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JVAC-15371; No. of Pages 7

ARTICLE IN PRESS

Vaccine xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Vaccine

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

The benefits of redesigning Benin's vaccine supply chain

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ARTICLE INFO

Article history:
Received 15 January 2014
Received in revised form 21 April 2014
Accepted 23 April 2014
Available online xxx

Keywords:
Benin
Vaccine
Supply chain
Computational modeling

ABSTRACT

Introduction: New vaccine introductions have put strains on vaccine supply chains around the world. While increasing storage and transportation may be the most straightforward options, it is also important to consider what financial and operational benefits can be incurred. In 2012, suboptimal vaccine coverage and impending vaccine introductions prompted the Republic of Benin's Ministry of Health (MOH) to explore ways to improve their vaccine supply chain.
Methods: Working alongside the Beninese MOH, we utilized our computational model, HERMES, to explore the impact on cost and vaccine availability of three possible options: (1) consolidating the Commune level to a Health Zone level, (2) removing the Commune level completely, and (3) removing the Commune level and expanding to 12 Department Stores. We also analyzed the impact of adding shipping loops during delivery.
Results: At baseline, new vaccine introductions without any changes to the current system increased the logistics cost per dose ($0.23 to $0.26) and dropped the vaccine availability to 71%. While implementing the Commune level removal scenario had the same capital costs as implementing the Health Zone scenario, the Health Zone scenario had lower operating costs. This increased to an overall cost savings of $504,255 when implementing shipping loops.
Discussion: The best redesign option proved to be the synergistic approach of converting to the Health Zone design and using shipping loops (serving ten Health Posts/loop). While a transition to either redesign or only adding shipping loops was beneficial, implementing a redesign option and shipping loops can yield both lower capital expenditures and operating costs.

1. Introduction

Impending new vaccine introductions (NVIs) are prompting many low and middle income countries to examine whether their vaccine supply chains (i.e., the series of steps and components required to get vaccines from the national storage location to the population) are currently getting vaccines to their populations in a timely manner and can handle the added volume of new vaccines. In 2012, the Republic of Benin's Ministry of Health (MOH) was interested in determining how they could improve their vaccine supply chain. A December 2008 external review of Benin's Expanded Program on Immunization (EPI) found high maternal and infant mortality (397/100,000; 67/1000, respectively) [1] and that at least 15% of children are not currently receiving the complete set of recommended vaccinations, as measured by estimated DTP (diphtheria tetanus pertussis) third dose coverage [2]. The introduction of PCV13 (pneumococcal conjugate) vaccine in 2010 strained the current system (nearly tripling the volume of

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http://dx.doi.org/10.1016/j.vaccine.2014.04.090
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vaccine needed per fully immunized child) and forced the country to increase the current transport methods in an effort to cope with the added cold chain volume. A technical support team including Agence de Médecine Préventive (AMP), the HERMES logistics modeling team, PATH, and Transaid worked with the Benin MOH to explore different potential redesigns of the Benin vaccine supply chain and how they would compare with simply adding refrigerators and freezers to the current vaccine supply chain. This involved developing a detailed HERMES (highly extensible resource for modeling supply chains)—generated simulation model of the Benin vaccine supply chain which could serve as a "virtual laboratory" to test the effects of different changes [1,2].

2. Methods

2.1. HERMES Benin vaccine supply chain model

We developed a detailed, discrete-event simulation model of the Benin vaccine supply chain in our HERMES framework. Programed in Python, HERMES uses features provided by the SimPy package. Previous publications have described the structure of HERMES and HERMES-generated, country-specific models in detail [3–15]. Our Benin model represents an operational vaccine cold chain based on field data, with key physical components (e.g., every storage location, refrigerator, freezer, vaccine carrier, transport device, and vaccine vial) and dynamic processes (e.g., ordering, shipping, and vaccine administration) simulated over a one-year time interval with a warm-up period of six months. The model tracks each simulated vial as it travels through the supply chain and provides a wide range of outputs, including the location and severity of each bottleneck due to inadequate storage or transport capacity, as well as wastage due to expiry of unopened vials or unused doses in an opened multi-dose vial. Wasted doses are removed from the system and are taken into account when locations order vaccines.

