Vaccine 35 (2017) 2183–2188

Contents lists available at ScienceDirect

Vaccine

journal homepage: www.elsevier.com/locate/vaccine

Costing analysis and anthropological assessment of the vaccine supply chain system redesign in the Comé District (Benin) ☆

Xiao Xian Huang [a,*], Elise Guillermet [a], Jean-Bernard Le Gargasson [a], Daleb Abdoulaye Alfa [b], Romule Gbodja [b], Adanmavokin Justin Sossou [c], Phillippe Jaillard [a]

[a] Agence de Médecine Préventive, France
[b] University of Abomey-Calavi, Benin
[c] Benin's Ministry of Health, Benin

ARTICLE INFO

Keywords:
Supply chain
Health logistics
Logistics cost
HERMES
Vaccination programs
EPI
Health workforce
Low- and middle-income countries
Benin

ABSTRACT

Objective: At the end of 2013, a pilot experiment was carried out in Comé health zone (HZ) in an attempt to optimize the vaccine supply chain. Four commune vaccine storage facilities were replaced by one central HZ facility. This study evaluated the incremental financial needs for the establishment of the new system; compared the economic cost of the supply chain in the Comé HZ before and after the system redesign; and analyzed the changes induced by the pilot project in immunization logistics management.
Method: The purposive sampling method was used to draw a sample from 37 health facilities in the zone for costing evaluation. Data on inputs and prices were collected retrospectively for 2013 and 2014. The analysis used an ingredient-based approach. In addition, 44 semi-structured interviews with health workers for anthropological analysis were completed in 2014.
Results: The incremental financial costs amounted to US$55,148, including US$50,605 for upfront capital investment and US$4543 for ongoing recurrent costs. Annual economic cost per dose administered (including all vaccines distributed through the Expanded Program on Immunization (EPI)) in the Comé HZ increased from US$0.09 before system redesign to US$0.15 after implementation, mainly due to a high initial investment and the operational cost of HZ mobile warehouse. Interviews with health workers suggested that the redesigned system was associated with improvements in motivation and professional awareness due to training, supportive supervision, and improved work conditions.
Conclusions: The system redesign involved a considerable investment at HZ level. Benefits were found in the reduction of transportation costs to health posts (HP) and commune health center (CHC) levels, and the strengthening of health workers professional skills at all levels in Comé. The redesigned system contributed to a decrease in funding needs at HP and CHC levels. The benefits of the investment need to be examined after the introduction of new vaccines and after a longer period.

1. Introduction

Vaccine supply systems are an important component of immunization programs both in terms of vaccine availability and program costs. According to a study of 94 low- and middle-income countries, supply chain costs were the third biggest cost driver for vaccination programs, after vaccine cost and delivery cost [1]. In many countries, vaccine supply systems are still based on patterns developed in the 1970s. However, with the introduction of new vaccines, existing vaccine distribution systems no longer have sufficient capacity [2–4]. Moreover, the management of available resources for vaccine supply systems is inefficient. A recent study examining the structure of vaccine supply chains in the 57 countries eligible for support from Gavi, the Vaccine Alliance (i.e., "Gavi-eligible countries") indicated that most of the existing cold chain system can be simplified and consequently reduce operating costs.

In this context, in 2013, the LOGIVAC project,[1] jointly implemented by Agence de Médecine Préventive (AMP) and the World

☆ Open Access provided for this article by the Gates Foundation.
* Corresponding author at: Agence de Médecine Préventive (AMP), Immeuble J.B Say, 13 Chemin du Levant, 01210 Ferney Voltaire, France.
E-mail addresses: xxhuang@aamp.org (X.X. Huang), eGUILLERMET@aamp.org (E. Guillermet), jblegargasson@aamp.org (J.-B. Le Gargasson), dalebalfa@yahoo.fr (D.A. Alfa), gbodjar@yahoo.fr (R. Gbodja), sossoujustinadanmavokin@yahoo.fr (A.J. Sossou), pjaillard@aamp.org (P. Jaillard).

[1] For more information on the LOGIVAC project, go to http://amp-vaccinology.org/activity/logivac.

http://dx.doi.org/10.1016/j.vaccine.2016.12.075
0264-410X/

Health Organization (WHO), redesigned the vaccine supply chain in the Comé HZ, a pilot site chosen by Benin's Ministry of Health (MoH), with a total population of 340,000 in 2014 [5,6]. The aim of the pilot was to test the new system in a real setting before its extension countrywide.

