Centralized Vs. Community-Based IRS Delivery Models:

A Threshold Cost-Analysis

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INTRODUCTION:

Symptoms of malaria afflict five hundred million people annually and approximately two hundred forty million new cases occur every year.[1] Malaria disproportionately affects the poorest of populations, with the highest prevalence in areas of Sub-Saharan Africa, Asia, Latin America and the Middle East.[1] Approximately 40% of the world's population is considered at risk of contracting malaria and the case mortality of the disease is highest among children under the age of 5.[1]

Symptoms of the disease begin with fever, headache and vomiting. They normally appear about fifteen days after the malaria parasite has entered the body from a mosquito bite. [2] If not treated, malaria can block blood flow to vital organs, potentially causing death, especially in children and pregnant women. Treatment for the disease usually relies on a program with artemisinin-based combination therapy (ACT) and intermittent preventive treatment (IPT) for pregnant women, as well as preventative measures for those at risk of infection through the use of Insecticide-Treated Bed Nets (ITNs) and/or Indoor Residual Spraying (IRS) [2].

Such a multi-faceted malaria control program was started in early 2004 for Bioko Island. Bioko Island is a part of Equatorial Guinea and is approximately 40 miles off the west coast of Cameroon. It has a population of just fewer than 200,000 and has substantial natural resources, including large quantities of natural gas and oil. Prior to 2004, malaria was highly endemic on Bioko Island; in 2004, malaria was found to have an estimated mortality rate of 86% for children under the age of 5[3].

With funding from a private sector consortium led by Marathon Oil in partnership with the government of Equatorial Guinea, the Bioko Island Malaria Control Project

(BIMCP) began in 2004. Wide-scale IRS started in 2004, followed by case management, including definitive diagnosis and effective treatment with ACT and IPT to pregnant women, the subsequent year. Distribution of free ITNs to the local population began in 2006. Since the start of the project, the incidence of malaria among children under the age of 15 has dropped precipitously, from 46% in 2004 to 26% in 2006 and the number of infected mosquitoes caught per 100 households has dropped from 2.25 to 0.1 during the same time period[3].

The IRS campaign conducted on Bioko Island has largely followed a centralized management approach that relies on a support / logistics team headquartered in the capital city of Malabo. Under this centralized plan, 14 spray supervisors oversee approximately 70 sprayers, all from the city of Malabo, who canvass the entire island and spray as many households as possible within the designated timeframe of 5 months[4]. Spray campaigns operate on a continuous rotating schedule that dictates 5 months of spraying, followed by 1 month of rest, resulting in 2 spray campaigns every year.[4]

IRS works through preventing the transmission of malaria from person to person. The type of mosquito most likely to spread the malaria vector typically bites at night and indoors. When it bites, it finds the nearest vertical surface to land in order to process the blood it has just received. If it were to bite an infected person, it could then move on to infect others. By spraying the walls of homes, the mosquito is killed upon landing there and prevented from spreading the vector[3].

Due to the evolving scope of the BIMCP (i.e. ITN distribution, case management, and IPT distribution, the IRS program) it was recently reevaluated after four years of operation in order to identify possible sources of inefficiencies. Here a framework for decentralizing the spraying campaigns to a community-level was suggested as a method of potentially saving project resources. Such a framework would involve dividing Bioko Island into geographical target areas that would house community sprayer teams responsible for conducting IRS in only their designated communities. If properly planned and implemented, it is believed that a decentralized IRS campaign will induce significant cost-savings due to the need for a smaller spraying timeframe while maintaining IRS coverage that is comparable to or perhaps better than the current centralized system[4].

There are also a number of other potential benefits inherent in the implementation of such a system. By employing local sprayers, the decentralized system may lead to more local involvement in the project, which in turn may engender greater acceptance of spray teams into community households, as well as greater oversight by community leaders. Community involvement may also improve the efficacy of other interventions such as having local spray teams ensure proper use of ITNs in each household they visit[4].

The drawback to the implementation of community-based IRS is a loss of central control. Centralized IRS campaigns are inherently better organized and more systematic in their coverage. Community-based IRS would require more coordination and oversight to ensure all households that are receptive to having their houses sprayed are, in fact, sprayed[4].

