

The Cost of Routine *Aedes aegypti* Control and of Insecticide-Treated Curtain Implementation

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Abstract. Insecticide-treated curtains (ITCs) are promoted for controlling the Dengue vector *Aedes aegypti*. We assessed the cost of the routine *Aedes* control program (RACP) and the cost of ITC implementation through the RACP and health committees in Venezuela and through health volunteers in Thailand. The yearly cost of the RACP per household amounted to US\$2.14 and \$1.89, respectively. The ITC implementation cost over three times more, depending on the channel used. In Venezuela the RACP was the most efficient implementation-channel. It spent US\$1.90 (95% confidence interval [CI]: 1.83; 1.97) per curtain distributed, of which 76.9% for the curtain itself. Implementation by health committees cost significantly ($P = 0.02$) more: US\$2.32 (95% CI: 1.93; 2.61) of which 63% for the curtain. For ITC implementation to be at least as cost-effective as the RACP, at equal effectiveness and actual ITC prices, the attained curtain coverage and the adulticiding effect should last for 3 years.

INTRODUCTION

About 2.5 billion people in more than 100 countries are at risk of infection with dengue, a vector-borne disease mainly transmitted by *Aedes aegypti*, which yearly affects 50 million persons¹ and causes 24,000 deaths.² In the absence of a vaccine, the only approach to prevent the disease is vector control: reducing mosquito abundance, reducing adult mosquito life span, and preventing mosquito-human contact.³

Combinations of indoor and outdoor application of chemical or biological larvicides and insecticides are most widely used to this end, often complemented with environmental management.^{1,4} The success in routine settings is variable, caused by an insufficient scale of implementation and poor acceptability or absence of community involvement.^{4–10} Additionally, this approach requires continuous efforts and is expensive and difficult to sustain.^{5,11}

In search for alternatives, the efficacy of novel tools such as long-lasting insecticide-treated materials (window curtains and water container covers) has been tested recently.^{12,13} They showed promising results but their effectiveness depends on the attained coverage and on the initial level of *Ae. aegypti* infestation.¹⁴ Routine *Ae. aegypti* control programs could possibly implement these tools at large scale, but the cost thereof has not been documented yet. Furthermore, this cost might vary in the function of the set up of the routine program and be modified by community involvement in the distribution of the tools.

We report here on the costs of routine *Ae. aegypti* control in two socio-economically contrasting dengue endemic settings in Venezuela and Thailand, compare the cost of two different strategies for insecticide-treated curtains (ITCs) implementation in Venezuela and describe the cost of an alternative strategy in Thailand. We also explore the scope for cost-effective ITC deployment.

MATERIALS AND METHODS

Study settings. In Venezuela, the study was conducted in Valera (urban; 128,556 inhabitants) and San Rafael de Carvajal (suburban; 44,213 inhabitants) in Trujillo state. The average temperature varies between 24 and 26°C and there are two rainy seasons: March–April and September–October. Breteau indices (BI) reach 8 and 42, and Pupae per person indices (PPI) 0.2 and 0.9 in urban and suburban areas, respectively. Dengue is endemic, with 262–746 cases per 100,000 inhabitants (2006–2008) reported by the Regional Direction of Epidemiology and Statistics (Trujillo state Health Ministry).

The study site in Thailand was Laem Chabang (urban; 80,357 inhabitants) in Chonburi Province. The average temperature oscillates around 28°C and the rainy season runs from August to October. The BI and PPI reach 45 and 0.51, respectively, and dengue is endemic. The Laem Chabang municipal hospital reported 90 confirmed cases between August 2006 and July 2007.

The routine *Ae. aegypti* control programs. The vector control program in Trujillo deals with dengue and chagas disease, but its 24 members devote 85–90% of their time to *Ae. aegypti* control. Activities comprise adulticiding (indoor spraying with malathion 94% ultra-low-volume [ULV] in emulsion at 16% or 8%) and larviciding (with Abate 1% or 4%) in a radius of 200 m around a reported Dengue case. When the number of clinical cases starts increasing substantially, local outdoor spatial spraying by truck with malathion 94% ULV is added.

