The Role of Expert Judgment in Counterterrorism Risk Assessment

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Terrorists are frequently modeled as rational decision-makers with utility functions.

In this approach, the utility function should ideally reflect the adversary’s cultural and ideological beliefs and goals:

Making multivariate measures of target attractiveness realistic.

One crucial elicitation task is then to use expert judgments to derive estimates for terrorist attribute weights.
Terrorist organizations may differ in important ways:

For example, organizations may differ in their levels of hostility
Different groups may put different weights on attributes such as religion, politics, organizational finances, reputation, and loss of human life
Groups may differ in whether their goals are practical vs. apocalyptic
Terrorists may care about both attack difficulty and attack consequences
Some targets may also have symbolic value (e.g., the Golden Gate Bridge)

All of these attributes can be captured in utility functions
Even more challenging, some attributes important to the terrorists may not be known by the defender
Past work has shown that different single-attribute terrorist utility functions yield different optimal budget allocations.
Use of more realistic multi-attribute terrorist objective functions also leads to greater levels of defensive hedging at optimality

But assessing multi-attribute utility functions for terrorists is hard:
- Terrorist goals and motivations are typically not well understood
- Major terrorist attacks are relatively rare
- Many intelligence experts are not quantitatively trained, or are reluctant to express their knowledge in quantitative form
Assume that the terrorist’s utility function is linear and additive

\[ U_n = \sum_{m=1}^{M-1} a_{nm} W_m + Y_n W_M \]

\( U_n \) = utility of target \( n \)
\( M \) = number of terrorist attributes
\( a_{nm} \) = utility of target \( n \) on attribute \( m \) (\( m = 1 \ldots M-1 \)) (known)
\( W_m \) = weight of attribute \( m \) (uncertain)
\( Y_n \) = utility of target \( n \) on any unobserved attributes (uncertain)
ELICITATION METHODS

• Probabilistic inversion (PI)
  (Cooke et al. 2004; Kraan and Bedford 2005; Neslo et al. 2011)
  • Generates probability distributions over the parameters of interest
    (e.g., attacker attribute weights $W$, values of unobserved attributes $Y$)
    that best fit the stated rank orderings

• Bayesian density estimation (BDE)
  (Ferguson 1973, 1974)
  • Uses expert rank orderings as observations to update the defender’s
    prior knowledge
  • To get posterior distributions for the parameters of interest ($W$, $Y$)
Traditional methods for elicitation of attribute weights include the ratio method, swing weights, trade-off and pricing-out methods.

However, these methods can be expensive and time consuming: And may require training of experts with non-quantitative backgrounds.

Moreover, assessing uncertainty over attribute weights would require the estimation of subjective probability distributions.

Ordinal rankings (e.g., SMARTER) are widely believed to be easier: And may even be more reliable.

However, SMARTER yields only point estimates of attribute weights.
Probabilistic inversion permits a simple expert-elicitation process

Intelligence experts are asked to give only ordinal judgments:
   E.g., to rank the attractiveness of potential targets or attack strategies

These ordinal rankings are then used to mathematically derive cardinal estimates of attribute weights

This works because the weights are required to sum to 1:
   Without a similar constraint, cardinal estimates could not be obtained
Probabilistic inversion can generate probability distributions over attribute weights, without distributional assumptions such as normality.

The goal is to find a probability distribution over input quantities:
- E.g., attribute weights
that best reproduces marginal distributions over model outputs:
- E.g., experts’ rank orderings of target attractiveness

To avoid cases with no feasible solution:
- Wang and Bier (2013, 2015) explicitly account for any unobserved attributes
ELICITATION PROCESS

K experts are asked to rank the top R out of N targets:
   Based on attractiveness to the terrorist

Method permits ties, partial orderings with R < N:
   Experts can also rank some of the least attractive targets

Expert judgments yield an empirical distribution of the probability that
a particular target will be ranked in the r\textsuperscript{th} place

For example, let 3 experts rank 2 targets:
   If only one of the three experts thinks that target 1 is the more attractive, then the
   empirical probability that target 1 will be ranked first is 1/3
Probabilistic inversion finds a distribution over the weights $W$ (and the unobserved attribute $Y$) to match the empirical distribution.

Can be solved approximately using Monte Carlo simulation:
- Generate independent samples for the parameters $W$ and $Y$
- Determine how much weight to put on each sample to match the empirical distribution of experts’ rank orderings
Illustrative Case Study

• Suppose that intelligence experts are asked to rank-order (a subset of) the 20 major US cities:
  • Based on their attractiveness to adversaries
  • Considering two known attacker attributes, property loss and population density

• We consider groups of hypothetical experts differing in such factors as:
  • Importance of any unobserved attribute(s)
  • Whether a larger value of a particular attribute means higher utility to the adversary
Attribute values for U.S. cities with high terrorism losses

