Optimizing national immunization program supply chain management in Thailand: an economic analysis

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SUMMARY

Objectives: This study aimed to conduct an economic analysis of the transition of the conventional vaccine supply and logistics systems to the vendor managed inventory (VMI) system in Thailand.

Study design: Cost analysis of health care program.

Methods: An ingredients based approach was used to design the survey and collect data for an economic analysis of the immunization supply and logistics systems covering procurement, storage and distribution of vaccines from the central level to the lowest level of vaccine administration facility. Costs were presented in 2010 US dollar.

Results: The total cost of the vaccination program including cost of vaccine procured and logistics under the conventional system was US\$0.60 per packed volume procured (cm^3) and US\$1.35 per dose procured compared to US\$0.66 per packed volume procured (cm^3) and US\$1.43 per dose procured under the VMI system. However, the findings revealed that the transition to the VMI system and outsourcing of the supply chain system reduced the cost of immunization program at US\$6.6 million per year because of reduction of un-opened vaccine wastage.

Conclusions: The findings demonstrated that the new supply chain system would result in efficiency improvement and potential savings to the immunization program compared to the conventional system.

Key words: national immunization program, logistics, cost analysis, Thailand

Introduction

Universal vaccination program has played an important role in disease prevention. The program success is greatly based on effective and efficient supply chain and logistics system.

Criteria for good supply chain management comprises of six rights, i.e. product (correct product as per request), quantities (correct as per request), place (sent to requested organization), time (timely supply), quality (no damage or with appropriate condition e.g. temperature) and costs (appropriate service charge or cost). World Health Organization

(WHO) has launched the Effective Vaccine Management (EVM) Initiative focusing on key concepts on lower stock levels, reduced wastage, accurate forecast of vaccine requirements, and prevention of equipment break-downs.¹ WHO and PATH implemented a collaborative project called Optimize from 2007 to 2012 aiming to develop immunization systems and technologies including conducting studies and analysis on outsourcing of vaccine supply chain and logistics to private sector in several countries including Thailand.² Zaffran *et al* provided the evidence of importance of vaccine supply and logistics systems in the recent review of studies in Senegal and Tunisia under project Optimize.³ The review indicated that in some countries, either un-opened or opened-vial vaccine wastage was accounted for 50%. Most un-opened vaccine wastage can be attributed to supply chain process. Stockouts are also caused by inappropriate supply chain system. It is recommended that immunization supply system may increase efficiency and effectiveness by outsourcing certain function of private or parastatal agency, which is corresponding to the Thai policy. Information technology and human resources may also pose concerns for supply chain systems.

Thailand is one of the countries that have demonstrated the importance of optimizing national immunization program supply chain management. Prior to 2009, the Thailand Department of Disease Control (DDC) managed the vaccine supply chain and logistics system (the conventional system). The vaccine logistics systems started with the delivery of vaccines

