Resilience in Disease Outbreak Response: Modeling Medical Laboratory Networks in Developing Countries

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Health System Logistics

Infectious disease outbreaks can arise suddenly, spread rapidly, and kill thousands. Poor response can lead to exponentially growing resource demands.

Goal: Deploy surveillance and treatment resources to minimize impacts to population health

Sandia is applying integrated models of health systems, disease propagation, and logistics to help improve performance and security in several countries.

Information

Detection and Surveillance ← Resources

Population and Disease Movement

Implementing Controls ← Resources

Planning Responses

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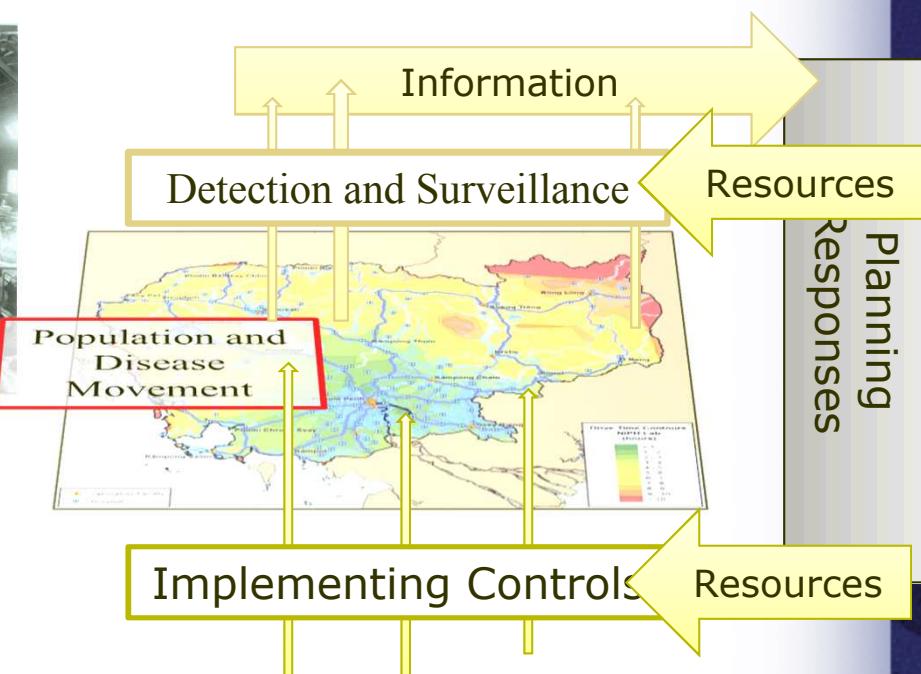
Ebola outbreak inspired the current model