Any malaria control project is appropriately evaluated by the effect it has on the youngest of the population. With an average bite rate of three hundred and fifty per day per person, it is expected that a large portion of the population will eventually receive the malaria vector in Bioko. However, greater damage is far more likely to occur if the infection happens at a young age. As mentioned earlier, the mortality of those under 5 years old infected with malaria is extraordinarily high and much more so than those who are over 5[4].

In order to determine whether a decentralized method of indoor residual spraying is cost effective, we conducted a cost-effectiveness analysis (CEA) on the incremental cost savings of the method with the subsequent difference in cases averted in the population under 5 years of age on Bioko Island. We will use cost data and detailed census data provided by BIMCP in order to estimate the potential costs of the proposed intervention.

The primary outcome of interest is the ratio of incremental cost savings to incremental cases averted.

METHODS

We will use a computer-based simulation model of malaria incidence in Bioko Island, Equatorial Guinea to compare the costs and effects of altering delivery methods of Indoor Residual Spraying (IRS). Age-specific measures of these inputs were derived through the estimated reductions in incidence shown in previous studies conducted in high transmission areas similar to Bioko Island.[1] We also use data compiled from the malaria control project on Bioko Island to determine the probability and cost of IRS delivery per household under each delivery model and the related chance of malaria infection among sprayed and unsprayed households.

Estimations of Cost

The financial costs associated with this project include the costs of the chemicals involved in the spraying, training and payroll expense for the sprayers, management and supervision expenses, and costs of transportation.

Category	**Centralized Spraying Method** (people/combined work days)	**Community Based** (people/combined work days)	**Estimated Budget Differences**
Core Supervisors	14/ (14x365) = 5,110	16/ (16x155) = 2480	**Community Supervisors** will cost **51.5%** less than in centralized method
Core sprayers	70/ (70x365) = 25,550	NA	**Community Sprayers** will cost approximately **38.7% less** than in the centralized method.
Rural Community Sprayers IEC	NA	60/ (60x22x2) = 2,640	
Urban Community Sprayers IEC	NA	148/ (148x44x2) = 13,024	

fig 1: Personnel data taken from Allen

Cost savings for the de-centralized method are the result of a decrease in the number of days required to spray homes. Under the centralized method, spray teams are deployed throughout the island for the entire year. Because the spray only lasts six months, two sessions must be done in each home. As it currently operates, this requires the 70 core sprayers on the island to operate on a yearlong basis to maintain spray levels appropriate for protection.

The decentralized spraying method requires more sprayers as well as more supervision due to the loss of a centralized control. In doing this, however, they increase the speed with which they can deliver the spray to homes. Each spray team needs 22 days in a rural community to spray the homes and 44 days in an urban community. Because the chemicals still need to be applied twice a year, these days are doubled to total 15,664 days of spraying compared to the 25,550 days required with the centralized method. Supervision requires less time because a larger portion of the year is now inactive.[2] The result is cheaper personnel costs.

The total annual cost of IRS using the centralized version in 2006 was $6,787,747.[6] This includes both spray sessions during the year. Using the analysis calculated by Allen, we attributed the total cost of the decentralized method to be $5,742,940. This is an incremental difference of $1,044,807 which will be used in the calculation of cost per house sprayed.

Because the total cost of the project includes benefits to inhabitants older than our target population, we adjusted the costs to get a more reasonable figure for the cost per case averted. The under 5 population constitute 19.75% of the total population so we attributed $1,340,782 of the intervention to our population of interest. Using the analysis calculated by Allen regarding the cost savings of a community based approach; we estimate the costs from the decentralized method to be $1,134,407. This is an incremental difference of $206,375.

Estimations of Effectiveness

The effectiveness variable in getting homes sprayed is the result of three different measurements: the probability that a home will get visited by the spray team, the probability the owners are at home and the probability that they allow the sprayers to spray. The effectiveness variable is determined in this manner:

P(sprayers visit) X P(owners are home) X P(spraying is allowed) = effectiveness in spraying homes

The population in Bioko Island is 198,851 with approximately 39,770 households and 5 occupants per household. In 2006, the IRS program sprayed 77% of the households on Bioko Island, which resulted in a population of approximately 153,115 people living in a sprayed household.[5] In the decentralized model, the coordination of the community spraying teams may be less effective initially in both the probability of a house being sprayed and the incidence of malaria after being sprayed due to the logistical difficulty of organizing all eight teams at once. To account for this uncertainty, we ran a threshold analysis to determine how effective this spraying method must be in order to be equally cost effective as the centralized method given its reduced cost.

