Identifying Critical Nodes within a Critical Infrastructure Network

Patric Harrington

Advisor – Dr. Panagiotis Giannakis

GEOG 596A

October 23, 2023

Agenda

- Professional Background
- Background
- Goals and Objectives
- Proposed Methodology
- Proposed Dataset
- Anticipated Results
- Project Timeline
- Possible Presentation Venue

Professional Background

- Served over 8 years in the United States Army as a Geospatial Imagery Intelligence Analyst
  - Operation Freedom's Sentinel & Resolute Support
  - Operation Juniper Shield

- Fun Fact!
  - Met President Obama's dog, Bo, in 2012.

Background

- Cyber realm is the battle space of the future for nations to wage war on.
- Cybercrime against critical infrastructures such as nuclear reactors, power plants, and damns have been increasing over time (Plachkinova & Vo, 2023).
- Critical infrastructure systems are vulnerable to damage from natural disasters, component aging, an increase in demand, climatic change and terrorist attacks (Kizhakkedath & Tai, 2021)
- Identifying critical infrastructure and knowing which areas are key to defend is crucial in national defense.
- To ensure countries identify and fund crucial infrastructure, critical node analysis should be conducted.

Proposed Methodology

- Utilize multiple centrality algorithms to see which one identifies critical nodes (subset of the American power grid) accurately and efficiently.
  - Global Structural Model (GSM)
    - Consists of self and global influences (Ullah, Wang & Shen, 2021)
  - Local-and-Global-Centrality
    - Concentrates on both local and global structure-based methods ((Ullah, Wang, Sheng, Long, Khan & Sun, 2021))
  - Communication Probability and Relative entropy and Improved Technique for Order Preference by Similarity to Ideal Solution (CPR-TOPSIS)
    - Importance of each node in the network is evaluated from the view of global, local and location information dimensions and ranked through the weight TOPSIS (Dong, Xu, Meng & Yang, 2022)
  - HIC centrality (HIC)
    - Composed of the H-index, k-shell iteration factor and clustering coefficient (Ullah, Wang, Sheng, Long, Khan & Sun, 2021)

Proposed Methodology

Algorithm 1 – Global Structural Model	
Construct the network	Gather data from real-world dataset to identify complex network
Calculate global influence	$GI(v_i) = \sum_{i \neq j} \frac{Ks(v_j)}{d_{ij}}$
Calculate self influence	$SI(v_i) = e^{\frac{Ks(v_i)}{N}}$
Calculate total influence	$GSM(v_i) = SI(v_i) \times GI(v_i)$ Greater the influence, the higher the ranking of node

Figure 1 – Flowchart for Global Structural Model (Ullah, Wang & Shen, 2021)

Proposed Methodology

Algorithm 2 – Local-and-Global-Centrality	
Calculate local influence	$LI_{(v_i)} = \frac{d(v_i)}{n}$
Calculate global influence	$GI_{(v_i)} = \sum_{i \neq j} \frac{\sqrt{d(v_j) + \alpha}}{d_{ij}}$
Proposed LGC	$LGC_{(v_i)} = LI_{(v_i)} \times GI_{(v_i)}$
	$LGC_{(v_i)} = \frac{d(v_i)}{n} \times \sum_{i \neq j} \frac{\sqrt{d(v_j) + \alpha}}{d_{ij}}$

Figure 2 – Local-and-Global-Centrality Workflow
(Ullah, Wang, Sheng, Long, Khan & Sun, 2021)

Proposed Methodology

Algorithm 3 – CPR-TOPSIS	
Create a decision matrix	$A' = (a'_{ij})_{N \times N}$
Normalize the decision matrix	$x'_{ij} = \frac{x_{ij}}{\sqrt{\sum_{t=1}^{N} x_{tj}^2}}, \quad i = 1, 2, \ldots, N, \quad j = 1, 2, 3$
Calculate the positive ideal solution Q* and negative ideal solution Q-	$Q^* = \{Q_1^{max}, Q_2^{max}, Q_3^{max}\}, \quad Q^- = \{Q_1^{min}, Q_2^{min}, Q_3^{min}\}$
Determine the weight of each criterion	$w_j = \frac{Y_j}{\sum_{t=1}^{3} Y_t}, \quad j = 1, 2, 3$
	$Y_j = -\frac{1}{ln\ N} \sum_{i=1}^{N} x'_{ij} \cdot ln\ x'_{ij}$
Compute the distance from the positive ideal solution and the negative ideal solution	$\begin{cases} E^+(v_i) = \sum_{j=1}^{3} w_j \left[(Q_j^{max} \cdot log \frac{Q_j^{max}}{x'_{ij}}) + ((1 - Q_j^{max}) \cdot log \frac{(1 - Q_j^{max})}{(1 - x'_{ij})}) \right] \\ E^-(v_i) = \sum_{j=1}^{3} w_j \left[(Q_j^{min} \cdot log \frac{Q_j^{min}}{x'_{ij}}) + ((1 - Q_j^{min}) \cdot log \frac{(1 - Q_j^{min})}{(1 - x'_{ij})}) \right] \end{cases}$
Obtain the relative closeness to the ideal situation	$CD(v_i) = \frac{E^+(v_i)}{E^+(v_i) + E^-(v_i)}$
Rank the alternatives in ascending order of $CD(v\mathbf{i})$	