In Laem Chabang, the municipal government organizes the routine *Ae. aegypti* control. Activities consist of swing thermal fogging with portable equipment, outdoor and indoor, in a radius of 100 m around a clinical Dengue case, two to three spatial outdoor spraying campaigns per year, by truck, covering the whole municipality (both with deltamethrin ULV) and periodic distribution of Abate 1% among all households. The 5-person municipal vector control team and 110 village health volunteers, occasionally supported by the municipal hospital, carry out all activities.

The ITC interventions. In Trujillo, 10 clusters of around 400 houses were purposively selected from the 18 districts that had dengue notification rates of at least 400/100,000 inhabitants. The inclusion criteria at cluster level were

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middle or low socio-economic status (the number of high socio-economic level clusters was small and they were not representative of the overall area) with fewer than 50% of the population residing in apartment blocks (for operational reasons). The ITC (PermaNet, Vestergaard Frandsen Group S.A., Lausanne, Switzerland) used were white, plain, 2 × 2 m, with long-lasting 55 mg/m² deltamethrin impregnation and UV protection. They were implemented through two different channels, each in five randomly allocated clusters: the routine vector control program (the “Vertical Model”) and the local Health Committees, existing grass-root organizations attached to health centers (the “Partnership Model”).

The curtains in Laem Chabang had the same characteristics but were smaller and came in two sizes (1.5 × 1.5 m for windows, 1.5 × 2 m for doors). They were distributed in 22 clusters by the village health volunteers supervised by the Municipal Vector Control Program and a team of the Chonburi Regional Disease Control Office (the “Partnership with Supervision Model”). The clusters, of around 100 houses and defined by infrastructural boundaries, were randomly selected in four town districts with urban characteristics.

These three models were developed through negotiation with all stakeholders in Venezuela and Thailand and perceived as appropriate and functional approaches for ITC distribution in the local context.

Curtain implementation chain. In both countries, the implementation process can be divided into two stages: Set up and preparation of ITC distribution and actual distribution to the households. After distribution no specific activities were developed. In Venezuela, ITC were shipped to the port of La Guaira, transported to the Research Institute in Trujillo, and subsequently to the warehouse of the vector control program (Vertical Model) or to the offices of the local Health Committees (Partnership Model). In the Vertical Model three meetings with researchers and the vector control team were held to share technical information on the ITC before distribution. The research team also held one meeting with the communities to explain the project. In the Partnership Model, three training sessions were organized with each health committee to empower and technically prepare it.

Distribution in the Vertical Model clusters was organized in line with the routine Abate distribution. In 5 working days in July 2007, 3 teams of 5 men visited all households, handed over the ITCs, and provided information on their use. In the Partnership Model, each local health committee first mobilized its members, local leaders and volunteers to promote the ITCs in the community. Actual distribution occurred from mid-July to mid-September 2007 by a house-to-house visit, mainly between 5 and 8 p.m. In both models, the number of ITC distributed corresponded to the number of windows, with a maximum of 5 per household. Residents of study households themselves hung up the ITC, without assistance of the distributors.

In Thailand ITC were shipped to the port of Bangkok, transported to the warehouse of the Regional Disease Control Office, subsequently to the Laem Chabang Municipality, and finally to the houses of the Village Health Volunteers. A first meeting between the research team, the leaders of all involved communities, and Municipal Health Authorities, clarified the objective and process of the intervention. Then, in all clusters Village Health Volunteers were selected among the existing ones and they assisted with a 1-day training session organized by the research team.

Actual curtain distribution in the Partnership with Supervision Model clusters took place in March–April 2007. The Village Health Volunteers provided to every household a leaflet with instructions on the use and maintenance of ITC, and briefly explained its content. A maximum of 5 curtains per house (1 for the door and 4 for the windows) were distributed, and the residents of the study households hung up the ITCs. If curtains were not hung up at a check-up visit 1 week after distribution, residents were encouraged to do so and assisted if necessary.