Sandia delivered quick-response operational models to guide operational planning


SNL Liberia Network Model Diagram
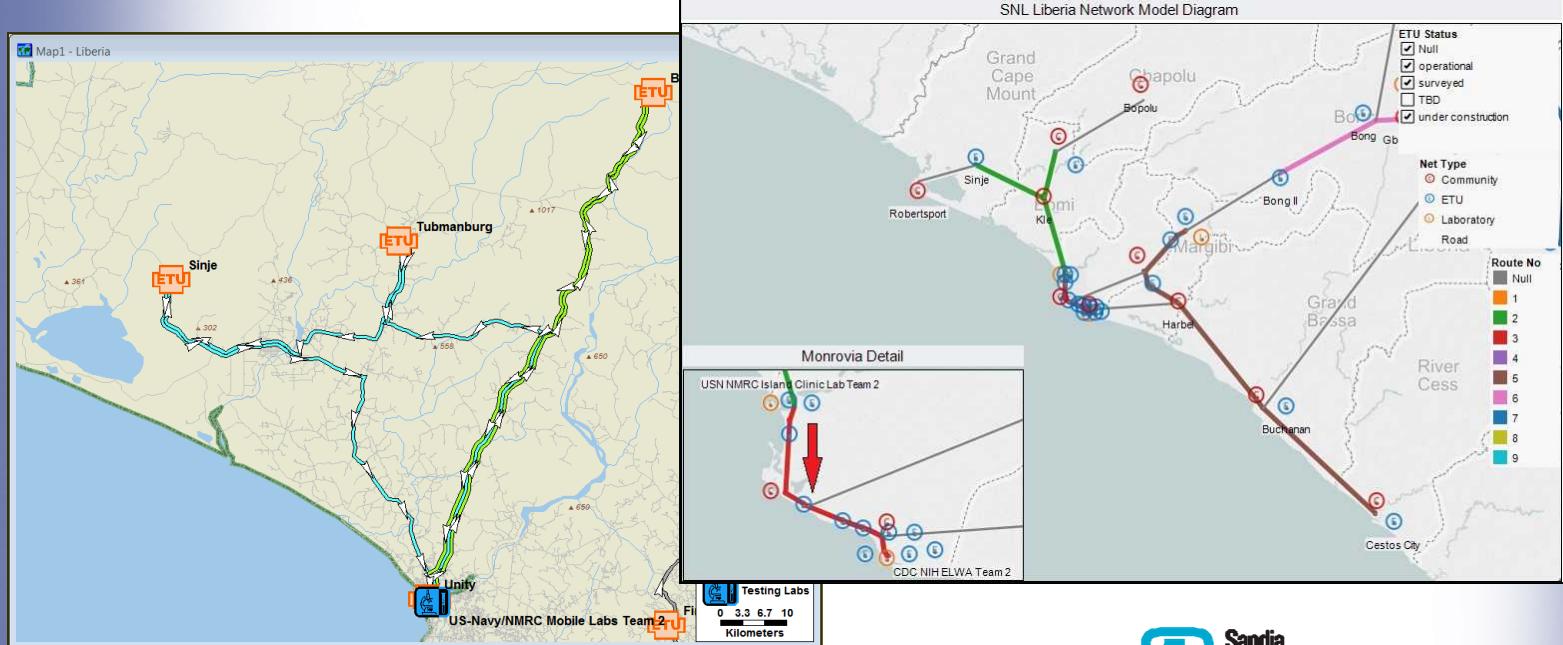
Problem: Slow Ebola Diagnosis in Liberia

- Rough roads, long distances slowed sample transport

- Blood samples took days to reach Ebola diagnostic labs

- Sandia modeled sample transport

- Model showed how to improve system and improve delivery of healthcare

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System modeling shows importance of transport


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Symptomatic          Sample Draws        Sample              Sample Testing
Patients                                 Transport