1 from the producer/importer to the central warehouse of the pharmacy unit, located in the
2 DDC. Vaccines were transported to 12 disease prevention and control regional offices, then
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4 to 76 provincial health offices, to district health offices, and finally to about 10,000 health
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6 service facilities (including hospitals and health centers) (Figure 1). To streamline the vaccine
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8 supply and logistics system and improve information flow, the National Health Security
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10 Office (NHSO) and DDC launched a pilot project in 2009 to outsource vaccine supply
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12 management to the Government Pharmaceutical Organization (GPO), a state enterprise under
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14 Thailand Ministry of Public Health. As part of the outsourcing arrangement, the GPO
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16 introduced and managed a vendor managed inventory (VMI) and contracted a private
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18 logistics company to distribute vaccines and related commodities in 28 of 76 provinces. Since
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20 2010, the NHSO has been solely in charge of procuring and distributing vaccines for the
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22 Expanded Program on Immunization (EPI) and has continued to outsource its procurement
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24 and distribution functions to the GPO (Figure 2). In late 2010, the VMI system was expanded
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26 to the whole country.
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30 VMI is a streamlined approach for inventory management and order fulfillment. One of key
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32 features of VMI involves collaboration among suppliers and customers, which changes the
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34 traditional procurement and distribution processes. Instead of sending purchase orders
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36 indicating the types and doses required, customers electronically send inventory information
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38 to the supplier. The supplier generates replenishment orders for the customer based on the
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40 inventory level (demand). The process is guided by objectives that are mutually agreed upon
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42 for the customer's inventory levels, fill rates, and transaction costs.⁴ Waller et al described
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44 the main advantages of VMI on cost reduction and customer service improvement.⁵
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54 In Thailand, the VMI system starts at the central warehouse and vaccines are supplied
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56 directly to the hospitals in each district designated as district warehouses. Vaccines and
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58 related commodities are then distributed from the district warehouses to primary care units
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(PCUs) (i.e. sub-district health centers or hospital immunization clinics). The vaccine inventory is managed at the central warehouse through the secure internet portal (VMI webpage). The information regarding the present stock of vaccines at the district warehouse is collected and recorded by the hospital pharmacy department and submitted to the central warehouse on a monthly basis. The central warehouse then prepares and delivers the vaccines according to the demand.

Anecdotal evidence suggests that VMI offers higher management efficiency for the vaccine supply chain system and will reduce unopened-vial vaccine wastage.⁶ However, there is no empirical evidence to support the benefits of VMI for vaccine products in the public sector. Therefore, this study aimed to conduct an economic analysis of the supply chain systems of the national immunization program (NIP) in Thailand. The study was supported by the project Optimize, a collaboration between the World Health Organization and PATH (<http://www.path.org/publications/detail.php?i=2019>).

Methods

Study design

This study was designed as a post-implementation economic analysis. We employed a micro-costing and ingredients based approaches from the government perspective. Costs were calculated from a summation of costs of all system levels or components of the program. The study compared the total costs and unit cost of two vaccine supply chain systems (outsourcing and transitioning to VMI vs. conventional). Due to limitations in data collection process, the analysis did not include the costs from supporting units (for instance, administration department of hospital), hidden costs of inventory (for instance, excessive inventory and stock-outs), and start-up costs (for instance, training on introduction of VMI

system). All costs were presented in 2010 US dollar (exchange rate: US\$1=31.69 Thai baht [THB]).⁷

Study sites, data sources, and data collection

The study sites included the central level vaccine management unit at NHSO and DDC and 12 health management regions (covering 76 provinces, 878 districts) of Thailand to ensure national representative samples. For each of 12 health management regions, one province was purposely selected. For the VMI system, the study covered the NHSO, 12 provincial hospitals, 12 district hospitals and 24 health centers. For the conventional system, the study sites covered the central warehouse at the DDC, 12 disease prevention and control regional offices, 12 provincial health offices, 12 district health offices, and 24 health centers. In both conventional and VMI system, health centers are the only common study site so the data from both systems were collected from the same health centers.

Data collection forms were developed specifically for conventional and VMI systems and for each facility type, and were field tested for content validity by researchers prior to use. The data collection forms contained the following sections: 1) key activities and workflow, 2) resources used, 3) costing information for each type of resource, and 4) quantities of vaccine supply. Logistics activities of both systems were defined for all levels and included activities of estimating target quantities, preparing and submitting request forms, collecting or receiving vaccines, completing inventory registration, storing vaccines, and monitoring temperature. The total logistics costs at each level included cost of purchasing, cost of storage and inventory management (vaccine storage), and cost of transportation (vaccine distribution). The number of doses and packed volume of the vaccine procured were collected for each vaccine type. Data were collected through face-to-face interviews with health staff at sampled health facilities between July 2010 and January 2011. Quantities of vaccine supply and costing information were retrospectively collected for a period of four months from the

interview date for the VMI system to capture vaccine information prior to the transition to VMI. For the conventional system, data were also collected for the period of four months in the first half of 2009 before the transition took place in 2010. The data collected from four months period was at least six months before the date of transition to VMI in 2010. Similarly, data of logistics system are from 4-month period which was at least 6 months after the date of transition to VMI.

