Graph Theory Application in Criminal Network Analysis

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***Abstract*—With the vast world we have, crime isn't an unfamiliar problem. We don't know when, how, or who is responsible of crime that will happen. Sometimes we can prevent it, sometimes we can't. With graph theory, we can create a visualization of a crime network happening in a small area, city, or even a country. Similar to a social network, crime network will reveal all person connections with others in positive or a negative way. So it will make the authority to keep an eye on every ex-criminals or future criminals and take an action before something bad happened. This paper will provide how graph theory can be used to a criminal network analysis to provide a better visualization that can help reduce percentage of crime.**

***Keywords*—Crime, graph, network, analysis.**

I. Introduction

Before Internet was found, crime fighters such police officers deal justice in a hard way. They have to be present when a crime happened to stop it. This of course is not effective because some factors like manpower, city size, or crime size are really affecting how much percentage of crimes can be prevented or stopped by the authority. Some criminals even have larger connections with other large criminals that make crime fighting be like an endless fight if the root has not been revoked. We never know when a crime will happen, but a crime can happen anytime.

Another example is detectives. Frequently, detectives are able to solve crime cases. But how they solve it is still ineffective. They have to start from every evidence they found in the scene, asking questions to every witness and suspect, then they can make a conclusion but without certainty if the suspect is really the bad guy. And sometimes, even the good can be blamed.

After Internet and development of information technology, crimes can be solved faster and much more effective. In the new technology era, every government should have detailed data of every person that live in the country. These data can be used to monitor every citizen in social, economic, medical history, and even crime analysis. This analysis can be implemented by using Graph Theory which will link every data that we have a about the society to determine how things are in a social way, economic way, or criminal way. These enormous data combine with a way to visualize them will be helpful to any department, such as social data for social department, and we are making about crime network analysis so justice department can use it to analyze crime condition, suspected crime that will happen, people that in suspicion of upcoming crime, or ex-criminals that have to be supervised. With the help of this analysis, hopefully the percentage of crime can be reduced in a significant way.

II. Theoretical Basis

A. Graph

The concept of graph theory was first introduced in 1735 to solve the problems of the Seven Bridge of Köögigberg. Leonhard Euler, a Swiss mathematician, studied this problem and then succeeded in building a solution that gave birth to the concept of the Eulerian Graph. Until now, Euler has been deployed on the basis of graph and is called the Father of Graph Theory.

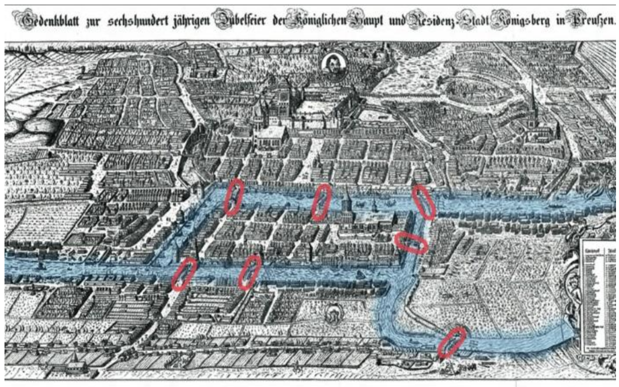
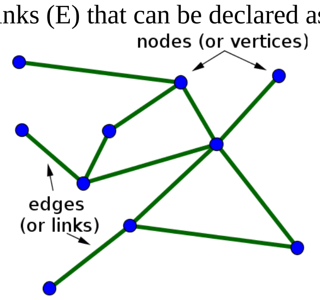


Figure 1. Seven Bridges of Königsberg
Source : http://www.phymath.com/introduction-to-the-seven-bridges-of-konigsberg/

Graph consist of at least one node or vertice (V) or more, and edges or links (E) that can be declared as G = (V,E).



B. Graph Terminology

1. Adjacent

Two vertices on a non-directional graph G are said to be neighbors when they are connected directly to a side. In other words, u is adjacent to v if (u, v) is a side in graph G.