  ⬭                  ┌──────────────┐                    ┌──────────────┐
Community    ──▶     │    Ebola     │      ──▶            │ Diagnostic   │
                     │  Treatment   │                     │    Lab       │
                     │    Unit      │                     │              │
                     └──────────────┘                     └──────────────┘
                            ▲                                    ▲    ▲
                            └──────────────────┐                 │    │
                                    Test Results                 │    │
                                                          ┌──────────────┐
                                                          │   Supplies   │
                                                          └──────────────┘
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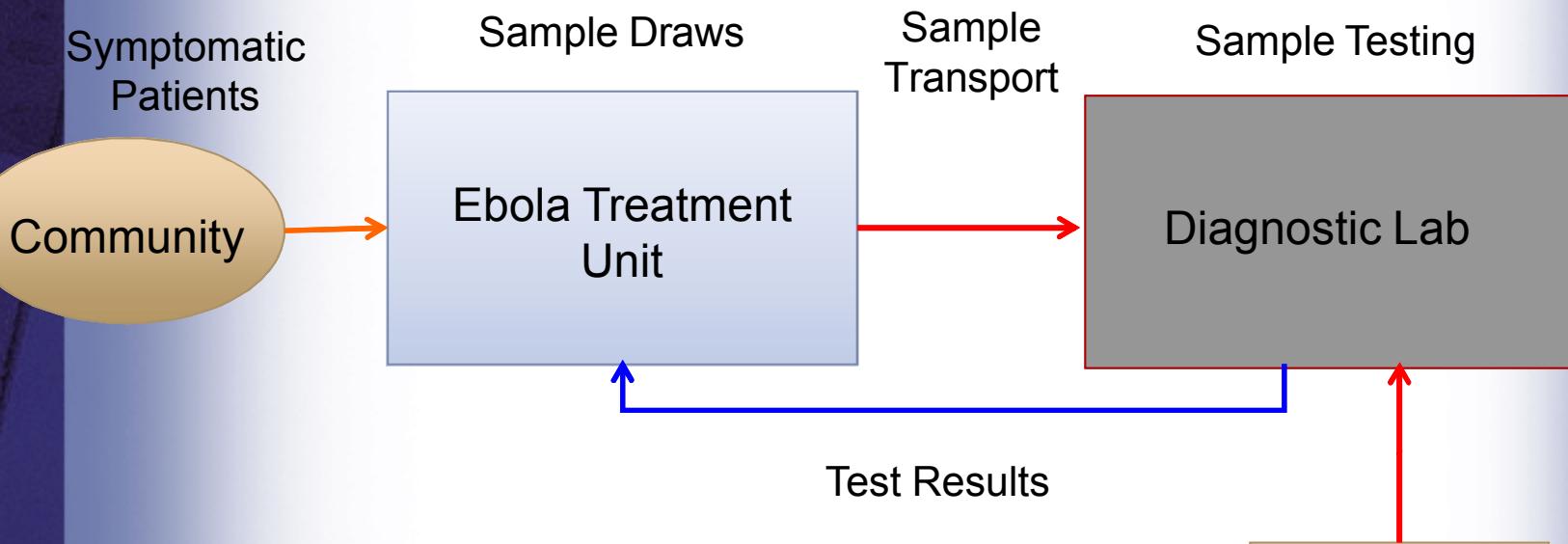
Modeling disease and treatment process showed public health benefits of better lab network.

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# Impacts: Network modeling in Liberia and Sierra Leone

- Used by DoD, CDC, NGOs, Liberia Ministry of Health

- Validated in-country

- USAID used results to implement national lab transport network

- Drawdown analysis for Liberia and Sierra Leone

- Operational feasibility of UAV outbreak-response deployment

- Apply lessons learned elsewhere?

Scenarios

— Surface transport (baseline)

— Direct UAV flight to Foya Lab

— Direct UAV flight to Foya, surface transport to LIBR

— Quad-copter to collection point, surface transport to Foya lab

Community
Primary - Unpaved
Secondary - Unpaved
Other Roads - Unpaved
Path
Portage
Driveway

Drone pickup location
Community accessible by path only
Drone route

0 5 10 15 20 25 30 35 40 45 50
Kilometers

Processes and Metrics

Communities diseases in populations

Clinics draw Samples

Labs analyze and report

Patient Access Patients choose clinics

Sample Transport Couriers take samples to a lab

Disease Contagion

Sample Collection

Investigation Ministry of Health and NGO programs do surveillance and outbreak investigation

Sample Analysis

System Performance:

- Throughput
- Cost
- Timeliness
- Security

Modeling laboratory networks in developing countries
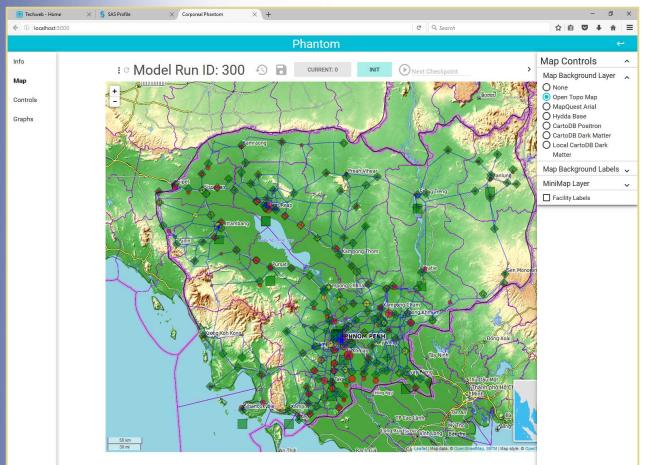
Map-based user interface

