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

Arunabha (Arun) Sen[1 2]

[1]School of Computing and Augmented Intelligence
Arizona State University

[2]School pf Computing
National University of Singapore (on sabbatical from ASU)

Network Architectures and Services Group
TU Delft
18 March 2022

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)

Incidence No.	Date, Time & Location	Victim Id.	Trafficker Id.	Trafficker Type	Destination City	Intermediate Cities	Originating City
I_1	$\cdots$	V_1	T_1	"Romeo"	C_1	C_2, C_3, C_4	C_5
I_2	$\cdots$	V_2	T_2	"Boss"	C_1	C_3, C_6	C_7
I_3	$\cdots$	V_3	T_3	"Boss"	C_1	$\emptyset$	C_8
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
I_n	$\cdots$	V_n	T_n	"Boss"	C_1	$C9$	C_{10}

TABLE I
HUMAN TRAFFICKING INCIDENCE DATA IN LOCAL LAW ENFORCEMENT RECORDS OF CITY C_1

Figure 1: Human Trafficking Incidence Data

Data Driven Modeling and Analysis

- 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

Human Trafficking Routes

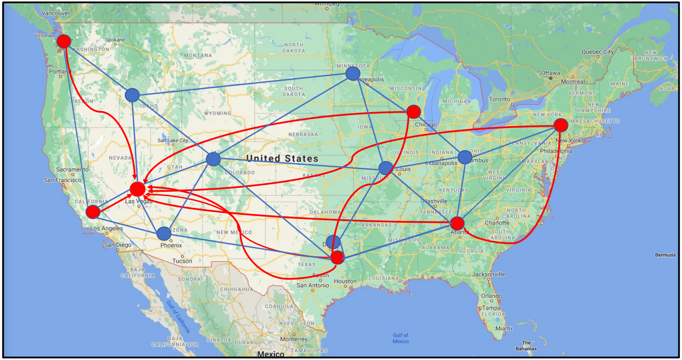

Figure 2: Logical Paths: Multiple Sources to a Single Destination

Human Trafficking Routes

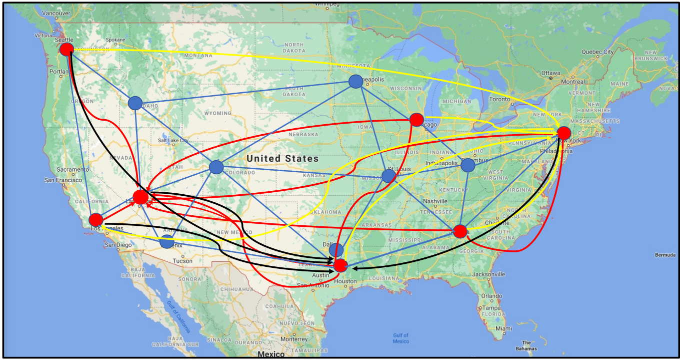

Figure 3: Logical Paths: Multiple Sources to Multiple Destinations

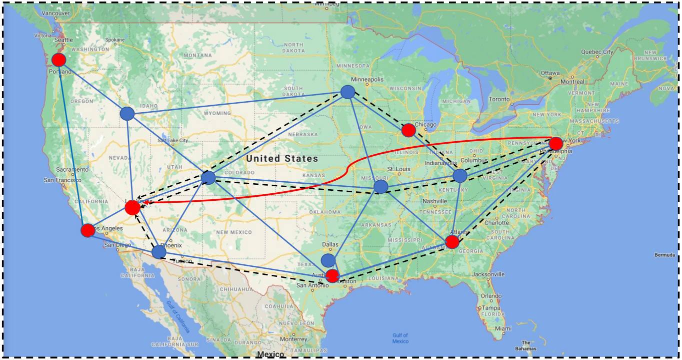

Figure 4: Single Logical Path: Multiple Physical Paths

Human Trafficking Incidence Data

Destination City	Originating City	Traffic Volume	Logical Path	Physical Path
C_1	C_2		$C_1 \leftarrow C_3 \leftarrow C_4 \leftarrow C_2$	$C_1 \leftarrow C_3 \leftarrow C_6 \leftarrow C_7 \leftarrow C_4 \leftarrow C_2$
C_1	C_2		$C_1 \leftarrow C_3 \leftarrow C_4 \leftarrow C_2$	$C_1 \leftarrow C_3 \leftarrow C_{12} \leftarrow C_4 \leftarrow C_2$
C_1	C_2		$C_1 \leftarrow C_3 \leftarrow C_4 \leftarrow C_2$	$C_1 \leftarrow C_3 \leftarrow C_9 \leftarrow C_{11} \leftarrow C_4 \leftarrow C_2$
C_1	C_2		$C_1 \leftarrow C_3 \leftarrow C_4 \leftarrow C_2$	$C_1 \leftarrow C_{12} \leftarrow C_3 \leftarrow C_4 \leftarrow C_2$
C_1	C_2	10 ($C_1 \leftarrow C_2$)	$C_1 \leftarrow C_3 \leftarrow C_4 \leftarrow C_2$	$C_1 \leftarrow C_3 \leftarrow C_{17} \leftarrow C_4 \leftarrow C_2$
C_1	C_2		$C_1 \leftarrow C_3 \leftarrow C_4 \leftarrow C_2$	$C_1 \leftarrow C_3 \leftarrow C_4 \leftarrow C_{20} \leftarrow C_2$
