1	10	1	0	N/A	1	12.5
	14	9	0	N/A	6	11.3	1	0	N/A	1	8.4	1	0	N/A	0	N/A
8	15	5	0	N/A	0	N/A	2	0	N/A	0	N/A	1	1	-0.2	0	N/A
	16	5	0	N/A	0	N/A	2	0	N/A	0	N/A	1	0	N/A	0	N/A
9	17	8	0	N/A	0	N/A	1	0	N/A	1	16.5	1	1	1	0	N/A
	18	8	0	N/A	0	N/A	1	0	N/A	1	14.8	1	0	N/A	1	8.1
10	19	9	4	0.7	2	9.7	2	0	N/A	0	N/A	1	1	-2.4	0	N/A
	20	9	4	-0.9	1	12	2	0	N/A	0	N/A	1	1	1.9	0	N/A
11	21	11	0	N/A	1	8.7	4	0	N/A	4	14.5	1	1	-0.6	0	N/A
	22	11	0	N/A	1	10.9	4	0	N/A	4	15.2	1	1	-1.8	0	N/A
12	23	11	0	N/A	0	N/A	6	0	N/A	4	9.7	1	0	N/A	0	N/A
	24	11	10	0.4	0	N/A	6	0	N/A	1	8.1	1	0	N/A	0	N/A

Annex 2. Estimating cold chain capacity

The number of vaccine doses, packed volume, and unit price of additional vaccine were estimated by researchers (Table A2). Working time and office materials were assumed constant. Outsourcing costs were estimated based on the value of additional vaccines. Capital costs and the cost of electricity of additional cold containers were included. To estimate the additional cold chain capacity, available capacity of the cold chain was compared to the capacity required by adding new vaccines. The volume of additional vaccines was estimated from average packed volume per dose and total number of doses of additional vaccines.

Table A2. Packed volume of vaccines.

Vaccine	Vial size (dose/vial)	Packed volume/dose (ml)
Bacille Calmette Guérin	10	3[a]
Hepatitis B	2	1.5
Diphtheria-tetanus-pertussis/Hepatitis B	10	3
Diphtheria-tetanus-pertussis/Hepatitis B	2	1.5
Diphtheria-tetanus-pertussis	10	3
Oral polio	20	1.5
Measles	10	3
Measles-mumps-rubella	10	6[a]
Measles-mumps-rubella	1	3[a]
Japanese encephalitis	2	1.5
Diphtheria-tetanus toxoids	10	3

a. Includes diluents (although diluents do not require cold chain, in practice, they are kept in the cold chain.)