Configurable process modeling

Model combines data, modeling and intuitive user interface for metric-based decision making
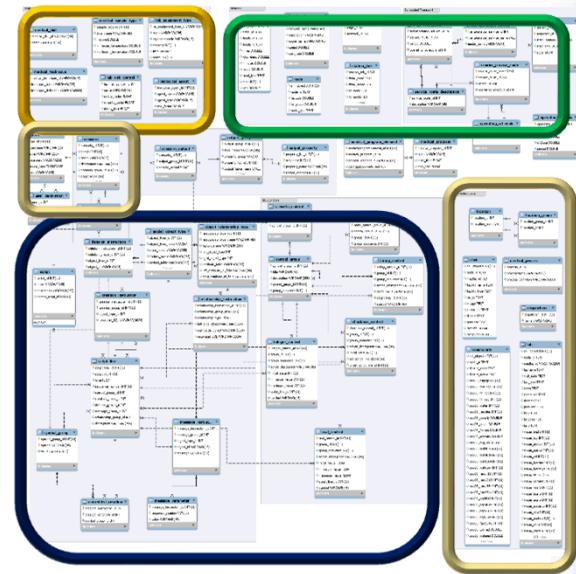
Database of laboratory and network information

Flexible deployment options
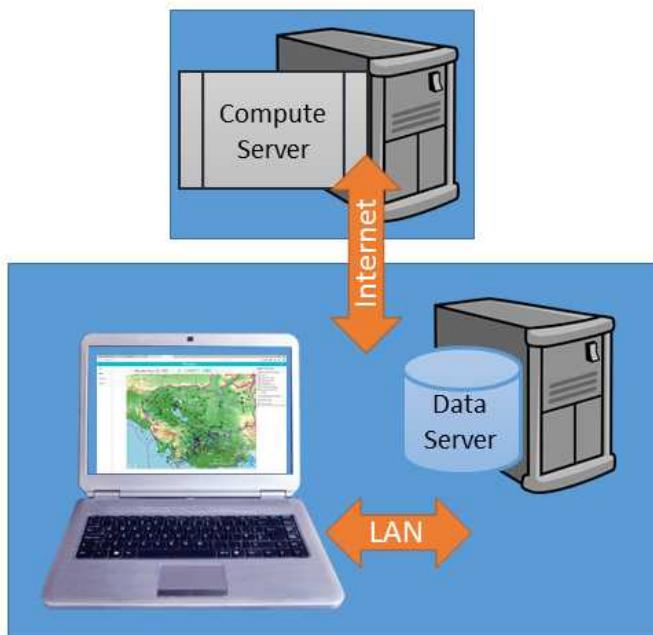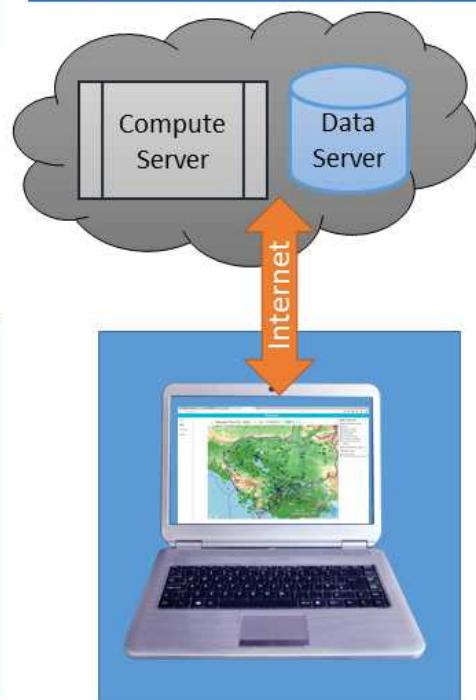
What-if analysis answers specific questions