C_1	C_2		$C_1 \leftarrow C_8 \leftarrow C_2$	$C_1 \leftarrow C_3 \leftarrow C_{16} \leftarrow C_7 \leftarrow C_8 \leftarrow C_2$
C_1	C_2		$C_1 \leftarrow C_8 \leftarrow C_2$	$C_1 \leftarrow C_6 \leftarrow C_8 \leftarrow C_2$
C_1	C_2		$C_1 \leftarrow C_2$	$C_1 \leftarrow C_{24} \leftarrow C_2$
C_1	C_2		$C_1 \leftarrow C_7 \leftarrow C_2$	$C_1 \leftarrow C_3 \leftarrow C_6 \leftarrow C_7 \leftarrow C_4 \leftarrow C_2$
...	...	...	...	...
...	...	...	...	...
...	...	...	...	...
C_1	C_{10}		$C_1 \leftarrow C_{24} \leftarrow C_{27} \leftarrow C_{10}$	$C_1 \leftarrow C_{24} \leftarrow C_{27} \leftarrow C_{29} \leftarrow C_{10}$
C_1	C_{10}		$C_1 \leftarrow C_{20} \leftarrow C_{10}$	$C_1 \leftarrow C_{20} \leftarrow C_{27} \leftarrow C_{10}$
C_1	C_{10}	5 ($C_1 \leftarrow C_{10}$)	$C_1 \leftarrow C_{27} \leftarrow C_{10}$	$C_1 \leftarrow C_{26} \leftarrow C_{27} \leftarrow C_{29} \leftarrow C_{10}$
C_1	C_{10}		$C_1 \leftarrow C_{10}$	$C_1 \leftarrow C_6 \leftarrow C_7 \leftarrow C_{20} \leftarrow C_{12} \leftarrow C_{10}$
C_1	C_{10}		$C_1 \leftarrow C_7 \leftarrow C_9 \leftarrow C_{10}$	$C_1 \leftarrow C_7 \leftarrow C_9 \leftarrow C_{26} \leftarrow C_{10}$

TABLE II

MAPPING OF LOGICAL PATHS INTO PHYSICAL PATHS

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

Visualization of U.S. Interstate Network Graph

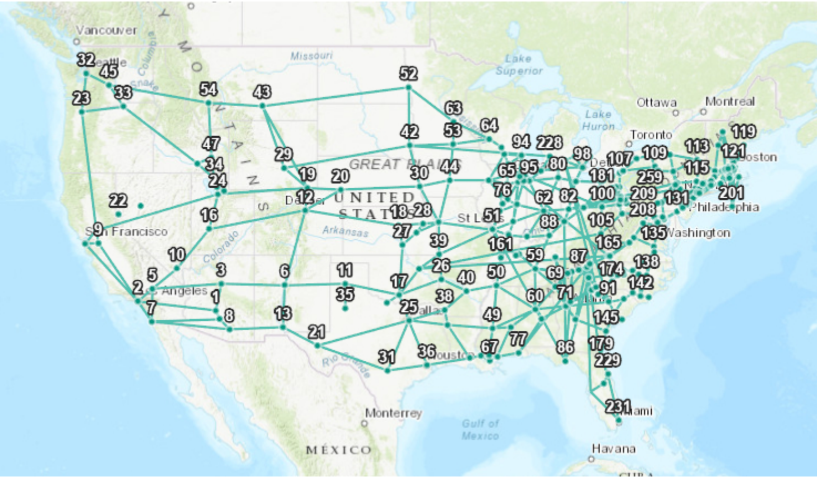

Figure 6: U.S. Interstate Graph created with 280 nodes and 475 edges

Logical to Physical Path Mapping Problem

- 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

Logical to Physical Path Mapping Problem

- 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:`

$$(\texttt{i}) \quad \sum_{i=1}^{m} IC(e_i) x_i \leq B_L$$

$$(\texttt{ii}) \quad y_j = 1, \quad \texttt{if} \quad x_i = 1 \quad \texttt{and} \quad e_i \in P_j$$

$$(\texttt{iia}) \quad y_j = 1, \quad \texttt{if} \quad \sum_{e_k \in P_j} x_k \geq 1$$

$$(\texttt{iib}) \quad y_j \leq \sum_{e_k \in P_j} x_k$$

$$(\texttt{iic}) \quad \forall e_k \in Pj, \quad y_j \geq x_k$$

Interdiction Payoff Maximization Problem

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

`Subject to the Constraints:`

$$(\texttt{iii}) \;\; \forall y_j, 1 \le j \le p, \quad y_j = 0/1$$

$$(\texttt{iv}) \;\; \forall x_i, 1 \le i \le m, \quad x_1 = 0/1$$