The system redesign followed the strategy proposed by Brown et al. [6]. Before the introduction of the new system, the four vaccine stores based in CHCs in Comé HZ served all health facilities in the area. Every month, staff at a lower administrative level health facility went to the nearest CHC to pick up the vaccines they needed for the coming month. In the redesigned system, CHCs no longer serve as vaccine storage facilities but only as vaccine delivery points, as is the case with HPs. This implied no change in cold chain equipment (CCE) or staffing at CHC level, and although their functions have changed, the number has remained the same. A storage facility was established to hold vaccine stockpiles for the whole Comé HZ, a so-called "HZ store." It was equipped with a 4×4 vehicle serving as a mobile warehouse. On a monthly basis, the mobile warehouse collects vaccines from the regional vaccine storage facility and distributes them to the 37 HPs and four CHCs through four shipping loops.[2] Brown et al. [6] predicted a decrease in logistics costs brought about by the new supply chain system.

Our study evaluated the financial needs for the introduction of the new system, and compared the economic costs of the supply chain in Comé before and after system redesign. An anthropological study was conducted to further assess the changes induced by the pilot project, notably on vaccine logistics management and health workers' daily conditions. These evaluations were conducted to inform budget planning and policy making in preparation for the deployment of the redesigned system on a national scale in Benin, and for other countries interested in redesigning their supply chains.

2. Methods

This analysis is composed of a costing analysis and an anthropological study.

2.1. Costing analysis

The cost evaluation was based on retrospective data and limited to Comé HZ. The cost perspective was that of the national immunization program (NIP). The investigated period was 2013 and 2014. The demonstration project procured a number of solar powered CCE in health facilities without CCE or with non performance, quality and safety (PQS), outdated equipment, while other equipment used in the HZ are powered by electricity or kerosene. The economic evaluation aimed to represent these different contexts. Therefore, purposive sampling methods were used to draw a sample from 37 HPs, based on the following criteria: location (i.e., commune), and CCE energy source (i.e., grid, kerosene, and solar). Once categorized, facilities were randomly selected. All four CHCs were included in the sample. In all, 19 health facilities were selected for the economic evaluation.

There are multiple probabilities of being selected through the sampling method. This probability was accounted for when calculating the average cost for all health facilities in Comé. The inverse of the probability of each health facility being selected was used as the weight to calculate the weighted average of logistics cost per health facility.

As the data collection was conducted at the end of 2014, the whole year data for 2014 were not available when the data collection began. In order to maintain consistency between the two years, we collected the cost data for the first six months of each year. We then multiplied the cost for the first six months by two to get the estimation for a 12-month period. The assumption is then that the cost flow is stable over the year.

In order to show the cash investment needed to establish the HZ office and the annual economic cost of running the new system, we calculated both the incremental financial cost for initial investment and the annual economic cost. The incremental financial costs included the cash payment for upfront capital investments and ongoing recurrent operations for the creation of the HZ store and mobile warehouse and its first working year.

The total annual economic cost of the supply chain in Comé examined the cost of all resources used in the vaccine supply chain at HP, CHC, and HZ levels for one year. It was composed of capital and recurrent costs. Recurrent costs included the cost of salary, per diem (mainly for training, vaccine distribution, and other), and fuel. Capital costs consist of infrastructure, vehicles, and HZ-level training. An "ingredient-based approach" was used to calculate cost by input, i.e., for each input, its cost corresponds to the quantity of inputs used in the system multiplied by its unit price. The simple straight line depreciation was used to annualize capital inputs, corresponding to the initial investment divided by the input's number of useful life years (ULY). Based on discussions with local experts, ULYs were set at 10 years for vehicles, refrigerators, and freezers; five years for coolers and vaccine carriers; five year for logisticians' academic training[3]; and 25 years for buildings.

The quantity of human resource used for logistic activities was measured by full time equivalents (FTEs), i.e., the sum of the time per month that health staff spent on each of the EPI logistics related activities. Salary cost per minute varied according to staff position. It was calculated by dividing the monthly salary[4] of an employee by his total monthly working time in minutes. We assumed that staff worked eight hours per day and five days per week.

The cost per dose administered was calculated in regards to the total number of vaccine doses administered in Comé HZ in a one-year period according to local registration. When the cost was evaluated in local currency, i.e., FCFA (West African CFA francs), the exchange rate of US$1 equaling 483 FCFA[5] was applied to obtain the value in US dollars.