Perspective of the cost study, cost classification, data collection, and analysis. We took the societal perspective¹⁵ to estimate the cost of the routine *Ae. aegypti* control programs and the economic resources consumed by each implementation model.

We classified all cost as recurrent (personnel, supplies and materials, operation and maintenance of vehicles and equipment, utilities, rent of transport or infrastructure) or as capital (ITC, depreciation of vehicles, equipment).¹⁶ The ITC were donated, but we costed them at their actual price provided by the manufacturer. In line with Armien,¹⁷ we added 20% of administrative cost for the routine *Ae. aegypti* control programs.

We measured the time that health sector personnel, researchers, and volunteers used from daily records of time spent per activity or from semi-structured interviews. For formally used personnel the value of the time was deduced from their gross salary. Per diems for outreach activities were included in the category of personnel cost. Volunteers were not paid, but to value the time they invested we used the minimum wage rate per hour, US\$1.19 in Trujillo and \$0.65 in Laem Chabang.

Supplies and materials included insecticides and larvicides, fuel for spraying, office material, supplies for personnel (gloves, protecting clothing, etc.), and others (spare parts for vehicles and spraying equipment, lubricants and fuel for transportation). The information on quantities consumed was obtained from daily/monthly use records. All supplies and materials were costed at market prices. Expenditure on utilities (electricity, water, telephone) and on maintenance and rent of vehicles and equipment was extracted from accountancy records. The operating cost of the vehicles was estimated from km traveled or fuel consumed.

The depreciation of the capital goods was allocated proportional to the time of use. We valued it by annuitizing,¹⁸ at 3% interest rate, normal length of life, 20% scrap value, and market price replacement cost.

The total number of ITCs distributed and the number of households that accepted to receive and intended to use the curtains (≥ 1 curtain in the household) was obtained from signed-off distribution forms. The number actually hung and household coverage (≥ 1 curtain in the household) were verified in a survey of 508 and 373 randomly selected households in Venezuela and Thailand respectively.¹⁹

All costs were calculated at 2007 prices and converted to US\$ at the official exchange rate (Venezuela: 2150 Bs = 1 US\$, Thailand: 33 BTH = 1 US\$). For the routine *Ae. aegypti* control programs, we calculated the yearly cost per household in Trujillo State and Laem Chabang Municipality. For the different implementation models, we calculated the average cost per curtain distributed, inhabitant, household, and household covered at distribution (i.e., accepting at least one curtain) in the intervention clusters.

TABLE 2
Total cost (US\$) and average cost* per insecticide-treated curtains (ITC) distributed: Trujillo, Venezuela and Laem Chabang, Thailand, 2007

