Agenda

➡ Client Background
➡ Problem Description
➡ Solution Strategy
➡ Model
➡ Deliverables
➡ Value
Client Background

World Health Organization

- Responsible for providing leadership to all UN member nations on global health matters

Public Health Mapping Group

- Data analysis, process and visualization via Geographic Information Systems (GIS)
Problem Description

➡️ Malaria
  • 300-500 million cases per year and over 1 million deaths
  • Prevention methods
    • Indoor Residual Spraying (IRS)
    • Long-Lasting Insecticide Treated Bed Nets (LLIN)

➡️ No existing procedure for optimal allocation of limited prevention resources
  • Arbitrary distribution
  • Detrimental effects of excessive spraying
Solution: Strategy

Create a systems-based approach to minimize the incidence of malaria with limited resources.

Swaziland as pilot country
- Historical data availability
- Wide range of conditions

http://www.mara.org.za/
http://en.wikipedia.org/wiki/Swaziland
Data Sources

→ Mapping Malaria Risk in Africa (MARA)
  - Percentage risk estimation by region
  - 5x5 km spatial resolution
  - Start and end months of high malaria transmission

Swaziland: First Month of the Malaria Transmission Season

Swaziland: Last Month of the Malaria Transmission Season

http://www.mara.org.za/
Data Sources

→ HealthMapper

Road Infrastructure

Facility Infrastructure
Data Sources

- Costs and other intervention data
  - World Health Organization Malaria Costing Tool
  - UN Millennium Project
Model Objective

- An optimization model will allow for a systems-based approach to resource allocation and deployment for malaria prevention.

- Decisions include:
  - Where to locate Distribution Centers (DCs)
  - How many DCs to open
  - When DCs should be open
  - What regions DCs should serve
  - When to cover each zone
  - Number of people to protect in each zone
  - Labor, trucks, equipment, insecticide/nets to base at DCs
  - Labor, trucks, equipment to allocate to each zone
Model Overview

DC Placement Heuristic

Zone Assignment Heuristic

Resource Deployment Model

Decision Tool
DC Placement Heuristic

➔ Potential locations for DCs
  • Factors considered:
    • Population
    • Malaria risk
    • Infrastructure

➔ Scalable for other countries
  • Distance constraints adjusted by estimated area

\[
\text{Max. distance from center point: } \frac{d \cdot \sqrt{2}}{2}
\]
\[
\text{Min. distance between DCs: } \frac{d \cdot \sqrt{2}}{n / 2}
\]

*where \( d \) represents \( \frac{1}{2} \) the (estimated) height of the country, and \( n \) the number of DCs
DC Placement Heuristic

Malaria Risk

Population

Swaziland: Distribution of Endemic Malaria

Swaziland: Total Population Distribution 1995

Swaziland: 5 DC Placement
Zone Assignment Heuristic

Customer zones are serviced by a single DC
  • Straight-line distance: DC to customer zone
  • Road factor of zone considered (paved, unpaved)
IRS Resource Deployment Model

➡️ Objective: Maximize the number of people protected by a prevention method who are at risk of malaria.

➡️ Output: scheduled deployment plan

• What zones to target for spraying
• When to deploy in each zone
• How many people in each zone to protect
• Resources to base at DCs
Assumptions

⇒ MARA
  • Risk and transmission season accurately represented by MARA
  • 5x5 km MARA grids aggregated into ~15x15 km zones

⇒ Intervention
  • IRS with DDT
  • Materials ordered once per year, prior to deployment
  • 1 spray cycle per year
  • Straight line distances adjusted for road conditions of zone
## IRS Constraints

Deployment restricted by:

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Relative Effectiveness</th>
<th>Costs/Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Truck capacity</td>
<td>• Duration of DDT effectiveness</td>
<td>• Labor wages</td>
</tr>
<tr>
<td>• DC capacity</td>
<td>• Concentration of DDT per m²</td>
<td>• Opening and operating DCs</td>
</tr>
<tr>
<td>• Amount of resources based at DCs</td>
<td>• Coverage rate of spray personnel</td>
<td>• Vehicle rental and travel costs</td>
</tr>
<tr>
<td>• Zone population</td>
<td></td>
<td>• Equipment purchase and repair</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Cost of DDT</td>
</tr>
</tbody>
</table>
LLIN Resource Deployment Model