Once parameterized, the flow of vaccines through the system is simulated through dynamic interactions of ordering, storage, transport, and vaccination events. Demand for vaccines is modeled stochastically at each location through vaccination sessions drawing from a Poisson distribution around the expected number of patients from yearly census estimates. This, in addition to stochastically scheduled events in the dynamic simulation, requires running each scenario over several iterations to gather average statistics for key metrics.

2.2. Data collection

Data collection tools were adapted from existing tools developed and utilized by Project Optimize to assess resource use and logistics costs of the national immunization program vaccine supply chain, tailored to incorporate the data needs for HERMES. The effective vaccine management (EVM) tool was adapted to collect additional data for the HERMES model, while the cold chain equipment management (CCEM) and stock management tool (SMT) further augmented model details. This included a questionnaire for each level of the supply chain to capture the resource use for the storage and distribution functions of the supply chain, as well as the stock movement data. Data collected included information on human resources, vaccine stock over a one year period, cold chain equipment type and specifications, and transport mode, frequency, and routes from the National Warehouse, Department and Regional Stores, 16 Commune Stores and 16 Health Posts (one from each commune). These records estimated the annual economic costs for each facility for cold chain, human resources, and transport. Additional cost metrics included total cost per dose delivered, long-term costs, and cost savings. The 2009 Benin comprehensive multiyear plan (cMYP) was used to supplement the cost estimates. Each geographic location in the supply chain was determined using a combination of data received from the country and location searches on Google Maps.

The total recurring logistics operating costs per year for the vaccine supply chain came from the following formula:

$$\text{cost}_{\text{total}} = \text{cost}_{\text{labor}} + \text{cost}_{\text{storage}} + \text{cost}_{\text{transport}} + \text{cost}_{\text{building}},$$

where

$$\text{cost}_{\text{labor}} = \Sigma_{\text{employees}}\, \text{cost}_{\text{per employee}}$$

$$\text{cost}_{\text{storage}} = \Sigma_{\text{storage device units}}\, \text{cost}_{\text{per storage device unit}}$$

$$\text{cost}_{\text{transport}} = \Sigma_{\text{transport routes}}\, \text{cost}_{\text{per transport route}}$$

$$\text{cost}_{\text{building}} = \Sigma_{\text{buildings}}\, \text{cost}_{\text{per building}}$$

The following expressions define the annual recurring unit cost for each of the categories:

- *Annual Unit Labor Costs*

$$\text{cost}_{\text{per employee}} = \text{cost}_{\text{employee's annual salary and benefits}} \times \%\ \text{of time dedicated to vaccine logistics}$$

- *Annual Unit Storage Costs*

$$\text{cost}_{\text{per storage device unit}} = \text{cost}_{\text{storage device unit energy usage}} + \text{cost}_{\text{storage device unit maintenance}} + \text{cost}_{\text{storage device unit depreciation}}$$

- *Annual Unit Transport Costs*

$$\text{cost}_{\text{per transport route}} = \text{cost}_{\text{per km}} \times \text{distance traveled} + \text{cost}_{\text{per diems for route}}$$

$$\text{cost}_{\text{per km}} = \text{cost}_{\text{vehicle maintenance per km}} + \text{cost}_{\text{vehicle depreciation per km}} + \text{cost}_{\text{fuel per km}}$$

$$\text{cost}_{\text{fuel per km}} = \frac{\text{cost}_{\text{fuel per liter}}}{\text{fuel efficiency of vehicle}_{\text{km per liter}}}$$

- *Annual Unit Building Costs*

$$\text{cost}_{\text{per building}} = \left(\text{cost}_{\text{annual depreciation}} + \text{cost}_{\text{annual utilities}}\right) \times \%\ \text{of building utilized for vaccine logistics}$$

Building costs were based on information from the cMYP, and per diems were based on conversations with an in-country professional reference.

The model included Benin's seven current World Health Organization (WHO) EPI vaccines (Appendix A). To explore NVI we modeled scenarios with the Rotarix rotavirus vaccine (Rota) introduced into the routine vaccination schedule. As the size of this presentation is similar to other potential introductions, such as the meningococcal vaccine or the human papilloma virus vaccine (HPV), the results can be considered relevant to these planned NVIs.