	Venezuela						Thailand		
	Vertical model			Partnership model			Partnership model with supervision		
	Total cost	Average cost p.c.d.†**	%	Total cost	Average cost p.c.d.	%	Total cost	Average cost p.c.d.	%
Set up									
<i>Delivery to the distribution points</i>									
Personnel	433.5	0.06	3.2	808.5	0.14	5.9	298.6	0.05	2.3
Cost ITC	10,520.8	1.46	76.9	8581.9	1.46	63.0	6,897.4	1.06	54.0
Custom	18.6	0.003	0.1	15.2	0.003	0.1	0.00	0.00	0.0
Supplies and materials	2.3	0.0003	0.002	2.3	0.0004	0.02	30.7	0.005	0.2
Utilities	148.5	0.02	1.1	166.4	0.03	1.2	2.9	0.0004	0.02
Transport operation or rent	283.2	0.04	2.1	286.8	0.05	2.1	1,296.2	0.20	10.1
<i>Subtotal</i>	<i>11,406.9</i>	<i>1.58</i>	<i>83.4</i>	<i>9,861.1</i>	<i>1.68</i>	<i>72.4</i>	<i>8,525.8</i>	<i>1.31</i>	<i>66.7</i>
<i>Training and Promotion</i>									
Personnel	505.6	0.07	3.7	603.4	0.10	4.4	772.1	0.12	6.0
Supplies and materials	5.9	0.001	0.04	106.2	0.02	0.8	110.9	0.02	0.9
Utilities	99.3	0.01	0.7	20.4	0.003	0.1	7.4	0.001	0.1
Transport operation or rent	85.6	0.01	0.6	24.5	0.004	0.2	62.2	0.01	0.5
Rent of building	0.0	0.0	0.0	0.0	0.0	0.0	463.6	0.07	3.6
<i>Subtotal</i>	<i>696.4</i>	<i>0.10</i>	<i>5.1</i>	<i>754.5</i>	<i>0.13</i>	<i>5.5</i>	<i>1,416.4</i>	<i>0.22</i>	<i>11.1</i>
Total set up	12,103.3	1.68	88.5	10,615.5	1.81	77.9	9,942.1	1.53	77.8
Distribution									
Personnel	1,263.5	0.18	9.2	2,980.5	0.51	21.9	1,624.9	0.25	12.7
Supplies and materials	31.8	0.004	0.2	22.7	0.004	0.2	1005.9	0.15	7.9
Utilities	0.0	0.0	0.0	0.0	0.0	0.0	6.1	0.00	0.05
Transport operation or rent	128.4	0.02	0.9	0.00	0.00	0.0	122.8	0.02	1.0
Capital amortization costs	147.9	0.02	1.1	0.0	0.0	0.0	81.1	0.01	0.6
Total distribution	1,423.7	0.22	11.5	3,003.2	0.51	22.1	2,840.8	0.43	22.2
ALL COSTS	13,674.9	1.90	100.0	13,618.7	2.32	100.0	12,782.9	1.96	100.0

* Numbers were rounded.

† p.c.d. = per curtain distributed.

ecologies, mixes, and intensities of activities hamper cross-country comparisons. A recent study of a wide variety of interventions in different settings²¹ reports cost per household ranging from US\$0.48 in the Philippines to \$8.38 in México. Our estimates for Venezuela (US\$2.14) and Thailand (US\$1.89) are at the lower end of this range. On the other hand, Suaya²⁰

TABLE 3
Structure, output, and unit costs of insecticide-treated curtains (ITC) distribution: Trujillo, Venezuela, and Laem Chabang, Thailand, 2007

	Venezuela		Thailand
	Vertical model	Partnership model	Partnership model with supervision
Number of inhabitants	9,248	10,262	4,179
Number of households	1,965	2,145	2,036
Number of clusters	5	5	22
Average number of houses per cluster	393	429	93
Number of ITC distributed	7,206	5,878	6,507
% of households covered at distribution	78.7	75.7	94
Average number of ITC distributed per household	4.66	3.62	3.4
Number of persons distributing ITC	12	26	96
Total number of hours worked	480	2,848	1,708.5
Productivity (ITC/person/hour)	15.01	2.06	3.81
Average number of days to cover 1 cluster	1	24	7
% of households covered at 22 month	37.9	38.9	59.7*
Cost per distributed curtain	1.90	2.32	1.96
Cost per inhabitant	1.48	1.33	3.05
Cost per household	6.95	6.34	6.27
Cost per household covered	8.84	8.38	6.68

* At 18 months.

reported a yearly cost of US\$0.60 per household for applying larvicides biannually, using temporary personnel and attaining 23.0% coverage. In terms of type of activity and personnel used (volunteers) this comes close to the control program in Laem Chabang. The cost structure is also similar, insecticides and larvicides followed by personnel, but the resource use per household per year is higher in Laem Chabang because of additional biannual adulticiding in the whole municipality. Armien¹⁷ reported a cost of US\$4.40 per household during a Dengue epidemic in Panama. Despite higher resource consumption attributable to proportionally more personnel, with higher nominal wages, and, obviously, higher consumption of insecticides and larvicides, the cost structure is similar to the one we observed in Trujillo. The main driver is the use of professional personnel, and supplies, including insecticides and larvicides, only range second. The same pattern, but at a substantially higher yearly cost per household, because of much higher program intensity, is also observed in Cuba.¹¹