Estimations of Health Effects

The efficiency of the two programs was measured in terms of the prevalence of malaria in the area where the programs were implemented. We assumed the difference between the two groups to be the effect of the IRS program and not any difference in the use of bed nets or any other factor. This assumption is valid given that the incremental application of malaria control methods allowed for substantial gathering of evidence of IRS effectiveness with and without bed nets.

The incidence of malaria in Bioko Island in 2006 was 26%.[5] Compared with the incidence of malaria prior to the control project began, this amounts to 40,396 cases averted as a result of the centralized spraying method.

The population of under 5 citizens in Bioko in 2006 was 39,278. Using the incidence rate currently on the Island, we approximate that 10,212 under 5 citizens will contract Malaria with 7,889 cases averted as a result of the IRS project. There were 8,798 deaths due to malaria in under 5's in Bioko in 2006 giving a case mortality rate of 86.2%.

A study conducted by Kleinschmidt et al in Bioko found that spraying houses did have a herd immunity effect on the population. Before the malaria control campaign had begun, prevalence of malaria on Bioko was at 46% in 2004. That same year, the malaria control project began a campaign of offering bed nets and a centralized IRS program. By 2006 the prevalence on the Island had dropped to 26%. This was further disaggregated to determine the incidence rates in households that did receive IRS (23.5%) and the rate in houses that did not (34%).[5]

Because our model is concerned with the prevention of infection in children under 5, our model followed a cohort of theoretical Bioko Island inhabitants over that course of their lifetime. From the outcomes of these models, we are able to derive relative cost-effectiveness measures for each IRS model from the perspective of society.

Study Design

The main factors influencing cost and effectiveness in the two spraying models are presented in figure 2. The tree is separated at the decision node based on the centralized method of spraying or the decentralized method. From here the population is split into whether or not their homes were sprayed based on the probabilities listed in Kleinschmidt et al's paper, then separated into the probability of becoming infected.

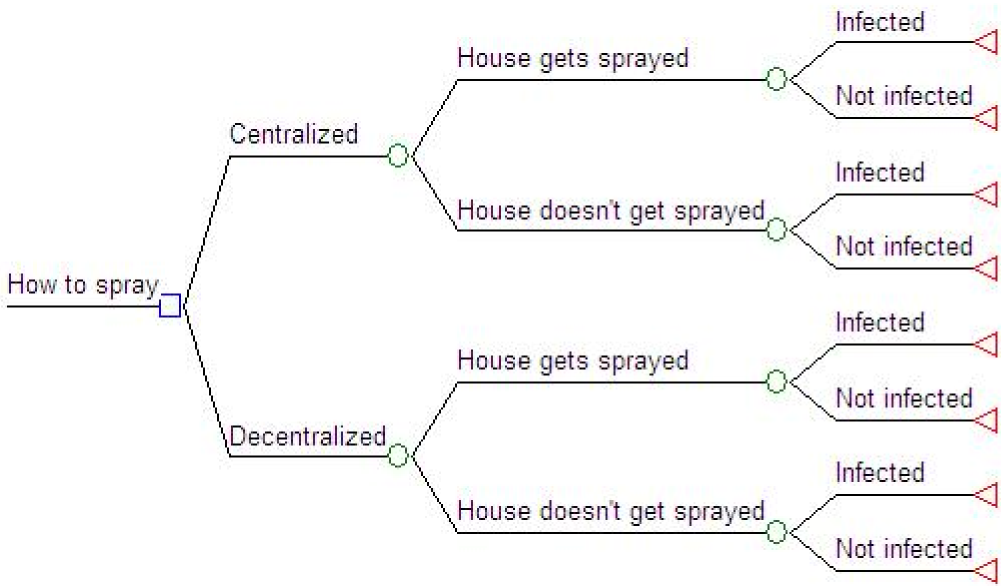

fig. 2: Decision tree

Study Outcomes

Our study is limited by the lack of data concerning the effectiveness of the community-based program in preventing malaria. This uncertainty is present in two important variables: the percentage of households receiving IRS and the incidence of malaria within those households. To account for this, we ran a threshold analysis for both of these variables to determine how effective each one would have to be in order to be equally cost effective as the centralized method.

