Interdicting Smuggled Nuclear Material: Models of Smuggler Movement

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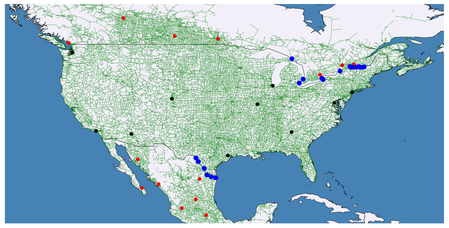
Three Models of Smuggler Behavior

Conservative: Smuggler picks optimal path to avoid detection

Markovian: Smuggler uses a directed random walk

Mixed: Smuggler makes choices, but randomness also plays a role

Goal: Place detectors on border crossings to prevent smuggler from reaching sensitive areas



Question: How robust is detector placement to models of smuggler movement?

Adversarial Design of Markov Decision Processes

Indices and Sets:

$s \in \mathcal{S}$	set of nodes / states
$a \in A_s$	set of actions for each state

Interdiction Budget Data:

$c_{s,a}$	cost of interdicting action a in state s
b	total interdiction budget

Smuggler Distribution Data:

ω	all the folliwng data can be uncertain, ω captures this uncertainty
w_s	initial location
$p(s' \mid s, a)$	probability of transitioning to s' from s when a is performed in s
$r_{s,a}$	reward of performing action a in state s, encodes destination

Decision Variables:

$x_{s,a}$	expected number of times smuggler uses action a in state s, depends on ω
$z_{s,a}$	is action a in state s interdicted? one answer for all ω

Given a scenario and a design, the smuggler's control problem:

$$
\begin{aligned}
h(z,\omega) = \max_{x} \; & \sum_{s \in \mathcal{S}} \sum_{a \in A_s} r_{s,a} x_{s,a} \\
\text{s.t.} \; & \sum_{a \in A_s} x_{s,a} = w_s + \sum_{s' \in \mathcal{S}} \sum_{a \in A_{s'}} p(s \mid s', a) x_{s',a}, \; \forall s \in \mathcal{S} \\
& x_{s,a} \geq 0, && \forall s \in \mathcal{S}, a \in A_s. \\
& x_{s,a} \leq M_{s,a}(1 - z_{s,a}), && \forall s \in \mathcal{S}, a \in A_s,
\end{aligned}
$$

The design problem on top:

$$
\begin{aligned}
\min_{z} \; & \mathbb{E}_{\omega}\left[h(z,\omega)\right] \\
& \sum_{s \in \mathcal{S}} \sum_{a \in A_s} c_{s,a} z_{s,a} \; \leq b
\end{aligned}
\tag{1}
$$

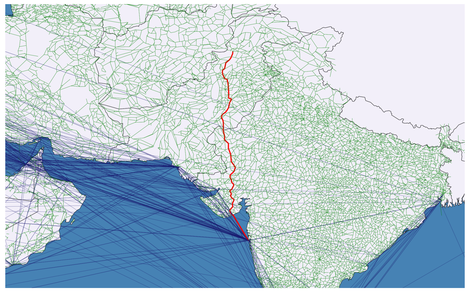
The $z_{s,a}$ variables capture initial design

The $x_{s,a}$ variables capture smuggler movement

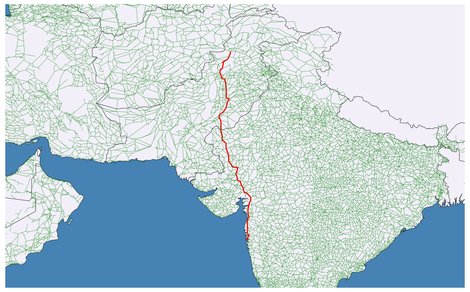
Constraint (1) is an interdiction budget constraint

$h(z,\omega)$ is concave in z, but there exists a standard transformation

Shortest Distance or Google Maps Route



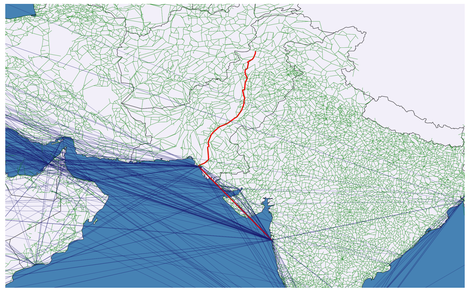
Max Reliability, Forced Land



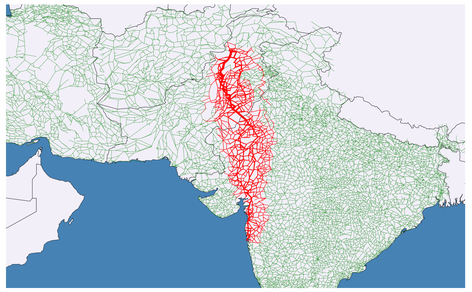
"…heroin from Afghanistan, which is smuggled via *the "Balkan Route" of Turkey-Bulgaria-Macedonia-Albania to Italy*, Montenegro, Greece, and the rest of Western Europe." — the International Narcotics Control Strategy Report, US State Department

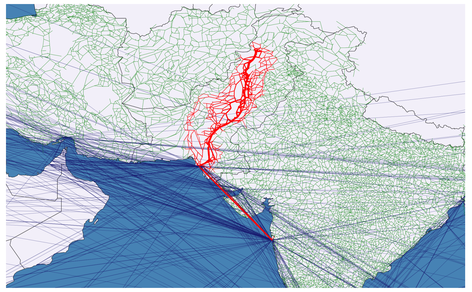
Network gives *Turkey, Bulgaria, Serbia, Slovenia, Italy, France*.

Max Reliability



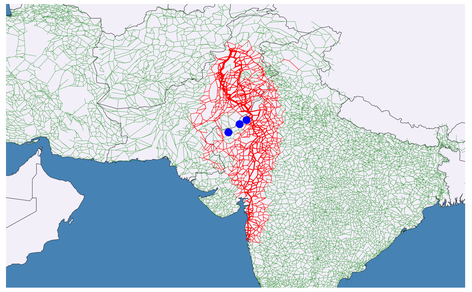
Mixed Movement Model





"The terrorists navigated across the Arabian Sea to Mumbai from Karachi…[they] took…pistols bearing the markings of a gun manufacturer in Peshawar…"" — New York Times reports, based on Indian government dossier.

Adaptable Smuggler



Current and Future Directions

- Continued collaboration with Los Alamos.
- Custom algorithm design:
  - Already developed some fast algorithms for Conservative model.
  - Some algorithms exist for Markovian model.
  - Developing fast algorithms for the Mixed model.
- Using nice algorithms, we can answer the original Question.
- Event search and forensics, research in progress:
  - Suppose we capture a smuggler.
  - What can we say about the smuggler's source and destination?
  - If we know an event is occurring, where do we look for the smuggler?
- What about alternate smuggler strategies? For example, splitting material?