Interactive optimization of system design and operation

Scenario 3: Outbreak Surge Capacity

- Show how transport system responds to ILI outbreak
- understand capacity issues

ILI Outbreak in Memot

ILI Surveillance Samples on CDC ILI Network

Test Case

19

Scenario 2: Shared Transport

- Example of transport planning
- Use HIV network to show cost and delay from sharing sample transport couriers between programs

HIV Samples on Shared Transport network

Test Case

17

Scenario 1: Lab Consolidation

- This Example uses part of TB sample transport network
- Baseline: TB testing at CNAT, Battambang, and Kampong Cham
- Test Case: Shift Kampong Cham TB sample analysis to CNAT

CAMBODIA

Baseline

CAMBODIA
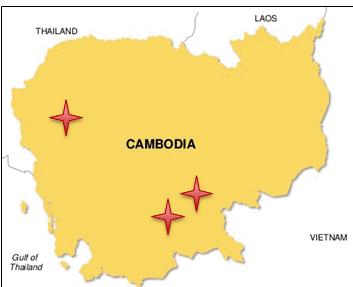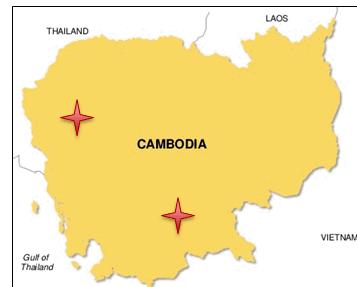
Test Case

15

Using data from MoH, NAMRU-2, AFRIMS, CDC, MSF, WHO
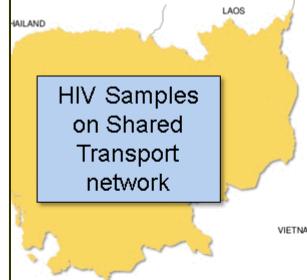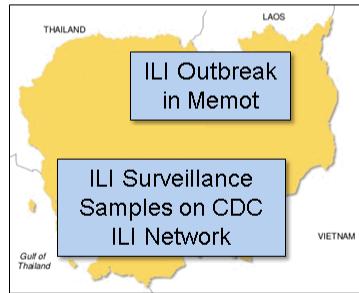
Example Analysis: Planning POC adoption

- Model Point of Care (POC) diagnosis effects on system metrics: cost, turnaround time, surge capacity, sustainability

- Example: Replacing centralized lab tests with distributed GeneXperts
  - Case 1: Planning most cost effective deployment of GXE to augment Abbott m2000 for annual HIV total viral load testing
    - Collaboration with CDC in-country HIV chief
    - Analysis: *Balancing costs, speed and robustness of adoption*
  - Case 2: GXE to replace culture based TB testing
    - Cambodia recently acquired 40 GXE instruments with Global Fund grant
    - Little planning in acquisition or roll out
    - Selected purchase rather than reagent rental agreement
    - Analysis: *Potential for system failure due to front-loaded investment rather than staged expenditure*

