Automated Outbreak Detection in Hospitals and Communities

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NIH Models of Infectious Disease Agent Study (MIDAS)
Hospital Outbreak Detection
Hospital Outbreak Detection

- Required of every hospital
- Infection Control program
- Critical elements
  - Correct assessment
  - Timely identification
  - Rapid response
  - Tracking of containment
  - Confidence in resolution
Current Issues in Outbreak Detection

- Incomplete ascertainment
  - Limited surveillance
  - Clinician report

- Routine tracking of a few organisms
  - MRSA, VRE, ESBL
  - Labor intensive
  - Criteria not standardized
  - No statistical basis
Need for Automation

- Outbreaks can involve
  - Any of hundreds of organisms
  - Any hospital unit
  - Any clinical service
  - Medical equipment

- Microbiologic data readily available

- Statistical assessment needed
Ideal Outbreak Detection

- Assesses
  - All pathogens
  - Units, service, antibiotic profile
- Statistically based
- Avoids empiric rules
  - 3 nosocomial cases in 2 weeks
WHONET

- WHO sponsored free software*
- Describes microbiologic data
  - Management
  - Analysis
- 1200 laboratories
- 80 countries
- 17 languages

* www.who.int/drugresistance/whonetsoftware
WHONET Use in the World

- **African Regional Office of WHO (AFRO)**
  - Algeria, Kenya, Namibia, South Africa, Tanzania, Zambia

- **Eastern Mediterranean Regional Office of WHO (EMRO)**
  - Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Pakistan, Saudi Arabia, Tunisia

- **European Regional Office of WHO (EURO)**
  - Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Iceland, Ireland, Israel, Italy, Latvia, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, Spain, Sweden, Ukraine, United Kingdom

- **Pan-American Health Organization (PAHO)**
  - Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Mexico, Nicaragua, Panama, Paraguay, Peru, United States, Uruguay, Venezuela

- **South-East Asian Regional Office of WHO (SEARO)**
  - India, Indonesia, Sri Lanka, Thailand

- **Western Pacific Regional Office of WHO (WPRO)**
  - China, Hong Kong (China), Japan, Republic of Korea, Malaysia, Philippines, Singapore, Taiwan, Viet Nam
Analysis type

Study = RIS and test measurements
All antibiotics

Organisms

pae    Pseudomonas aeruginosa

Isolates

Data files

w2004bwh.dbf

Output to: Screen

Begin analysis

Exit
Patients with *Staphylococcus aureus* Isolates
%RIS & Histograms: *Ps. aeruginosa*

### Analysis Results

<table>
<thead>
<tr>
<th>Code</th>
<th>Antibiotic name</th>
<th>Breakpoint</th>
<th>Number</th>
<th>%R</th>
<th>%I</th>
<th>%S</th>
<th>%?</th>
<th>%R 95%</th>
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<tr>
<td>AMK_ND30</td>
<td>Anikacin</td>
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<td>336</td>
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<td>15.5</td>
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<td>83.9</td>
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</table>

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**Gentamicin**

![Gentamicin Graph](attachment:image.png)
Purpose

The SaTScan™ software analyzes spatial, temporal and space-time data using the spatial, temporal, or space-time scan statistics. It is designed for any of the following interrelated purposes:

- To perform geographical surveillance of disease, detect spatial or space-time disease clusters, and see if they are statistically significant.
- To test whether a disease is randomly distributed over space, over time or over space and time.
- To evaluate the statistical significance of disease cluster alarms.
- To perform repeated time-periodic disease surveillance for the early detection of disease outbreaks.

The software may also be used for similar problems in other fields such as archaeology, astronomy, criminology, ecology, economics, engineering, genetics, geography, geology, history or zoology.

Data Types and Methods

SaTScan uses either a Poisson-based model, where the number of events in an area is Poisson-distributed, according to a known underlying population at risk; a Bernoulli model, with 0/1 event data such as cases and controls; a space-time permutation model, using only case data; an ordinal model, for categorical data; or an exponential model for survival time data with or without censored variables. The data may be either aggregated at the census tract, zip code, county or other geographical level, or there may be unique coordinates for each observation. SaTScan adjusts for the underlying inhomogeneity of a background population. It can also adjust for any number of categorical covariates provided by the user, as well as for temporal trends, known space-time clusters and missing data. It is possible to scan multiple data sets simultaneously to look for clusters that occur in one or more of them.