Studies on the costs of implementing ITC to control *Ae. aegypti* have, to our knowledge, not been performed before. Because we took a societal perspective we included the opportunity cost of the time of the volunteers, and we covered all financial and economic costs of the supply chain from the manufacturer to the household. Curtain implementation is more efficient, from the societal perspective, when executed by the routine *Ae. aegypti* control program. The productivity in terms of number of curtains distributed per man per hour is substantially higher than in the Partnership Models, relying on volunteers, probably because professional staff has experience distributing vector control tools, does so in a standardized way, and has the necessary logistic support. Notwithstanding the distribution of the ITCs by unpaid volunteers leads to savings

from the point of view of the Ministry of Health. However, time invested by the community constitutes an opportunity cost that should be taken in to account.¹⁵ Furthermore, the comparable coverage decline after 18 months indicates that distribution by partnership models does not lead to more sustainability. This should be linked to the fact that, after distribution, no further activities were developed to promote continued ITC use. It is also in line with observations that involving communities in complementing and rather than substituting for activities of the routine program leads to more effective and sustainable *Ae. aegypti* control.^{8,22,23} A partnership model wherein community members concentrate on promoting uptake and sustained use of ITC and the control program takes care of the actual distribution might be preferable.

Very few studies have reported on ITC effectiveness and no clear evidence exists on the effectiveness of routine *Ae. aegypti* control programs. The latter should not be a surprise, given the little evidence on the effectiveness of the building blocks of such programs, be it (peri-) domestic spraying against adult mosquitoes²⁴ or chemical and biological interventions targeting immature stages.²⁵ Erlanger and others²⁶ ventured a meta-analysis and found, in an array of controlled studies of variable quality, a more than 3-fold reduction in Breteau index with chemical control combined with environmental management. For ITC, Kroeger and others¹² imputed a 2.5- to 3-fold decrease in the pupae per person index at 9 and 12 months in Venezuela and Mexico, respectively, but could not fully control for temporal trends. Vanlerberghe and others¹⁴ showed that the effect of ITC depends on coverage and that with 50% coverage a 2-fold reduction in Breteau index can be expected. However, both these studies measured the incremental effect of ITC on top of the unknown effects of existing routine vector control programs and could not assess the effectiveness of either alone—let be their interaction.

Let us assume, for the sake of argument, that routine ITC implementation were as effective as the multi-modal current routine interventions in Venezuela and Thailand. Then—because ITC implementation costed over three times per household more than routine control activities—this effectiveness should last for about 3 years to make ITCs equally cost-effective. This may not be a very plausible assumption. First, the manufacturer announces a residual adulticiding efficacy of up to 2 years (<http://www.vestergaard-frandsen.com/permanet-curtain-e-brochure.pdf>, accessed 22/05/2008). To date the only published evidence under field conditions relates to—admittedly, excellent—effectiveness after 12 month.²⁷ Second, ITC coverage in Venezuela decreased, in our study, to less than 40% at 22 months. The picture would of course change if the cost of ITC implementation could be reduced. Because the curtain itself is the main cost driver, and since the other costs can hardly be compressed, this requires a substantial reduction of the ITC price set by the manufacturer.

Notwithstanding, in countries that already invest heavily in routine *Ae. aegypti* control, program managers may possibly consider the use of ITC to partially replace other chemical control activities directed at the adult vector. Unfortunately, no hard evidence permits to estimate whether ITC implementation, current routine control, or a combination of both, would be more cost-effective in concrete epidemiological situations. More in-depth economic studies of *Ae. aegypti* control methods and strategies are urgently needed to guide policy formulations.

Received September 23, 2010. Accepted for publication January 17, 2011.

Acknowledgments: We are grateful to the populations, health committees, and village health volunteers who participated in the study. We thank the field research teams for their interaction with the communities and for conducting the entomological, economic, and coverage surveys. We are indebted to the vector control programs for making the cost data from the municipal level available. We also thank Vestergaard-Frandsen for providing the ITCs free of charge.

Financial support: The study reports partial results of the project DENCO-Towards successful dengue prevention and control, financed by the European Union (INCO-CT-2004-517708).

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