To collect the above mentioned cost a questionnaire was addressed to each health facility manager in the sample. The cost for vaccine supply in each health facility was estimated. Then the weighted average of supply chain cost for health facilities was calculated by health facility category (including HP, CHC, and HZ). The total cost for each health facility category is the product of the weighted average cost and the total number of health facilities in this category. The total cost for Comé HZ is then the sum of the total cost for each health facility category.

2.2. Anthropological study method

To assess changes in professional identities and roles, we conducted semi-structured interviews with health workers at Comé HZ, HPs, and CHCs. At HZ level, seven persons with responsibilities and tasks for vaccine and supply chain management were interviewed.

In CHC and peripheral health facilities two health workers per establishment were selected on account of their responsibility for, or participation in, vaccine management. One official from the community health committee (*comité de gestion*) per establish-

[2] Detailed presentation of the system can be found in Brown et al. [6].

[3] Normally the logistician stays on the same post for no more than five years.

[4] Per diem was not counted in the salary.

[5] Exchange rate in December 2013: http://www.xe.com/fr/currencytables/?from=USD&date=2013-12-01.

ment was also interviewed, depending on his or her involvement in monitoring vaccine quality (according to the health workers). These interviews sought to assess the responsibilities and practices of personnel working in vaccine logistics management who were affected by the system redesign in Comé.

Purposive sampling was used to ensure inclusion of the most informed and concerned individuals (Table 1). Of the 37 HPs in Comé, 15 were selected for interview. The four CHCs were automatically included. In total, between April and July 2015, two local researchers interviewed 16 individuals from CHCs and 28 from HPs, making a total of 44 interviews.

Interviews were recorded, fully transcribed, and responses were coded with NVivo software based on preselected themes identified in the protocol. Quotations from different interviews regarding the same topic were compiled and compared to identify all existing viewpoints. Quantitative analysis was used to specify the rank of themes emerging from the interviews.

Table 1
Description of criteria for peripheral health facilities selection.

Commune	Peripheral health facilities	Specificity
Bopa	Badazoui	Hard to reach in rainy conditions. Solar and kerosene powered equipment
	Possotomé	Easily accessible. Electrical equipment
	Yégodoé	Hard to reach in rainy conditions. Kerosene equipment
	Gbakpodji	Solar equipment breakdown
	Lobogo	Vaccine shortage reported during supervision
Comé	Honvè-Comé	Nano-Q™ ice box
	Kpétou	Electrical equipment breakdown
	Agatogbo	Stores vaccines for the Kpétou health facility
Grand-Popo	Avloh	Solar equipment. Has a pirogue (small boat). Hard to reach
	Djanglamey	Kerosene equipment
	Sazoué	Easily accessible. Solar equipment
	Hilla-Condji	Frequent blackouts. Electrical equipment
Houéyogbé	Honhoué	Solar and kerosene equipment
	Sè	Electrical equipment
	Tokpa	Hard to reach. Solar and kerosene equipment

3. Results

The incremental financial costs for the implementation of the redesigned system and its first year in operation amounted to US $55,148 (including US$50,605 for upfront investment), and US $4543 for ongoing costs (Table 2).

On average, one HP spent US$403 in 2013 on its supply chain. The cost was doubled at CHC to US$737 per year. In 2014, the cost at HP increased slightly to US$421, while that of CHC decreased to US$616 (Table 3).

In aggregation, the economic cost of the vaccine supply chain in Comé amounted to US$17,847 in 2013 versus US$29,529 in 2014, with a difference of US$11,683, mainly due to the cost of the newly established HZ vaccine store. The total EPI doses administered declined slightly, from 201,365 in 2013 to 196,950 in 2014. Economic cost per dose administered was US$0.09 before the system redesign, and US$0.15 after (Tables 3 and 4).

The upfront investment was annualized to the obtain capital cost for the HZ store and mobile warehouse in 2014, i.e., US $6945. By incorporating the capital cost at HZ level, the total capital cost in Comé increased by 57% between 2013 and 2014, from $12,258 to $19,264. The capital cost per dose administered increased from US$0.06 to US$0.10 (Table 3). The ongoing cost of HZ store and mobile warehouse corresponds to the first year recurrent cost at HZ level. By incorporating this recurrent cost, the total recurrent cost in Comé increased by 79%, from US$5589 to US $10,266. The recurrent cost per dose administered increased from US$0.03 to US$0.05.