# POC for TB testing: Baseline
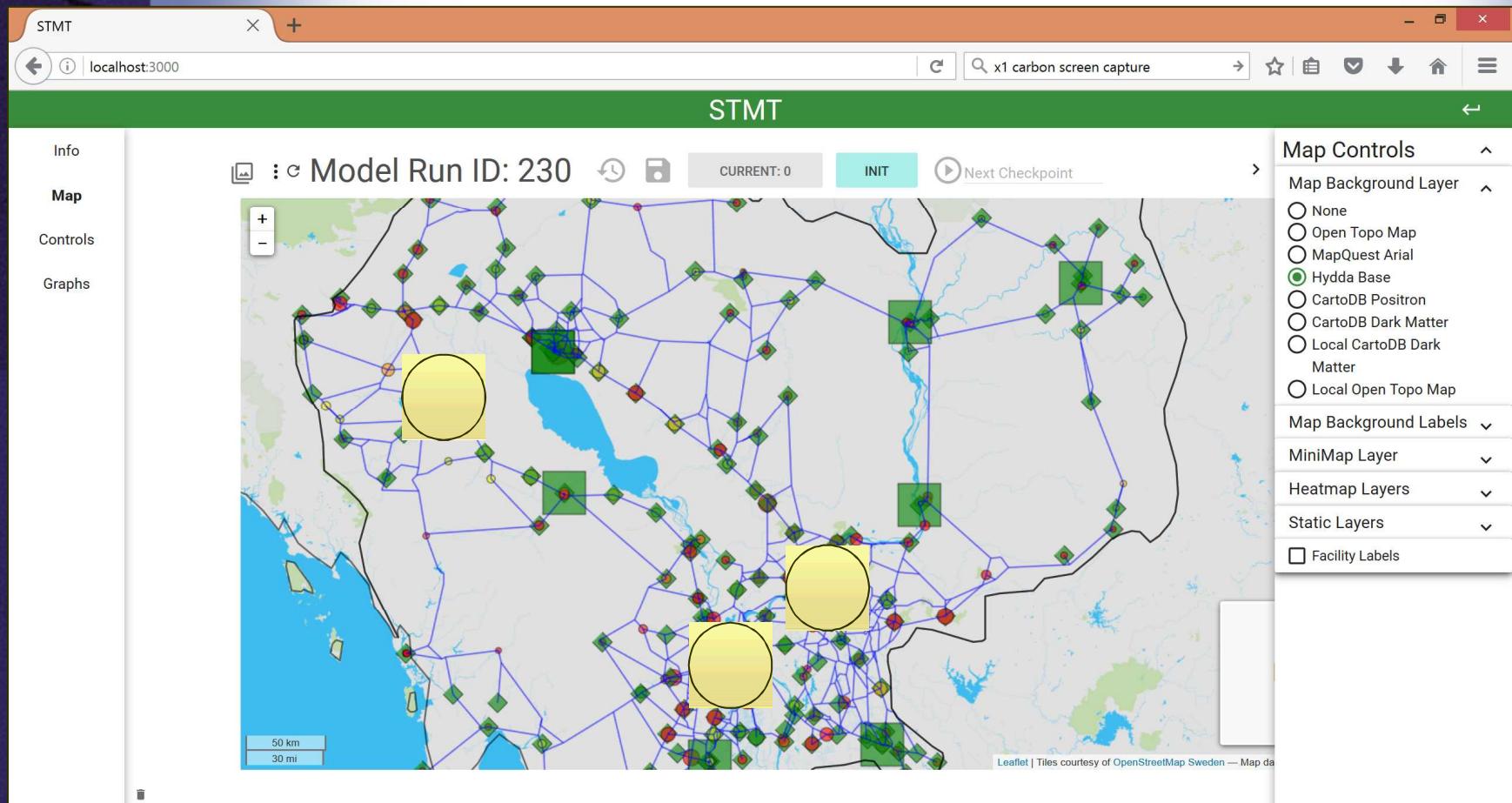
Centralized TB testing at Battambang, Phnom Penh, and Kampong Cham