2. Incident

For any side e = (u, v), the e side is said to be next to the vertices u and n.

3. Degree

The degree to which a node in a non-directional graph is the number of sides adjacent to that node.

4. Path

The length path n of the initial vertex v_o to the destination node v_n in graph G is a sequence of vertices of vertices and sides formed $v_0, e_1, v_1, e_2, v_2, e_3, v_3, ..., v_{n-1}, e_n, v_n$ in such so $e_1 = (v_0, v_1), e_2 = (v_1, v_2), ..., e_n = (v_{n-1}, v_n)$ are the sides of graph G.

5. Empty Graph

The graph whose set of sides is an empty set is called an empty graph and is written as N_n, in which case n is the number of vertices.

6. Circuit

In a graph, a circuit is a path that starts and ends at the same node.

7. Isolated Vertices / Node

A remote node is a node that has no side adjacent to it. Or it can also be stated that the isolated node is a node that neither neighboring the other nodes.

8. Subgraph

Let G = (V, E) be a graph. G1 = (V1, E1) is a subgraph of G if V1 subset of V and E1 subset of E. The complement of subgraph G1 to graph G is graph G2 = (V2, E2) such that E2 = E - E1 and V2 are nodes which the E2 members are side by side with

C. GRAPH TYPES

In this paper, the type of graph we refer to is planar, weighted, non-directional and dual graph.

1. Planar Graph

A graph is said to be planar if the graph can be represented on a plane such that no side intersects.

2. Weighted Graph

A weighted graph is a graph that each side is given a value.

3. Undirected Graph

An undirected graph is a graph that don't have any direction or orientation.

4. Dual Graph

A graph that have vertices for every face in a planar graph G. The dual graph has side if and only if the two faces of G are separated from each other by a side. If the same face is present on both sides of a side, then what is formed is a prop.

III. CRIME NETWORK ANALYSIS

A. KEY TERMS

1. Offender and Co – Offender

Sometimes a criminal can go solo, or even have another relationship with a different criminal and commit a crime together. These will be shown with edges that link a crime type to a group of people.

2. Crime Groups

This often represented by a number of people that's swarmed in a particular area of a graph that indicated a group of criminals working together in some type of crime or even a larger group that have some sub-groups of criminals.

B. KEY CONCEPTS

1. Crime Pattern Theory (CPT)

This theory consists of four key points :

a. Complexity of a criminal event

b. Crime isn't random

c. Criminal opportunities isn't random

d. Offenders and victims are not phatological in their perspective

2. Graph Theory

Which is already explained above.

3. Degree

How many links of incident / crime action to a person (vertices).

4. Betweenness

How many times a node can be linked as a bridge along the shortest path between two nodes.

5. Eigenvector

A measure of a node's influence in a network. In equations, for a given graph G = (V,E) with |V| vertices let $A = (a_{v,t})$ be the adjacency matrix. The relative centrality score of vertex v can be defined as:

$$Xv = \frac{1}{\lambda} \sum_{t \epsilon M(v)} Xt = \frac{1}{\lambda} \sum_{t \epsilon G} Av, t\, Xt$$

Where ***M(v)*** is a set of neighbors of the corresponding vertex and λ is a constant.

C. ANALYSIS

By using graph theory and its terminology, we can indicate of how a big scheme of crime works, or how crime status in a neighborhood. People is represented by nodes, which indicated that the person is involved in a criminal network. Edges is to represent connections between nodes, where that connection can be anything, important connections, bad relationship, closeness, rank in the organization, or just a mere connection between two individuals.

We can use any graph type to represent the network, which is the most suitable to represent with the data that we have. The bigger the graph, the larger the criminal network. CPT or Crime Pattern Theory is used by the person in charge of solving the problem, so we only use 2 until 5 in the key concepts to analyze some problem that is represented by graph to find effective ways in solving / taking down a criminal network from the system. This of course, only examples and need to be represented in different ways if the case is different.