In the redesigned system, CHCs were no longer responsible for vaccine storage. In 2014, their recurrent costs were reduced by 38% and their capital cost by 3%. At HP level, the recurrent and capital costs remained relatively stable (Table 3).

Regarding the cost profile by input, in the previous logistics system, CCE and transportation cost (vehicle capital cost plus fuel cost) represented 37% of total logistics cost each, followed by human resources at 24%. After the system redesign, the share of transportation cost increased to 44%, followed by human resources at 27%. In addition, fuel costs were reported in 2014 for travel to annual training sessions and for transferring vaccines from one facility to another in case of stock outs (eight facilities). However, with the new system there were no more transportation costs for collecting the vaccines from CHCs.

The share of CCE reduced to 25% (Fig. 1). The decrease in the share of CCE cost within the total cost of the new system is due to an increase, at HZ level, of salary and per diem (logistician and driver), as well as the higher cost of vehicle and fuel, rather than the decrease of CCE cost in absolute terms.

Table 2
Financial cost: Up-front and ongoing costs for the establishment of the redesigned system (in USD).

	2014	USD
Up-front capital investments	Mobile warehouse	30,915
	Training for HZ logistician (including two years registration fees and accommodation costs)	16,846
	HZ vaccine store cold chain equipment	2844
	Total	**50,605**
Recurrent ongoing costs	Car insurance	816
	HR (logistician + driver)	2484
	Fuel	1242
	Total	**4543**
Total incremental financial cost for the first year		**55,148**

Concerning work time, HPs and CHCs spent on average seven and nine hours respectively per month on vaccine supply and storage activities in 2013 (Table 5). From 2013 to 2014, the average working time per month for HPs declined half an hour, while time at CHCs increased by more than two hours on average.

The main increases in working time at HP levels were found in the following activities: vaccine reception, equipment maintenance, and vaccination monitoring. In the anthropological interviews, health facility workers explained this increase by a higher motivation to apply best practices with the assistance of the HZ logistician.

At CHC level, increased working time was mainly due to the four hours per month CHC staff spent on information computerization, an activity introduced with the new system; this represented 35% of CHC total working time on vaccine management.

The main source of time saved was on vaccine collection. In 2013, HPs and CHCs spent on average 44 and 118 min respectively per month for vaccine collection (including round trips for vaccine pickup). With the new vaccine distribution mode in the redesigned system, this time was saved (Table 5).

The anthropological interviews suggested that real time savings with the new vaccine distribution mode could be even higher in some settings, depending on the distance and type of road. For HPs situated far from CHCs, the time spent on vaccine collection should also include the time for: negotiating motorcycle use with colleagues; negotiating money for fuel with relevant parties; repairing engine failures or flat tires; dealing with road accidents before or during trips; and waiting at CHCs for vaccines that were

Table 3
Average cost by health facility and total cost per year by health facility level (in USD).

	Weighted average cost per health facility		Total cost in Comé by facility level		
	2013	2014	2013	2014	Variation
Recurrent cost			5320	9500	79%
HP	*120*	*135*	*4172*	*4247*	*2%*
CHC	*287*	*177*	*1148*	*710*	*−38%*
Mobile warehouse and zonal delivery		*4543*		*4543*	*–*
Capital cost			12,258	19 264	57%
HP	*283*	*286*	*10,457*	*10,564*	*1%*
CHC	*450*	*439*	*1800*	*1755*	*−3%*
Mobile warehouse and zonal delivery		*6 945*	*–*	*6 945*	*–*
Total cost			***17,847***	***29,529***	***65%***
HP	*403*	*421*			
CHC	*737*	*616*			
Total administered doses per year			201,365	196,950	−2%
Total cost per doses administered			**0.09**	**0.15**	**69%**
Recurrent cost/dose administered			*0.03*	*0.05*	*88%*
Capital cost/dose administered			*0.06*	*0.10*	*61%*

Note: HP – health post; CHC – commune health center.

Table 4
Aggregated supply chain cost in Comé by input and health facility type in 2013 and 2014 (in USD).