Test case: Add GeneXperts
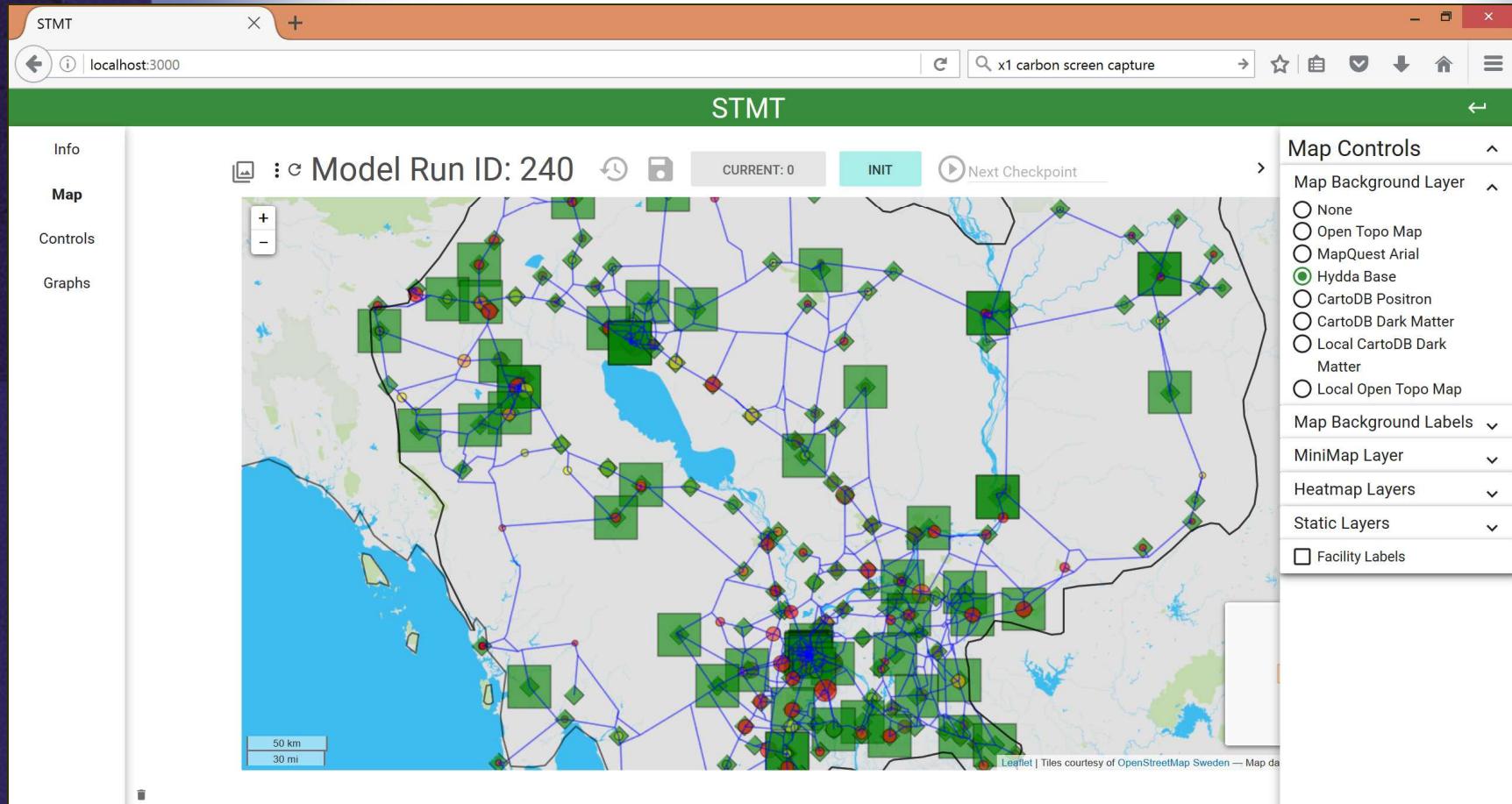
Deploy GXE at all district and provincial hospitals.
Shut down centralized TB testing