Note unusually high population density for Jersey City

<table>
<thead>
<tr>
<th>Urban Area</th>
<th>Property Loss ($ million)</th>
<th>Population Density (per sq mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New York City</td>
<td><strong>413</strong></td>
<td>8,159</td>
</tr>
<tr>
<td>Chicago</td>
<td>115</td>
<td>1,634</td>
</tr>
<tr>
<td>San Francisco</td>
<td>57</td>
<td>1,705</td>
</tr>
<tr>
<td>Washington DC</td>
<td>36</td>
<td>756</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>34</td>
<td>2,344</td>
</tr>
<tr>
<td>Philadelphia</td>
<td>21</td>
<td>1,323</td>
</tr>
<tr>
<td>Boston</td>
<td>18</td>
<td>1,685</td>
</tr>
<tr>
<td>Houston</td>
<td>11</td>
<td>706</td>
</tr>
<tr>
<td>Newark</td>
<td>7.3</td>
<td>1,289</td>
</tr>
<tr>
<td>Seattle</td>
<td>6.7</td>
<td>546</td>
</tr>
<tr>
<td>Jersey City</td>
<td><strong>4.4</strong></td>
<td><strong>13,044</strong></td>
</tr>
<tr>
<td>Detroit</td>
<td>4.2</td>
<td>1,140</td>
</tr>
<tr>
<td>Las Vegas</td>
<td>4.1</td>
<td>40</td>
</tr>
<tr>
<td>Oakland</td>
<td>4</td>
<td>1,642</td>
</tr>
<tr>
<td>Orange County</td>
<td>3.7</td>
<td>3,606</td>
</tr>
<tr>
<td>Cleveland</td>
<td>3</td>
<td>832</td>
</tr>
<tr>
<td>San Diego</td>
<td>2.8</td>
<td>670</td>
</tr>
<tr>
<td>Miami</td>
<td>2.7</td>
<td>1,158</td>
</tr>
<tr>
<td>Minneapolis</td>
<td>2.7</td>
<td>490</td>
</tr>
<tr>
<td>Denver</td>
<td>2.5</td>
<td>561</td>
</tr>
</tbody>
</table>
SAMPLE RESULTS

Values of unobserved attribute

Note high values for LA, Vegas!
Suggest a missing attribute
E.g., entertainment industry
NEGATIVE ATTRIBUTE WEIGHTS

• Experts may differ on whether a larger value of a particular attribute corresponds to higher or lower attacker utility:
  • For example, do adversaries want to maximize or minimize fatalities?

• We allow the $W_m$ to take on negative values, while constraining the sum of the absolute weights $|W_1| + \ldots + |W_M| = 1$
AVERSION TO POPULATION DENSITY

Almost surely negative

Conflicting opinions on population density
FULL VS. PARTIAL ORDERINGS

Ranking the top 3 and the worst strategy does almost as well as ranking all 8
FULL VS. PARTIAL RANK ORDERINGS

- Ranking roughly 50% of the targets yields reliable results:
  - Where reliability is measured by the (normalized) Euclidean distance between the mean weights elicited using full versus partial rankings
- However, even fewer rankings often still give good results
Wang and Bier (2015) found that ranking roughly 50%:
E.g., the top 5 of 10, the top 10 of 20, or the top 20 of 50
yields reliable results in most cases

When there are only 2 known attributes:
Then asking stakeholders to provide only the top 5 out of 50 alternatives (top 10%) produces reliable estimates for the attribute weights

More rankings are needed for problems with more attributes
CONVERGENT VALIDATION

• PI and/or BDE can also be used for convergent validation with direct elicitation methods:
  • Differences between indirect and direct elicitation could be used as a basis for further discussion with the experts
RELATIONSHIP BETWEEN PI AND BDE

• PI uses only *marginal* rank orderings, whereas BDE captures *correlations* among rankings of targets provided by experts

• The PI distribution coincides with the BDE result with the *highest entropy*, among all possible ordinal judgments that have the same marginal rank orderings
CORRELATIONS OF TARGET RANKINGS

• Assume experts who rank target 1 higher than target 2 also rank target 3 higher than target 4 (and vice versa)
• Thus, the experts form two “schools of thought”
• These schools of thought are better reflected by $BDE$ than $PI$

![Correlation Graphs](Slide 23 of 26)
**TENDENCY TO MULTIMODAL DISTRIBUTIONS**

- **BDE** is more likely to generate multi-modal distributions than **PI**
SCHOOLS OF THOUGHT

• When large numbers of experts seem to form different schools of thought (i.e., subgroups of experts who hold similar views):
  • BDE may be a more appropriate approach

• By contrast, when there is only a small number of experts, apparent subgroups may be purely due to chance:
  • PI may be better in this case, if we do not want elicited distributions to be too sensitive to minor differences in judgments
CONCLUSIONS

• Expert elicitation can be used to assess terrorist attribute weights

• Indirect elicitation, based on ranking (a subset of) terrorist targets or strategies, can perform at least as well as direct elicitation:
  • With much less elicitation burden

• This approach is better suited to modeling terrorist organizations like Al Qaeda than to lone-wolf terrorism