	2013	2014	Δ in%
Recurrent cost	5589	10,266	79%
- Salary	2833	5667	100%
- HP	*2457*	*2631*	*7%*
	(136)	*(111)*	
- CHC	*376*	*551*	*47%*
	(30)	*(88)*	
- BDZ	*–*	*2484*	*–*
- Per Diem	1648	2141	0%
- HP	*1516*	*2025*	*1%*
	(153)	*(156)*	
- CHC	*133*	*116*	*-13%*
	(19)	*(25)*	
- BDZ	*–*	*–*	*–*
- Fuel	1108	2458	122%
- HP	*469*	*357*	*-24%*
	(18)	*(20)*	
- CHC	*639*	*43*	*-93%*
	(103)	*(7)*	
- BDZ		*2059*	*–*
Capital cost	12,258	19,264	76%
- Cold chain equipment	6444	6789	1%
- HP	*5817*	*5924*	2%
	(435)	*(439)*	
- CHC	*627*	*581*	-7%
	(61)	*(61)*	
- BDZ	*–*	*284*	*–*
- Vehicle	5407	8699	61%
- HP	*4278*	*4278*	0%
	(123)	*(123)*	
- CHC	*1129*	*1129*	0%
	(169)	*(169)*	
- BDZ		*3291*	*–*
- Building	406	406	0%
- HP	*362*	*362*	0%
	(19)	*(19)*	
- CHC	*44*	*44*	0%
	(19)	*(19)*	
- BDZ		*–*	*–*
- Training		3369	
- HP		*–*	
- CHC		*–*	
-BDZ		*3369*	
Total	**17,847**	**29,529**	**65%**

Note: Δ – increase in 2014 relative to 2013; HP – health post; CHC – commune health center.
Numbers in the paragraph are standard deviation.

not available. In interviews, health workers in some of the remote HPs explained that vaccine collection could take up to half a working day.

The anthropological study revealed other non-monetary benefits on working conditions and system performance after the system redesign. Interviews with 44 health workers highlighted the following advantages provided by the new system: higher availability of vaccines (32 interviewees); lower stress (24 interviewees); no more road accidents during transportation (18 interviewees); fewer conflicts with health workers at CHCs during distribution (15 interviewees); and time saved for patient care (11 interviewees) (Table 6).

4. Discussion

This study provides field evidence on the cost variation following a supply chain redesign in Comé, Benin. The logistics cost per vaccine dose administered was estimated at US$0.09 in 2013 and at US$0.16 in 2014.

The cost increase was principally attributed to the creation and functioning of the HZ store and mobile warehouse, and replacement of underperforming CCE in a number of HPs, with highly performing solar powered equipment.

HERMES (Highly Extensible Resource for Modeling Supply Chains) simulation did not predict a decrease of cost per dose administered after the system redesign if the rotavirus vaccine was not introduced throughout the whole national system [6]. When comparing the initial vaccine supply chain structure operating costs with the scenario of removing the commune level, the cost either increased (no loops) or remained constant (with loops). The efficiency gains with the HERMES model were observed only in the case of rotavirus introduction. However, the rotavirus vaccine has not been introduced in Benin since then. The total number of EPI vaccine doses administered even declined slightly in the Comé HZ. As such, the new system was actually underused. This partly contributed to the increase of cost per dose administered. We should bear in mind that this study covered the Comé HZ only, which limits the comparability of the study's results with other estimates in the literature that provide, for instance, the cost per dose administered countrywide [4,6–8].

At HP and CHC level, although the study does not allow for the isolation of the impact of system redesign from all other factors that could influence logistic costs, we observed a correlation

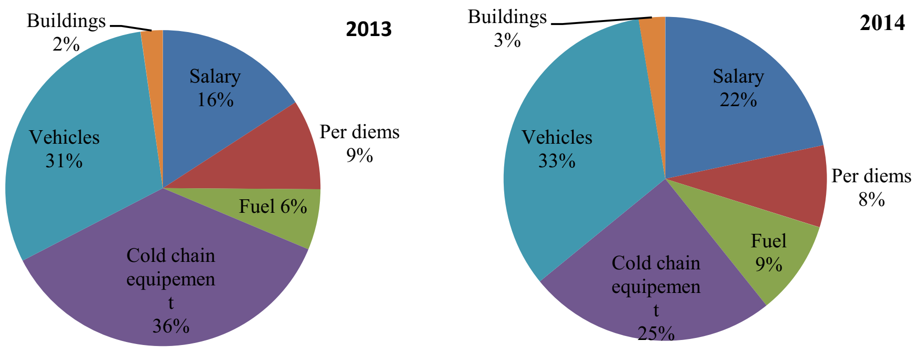

Fig. 1. Distribution of Comé health zone logistics costs by input in 2013 and 2014.

