A Bayesian Approach for Assessing Confidence in a Biological Warfare (BW) Detection Event

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Background

• BW detection challenges
  – Diversity of potential agents
  – Very low effective concentrations
  – Many properties in common with natural background constituents, present in much higher concentrations

• Reliability of results
  – Most current technologies lack high specificity
  – Fielded systems incorporate multiple technologies and/or arrays

• Reliability can be further enhanced by fusing multiple detection results with other BW attack indicators

OBJECTIVE – Present conceptual Bio Detection Decision Model to stimulate application development
**Biological Detection Decision Model**

- **C4ISR Data**
- **INTEL Data**
- **CBRN Data**
- **Weather Data**
- **Medical Data**

Pr (BW | Evidence) = Probability that a BW attack has occurred given all available information
Key Decision Model Elements

- **Detector Performance**
  - Receiver Operating Characteristic (ROC) curves

- **Decentralized Observations**
  - Geographic Areas of Interest (AOI)
  - Valid Time Intervals

- **Decision Methodology**
  - Bayesian Belief Network \( \rightarrow \Pr (BW \mid \text{Evidence}) \)
Receiver Operating Characteristic (ROC)

Each ROC curve is a function of response time, agent and background conditions; a detector is represented by a family of such curves.

Sensitivity & Selectivity can be computed from performance data, but what we really want to know is Pr (BW|Det) or Pr (~BW|~Det).

<table>
<thead>
<tr>
<th>Threshold</th>
<th>Sensitivity</th>
<th>Selectivity</th>
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</thead>
<tbody>
<tr>
<td>Low</td>
<td>0.9</td>
<td>0.6</td>
</tr>
<tr>
<td>Medium</td>
<td>0.7</td>
<td>0.8</td>
</tr>
<tr>
<td>High</td>
<td>0.5</td>
<td>0.9</td>
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</table>

Sensitivity = Pr (Det|BW) = TP/(TP+FN)
Selectivity = Pr (~Det|~BW) = TN/(TN+FP)
Define valid time interval \([ t(i), t(i+j) ]\) for each zone.
Bayesian Networks

1-Detector Network

- BW Attack
  - Pr (BW) = 0.5
  - Pr (BW | Det) = 0.74
- Detector
  - Pr (Det | BW) = 0.9
  - Pr (~Det | ~BW) = 0.6

2-Detector Network

- BW Attack
  - Pr (BW) = 0.5
  - Pr (BW | Det1, ~Det2) = 0.58
- Detector 1
  - Pr (Det | BW) = 0.9
  - Pr (~Det | ~BW) = 0.6
- Detector 2
  - Pr (Det | BW) = 0.9
  - Pr (~Det | ~BW) = 0.6

Directed Acyclic Graph:
- Node = random variable
- Arc = probabilistic correlation
- Discrete Variables: Observed = known, State = unknown
- Inference by Bayes’ Rule: Pr (B|A) = Pr (A|B) x Pr (B) / Pr (A)
Advantages of Bayesian Networks

• Provide a means to decompose a joint probability distribution into a set of local distributions
  – Model structure independent from quantification of conditional probabilities
    • Nodes → Pertinent Variables
    • Arcs → Linkages (Dependencies)
  – Only local distributions require quantification
    • Subjective beliefs and discrete or continuous probabilities can be used
    • Efficient inference algorithms guarantee computation of joint distribution

• Successfully applied to diverse military applications
  – Unmanned Underwater Vehicle control system
  – Ship anti-torpedo and anti-missile defense systems
  – Mine detection
  – Ground/air target tracking
  – Commander’s decision aids
Bayesian Network Model

| BW Attack Indicators                  | Positive Detections | Pr (BW | Evidence) |
|---------------------------------------|---------------------|------------|
| Threat_level = Moderate               | None                | 0.02       |
| Met_stability = Neutral               | Det_1               | 0.53       |
| Radar_detect = Aircraft               | Det_1, Det_3 & Det_A| 0.96       |
Biological Detection Information Flow

Net-Centric Environment

- Biological Detectors
- NBC Reports
- Other COIs
- CBRN COI*
- Bio Detection Decision Model

* Community of Interest
Conclusions

• Bayesian Networks provide the basis for a coherent biological detection decision model
  – Effectively fuse prior beliefs and probabilities with diverse detector and battlefield observations
  – Provide numerical probability that a BW attack has occurred
  – Substantially increase reliability of generic BW detectors
  – Provide IPB decision tool for allocation and placement of BW detection assets

• Areas for further investigation
  – Identification of all pertinent variables and linkages
  – Methodology to account for spatial and temporal dispersion of detector results
  – Application of likelihood methods for agent classification or identification