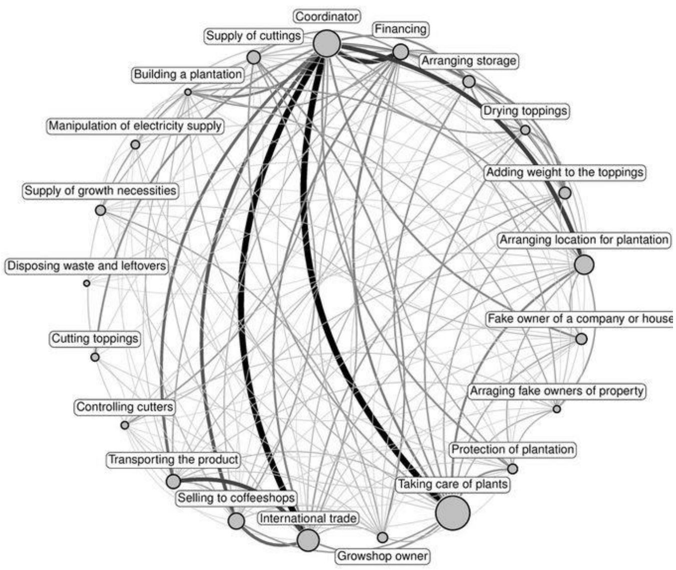


Figure 2. Example of Cannabis Trade Network
Source : https://www.nature.com/articles/srep04238

From the figure above, we can see several people in a large cannabis trade system with their own particular role. A node represents one person, with their own role and the size of the node represents how important they are. Bolder edges indicates that how important a connection between two nodes is. By visualizing like the graph above, authorities can take moment to think who is to investigate and capture, the one that don't have many connections (or even don't have connections to the big important man of the system) or the one sit at the top of the system.

By using eigenvector's equation with λ as constant, we can conclude that the Coordinator is the one that have the highest relative centrality score since he is the one with more connections rather than the manipulator of electricity supply. Therefore, authorities can take down the system with the help of detailed graph theory.

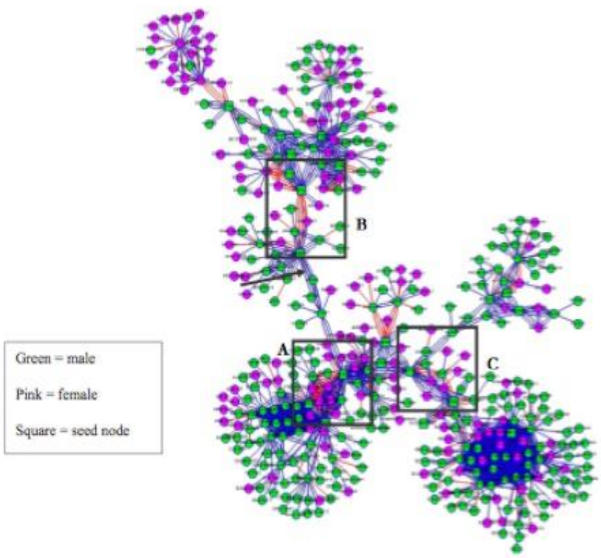


Figure 3. Example of Gang Members Social Network
Source : http://www.core77.com/posts/22462/Visualizing-Criminal-Networks-to-Help-Police-Solve-Crime

Another different approach of a graph theory is presented from Figure 3. It indicates a large number of people and organize them into groups within the graphs. While these groups are linked into each other, further inside also there is connections between people in the gang groups as well. With green as males and pink as females, these nodes come from the square or as indicated it's the seed node. We can see that in this graph, some area is more condensed and crowded than others which mean it indicates the number of people (sometimes strength) of the group. And the closer a node to a center of a group, the faster he/she to get information from other group, or within the group itself, or higher position in the group.

This data that brought by Virginia Commonwealth University for Richmond City Police to visualize the network of local gang groups in the city, to monitor and identify which group is related to each other or which member is related to another member in the same or different group.