Costing methods

Cost data included labor cost, material cost, and capital cost of cold chain and logistics systems. At each study site, resources used were quantified and unit cost was identified to determine the total cost. At each system level, mean, median and standard error of total costs and cost per dose were calculated with respect to each cost component, i.e. labor cost, material cost, and capital cost. The unit cost of the whole system was the summation of the unit cost (mean) of all facility levels. The total logistics cost of the country was derived from multiplying the unit cost by the total number of doses for all vaccines.

The cold chain and logistics equipment included cold containers, computers, and printers. The capital costs were estimated using a 3% discount rate.⁸ The costs of capital assets shared by other activities were allocated on the basis of percentage use. Labor cost was estimated from the product of time spent on each activity by each staff (worker-minute per activity per month) and worker-hour wage rate calculated from average monthly salary adjusted by 22 working days per month and 6 productive hours per day. Material costs included office supplies, electricity costs for cold chain, and transportation. The transportation cost was either the outsourcing fee (in the VMI system) or the estimation of distance and fuel cost per kilometer (in the conventional system). Outsourced logistics costs of the vaccine supply chain system were at 5% of the vaccine cost based on the NHSO official rate. Reference costs for transportation by motorcycles and cars were US\$0.063 and US\$0.126 per kilometer,

1 respectively. Electricity costs were estimated from electricity units (kilowatt-hour) and the
2 cost per electricity unit. Electricity units were calculated by multiplying compressor wattage
3 by the compressor's estimated running time, 8hours per day. The reference cost of electricity
4 was US\$0.091 per unit. Salary, reference costs and vaccine prices used for both systems
5 were that of 2010 value. Therefore, inflation or discounting was not applied.
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12 We also estimated the marginal cost required for scaling up the supply chain systems of
13 the EPI program. The cost per one additional vaccine was calculated based on the number of
14 doses, packed volume, and unit price of an additional vaccine, and obtained from the average
15 of the current EPI vaccines (Table 1). The staff time and use of office materials were
16 assumed to be about the same for both systems. Outsourcing costs were assumed to remain
17 the same at 5% of the value of additional vaccines procured. Capital costs of additional cold
18 containers and electricity costs were estimated. The number of additional cold containers was
19 determined by the difference between the available space of the containers and the space
20 needed for additional vaccine taking into account the total volume of the cold container (ft³),
21 percentage of volume sharing (to other purposes of using of the cold container), the volume
22 used by the existing vaccines, and the volume needed for additional vaccine estimated from
23 the average packed volume per dose (2.73 cm³) and total number of doses of additional
24 vaccine.
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44 **Data analysis**

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46 The cost of vaccine logistics per dose and per cm³ of packed vaccine supplied were computed for each
47 level and then summed to derive the unit cost for the whole system. The total annual vaccine logistics
48 cost of the national immunization program was derived from the overall unit cost for the whole
49 system multiplied by the total number of vaccine doses. The cost of the logistics system and the cost
50 of vaccine products were added to represent the cost of the program. The marginal cost per dose was
51 calculated as the total incremental logistics cost divided by the number of doses of additional vaccine.
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Due to limitation of sample size, probabilistic sensitivity analysis was conducted to explore variability of the results. Capital, labor and material costs of all levels were randomly selected by MS Excel function (gamma distribution). Simulation was iterated 1,000 times. The results were unit cost, total cost and difference between the systems.

Results

Costs of logistics systems, vaccines procured, and overall savings

Overall, the total logistics cost per health center, district distributor, and central supply of the VMI system was higher than those of the conventional system (Table 2), which resulted in a higher cost per dose procured. Labor was a major cost component of logistics costs at all levels of both systems except at the provincial and central level. The cost per dose procured at health center was the highest compared to other facility levels for both systems.