Comparison: Centralized vs POC without maintenance
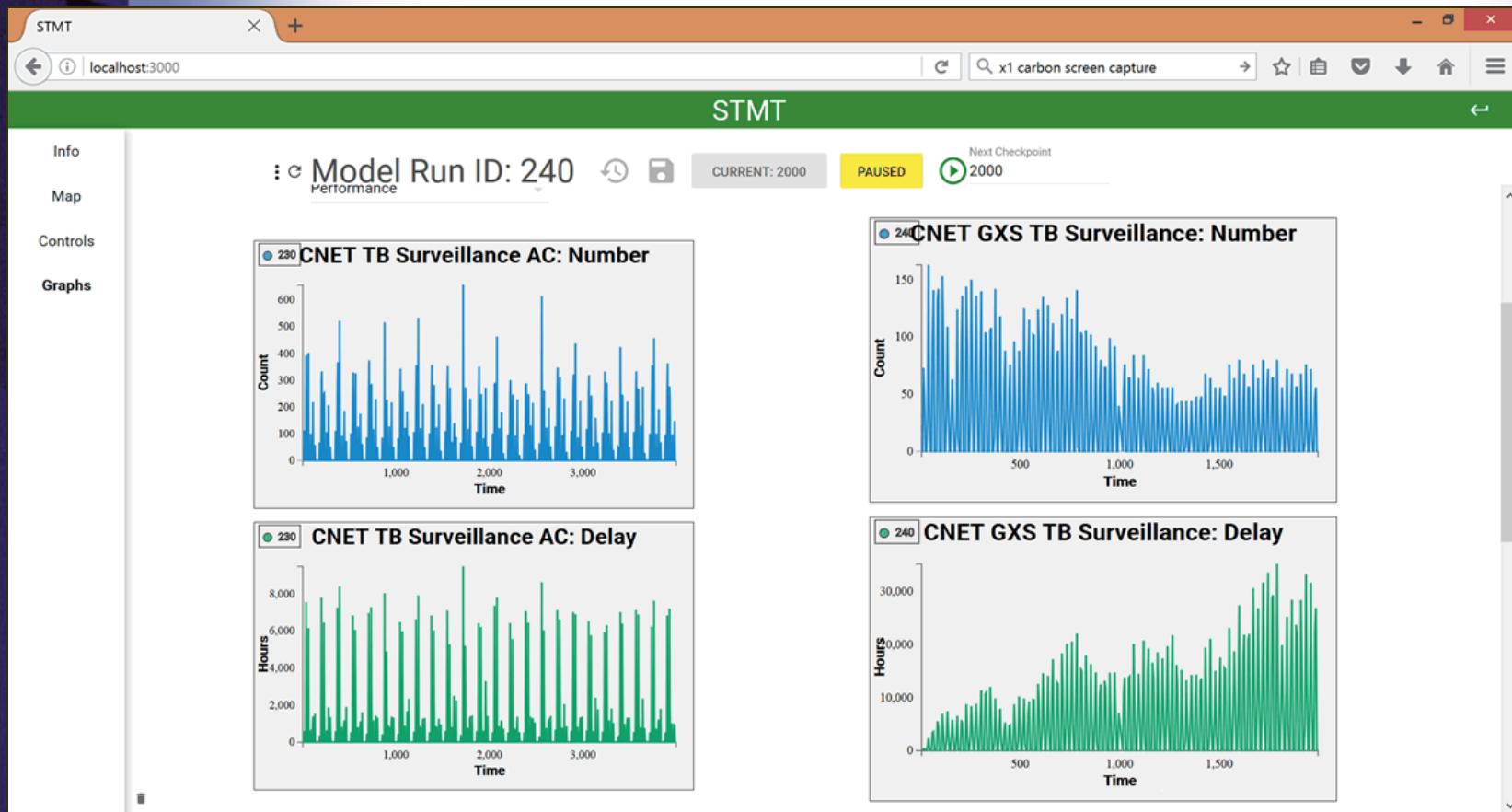
Centralized baseline (left): Steady performance
40 GeneXpert (right): Failure-based changes

Improving lab networks for resilient outbreak response

- Timely disease diagnosis is key to rapid public health response

- Historically lab networks overwhelmed by outbreaks

- Modeling can help maintain public health function during event and reconstitute baseline functions post-event

- Logistics modelling
  - Combines maps, lab data, and what-if analysis capabilities
  - Generates easy-to-interpret system metrics
    - Cost, Throughput, Quality, Security
    - Effectiveness of preparation and intervention
  - Helps decision makers plan effective system improvements to
    - Enhance outbreak response
    - Improve day-to-day operations
    - Improve security through capacity allocation and sample routing