Human Trafficking Interdiction Problem: A Data Driven Approach to Modeling and Analysis

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Modeling, and Analysis of Human Trafficking Networks

- U.S. National Science Foundation funded project: “A Holistic Approach to Discovery, Modeling, and Interdiction of Drug and Human Trafficking Networks in the U.S. Southwest”
- PI: Prof. Jorge Sefair, ASU
- Co-PI: Prof. Arun Sen (ASU), Prof. Dominique Roe-Sepowitz (ASU), Prof. Tony Grubesic Univ. of Texas, Austin)
- Senior Personnel: Prof. Rob Kooij TU Delft
Human Trafficking Incidence Data

- As a part of the agreement with Las Vegas Police department, we received significant amount of anonymized human trafficking incidence data.
- A summary of collected data is shown in the table below (only 8 out of more than 50 columns are shown in the table).

<table>
<thead>
<tr>
<th>Incidence No.</th>
<th>Date, Time &amp; Location</th>
<th>Victim Id.</th>
<th>Trafficker Id.</th>
<th>Trafficker Type</th>
<th>Destination City</th>
<th>Intermediate Cities</th>
<th>Originating City</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_1$</td>
<td>...</td>
<td>$V_1$</td>
<td>$T_1$</td>
<td>“Romeo”</td>
<td>$C_1$</td>
<td>$C_2, C_3, C_4$</td>
<td>$C_5$</td>
</tr>
<tr>
<td>$I_2$</td>
<td>...</td>
<td>$V_2$</td>
<td>$T_2$</td>
<td>“Boss”</td>
<td>$C_1$</td>
<td>$C_3, C_6$</td>
<td>$C_7$</td>
</tr>
<tr>
<td>$I_3$</td>
<td>...</td>
<td>$V_3$</td>
<td>$T_3$</td>
<td>“Boss”</td>
<td>$C_1$</td>
<td>$\emptyset$</td>
<td>$C_8$</td>
</tr>
<tr>
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<td>...</td>
</tr>
<tr>
<td>$I_n$</td>
<td>...</td>
<td>$V_n$</td>
<td>$T_n$</td>
<td>“Boss”</td>
<td>$C_1$</td>
<td>$C_9$</td>
<td>$C_{10}$</td>
</tr>
</tbody>
</table>

**TABLE I**

Human Trafficking Incidence Data in Local Law Enforcement Records of City $C_1$

**Figure 1:** Human Trafficking Incidence Data
Some of the incidence data has only the names of the originating and destination city.

Some others provide the names of a few intermediate cities that were visited on their way to the destination city.

Path information from the Incidence Data is *coarse grained*, i.e., provides only a very high level view of the path travelled. We refer to these paths as *Logical Paths*.

For interdiction purpose, we need more fine grained path information, i.e., the names of the intermediate cities and the roads travelled. We refer to these paths as *Physical Paths*.

As Physical Path information is unavailable from the Incidence Data, we compute the *most likely* Physical Path corresponding to a given Logical Path.

Logical Path to Physical Path Mapping Problem.
Figure 2: Logical Paths: Multiple Sources to a Single Destination
Human Trafficking Routes

Figure 3: Logical Paths: Multiple Sources to Multiple Destinations
Human Trafficking Routes