A total of 26.6 million and 20.6 million doses of vaccines were procured by the conventional system in 2009 and by the VMI system in 2010, respectively (Table 3). As a result, the total costs of vaccines procured for the conventional system (US\$22,976,732) was higher than the VMI system (US\$18,055,517). The total logistics costs of the VMI system, however, were US\$1,637,390 less than the conventional system. Table 3 reports the total and average logistics costs of the conventional and VMI systems including the savings from changing to the VMI system. For the VMI system, the logistics costs were based on the outsourcing cost of 5% of the cost of procured vaccine. The unit cost of procuring vaccines under the VMI was slightly higher than that of conventional system at US\$0.55 per dose and US\$0.26 per cm³ for the VMI and US\$0.48 per dose and US\$0.22 per cm³ for the conventional system.

The total cost of the vaccination program (total costs of vaccine procured plus total logistics costs) of the VMI system was US\$6,558,606 less than that of the conventional

system assuming that the coverage levels in both systems remain constant. Based on number of vaccines supplied in the VMI system, the cost of the vaccination program (both procurement and logistics) of the conventional system was US\$0.60 per packed volume procured (cm^3) and US\$1.35 per dose procured, and US\$0.66 per packed volume procured (cm^3) and US\$1.43 per dose procured for VMI (Table 3). To explore uncertainty on the results due to variability of cost at each service level, probabilistic sensitivity analysis was conducted. It was found that unit cost, total cost of logistics and total cost of the vaccination program of both conventional and VMI systems were less than those of the base case. However, difference of the total cost or savings due to VMI system was higher than those of the base case (Table 4).

Marginal cost of additional vaccine expanded

The outsourced logistics cost (5% of the vaccine product's cost) of additional vaccine was estimated using an average cost of current vaccines (US\$0.95). It was estimated that 8.3% of health centers require one additional refrigerator for either one or two additional vaccines, 50% (for one additional vaccine) and 54.2% (for two additional vaccines) of the district warehouses. These results indicate that an additional budget of US\$576,694 (US\$605,353) would need to be allocated for refrigerators if one (two) additional vaccines were to be added. The total incremental logistics costs estimated for the national level was US\$260,064 and US\$346,811 for one additional vaccine and two additional vaccines, respectively (Table 5). The marginal costs per dose and per cm^3 of one additional vaccine were US\$0.14 and US\$0.05, respectively. For two additional vaccines, marginal costs per dose and per cm^3 were US\$0.09 and US\$0.03, respectively.

Discussion

Main findings of the study

To our knowledge, this is the first study assessing the economic benefits of VMI and outsourcing of supply chain systems implemented in Asian countries. The findings demonstrated that the implementation of new supply chain system in Thailand resulted in savings to the immunization program compared to the conventional system. This information generally supports the decision made by government policy makers and might be beneficial to governments of other countries in optimizing the efficiency of their national immunization program.

The savings incurred are likely to stem from a number of reasons. First, the VMI system decreased un-opened vial wastage leading to the lower number of doses procured than the conventional system and consequently lowered the costs of the vaccination program. This is based on an assumption that birth cohort and vaccination coverage over the periods of conventional and VMI systems were not different. Second, the savings was attributed to streamlined vaccine distribution and elimination of vaccine storage at intermediate warehouses. With the use of information technology and a logistics agency, the VMI system reduces the number of logistics operators by bypassing regional and provincial levels, resulting in lower logistics costs implying more efficient use of resources. The efficiency of the VMI system corresponds to previous international studies.^{5,9} A case study on the continuous replenishment program at Johnson & Johnson revealed the advantages of VMI on improved customer service, reduced demand uncertainty, reduced inventory requirements, and reduced costs.⁵ In addition, Fox documented a case study of the VMI success of Black & Decker and Schering-Plough in inventory management.⁹

Further interpretation of the findings

The findings further suggested that outsourcing to a third-party logistics provider appear to be effective. Currently, outsourcing fee is at 5% of vaccine costs. However, as more data on the number/weight of vaccine packages delivered per year and the number and distance of customers become available, the actual costs could be estimated to allow economic consideration to be part of the fee formula with the GPO. The fee that is linked entirely to vaccine costs might not be suitable if there is a significant 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 more associated with the volume of packaging and the distance/number of shipments. From the analysis, since the total logistics costs of the VMI system are lower than those of the conventional system, assuming constant vaccine costs, the current outsourcing arrangement of vaccine logistics to a third party at a rate of 5% was deemed economically reasonable.

