Finding Criminal Groups in Suspect Networks

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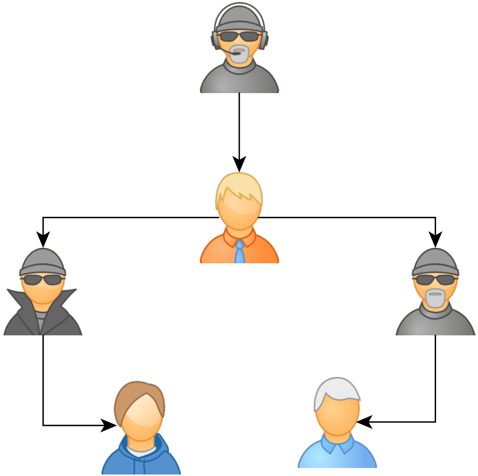
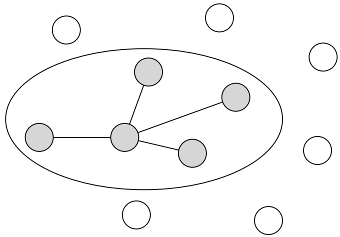
1. A criminal group is defined as a structured group formed by two or more people that is characterized by serious criminal activity over time, with high internal cohesion and a hierarchical and specialized structure[2]
2. The structure of a criminal group is given by the relationships between its members and is fundamental for the success of its operations.[1]



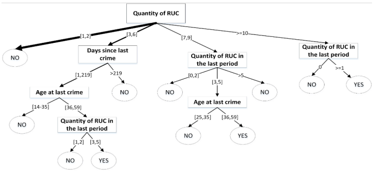
1. The STP in graphs is a combinatorial optimization problem that has been widely used in network design, integrated circuit design, localization problems, machine learning, systems biology, and bioinformatics[3].
2. The STP seeks a tree that interconnects a set of nodes S called terminals at a minimum cost.



1. The indicator pcg_i is introduced as the propensity of each individual $i \in N$ to belong to a criminal group
2. The general form for estimating pcg_i is given by:

$$pcg_i = f(s_i), \forall i \in N$$

where s_i is the set of relevant attributes of individual i and f is a function that transforms these attributes into a propensity value.



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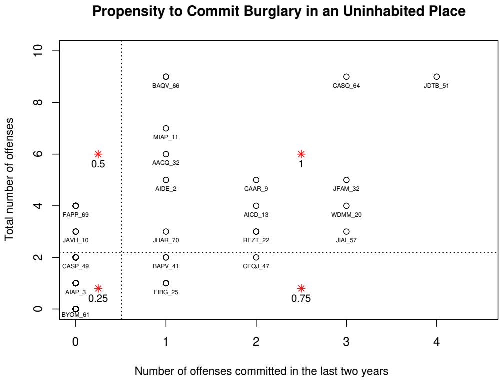
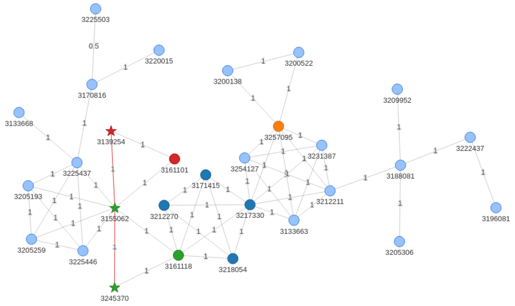
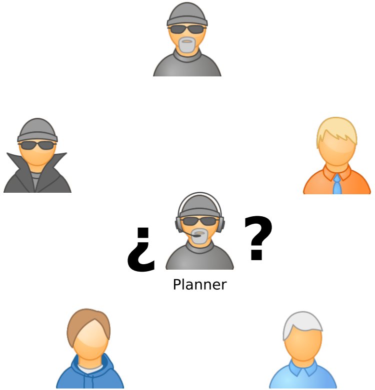


1. Criminal skills are represented by the criminal propensity *pcg* and trustworthiness through social distance between individuals d_{ij}
2. The social distance between two individuals is represented by a value between 0 and 1, where 1 represents the maximum distance between them.