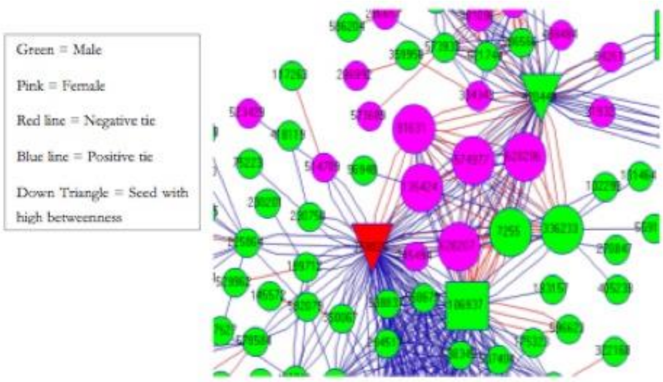


Figure 4. Zoom in from Figure 3
Source : http://www.core77.com/posts/22462/Visualizing-Criminal-Networks-to-Help-Police-Solve-Crime

If we look closer, the groups don't always have positive ties with each other, or from member to another member. It can be positive such as partnership in crime, family, married, or even negative like enemies. More negative connections from another node will indicates often clash between nodes or even groups and if there's also positive connections, the clash can develop to a bigger scale. This is the part that the justice department have to anticipate. To predict upcoming criminal events between some nodes in graph, how big is it, and take further investigation to prevent future damage.

More negative ties aren't meant to be certain events will come, but it is more likely than the ones that don't. It will give the authorities to plan some precaution, prevention, avoidance, or even an assertive impact to the groups so no harm is done. They can start with the seed node, which shown in the graph. Triangle seed nodes, with high betweenness that also show high relative centrality using eigenvector's equation will also show that that node is more likely to be involved if a big clash happened since he is in ties with the more person inside or outside the group.