Advertisement of net pickup place and time to zones

- time(0) ... time (DC open)

- Zone(s)
- Zone(s)
- Zone(s)

DCs open for net pickup and instruction on proper use

- time(DC open) ... time (DC close)

- Zone(s)
- Zone(s)
- Zone(s)

⇒ Adapted output

- When to open the DCs
- What zones to target
- Number of public health workers and supervisors at DCs
- Extent of advertising in targeted zones
Recommendation

Effective Coverage of Population (w/ $500k Budget)

- 31,587
- 40,660
- 41,645
- 42,082
- 42,057
- 41,055

# of DCs

Effective Coverage (1000s)

World Health Organization
**Recommendation**

→ Labor based at each DC

<table>
<thead>
<tr>
<th>DC</th>
<th>Zone</th>
<th>Labor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>136</td>
<td>35</td>
</tr>
<tr>
<td>2</td>
<td>219</td>
<td>35</td>
</tr>
<tr>
<td>3</td>
<td>435</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>537</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Recommendation

Deployment schedule

4DCs: Coverage in Period 14

4DCs: Coverage in Period 15

*For full deployment schedule, see animation
## Sensitivity Analysis

<table>
<thead>
<tr>
<th>Parameter: Spray rate per worker (houses/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
</tr>
<tr>
<td>Objective Value</td>
</tr>
<tr>
<td>Objective Value / Total Cost</td>
</tr>
<tr>
<td>% Δ from base</td>
</tr>
<tr>
<td>Parameter Value</td>
</tr>
<tr>
<td>% Δ objective / % Δ Parameter</td>
</tr>
</tbody>
</table>
Model Interface

Decision-making application using Excel and VBA
  - Linked to Xpress-MP
Deliverables

- Optimization model
  - Description, specification of model

- Decision-making tool
  - Test interface in Excel
  - Output

- Sensitivity analysis
  - Objective response to changes in parameters

- Documentation
  - All assumptions, processes, and methodology
Value

➡️ Use of heuristics to estimate expected current deployment behavior

➡️ 3 heuristic variations, prioritize zones to cover by:
   • Greatest risk first
   • Greatest population first
   • Greatest combined risk and population first

➡️ All variations assume:
   • 1 DC in Mbabane (capital)
   • Equivalent objective, budget, and resource constraints
## Value

<table>
<thead>
<tr>
<th></th>
<th>$/Person Covered/Year</th>
<th>% Cost Reduction in Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>$1.32</td>
<td>-</td>
</tr>
<tr>
<td>Heuristic 1</td>
<td>$2.19</td>
<td>-39.73%</td>
</tr>
<tr>
<td>Heuristic 2</td>
<td>$2.52</td>
<td>-47.62%</td>
</tr>
<tr>
<td>Heuristic 3</td>
<td>$2.58</td>
<td>-48.84%</td>
</tr>
<tr>
<td>Research Average*</td>
<td>$2.59</td>
<td>-49.03%</td>
</tr>
</tbody>
</table>

## Value

<table>
<thead>
<tr>
<th>Model</th>
<th>Effective Coverage</th>
<th>% Coverage Increase in Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>376,874</td>
<td>-</td>
</tr>
<tr>
<td>Heuristic 1</td>
<td>213,087</td>
<td>76.86%</td>
</tr>
<tr>
<td>Heuristic 2</td>
<td>187,070</td>
<td>101.46%</td>
</tr>
<tr>
<td>Heuristic 3</td>
<td>191,525</td>
<td>96.78%</td>
</tr>
</tbody>
</table>
### Value

<table>
<thead>
<tr>
<th></th>
<th># of People (millions)</th>
<th>% of at Risk Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total at Risk in Africa</td>
<td>672</td>
<td>-</td>
</tr>
<tr>
<td>Current Coverage</td>
<td>193.05</td>
<td>28.73%</td>
</tr>
<tr>
<td>Potential Coverage</td>
<td>378.79</td>
<td>56.37%</td>
</tr>
</tbody>
</table>

Africa alone loses an average of 12 billion US dollars of income per year, because of *malaria*. WHO/Gates Foundation Project

Malaria Atlas Project [http://www.map.ox.ac.uk](http://www.map.ox.ac.uk)
Summary

- Problem Description
- Solution Strategy
- Model
- Recommendations
- Value
Questions?