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BIOLOGICAL DEFENSE:
EVALUATING SENSOR ARRAY QUANTITY AND QUALITY VERSUS
DETECTION CAPABILITY

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# Biological Defense: Evaluating Sensor Array Quantity And Quality Versus Detection Capability

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Standard Form 298 (Rev. 8-98)  
Prescribed by ANSI Std Z39-18
AGENDA

- Part 1  Background
- Part 2  Design of Experiment
- Part 3  Data Analysis
- Part 4  Results & Conclusions
- Part 5  Questions
PART 1  BACKGROUND

- Project History
- Project Objectives
- Basic Definitions
Began as a project for SYST 798 at GMU
- Investigating quality versus detection capability of different sensor arrays using a fixed number of sensors to detect an Anthrax attack
- Project sponsored by the Defense Threat Reduction Agency (DTRA) through the Weapons of Mass Destruction Assessment and Analysis Center (WMDAAC) OR Cell

Study modeled the release of Anthrax from 8 different release points
- Used HPAC to generate plume data
Sought to understand the effectiveness of four different notional sensor types in a fixed sensor array
- Study the effects of agent amount (1 & 2 kg), wind speed (4, 8, 12 knots)
- Used perfect sensors (no false detections)

Time constraints required a definitive scope of the project
- Future studies were recommended
- This new study was designed to further the research and answer questions left unanswered
Project Objectives

- Model the release of a biological agent (Anthrax) into a protected area surrounded by notional sensors
  - Determine the effect of sensor sensitivity on detection capability
  - Determine the effects of using more or less sensors
  - Understand the cost vs. performance tradeoff
  - Use perfect (no false detections) and non-perfect sensors (require multiple detections to rule out false positives)
Basic Definitions

**ACPLA** — Agent Containing Particles Per Liter of Air (ACPLA), for Anthrax, 1 ACPLA = $1 \times 10^{-11}$ kg/m$^3$

— Measure of a sensor’s sensitivity level; the lower the number, the better the sensor

**Battle Space** — A 16x19 km rectangular area that contains the total geographical region that the release of agent is modeled within

**Defense Area** — Found inside the Battle Space, this 10x13 km rectangular area surrounded by sensors and contains the population/valuable assets to protect

**Detection/Hit** — When the concentration of agent around the sensor is above the threshold of detection

**HPAC** — Hazardous Prediction and Assessment Capability — models the propagation of the agent’s plume across the Battle Space
PART 2  DESIGN OF EXPERIMENT

- Hypothesis
- Scenario Design
- Defining the Battle Space
- Sensor Model
Hypothesis

- An increased quantity of cheaper, notional sensors will provide equivalent or better detection capability for less cost
  - Using more sensors reduces the space between sensors and reduces the likelihood of an agent’s plume slipping through undetected
  - Instead of buying more sensitive sensors, spend less money, buy more cheaper sensors for the equivalent detection capability at a reduced cost
Scenario Design

- Scenarios Modeled in HPAC
  - 0.5, 1 and 2 kg anthrax releases
    - 8 release points
    - Release height at 2 m, over .08 km distance
    - 90% purity with 60% dissemination efficiency
    - Atmospheric conditions constant for all releases
      - Scattered clouds, ambient temperature
    - Wind speed at 4, 8, and 12 knots
      - Wind direction toward center of defense area from the release point (worse case)
    - Two releases from four different terrain conditions
      - Mountain, Desert, Forest, and Stream
      - 3 km from sensor array
Defining the Battle Space

During model runs, wind blows from Release Point to center of Defense Area

Sensor Model

- Four generic types of notional sensors used based on their threshold of detection
  - 1, 10, 20, 30 ACPLA
    - Theoretical 1 ACPLA sensor used as basis for best possible detection capability

- Sensor Configuration
  - Rectangular perimeter defense
  - Tested 16, 28, 42, 65 and 129 sensors
    - Equally distributed around the perimeter of a 10x13 km rectangle
PART 3  DATA ANALYSIS

- Technical Methodology
- Average Detections
- Defining a Better Performance Metric
- Cost vs. Performance
Technical Methodology