1. The search for association can be seen as the process by which a criminal planner s plans a group crime by choosing other criminals.
2. The planner is rational and chooses criminals with the criminal skills that guarantee that the crime is carried out with the maximum utility.



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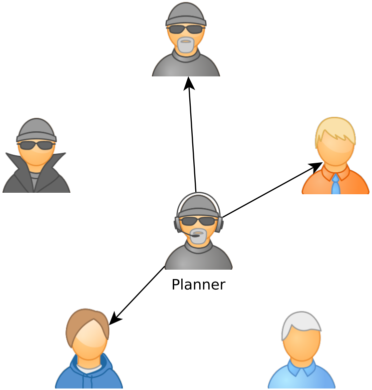
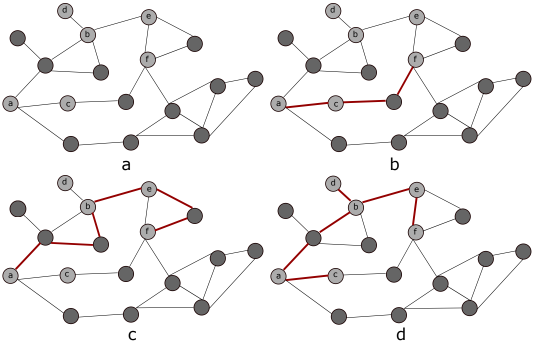


1. The planner is rational and chooses criminals with the skills that ensure that the crime is carried out with maximum utility.
2. The StRAM model determines the Steiner tree, rooted in the planner $s \in N$ of the crime.
3. Requires a single suspect to determine criminal groups



Decision variables

$$y_i = \begin{cases} 1 & \text{if } i \in N \text{ is in the criminal group} \\ 0 & \text{otherwise} \end{cases}$$

$$x_{ij} = \begin{cases} 1 & \text{if } (i,j) \in A \text{ is in the solution} \\ 0 & \text{otherwise} \end{cases}$$

$$f_{ij} = \text{flow through the arc } (i,j) \in A$$

Objective function

- Utility function of a crime planner

$$\max U = \frac{I}{pcg_{max}} \sum_{i \in N} pcg_i y_i - \frac{I\gamma}{d_{max}} \sum_{(i,j) \in A} d_{ij} x_{ij} - w \sum_{i \in N} pcg_i y_i$$

Constraints

- Predecessor constraint:

$$\sum_{i \in N} x_{ij} = y_j \qquad \forall j \in N \setminus \{s\} \qquad (1)$$

- Flow conservation:

$$\sum_{i \in N} f_{ij} - \sum_{i \in N} f_{ji} = y_j \qquad \forall j \in N \setminus \{s\} \qquad (2)$$

- Link of the variables:

$$f_{ij} \leq (|N| - 1) x_{ij} \qquad \forall (i,j) \in A \qquad (3)$$

- Maximum criminal propensity:

$$\sum_{i \in N} pcg_i y_i \leq \varphi pcg_{max} \qquad (4)$$

- Variable's domain:

$$f_{ij} \geq 0 \qquad \forall (i,j) \in A \qquad (5)$$

$$x_{ij} \in \{0,1\} \qquad \forall (i,j) \in A \qquad (6)$$

$$y_i \in \{0,1\} \qquad \forall i \in N \qquad (7)$$

The Public Prosecutor's Office of Chile Dataset

- The criminal network was provided by the criminal analysis unit of the Public Prosecutor's Office of Chile.
- The database consists of 1,666 crimes and 77 suspects.
- The dataset contains a criminal group of 12 members.