At the time of the study, Thailand had not fully implemented the VMI system and appropriate vaccine inventory software was not yet launched. The vendor (GPO) was unable to retrieve data on district warehouse inventories. District warehouse pharmacists had to transfer inventory data to the GPO/VMI web page manually. The overall VMI system was not able to reach the health center level. To improve the efficiency of the VMI system, follow-up studies should further explore the benefits of fully implementing VMI vaccine distribution system to the health center level and the logistics system between hospitals and health centers.

To generalize this study to other countries, it is essential to explore key drivers of cost savings due to VMI system. The potential key drivers were the followings: in-house vs. outsources systems (DDC vs. GPO managed systems), shortcut transportation (skipping regional and provincial warehouses of the VMI system, and web-based inventory management between central supply and district warehouse. Should VMI were to be adopted by other countries, there is a strong need to evaluate the current system and look for room for improvement. The change of management system to VMI and having outsourcing system might be a potential approach to improve efficiency and might be directly applicable to countries where system and relevant context are not different much from Thailand. In addition, even though it is not possible to provide direct evidence on comparable safety and effectiveness of VMI system, we are positive that a number of processes under this new system can indirectly ensure that. For example, the VMI system has shorter duration of transportation system and fewer storage sites, this is likely to link to the quality issues of vaccines transported which should be at least equal or better than conventional system.

Limitations of this study

A limitation on data collection deserved discussion. Data were collected only for a period of one year. While our findings demonstrated savings in the first year of implementation, more information and a longer study period will be needed to address the long-term costs and savings. Fluctuations in procurement are expected as the system is loaded with buffer stocks prior to the transition. While demonstrating the benefits of VMI system by evaluating the trend of vaccine supply over time, the fluctuations need to be taken into account as the VMI system continues.

1 Future research using interrupted time series regression analysis of multi-year data will be
2 useful to examine the effect of VMI program on the supply and total costs of the
3 immunization program.
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7 In summary, our findings provide clear evidence supporting that the use of vendor
8 managed inventory system leads to cost-savings to National immunization program of
9 Thailand. The reduction in the number of logistics distribution centers by bypassing regional
10 and provincial levels also contributed to lower logistics costs and more efficient use of
11 resources. Countries with similar settings and characteristics may consider using the findings
12 as part of evidence to improve the national immunization program.
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26 health offices, district health offices, hospitals, and health centers for valuable information
27 and collaboration for the study.
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33 ***Ethical approval***

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35 This study is exempted from ethics review because it is part of program review and routine
36 assessment. Data used is based on publicly available, anonymous survey and interview
37 procedures which participants are not vulnerable and participation did not induce undue
38 psychological stress or anxiety.
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involvement in the study design; in the collection, analysis, and interpretation of data; in the writing of the report; or in the decision to submit the article for publication.