Figure 4: Single Logical Path: Multiple Physical Paths
### Table II

Mapping of Logical Paths into Physical Paths

<table>
<thead>
<tr>
<th>Destination City</th>
<th>Originating City</th>
<th>Traffic Volume</th>
<th>Logical Path</th>
<th>Physical Path</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$</td>
<td>$C_2$</td>
<td></td>
<td>$C_1 \leftarrow C_3 \leftarrow C_4 \leftarrow C_2$</td>
<td>$C_1 \leftarrow C_3 \leftarrow C_6 \leftarrow C_7 \leftarrow C_4 \leftarrow C_2$</td>
</tr>
<tr>
<td>$C_1$</td>
<td>$C_2$</td>
<td></td>
<td>$C_1 \leftarrow C_3 \leftarrow C_4 \leftarrow C_2$</td>
<td>$C_1 \leftarrow C_3 \leftarrow C_{12} \leftarrow C_4 \leftarrow C_2$</td>
</tr>
<tr>
<td>$C_1$</td>
<td>$C_2$</td>
<td></td>
<td>$C_1 \leftarrow C_3 \leftarrow C_4 \leftarrow C_2$</td>
<td>$C_1 \leftarrow C_3 \leftarrow C_{11} \leftarrow C_4 \leftarrow C_2$</td>
</tr>
<tr>
<td>$C_1$</td>
<td>$C_2$</td>
<td></td>
<td>$C_1 \leftarrow C_3 \leftarrow C_4 \leftarrow C_2$</td>
<td>$C_1 \leftarrow C_3 \leftarrow C_{17} \leftarrow C_4 \leftarrow C_2$</td>
</tr>
<tr>
<td>$C_1$</td>
<td>$C_2$</td>
<td>10 ($C_1 \leftarrow C_2$)</td>
<td>$C_1 \leftarrow C_3 \leftarrow C_4 \leftarrow C_2$</td>
<td>$C_1 \leftarrow C_3 \leftarrow C_4 \leftarrow C_{20} \leftarrow C_2$</td>
</tr>
<tr>
<td>$C_1$</td>
<td>$C_2$</td>
<td></td>
<td>$C_1 \leftarrow C_3 \leftarrow C_4 \leftarrow C_2$</td>
<td>$C_1 \leftarrow C_3 \leftarrow C_{16} \leftarrow C_7 \leftarrow C_{12} \leftarrow C_2$</td>
</tr>
<tr>
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<td>$C_2$</td>
<td></td>
<td>$C_1 \leftarrow C_3 \leftarrow C_4 \leftarrow C_2$</td>
<td>$C_1 \leftarrow C_3 \leftarrow C_6 \leftarrow C_8 \leftarrow C_2$</td>
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<tr>
<td>$C_1$</td>
<td>$C_2$</td>
<td></td>
<td>$C_1 \leftarrow C_3 \leftarrow C_4 \leftarrow C_2$</td>
<td>$C_1 \leftarrow C_{24} \leftarrow C_2$</td>
</tr>
<tr>
<td>$C_1$</td>
<td>$C_2$</td>
<td></td>
<td>$C_1 \leftarrow C_7 \leftarrow C_2$</td>
<td>$C_1 \leftarrow C_3 \leftarrow C_6 \leftarrow C_7 \leftarrow C_4 \leftarrow C_2$</td>
</tr>
</tbody>
</table>

**Figure 5:** Mapping Logical Paths to Physical Paths
Logical to Physical Path Mapping Problem

- Factor to consider in Logical Path to Physical Path Mapping Problem
- Trafficker has a budget: Trafficker isn’t going to take a Physical Path that’s going to exceed trafficker’s travel budget
- Trafficker may or may not be aware of the risk of interdiction in a specific path segment (link on a road network graph)
- If a trafficker is aware of the risk of interdiction in a specific link, he most likely will take the least risky path, as long as the cost of the path doesn’t exceed the travel budget
- If a trafficker isn’t aware of the risk of interdiction in a specific link, all paths from the originating to the destination city whose cost is within the travel budget are equally likely
- Law enforcement authorities may or may not believe that the trafficker has information about risk associated with traveling a road segment and will use it in deciding on the Physical Path to be taken to travel to the destination
U.S. Interstate Network Graph Data Generation

- We created U.S. Interstate Network Graph (USING) for our study
- Data for USING is generated in the following way
- We used the map of U.S. Interstate highways to create USING data
- There are two sets of nodes in the graph
  - Set 1: The largest city in each of the lower 48 states is a node
  - Set 2: Intersection point of two Interstates is a node
- There are 280 nodes in USING
- Two nodes are connected by an edge if there’s Interstate highway segment that connects those to cities
- There are 475 edges in USING
- Visualization of U.S. Interstate Network Graph is shown in the next slide
Figure 6: U.S. Interstate Graph created with 280 nodes and 475 edges
Input (Physical Network): A graph $G = (V, E)$, where $V = \{v_1, \ldots, v_n\}$ and $E = \{e_1, \ldots, e_m\}$.

Each edge $e_i, 1 \leq i \leq m$ has a Travel Cost $c(e_i)$, and Interdiction Probability $g(e_i)$ associated with it.