Table 5
Monthly weighted average working time by activity and by health facility type (in minutes).

	HPs (in minutes)			CHCs (in minutes)		
	2013	2014	Δ	2013	2014	Δ
Vaccine needs estimation	49	53	3	49	49	0
Command preparation	31	34	2	36	36	0
Information computerization	0	5	5	0	240	240
Command verification and confirmation	18	15	−3	18	18	0
Temperature control	59	40	−19	85	85	0
Vaccine collection	44	0	−44	118	0	− 118
Vaccine reception	24	39	15	43	43	0
Storage	17	20	3	34	34	0
Equipment repair	19	10	−9	10	10	0
Equipment maintenance	74	92	18	45	45	0
Vaccination monitoring	79	89	11	64	75	11
Supervision support	10	0	−10	30	0	−30
Supervision	0	0	0	15	45	30
Total Full Time Equivalent (FTE)	**424**	**396**	**−28**	**545**	**679**	**134**

Note: HP – health post; CHC – commune health center.

Table 6
Advantages of the vaccine system redesign according to 44 health workers: the 10 main advantages.

Topics	# Quotations	Rank
Availability of vaccines (missed opportunities are avoided)	32	1
Lower stress for health workers in CHCs and peripheral health facilities	24	2
No more road accidents during transportation	18	3
Lower conflicts with commune health workers during distribution	15	4
Time saved for patient care	11	5
Better relations with patients (due to decreased waiting time for vaccines)	11	5
Continuity of cold chain	10	6
Breakages of vials are avoided	9	7
Time saved for outreach strategy	7	8
Better management of expiration dates	6	9
Better monitoring of temperatures	5	10
Barriers to access to commune health centers are avoided	5	10

Note: HP – health post; CHC – commune health center.

between the implementation of the new system and transportation cost variation. The fuel costs were reduced by 24% and 93% for HPs and CHCs respectively after the exemption of vaccine collection.

The professionalization of health workers for cold chain and vaccine management increased working hours on certain activities and thus human resources costs, but also improved health workers' awareness on how to preserve the quality of vaccines. An effective vaccine management (EVM) assessment,[6] was performed in Comé in 2014 to evaluate the redesigned system. It confirmed that health workers' capacity to manage vaccine logistics at service level had improved after the system redesign [9].

The interviews for this study highlighted the advantages perceived by health workers from the change of vaccine collection mode in terms of vaccine availability, improved working conditions, and time for logistics related activities or other care activities. These additional benefits, although not directly reflected in the economic analysis, should be considered in the added value of the redesigned system.

The increase of both recurrent and capital costs raises the question of the financial sustainability of the redesigned system. The regular inclusion of the HZ vaccine store and mobile warehouse operations in the HZ annual plan of action and budget, as it was done for year 2014, should facilitate its funding. The increase of recurrent costs at HP level is due to salaries and per diems paid by central and HZ levels. The redesigned system contributed to a decrease of funding needs at HP and CHC levels.

The incremental financial costs to set up an optimized supply chain are high and should be supported by the MoH and partners through domestic or foreign sustainable funding; and provision should be made by the MoH for replacement of cold chain and transport equipment. Introducing new vaccines as well as additional medical products into the redesigned system may contribute to its sustainability through the economics of scale and the possibility of other funding opportunities.

[6] Refer to: http://www.who.int/immunization/programmes_systems/supply_chain/evm/en/index3.html.

Findings from the programmatic, economic and anthropological evaluations led the MoH to decide the deployment of the redesigned system countrywide. A methodology was developed to redesign the immunization supply chain in each of the 33 remaining HZs in Benin, based on the demonstration project. To date, 10 HZs are implementing an optimized immunization supply chain.

This study contains some limitations which should be taken into consideration in the interpretation of the results. Firstly, the study period did not extend beyond the period of new project implementation. It was too early to measure the impact of the new system on the supply chain performance. In addition, no performance indicators, such as stock-out rate and availability of vaccines were collected. Consequently, we could not compare the performance of the new system with the former one and measure the value for money of the redesigned system.