REFERENCES

1. World Health Organization. Immunization supply chain and logistics. Available at:
http://www.who.int/immunization/programmes_systems/supply_chain/en/ (last accessed 26/05/2014).
2. OPTIMIZE. Outsourcing vaccine supply chain and logistics to the private sector. Available at:
http://www.who.int/immunization/programmes_systems/supply_chain/optimize/outsourcing_evidence_brief.pdf?ua=1 (last accessed 26/05/2014).
3. Zaffran M, Vandelaer J, Kristensen D, Melgaard B, Yadav P, Antwi-Agyei KO, et al. The imperative for stronger vaccine supply and logistics systems. *Vaccine*. 2013; **31** Suppl 2:B73-80.
4. Langley CJ, Coyle JJ, Gibson BJ, Novack RA, Bardi EJ. Managing supply chains; a logistics approach. South-Western: Cengage Learning; 2009.
5. Waller M, Johnson ME, Davis T. Vendor-managed inventory in the retail supply chain. *J Business Logistics* 1999; **20**:183-203.
6. National Health Security Office. The National Health Security (NHS) Board Approves New Vaccine Distribution System. Available at:
<http://www.nhso.go.th/eng/Files/content/255503/1d83a9cd-a5e0-4a9b-a72e-64bd074ac986-129775527653022500.pdf> (last accessed 25/12/ 2014).
7. Bank of Thailand. Rates of exchange of commercial banks in Bangkok metropolis Bangkok: Bank of Thailand; 2013. Available at:
<http://www2.bot.or.th/statistics/ReportPage.aspx?reportID=123&language=eng> (last accessed 04/12/ 2013).

8. Edejer TT-T, Baltussen R, Adam T, Hutubessy R, Acharya A, Evans DB, et al. Making choices in health: WHO guide to cost-effectiveness analysis. Geneva: World Health Organization; 2003.
9. Fox ML, editor. Integrating Vendor-Managed Inventory into Supply Chain Decision Making. American Production and Inventory Control Society (APICS) Annual International Conference; 1996.

Table 1 - Expanded Program on Immunization (EPI) vaccines in Thailand

Vaccine	Vial size (dose/vial)	Packed volume per dose (cm ³)	Price per vial (US\$ at 2010 prices)
BacilleCalmette-Guérin	10	3 ^a	2.21
Diphtheria-tetanus toxoid	10	3	1.74
Diphtheria-tetanus-pertussis	10	3	3.04
Diphtheria-tetanus-pertussis/hepatitis B	10	3	14.18
Diphtheria-tetanus-pertussis/hepatitis B	2	1.5	2.73
Hepatitis B	2	1.5	2.73
Japanese encephalitis	2	1.5	3.91
Measles	10	3	5.11
Measles-mumps-rubella	10	6 ^a	18.13
Measles-mumps-rubella	1	3 ^a	2.81
Oral polio	20	1.5	4.87

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

Table 2 - Logistics costs by facility level (US\$ at 2010 prices)

	Logistics costs (% of total)				Total doses procured	Cost per dose procured
	Labor	Material	Capital	Total		
<u>Conventional system</u>						
<u>Health center (n = 24)</u>						
Mean	266 (66%)	41 (10%)	97 (24%)	405 (100%)	1,344	0.39
Median	253	38	91	381	1,344	0.34
SE	21	3	7	21	167	0.04
<u>District (n = 24)</u>						
Mean	731 (68%)	112 (10%)	232 (22%)	1,075 (100%)	37,695	0.04
Median	763	104	145	1,077	27,300	0.03
SE	68	10	36	74	5,442	0.01
<u>Province (n = 12)</u>						
Mean	1,574 (36%)	350 (8%)	2,430 (56%)	4,355 (100%)	530,794	0.02
Median	1,155	343	1,758	3,321	314,482	0.01
SE	521	27	560	885	182,417	0.00
<u>Region (n = 12)</u>						
Mean	36,209 (62%)	4,719 (8%)	17,509 (30%)	58,437 (100%)	2,336,179	0.03
Median	30,936	4,480	10,695	46,042	2,286,493	0.03
SE	7,545	655	4,803	9,055	306,407	0.01
<u>Central (n = 1)</u>						
Mean	81,690 (45%)	33,836 (19%)	63,924 (36%)	179,450 (100%)	26,613,383	0.01
<u>VMI system</u>						
<u>Health center (n = 24)</u>						
Mean	265 (65%)	41 (10%)	105 (25%)	411 (100%)	1,481	0.47
Median	245	38	86	386	1,094	0.38
SE	21	3	10	23	238	0.11
<u>District (n = 24)</u>						

Mean	704 (59%)	126 (11%)	353 (30%)	1,183 (100%)	41,692	0.04
Median	531	108	307	981	32,280	0.03
SE	106	15	36	125	6,123	0.01

Central (n = 1)

Mean	4,066 (<1%)	904,439 ^a (99%)	21 (<1%)	908,527 (100%)	20,556,398	0.04
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Abbreviations: SE, standard error

^a Included outsourcing costs at 5% of the vaccine cost.