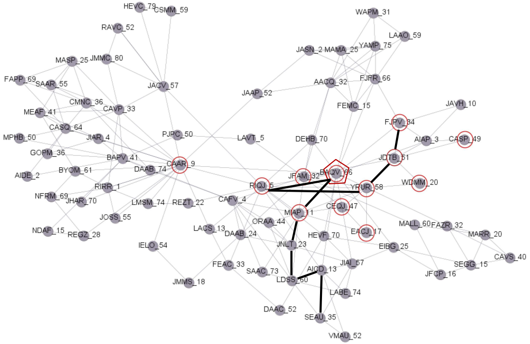


Figure: The network of 77 suspects.

Results

1. The performance of this model is evaluated with the performance of the *LiRAM*[4] and *SPA*[5] applied between pairs of suspicious individuals.
2. *StRAM* shows a slightly lower performance than *LiRAM* for each value of φ.
3. The confidence intervals intersect, therefore, there is no difference between the results of both models.

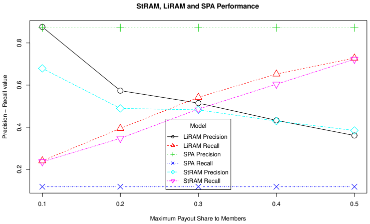


Figure: Precision and Recall to StRAM, LiRAM and SPA.

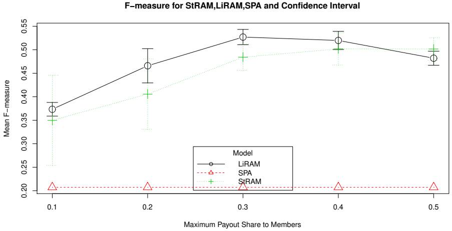


Figure: F-measure to StRAM, LiRAM and SPA

Results

1. A statistical hypothesis test of mean difference between the models was applied.
2. At a significance level of 0.05, the Shapiro-Wilk test indicates that the results are not normally distributed.
3. Levene's test indicates that there is no homogeneity in the variance ($\alpha = 0.05$).
4. The nonparametric Kruskal–Wallis test is applied. It is concluded that the results of both models are statistically similar ($\alpha = 0.05$).

Table: Results to statistical tests for different values of φ.

Results to Statistical Tests					
	Maximum Payout Share to Members P-value				
Test	$\varphi = 0.1$	$\varphi = 0.2$	$\varphi = 0.3$	$\varphi = 0.4$	$\varphi = 0.5$
Shapiro-Wilk (LiRAM data)	0.0000000034111	0.0021649	0.0027877	0.0117392	0.2396275
Shapiro-Wilk (StRAM data)	0.02501584	0.00374289	0.00201161	0.04011305	0.00056471
Levene	0.00006102	0.1438	0.05163	0.03224	0.03611
Kruskal-Wallis	0.8504	0.4327	0.07577	0.6481	0.2407

Conclusions

1. StRAM provides excellent results and even behaves comparably to existing approaches that start with two suspects.
2. Many criminal investigations begin with a single suspect. Therefore, the proposed model opens new avenues for applied research in criminal investigation.
3. Its application to a real-world case of crime analysis shows the potential StRAM has for crime investigation.

Future Work

1. It would also be interesting to apply StRAM without any confirmed cases and just using the propensity of members of potential suspects.
2. We will sequentially apply StRAM and update the model parameters each time a new suspect is confirmed.

[1] Carles Ortolà Boscà. Así son las redes terroristas más eficientes según las matemáticas. *Global strategy reports*, 1(53), 2020.

[2] Frank E. Hagan. "organized crime" and "organized crime": Indeterminate problems of definition. *Trends Organ Crim*, 9:127–137, 2006.

[3] Ivana Ljubić. Solving steiner trees: Recent advances, challenges, and perspectives. *Networks*, 77(2):177–204, 2021.

[4] Fredy Troncoso and Richard Weber. A novel approach to detect associations in criminal networks. *Decision Support Systems*, 128:113159, 2020.

[5] Jennifer J Xu and Hsinchun Chen. Fighting organized crimes: using shortest-path algorithms to identify associations in criminal networks. *Decision Support Systems*, 38(3):473–487, 2004.

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