In order to conduct this analysis, we held the second of the two variables constant with the centralized method and individually calculated the effectiveness measure necessary to create a cost effectiveness ratio equal to the ratio in the centralized method. In other words, when we calculated the threshold ratio for percentage of households sprayed, we assumed the incidence of malaria in houses sprayed using the decentralized version to be the same as that in houses sprayed by the centralized version (23.5%). Similarly, when we calculated the threshold for incidence in the decentralized version, we assumed the probability of a household getting sprayed to be the same as that of the centralized version (77%).

Our simulation utilizes a decision tree model to generate the incremental cost effectiveness between two groups progressing through models with a centralized IRS team or a community-based IRS team. Because we do not have effectiveness data for the decentralized version we calculated a range for the cost effectiveness of the model based on our threshold analysis. The data ranges from an assumption of the decentralized method being as effective as the centralized method (good case) to a situation where our two thresholds for probability of a house being sprayed and incidence of malaria were used (bad case).

RESULTS

The centralized IRS model prevents 7889 cases of malaria from occurring in the under 5 population for a cost effectiveness analysis ratio of $169.96 per under 5 case averted. It also sprays approximately 6049 households in the under 5 population for a cost of $1,122.13 per household sprayed.

The threshold analysis shows that in order to be equally cost effective, the decentralized version must spray at least 65.1% of the households. This is assuming the spraying method is just as effective at preventing malaria as the centralized method (incidence of 23.5% in households sprayed). If we hold the percentage of households sprayed constant at 77%, the decentralized method must have an incidence of malaria no higher than 27.2% in households sprayed in order to have an equal level of cost-effectiveness as that of the centralized method.

Spray Method	Cost per Case Averted	Cost per House Sprayed
Centralized Method	$169.96	$1,122.13
Decentralized Method (worst case)	$175.82	$1,122.13
Decentralized Method (best case)	$143.79	$949.43

fig. 3: Costs of spray methods

Worst Case

In a situation where our two threshold analysis values hold true in the decentralized program (65.1% of homes sprayed, 27.2% incidence in sprayed homes) the cost effective ratio for the program is $175.82 per case averted (6,452 cases) and $1,122.13 per household sprayed (5114 homes). The case averted ratio is less than that of the centralized method.

Best Case

In a case where the decentralized method has effectiveness values equal to that of the centralized method (77% of households sprayed, 23.5% incidence in sprayed households) the cost effectiveness ratio falls to $143.79 per case averted and $949.43 per household sprayed. Both are better averages than the centralized method.