Secondly, the actual standard ULY for vehicles might be shorter than that used in the study, given the poor road conditions and travel frequency. Some costs were not available or missing during data collection, which could potentially underestimate total costs. For instance, data on the proportion of energy costs used for the cold chain was incomplete or unreliable. As a consequence, no energy source costs were included in the results. The building costs at HZ level were also not available.

Thirdly, we should also be cautious when directly interpreting and comparing the two years. The low cost in 2013 can be explained by a less 'functional' system. On the contrary, LOGIVAC external intervention tends to induce an increase of activity levels as it is closer to a more functional system (besides the redesign of the system and the investment in CCE). For example logistics training implied higher operational costs at HP and CHC (human resources, fuel, per diems). In that sense, efficiency gains or absence of efficiency from the system redesign should be interpreted with this limitation in mind.

Contributors

In relation to the economic study, XXH developed the database, performed data processing, cost calculation, analysis, and interpretation of the data, and provided a major contribution to the study report and manuscript writing. In relation to the anthropological study, EG developed the study protocol, supervised data collection, conducted the analysis, and provided a major contribution to the anthropological results and discussion in the manuscript. JBLG developed the economic study protocol and tools, conducted the sampling, provided technical guidance on data analysis and interpretation, contributed to the writing of study report and participated in manuscript writing. DA and RG revised the anthropological study protocol and tools, conducted anthropological interviews, and contributed to data analyses and report writing; JS supervised economic data collection, and provided input on economic protocol development, sampling, data interpretation, report writing, and manuscript writing. PJ recruited the core team, oversaw the project development and implementation, and provided input on protocol development, data interpretation, analysis, study reports, and manuscript writing. All authors agreed on the final draft.

Role of the funding source

These studies were implemented as part of the LOGIVAC project, conducted jointly by AMP and the WHO, with a generous grant from the Bill & Melinda Gates Foundation (BMGF).

Conflict of interest

XXH, EG, JBLG, and PJ work for the Agence de Médecine Préventive, which receives grant-specific support from Bill and Melinda Gates Foundation. DA and RG work at University of Abomey-Calavi which has no financial relationship with this project. JS works for Benin's Ministry of Health.

Acknowledgements

We would like to acknowledge Benin's MoH for facilitating study implementation; the HERMES Logistics Modeling team for discussions on data analyses and results interpretation; Antoine Vollet, Sarah Chatanay, and Mélanie Avella for program operations management; Caroline Lebrun for her contributions to the protocol development; Bradford Gessner and Emmanuelle Assy for article review and valuable comments; Jean Kouassi for study coordination in the Comé HZ; and Sabrina Gaber for English editing.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.vaccine.2016.12.075.

References

[1] Portnoy A, Ozawa S, Grewal S, Norman BA, Rajgopal J, Gorham KM, et al. Costs of vaccine programs across 94 low- and middle-income countries. Vaccine 2015;33(Suppl. 1):A99–A108.
[2] Kaufmann JR, Miller R, Cheyne J. Vaccine supply chains need to be better funded and strengthened, or lives will be at risk. Health Aff (Millwood) 2011;30(6):1113–21.
[3] Andrus JK, Jauregui B, Oliveira LHD, Matus CR. Challenges to building capacity for evidence-based new vaccine policy in developing countries. Health Aff (Millwood) 2011;30(6):1104–12.
[4] Mvundura M, Lorenson K, Chweya A, Kigadye R, Bartholomew K, Makame M, et al. Estimating the costs of the vaccine supply chain and service delivery for selected districts in Kenya and Tanzania. Vaccine 2015;33(23):2697–703.
[5] AMP, WHO. Supply chain optimization operational research - Comé health zone, Bénin; 2013.
[6] Brown ST, Schreiber B, Cakouros BE, Wateska AR, Dicko HM, Connor DL, et al. The benefits of redesigning Benin's vaccine supply chain. Vaccine 2014;32(32):4097–103.
[7] Mvundura M, Kien VD, Nga NT, Robertson J, Cuong NV, Tung HT, et al. How much does it cost to get a dose of vaccine to the service delivery location? Empirical evidence from Vietnam's Expanded Program on Immunization. Vaccine 2014;32(7):834–8.
[8] Lee B, Brown S, et al. The business case for vaccine supply chain redesign in the Republic of Benin; 2013.
[9] Prasad K. Evaluation of LOGIVAC pilot project for strengthening immunization supply chain & logistics in the District of Comé, in Benin. UNICEF; 2015.