Financial Support and Developers

The SaTScan™ software and Web site were developed by Martin Kulldorff together with Information Management Services Inc.

Financial support for SaTScan was received from the following institutions branches and programs:

- National Cancer Institute, Division of Cancer Prevention, Biometry Branch [SaTScan v1.0, 2.0, 2.1]
- National Cancer Institute, Division of Cancer Control and Population Sciences, Statistical Research and Applications Branch [SaTScan v3.0 (part)]
- Alfred P. Sloan Foundation, through a grant to the New York Academy of Medicine (Farzad Mostashari, PI) [SaTScan v3.0 (part), 3.1, 4.0, 5.0, 5.1]
- Centers for Disease Control and Prevention, through Association of American Medical Colleges Cooperative Agreement award number MM-0870 [SaTScan v6.0].

Their financial support is greatly appreciated. The contents of SaTScan are the responsibility of the developer and do not necessarily reflect the official views of the funders.
SaTScan – Space and Time Scanning
**WHONET-SaTScan**

- Links microbiologic data analysis to statistical mining
- Enables hospital outbreak detection
  - Hospital-wide
  - By unit and related unit groups
  - By service and related service groups
  - By antibiotic resistance pattern
WHONET-SaTScan

- **Project Goal:**
  To automate hospital-associated outbreak detection and validate results in a survey of 2 physician leaders of Infection Control
Study Design:
6-year retrospective cohort study
1) Identify detection algorithm
2) Evaluate its utility
WHONET-SaTScan

- **Study Population:**
  All patients admitted to Brigham & Women’s Hospital
  750-bed tertiary academic hospital
  from 2001-2006
Outbreak Detection Methods

- All clinical cultures, 2001-6
- 2001 data for parameterization
- 2002-6 data for outbreak detection
Outbreak Detection
WHONET Data Input

- BWH Culture Results
  - All organisms, 2002-6
  - First-ever per patient
  - >Hospital Day 2

- Data Elements
  - Patient identifiers
  - Organism
  - Date of culture
  - Location of culture
  - Clinical service
  - Antibiotic profile
**SaTScan Analysis**

- Assesses temporal trends
  - Compares rates across organisms

- Assesses organism-specific rates
  - Using prior baseline in past year (365 days)
  - Stratified by unit, service, antibiotic profile
  - Provides daily alerts
Algorithm Development

- 1st alert must be initiated within 60d
- Alert will exist as long as threshold met
- Daily report of alerts
  - Repeat alert for incremental cases only
  - Can track containment

Example: 3 cases within 5 months triggers alert
Outbreak Alert
SaTScan Parameters

- Meaningful statistical threshold
  - One false alert per year per comparison
  - = recurrence interval of 1 in 365
  - = p<0.0027

- Max outbreak duration
  - no limit
WHONET SaTScan Report

- **Signal Alerts**
  - Daily report of all new alerts
  - Repeat alert of same cluster if cases increase

- **Alert Data**
  - Type of alert
  - 1st alert date
  - 1st culture date
  - Observed cases in outbreak
  - Expected cases in outbreak
  - Recurrence Interval
“Spatial” Assessments

- Entire hospital population
- Patient subsets
  - Hospital units
  - Clinical service
  - Antibiotic resistance profile
Output: Alert Report

- Signal Alerts
  - Daily report of new alerts
  - Repeat alert of same cluster if cases increase

- Alert Data
  - Type of alert
  - 1st alert date and 1st culture date
  - Observed cases in outbreak
  - Expected cases in outbreak
  - Recurrence interval
Algorithm Performance
Is it practical?
2002-6 Outbreak Alerts

- Median 12 annual alerts (7-16)
- Organisms
  - GP: 36%; GN 53%; Fungi 12%
- Outbreak Type
  - Antibiotic Profile 26 (41%)
  - Unit 18 (29%)
  - Hospital-wide 11 (18%)
  - Service 8 (13%)
- Outbreak Size
  - 2 patients 12 (20%)
  - 3-5 patients 27 (46%)
  - 6-10 patients 11 (19%)
  - >10 patients 9 (15%)
Does it capture known outbreaks?
Comparison to Known Outbreaks