- Simulated release of agent using HPAC
  - Captured concentration at every point in 100 X 100 matrix representing the Battle Space in 2 minute time steps over a 4 hour period
  - Imported data into Access Database

- Determined if, at any time, a concentration in the location of a sensor exceeded the sensor’s threshold of detection

_Hazard Prediction and Assessment Capability (HPAC) — government off-the-shelf software for use in modeling chemical and biological agents_
Average Detections

Number of Sensors

Average Detections

1 ACPLA
10 ACPLA
20 ACPLA
30 ACPLA
Defining a Better Performance Metric

- Averaging the detections does not provide any useful information
  - Result is an average and does not let one know if one or zero detections occurred with any scenario
    - More true of lesser agent amounts (0.5 kg case)
    - Zero detection results in casualties!
    - Difficult to account for non-perfect sensors

- Better performance metric is counting the number of releases where our detection criteria is met
  - >0 for perfect
  - >1 (at least 2 detections) or >2 (at least 3 detections) for non-perfect
Detection — >1 Required

% Scenarios Detecting vs. Number of Sensors

- 1 ACPLA
- 10 ACPLA
- 20 ACPLA
- 30 ACPLA
Detection — >2 Required

Number of Sensors vs. % Scenarios Detecting

- 1 ACPLA
- 10 ACPLA
- 20 ACPLA
- 30 ACPLA

CUBIC DEFENSE APPLICATIONS
0.5 kg Case Detection — >2 Required

Number of Sensors vs. % Scenarios Detecting

- 1 ACPLA
- 10 ACPLA
- 20 ACPLA
- 30 ACPLA
Cost vs. Performance

- Cost of a notional sensor was estimated using the following formula:
  - Better Sensor = 1.5 \times \text{Cost} \text{ Worse Sensor}
  - 20 \text{ ACPLA} = 1.5 \times \text{Cost} \text{ 30 ACPLA;}
  - 10 \text{ ACPLA} = 1.5 \times \text{Cost} \text{ 20 ACPLA; etc.}

- Notional cost estimates used to examine the general behavior of the system in order to observe trends

- Cost analysis does not include:
  - Deployment cost/sensor
  - Normal cost of everyday sensor usage
  - Cyclical maintenance cost/sensor/unit time
Perfect Sensor Cost

% Scenarios Detecting vs. Notional Cost

Notional Cost

$0 $50 $100 $150

75% 80% 85% 90% 95% 100%

1 ACPLA 10 ACPLA 20 ACPLA 30 ACPLA
>1 Detection Cost

Notional Cost

% Scenarios Detecting

$0 $50 $100 $150

1 ACPLA 10 ACPLA 20 ACPLA 30 ACPLA
>2 Detection Cost

Notional Cost

% Scenarios Detecting

$50 $100 $150 $200

1 ACPLA 10 ACPLA 20 ACPLA 30 ACPLA
PART 4  RESULTS & CONCLUSIONS
Results & Conclusions

- Total count of releases meeting detection criteria is a much better metric for evaluating the notional sensor array performance
  - Total counts of successful detection reveal the cases where little or no detections occur, while averaging the counts can be misleading
  - 30 ACPLA sensors could not achieve 100% performance, even with 129 sensors (360 m spacing between sensors)

- 0.5 kg scenarios were the main driver for reduced performance
  - This is a more realistic amount to manufacture than 2 kg
  - Consider using 0.25 kg to improve understanding of smaller scale attacks
Results & Conclusions

- 1 ACPLA sensors outperform all other sensors and cost less for 100% detection when considering *non-perfect* sensors
  - 10 ACPLA sensors perform very well and are also a good alternative, especially when 3 or more detections are required
  - 20 ACPLA sensors had more difficulty with the 0.5 kg cases, and might perform even worse for smaller attacks

- Based on the results, reject the hypothesis that an increased quantity of cheaper sensors provides an equivalent or better detection capability for less cost
  - Increased sensitivity performs better with smaller releases
  - Recommend less quantity with more quality