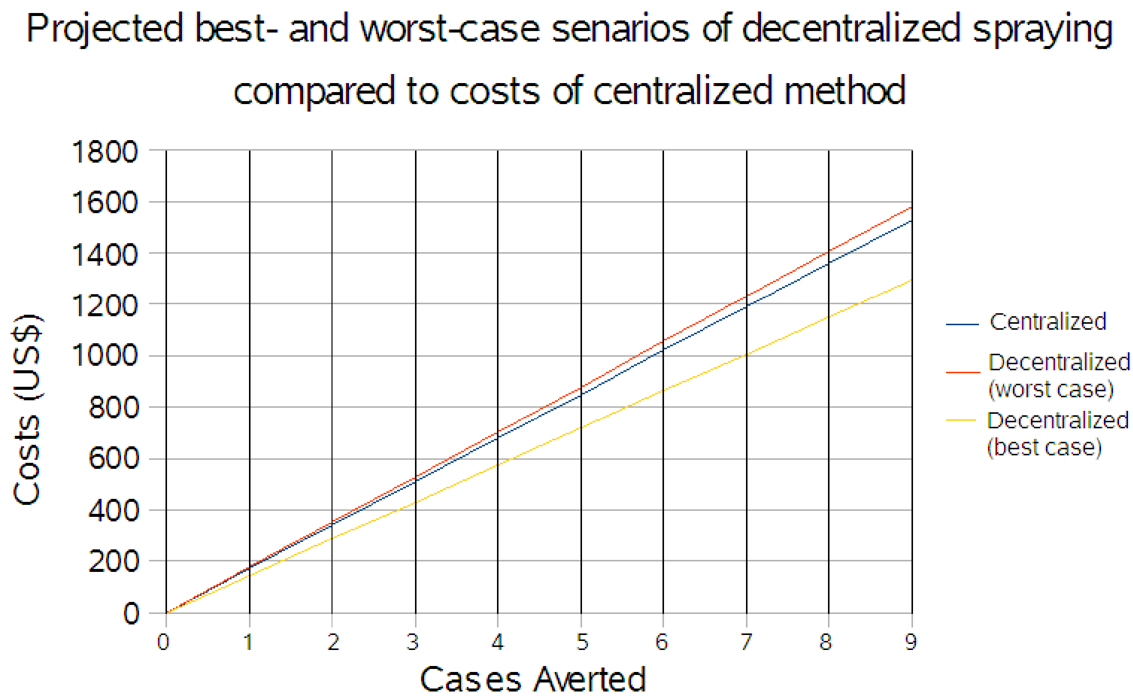

fig. 4: Graphic depiction of costs associated with centralized and decentralized methods

DISCUSSION

All figures associated with the decentralized model of IRS were calculated based in part by the speculation of Richard Allen of the MENTOR Institute. Allen hypothesizes that this method will not only cost less but end up being more effective, due to the fact that the sprayers are members of the community and lack the implicit agent-principal dilemma of the centralized version populated by sprayers from Malabo. In addition, Allen is optimistic that having local sprayers will increase the likelihood of being accepted into the populations home and make the residents more amenable to accepting advice regarding how to prevent malaria.

Because the decentralized method has yet to be instituted we can neither confirm nor deny Allen's projections regarding the effectiveness of the new method. His projections regarding cost, however, seem to be more stable as the community-based method does result in fewer spraying days and consequently less cost. It should, however, be noted that because we do not have data based on observation, we cannot conclude unequivocally that unforeseen costs will cause the decentralized method to be less cost saving or even more costly than the centralized method. It may also be less effective than our worst-case scenario threshold due to the relative lack of control over its implementation

Our study has other limitations that must be taken into account. Our estimates on costs are based on figures provided by Medical Care Development International and a presentation the project manager, Dr. Christopher Schwabe, gave to the American Society of Tropical Medicine and Hygiene. In this presentation, Dr. Schwabe lists the personnel costs of the program as an aggregate rather than by administration and sprayers. To make the most conservative estimate possible, we considered the lower of the two percentages proposed by Allen (38.7%) to be the cost savings from the decentralized method. A more appropriate calculation would cause the cost effectiveness ratio of the decentralized method to be even more cost effective than the centralized method.

Our data for the effectiveness of the centralized method is based on a 2006 household and parasitemia study. More recent data may reflect a change in malaria's prevalence on the Island. In addition, the incidence and prevalence rates for the Island as a whole were used as the estimates for children under 5 years old. If available, more age specific data may indicate a difference for our population of interest.

Finally, differences in the use of ITNs may have confounded the results of spraying methods. While every household has equal access to bed nets we cannot account for any idiosyncratic uses of the nets by the individual i.e. whether once distributed they are used or used correctly.

Future Use

The next step for this discussion is to gather data based on the decentralized method. Once we have a better concept of how effective and how inexpensive this method will be, we can better indicate if it is more or less cost effective than the centralized method.

Because malaria has such a pervasive and devastating presence on the Island, efficient use of the resources available is integral to its management. Until recently, an IRS program has not be utilized as a means of controlling the spread of the disease but the history of this method highlights its effectiveness. In the 1950's and 60's it was the liberal use of Dichloro-Diphenyl-Trichloroethane or DDT that halted the spread of malaria in most industrialized nations[2]. Past research has shown that using more modern chemicals in a systematic fashion is a cost effective means of transmission control[2]. What our research attempts to show is that it can be even more cost effective by giving control of the project to the people who stand to benefit most from it.

It should be noted that although the community-based IRS model may, in fact, be much more cost-effective, the organizations implementing the BIMCP project may decide that the determined threshold of acceptable household coverage is impossible for the hypothetical model to achieve. As the decentralized model relies on tremendous local buy-in and human resources that may be non-existent outside the capital of Malabo, it is important to consider other logistic variables that would affect the successful implementation of community-based IRS. Our analysis should only be used as an initial first step in assessing the potential adoption for a community-based IRS model.

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