- Identified by Infection Control
  - Identified all 4 outbreaks identified by Infection Control program
  - 3 of these were confirmed by PFGE
## 2004 Alert Summary

<table>
<thead>
<tr>
<th>Organism</th>
<th>Signal Type</th>
<th>Observed Cases</th>
<th>Expected Cases</th>
<th>Days to First Signal</th>
<th>Span of Signals</th>
<th>Recurrence Interval</th>
<th>IC Identified</th>
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</thead>
<tbody>
<tr>
<td><strong>Gram Positive Bacteria</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><em>E. faecalis</em></td>
<td>Resistance profile</td>
<td>4</td>
<td>0.6</td>
<td>18</td>
<td>25</td>
<td>667</td>
<td>N</td>
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<tr>
<td><em>E. faecium</em> (VRE)</td>
<td>Resistance profile</td>
<td>2</td>
<td>0.14</td>
<td>29</td>
<td>17</td>
<td>500</td>
<td>N</td>
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<tr>
<td><em>S. aureus</em></td>
<td>Ward</td>
<td>7</td>
<td>1.1</td>
<td>6</td>
<td>16</td>
<td>667</td>
<td>N</td>
</tr>
<tr>
<td><em>S. aureus</em> (MRSA)</td>
<td>Ward</td>
<td>8</td>
<td>1.4</td>
<td>6</td>
<td>54</td>
<td>10000</td>
<td>N</td>
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<tr>
<td><strong>Gram Negative Bacteria</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>A. baumannii</em></td>
<td>Resistance profile</td>
<td>15</td>
<td>7.5</td>
<td>18</td>
<td>52</td>
<td>10000</td>
<td>Y</td>
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<tr>
<td><em>A. baumannii</em></td>
<td>Hospital</td>
<td>20</td>
<td>8.3</td>
<td>3</td>
<td>57</td>
<td>625</td>
<td>Y</td>
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<td><em>A. baumannii</em></td>
<td>Ward</td>
<td>4</td>
<td>0.6</td>
<td>3</td>
<td>9</td>
<td>2000</td>
<td>N</td>
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<td><em>B. fragilis</em></td>
<td>Service</td>
<td>2</td>
<td>0.2</td>
<td>4</td>
<td>1</td>
<td>500</td>
<td>N</td>
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<tr>
<td><em>H. influenza</em></td>
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<td>4.2</td>
<td>18</td>
<td>14</td>
<td>455</td>
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<td>24</td>
<td>12</td>
<td>1111</td>
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<tr>
<td><em>P. aeruginosa</em></td>
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<td>0.2</td>
<td>2</td>
<td>7</td>
<td>476</td>
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<td><em>S. marcescens</em></td>
<td>Hospital</td>
<td>10</td>
<td>2.8</td>
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<td><strong>Fungi</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td><em>A. fumigatus</em></td>
<td>Hospital</td>
<td>7</td>
<td>1.4</td>
<td>20</td>
<td>57</td>
<td>417</td>
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</table>
Acinetobacter baumanii Isolates

Alert Duration: 49 days

1st Alert: 8 cases
Acinetobacter baumanii by Susceptibility Pattern

1st Alert: 8 cases

Alert Duration: 49 days
Is it useful?
Survey Tool

10/25/2004
Organism: Acinetobacter baumannii
Signal Type: Resistance profile
Description: ACFGLTN
Number of current cases: 8

1) Would you act on this information? Yes
   a) Print line list
   b) Notify ICP's for increased awareness
   c) Check line list for similar characteristics (unit, service, antibiotic profile)
   d) Assess background frequency of organism in microbiology databases
   e) Notify ICPs for full chart review
   f) Notify MD/nurse manager of unit/service

2) What is your level of concern? Medium

3) After reviewing the limited electronic data, what would you do next?
   a) Disregard
      b) Notify ICPs for increased awareness
      c) Assess background frequency of organism in microbiology databases
      d) Notify ICPs for full chart review
      e) Notify MD/nurse manager of unit/service

4) After reviewing the limited electronic data, what is your level of concern? Very high

Close
Survey Concordance: Level of Concern

- 2 Hospital Epidemiologists
- Simulated daily evaluation across 6 Years
- 51 clusters, all deemed of interest
- **Level of Concern:** 86% concordance