Table 3 - Comparison of outputs and costs (US\$ at 2010 prices) of the conventional and VMI systems

	Conventional system	VMI (5%)	Difference	VMI (7.5%)	Difference	VMI (10%)	Difference
<u>Logistics costs</u>							
Logistics cost per dose procured	0.48	0.55	0.06	0.57	0.09	0.59	0.11
Logistics cost per cm ³ of vaccine procured	0.22	0.26	0.04	0.27	0.05	0.28	0.06
<u>Total outputs</u>							
Total doses of vaccine procured	26,613,383	20,556,398	-6,056,985	20,556,398	-6,056,985	20,556,398	-6,056,985
Total packed volume procured (cm ³)	59,755,704	44,140,169	-15,615,535	44,140,169	-15,615,535	44,140,169	-15,615,535
<u>Total costs</u>							
Total cost of vaccines procured	22,976,732	18,055,517	-4,921,215	18,055,517	-4,921,215	18,055,517	-4,921,215
%	64	62		61		60	
Total logistics costs	12,901,755	11,264,365	-1,637,390	11,715,752	-1,186,003	12,167,140	-734,615
%	36	38		39		40	
Total cost of the vaccination program	35,878,488	29,319,882	-6,558,605	29,771,269	-6,107,218	30,222,657	-5,655,830
%	100	100		100		100	
Total cost per dose of vaccine procured	1.35	1.43	0.08	1.45	0.10	1.47	0.12
Total cost per packed volume procured (cm ³)	0.60	0.66	0.06	0.67	0.07	0.68	0.08
<i>Abbreviations: VMI, vendor managed inventory, Difference = VMI cost – Conventional cost</i>							

Table 4 – Results of probabilistic sensitivity analysis (US\$ at 2010 prices)

Cost	Group	Mean	Std. Deviation	95% Confidence Interval	
				lower bound	upper bound
Logistics cost per dose procured *	Conventional system	.3790	.0429	.3763	0.3816
	VMI system	.3591	.0521	.3559	0.3624
Logistics cost per cm ³ of packed volume of vaccine procured	Conventional system	.1688	.0191	.1676	0.1700
	VMI system	.1672	.0243	.1657	0.1687
Total logistics cost *	Conventional system	10,086,158	1,141,183	10,015,342	10,156,974
	VMI system	7,382,106	1,071,817	7,315,595	7,448,618
	Difference	-2,704,052	1,543,842	-2,608,249	-2,799,854
Total cost of the vaccination program *	Conventional system	33,062,891	1,141,183	32,992,075	33,133,706
	VMI system	25,437,623	1,071,817	25,371,112	25,504,135
	Difference	-7,625,267	1,543,842	-7,529,465	-7,721,070

Abbreviations: VMI, vendor managed inventory, Difference = VMI cost – Conventional cost
 * p<0.01 for t-test for Equality of Means of the two systems

Table 5 - Total and unit cost in scenarios of additional vaccine in the VMI system (US\$ at 2010 prices)

	Total logistics cost (% of vaccine product)	Total incremental logistics cost	Marginal cost per dose	Marginal cost per cm ³ of packed volume
One vaccine	11,556,810 (58%)	260,064	0.14	0.05
Two vaccines	11,639,791 (54%)	346,811	0.09	0.03

Figure(s)

Fig. 1. Conventional vaccine supply chain distribution system.

GPO=Government Pharmaceutical Organization, DDC=Department of Disease Control,
PCU=Primary care unit

Fig. 2. VMI vaccine supply chain distribution system.

NHSO=National Health Security Office, GPO=Government Pharmaceutical Organization, PCU=Primary care unit