

Finding Criminal Groups in Suspect Networks Using a Steiner Tree Approach

Fredy Troncoso^a Richard Weber^b Alex Barrales-Araneda^a

^aDepartamento de Ingeniería Industrial, Universidad del Bío-Bío

^bDepartamento de Ingeniería Industrial, Universidad de Chile

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① Introduction

② Background

Node-Weighted Steiner Tree problem

③ A new model based on Steiner trees

Steiner tree rational association model

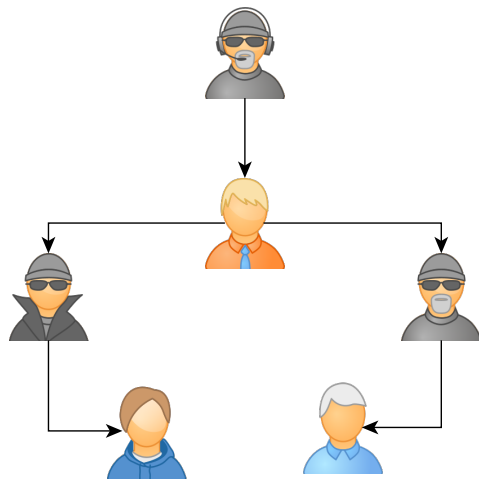
④ Results

The Public Prosecutor's Office of Chile Dataset

Test of the effectiveness of *StRAM*

⑤ Conclusions and Future Work

- 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]



Node-Weighted Steiner Tree problem

- 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.

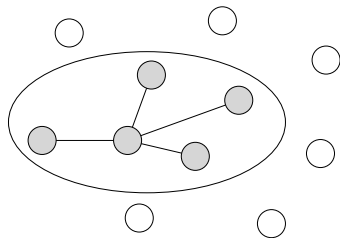
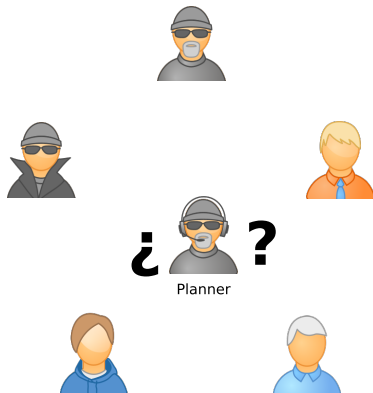


Figure: Figure ? $|S| = 4$

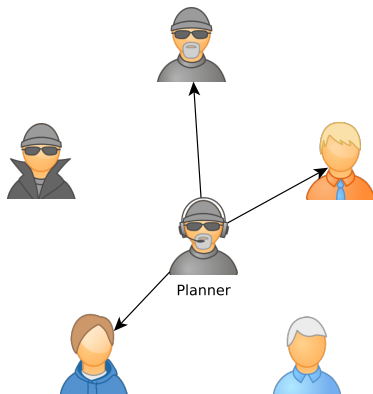
Steiner tree rational association model (StRAM)

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- 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.



Steiner tree rational association model (StRAM)

- 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.

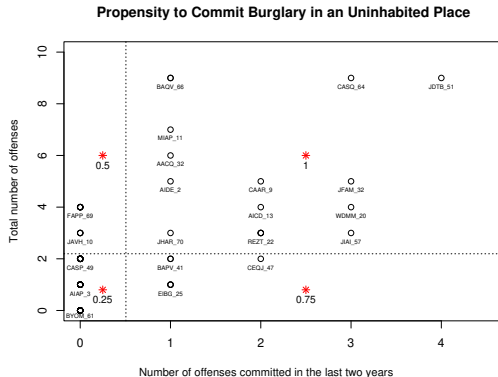


Figure: PCG values for network of 77 suspects

Objective function

- Utility function of a crime planner

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

Decision variables

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

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

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

Constraints

- Predecessor constraint:

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

- Flow conservation:

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

- Link of the variables:

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

- Maximum criminal propensity:

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

- Variable's domain:

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

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

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

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.

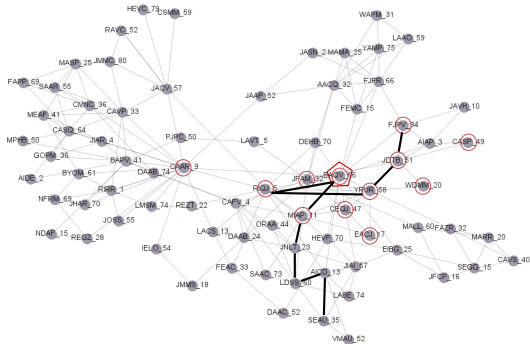


Figure: The network of 77 suspects.

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.

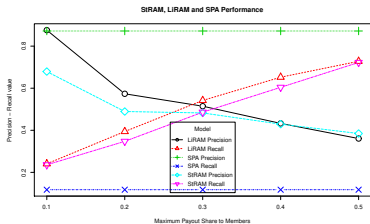


Figure: Precision and Recall to StRAM, LiRAM and SPA.

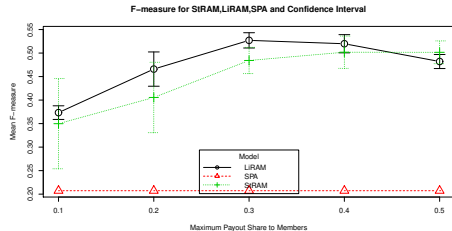


Figure: F-measure to StRAM, LiRAM and SPA

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.

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- FONDEF project ID20I10230ANID
- The Initiation Research Project 2060204IF/I
- Fondecyt Project 1181036
- Project ING 2030 I+D 20-34.
- Santiago based Complex Engineering Systems Institute (CONICYT PIA/BASALAFB180003).
- The Criminal Analysis Unit of the Public Prosecutor's Office of Región del Biobío-Chile



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