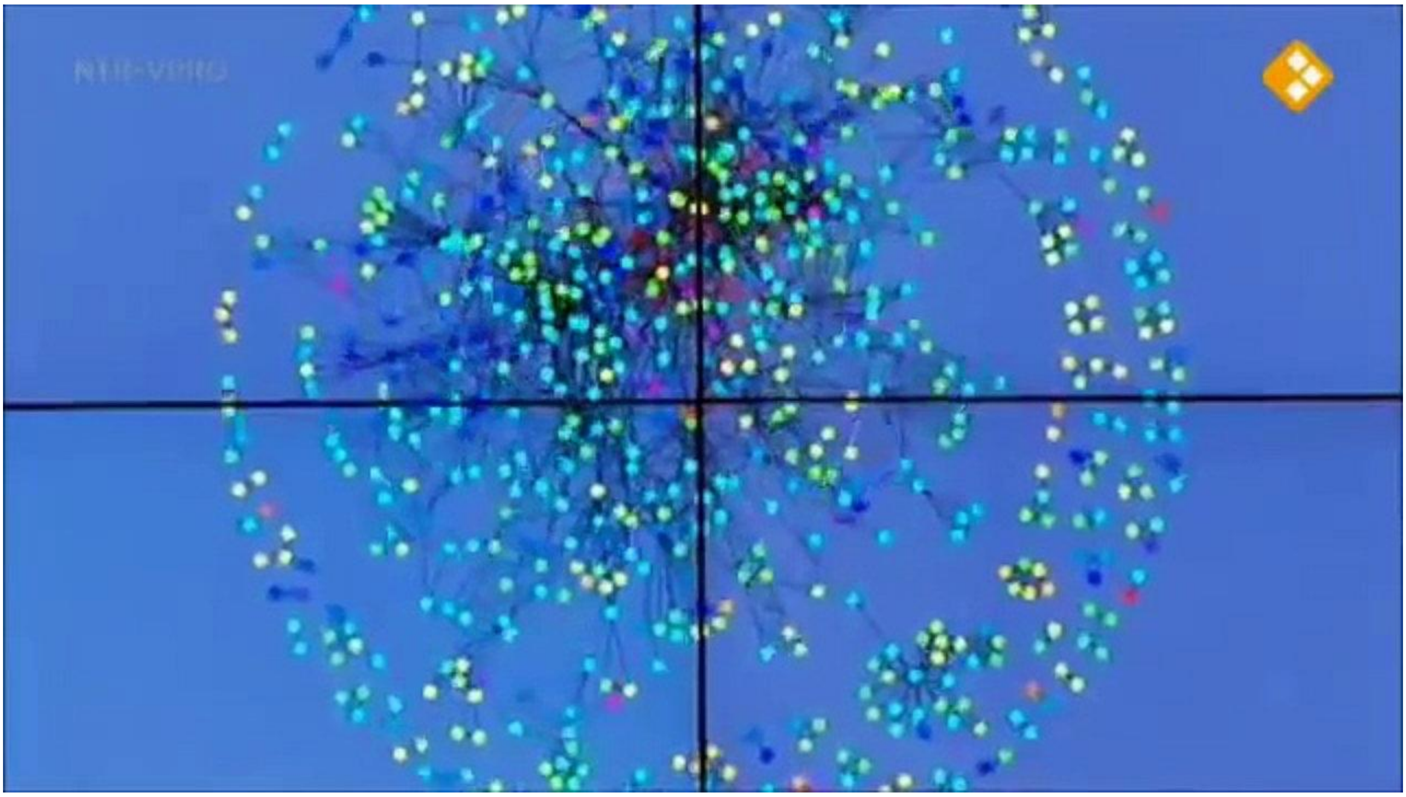


Figure 5. Visualization of a criminal network
Source : https://www.youtube.com/watch?v=Qhk9ciHlzzo

The figure above represent a more detailed visualization of a criminal network (apologize for the quality of the image) in a more interesting and big planar graph. As we can see, there's different color of nodes, more edges that connect to many ways, some *isolated* nodes, and it is bigger and more complicated than the last graph we analyzed. Within this graph, there is more detailed information of what is going on.

Different colors represent different information, such as blue is for a person which is the citizen of the country, different color means different nationality of a person in the graph. Edges means connections, how they communicate, with whom they communicate. The size of the node represents how much they communicate or how active they are in the network. And it is imperative to know that this network is not using a top to bottom system that's only one boss to coordinate all (which is easier to take down) but it consist of different groups with their own size, number of members, different leaders, sub-groups within the group, or even another group entirely that don't have any connection to the main group in the center (indicated by *isolated* groups in the sides) but still have a part in this criminal network visualized. From here now on, we can see that to monitor and take down such large network will take a long journey, but with graph representation it will take faster rather than raw data.

From here we can conclude that the main players are in the middle, where it is a large crime organization with several sub-groups that have its own leader, members, and system. While we are using our key concepts, that betweenness and eigenfactor's centrality value will give who is our main target, we have to see that sub-group leaders have higher centrality value than the leader of them all, because the most important man only receive connections from the sub-group leaders in the center, but sub-group leaders have more members. That means with our eigenfactor's centrality value, we can conclude that for now, sub-group leaders is the main target if we want to catch the big fish. That way, we can reduce the criminal network size sub – group by sub – group until there is none.

V. Conclusion

A detailed analysis on recently criminal activities is crucial to reduce the chances of upcoming ones. With graph theory, analysis can be visualized in a much more detailed, understandable, and effective way to monitor crime activities for authorities to take action. Also, authorities can learn the system of an unknown criminal activities that sometimes linked to a bigger scheme, or even a system of a large crime organization through graph visualization.

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PERNYATAAN

Dengan ini saya menyatakan bahwa makalah yang saya tulis ini adalah tulisan saya sendiri, bukan saduran, atau terjemahan dari makalah orang lain, dan bukan plagiasi.

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