Source/destination node pairs $(s, t)$ and any other intermediate nodes $(v_1, \ldots, v_k)$ that were visited (if known)

Trafficker’s budget $B_T$

Objective: Find the path $P$ from $s$ to $t$ (passing through $v_1, \ldots, v_k$), such that $C(P) \leq B_T$ and $I(P)$ is minimum, where $C(P)$ and $I(P)$ represent the cost and the interdiction probability of the path $P$ respectively

In words, $I(P)$ is the least risky path
Logical to Physical Path Mapping Problem

- $g_i$: probability of an edge $e_i \in E$ being *interdicted*.
- $h_i$: probability of an edge $e_i \in E$ not being interdicted.
- $s(P)$: probability (safety) of a path $P$ not being *disrupted*.
- A path $P$ is disrupted only if at least one of the edges that is part of the path $P$ is interdicted.
- Accordingly, safety of path $P$: $s(P) = \prod_{e_i \in P} h_i$
Logical to Physical Path Mapping Problem

- Logical to Physical Path Mapping Problem: Find a path $P$ from $s$ to $t$ (through $v_1, \ldots, v_k$ if appropriate) with the following objective/constraints
- **Maximize** $s(P)$
- Subject to the constraint (i) $c(P) \leq B_T$, and
- (ii) $P$ constitutes a valid path from $s$ to $t$ (through $v_1, \ldots, v_k$ if appropriate)
- The multiplicative objective function can be turned into an additive objective function with a logarithmic operator
- A valid path $P$ from $s$ to $t$ can be established by standard flow technique
In case the trafficker isn’t aware of the interdiction probability $g_i$ values associated edges, or incapable of figuring out the least risky path, all paths that are within the budget $B_T$ are equally viable.

In this case, from the law enforcement perspective, all paths that satisfy the trafficker’s budget are equally likely.

Accordingly, we developed an algorithm to compute all possible paths between a source-destination node pair, whose cost doesn’t exceed the specified budget $B_t$. 
Algorithm to compute all possible paths between a source-destination node pair within budget $B_t$
Interdiction Payoff Maximization Problem

- Input: A graph $G = (V, E)$, where $V = \{v_1, \ldots, v_n\}$ and $E = \{e_1, \ldots, e_m\}$.
- Each edge $e_i, 1 \leq i \leq m$ has an Interdiction Cost $IC(e_i)$, and Interdiction Payoff $IP(e_i)$ associated with it.
- $IP(e_i)$ is the number physical paths that will be disrupted by interdiction of the edge $e_i$.
- $IC(e_i)$ is the interdiction cost of the edge $e_i$.
- Interdiction Budget: Budget $B_L$ available to Law Enforcement Authorities for interdiction
- The goal of the this problem is to find a subset $E' \subseteq E$ that maximizes $IP(E')$, subject to the constraint that $IC(E') \leq B_L$.
- $IC(E') = \sum_{e_i \in E'} IC(e_i)$.
Interdiction Payoff Maximization Problem

- $x_i$: Binary variable associated with each edge $e_i \in E$
- $y_j$: Binary variable associated with each path $P_j \in \mathcal{P}$.
- $x_i = 1$, if the edge $e_i$ is interdicted, otherwise $x_i = 0$.
- $y_j = 1$, if the edge $e_i$ is interdicted and $e_i \in P_j$, otherwise $y_j = 0$.
- $E_j \subseteq E$: The set of edges that make up the path $P_j$.
- If any edge $e_i \in E_j$ is interdicted, then the path $P_j$ is disrupted.
Interdiction Payoff Maximization Problem

Objective function: Maximize: \[ \sum_{P_i \in \mathcal{P}} IP(P_i)y_i \]

Subject to the Constraints:

(i) \[ \sum_{i=1}^{m} IC(e_i)x_i \leq B_L \]

(ii) \[ y_j = 1, \text{ if } x_i = 1 \text{ and } e_i \in P_j \]

(iia) \[ y_j = 1, \text{ if } \sum_{e_k \in P_j} x_k \geq 1 \]

(iib) \[ y_j \leq \sum_{e_k \in P_j} x_k \]

(iic) \[ \forall e_k \in P_j, \ y_j \geq x_k \]
Interdiction Payoff Maximization Problem

Objective function: Maximize: \[ \sum_{P_i \in P} IP(P_i) y_i \]

Subject to the Constraints:

(iii) \[ \forall y_j, 1 \leq j \leq p, \quad y_j = 0/1 \]

(iv) \[ \forall x_i, 1 \leq i \leq m, \quad x_1 = 0/1 \]