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>Med.</th>
<th>High</th>
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<tr>
<td>High</td>
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</table>
**Survey Concordance: Action taken**

- **Action:** 82% concordance

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<tr>
<th>MD1\2</th>
<th>Wait</th>
<th>Investigate</th>
<th>Unit ALERT</th>
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<td>Wait</td>
<td>32</td>
<td>4</td>
<td>0</td>
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<tr>
<td>Investigate</td>
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<tr>
<td>Unit ALERT</td>
<td>1</td>
<td>1</td>
<td>10</td>
</tr>
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</table>
Comparison to Rule-Based Outbreaks

- Cluster-Based Rules
  - 3 cases in same unit within 2 weeks
  - For MRSA, “cluster alerts” were increasing as prevalence was rising. Some units were on alert for a year or more
  - Need statistical basis
<table>
<thead>
<tr>
<th>Year</th>
<th>Clusters (N)</th>
<th>Cases (Mean)</th>
<th>Mean Duration (Days)</th>
<th>Cluster Type</th>
<th>Clusters (N)</th>
<th>Cases (Mean)</th>
<th>Mean Duration (Days)</th>
<th>Cluster Type</th>
<th>Dual Detection</th>
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<td>14</td>
<td>10.8</td>
<td>96.5</td>
<td>Ward</td>
<td>1</td>
<td>14</td>
<td>67.0</td>
<td>Antibiotic Profile</td>
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<td>2003</td>
<td>11</td>
<td>11.1</td>
<td>100.3</td>
<td>Ward</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
<td>--</td>
<td>0</td>
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<td>2004</td>
<td>18</td>
<td>6.9</td>
<td>65.3</td>
<td>Ward</td>
<td>1</td>
<td>8</td>
<td>54.0</td>
<td>Ward</td>
<td>1</td>
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<td>2005</td>
<td>18</td>
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<td>52.4</td>
<td>Ward</td>
<td>3</td>
<td>3.7</td>
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<td>Ward, Ward/Service, Antibiotic Profile</td>
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<td>14.6</td>
<td>7.9</td>
<td>72.5</td>
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<td>1.4</td>
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<td>27.1</td>
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<td>0.2</td>
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<tr>
<td>Annual median</td>
<td>14</td>
<td>6.9</td>
<td>65.3</td>
<td></td>
<td>1.0</td>
<td>4.0</td>
<td>8.3</td>
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## W-S Algorithm vs IC 3-in-2wk VRE Surveillance

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<th>Infection Control Detection</th>
<th>WHONET-SatScan Detection</th>
<th>Dual Detection</th>
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<td></td>
<td>Clusters (N)</td>
<td>Cases (Mean)</td>
<td>Mean Duration (Days)</td>
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<td>7.6</td>
<td>71.2</td>
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<td>2003</td>
<td>12</td>
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<td>2005</td>
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<tr>
<td>2006</td>
<td>22</td>
<td>6.0</td>
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<tr>
<td>5-Year Total</td>
<td>87</td>
<td></td>
<td></td>
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<tr>
<td>Annual mean</td>
<td>17.4</td>
<td>7.1</td>
<td>67.1</td>
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<tr>
<td>Annual median</td>
<td>18</td>
<td>7.2</td>
<td>69.1</td>
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</tbody>
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WHONET-SaTScan for Hospital Outbreaks

- Pilot test suggests
  - Reasonable number of alerts
  - Expands surveillance capability
  - Accurate detection of major clusters

- Discordance with empiric IC detection rules suggests resources may be better directed at clusters less likely to represent chance phenomenon

- Broader real-time assessments needed
Next Steps

- Develop user-friendly interface
- Expand evaluation to larger number of community hospitals
- Enhance algorithm
  - Evaluate effect of screening
  - Look for additional resistance patterns
Hospital Clusters
Investigative Team

Susan S Huang, MD MPH
Deborah S Yokoe, MD MPH
John Stelling, MD MPH
Martin Kulldorff, PhD
Ken Kleinman, PhD
Hilary Placzek, MPH
Johanna Vostok, BS
Michael Calderwood, MD
Thomas F O’Brien, MD
and Richard Platt, MD MS