Figure 3 – Flowchart for CPR-TOPSIS (Dong, Xu, Meng & Yang, 2022)

Proposed Methodology

Algorithm 4 – HIC Centrality	
Calculating potential edge weights	**Wi,j is defined as** $W_{i,j} = \frac{H(i) \times Iter(i)}{1 + C(i)} + \frac{H(j) \times Iter(j)}{1 + C(j)},$
HIC Centrality	$HIC(i) = \sum_{j \in \Gamma i} W_{i,j},$

Figure 4 – HIC Centrality Workflow (Meng, Xu, Yang, Tu, 2021)

Proposed Dataset

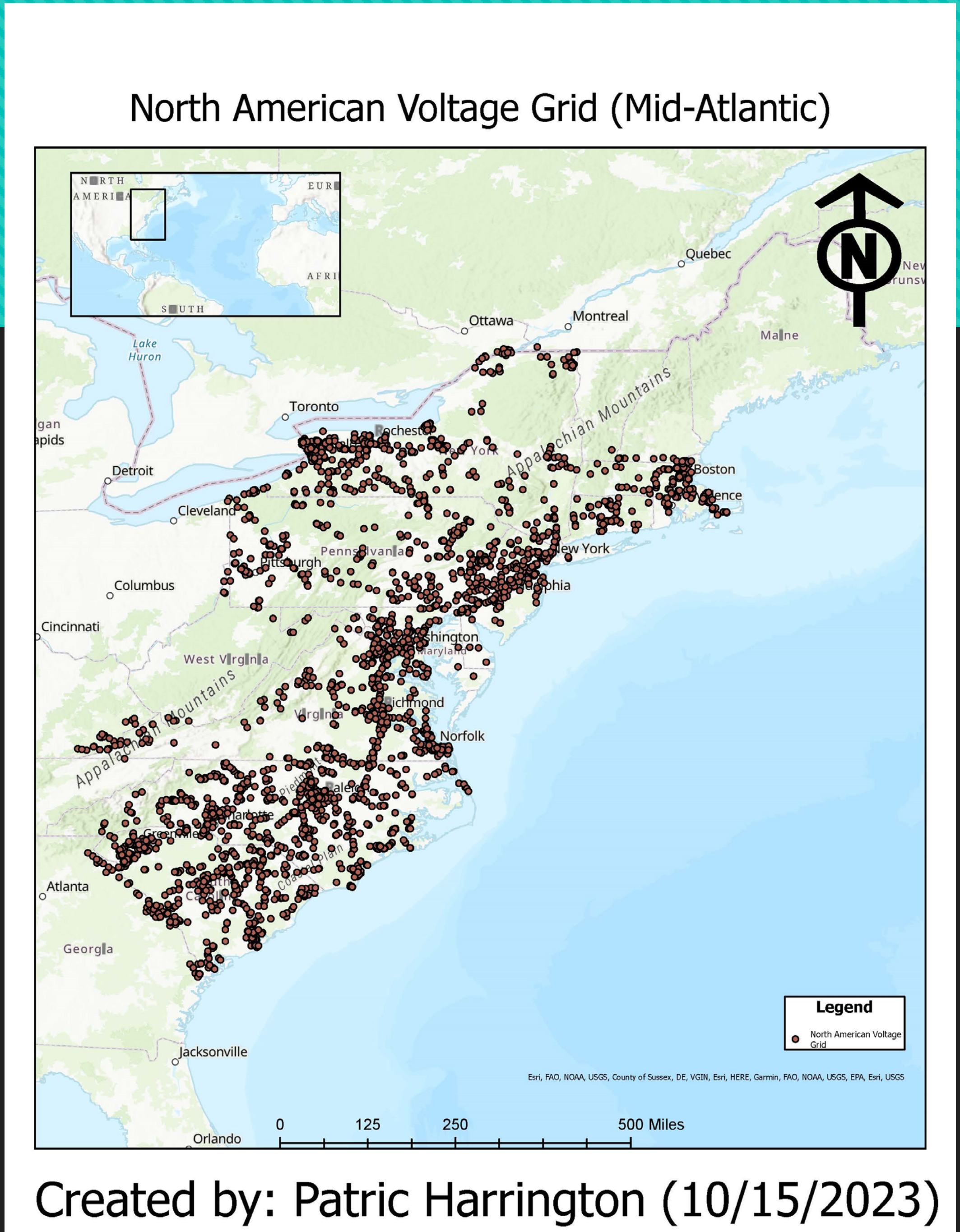

Figure 5: Mid-Atlantic Voltage Grid Map (OpenStreetMap, n.d.)

Anticipated Results

- Through literature review, CPR-TOPSIS ranked first in speed and accuracy when utilized against Local-and-Global-Centrality.
  - However, these four algorithms have not been tested against one another.
- CPR-TOPSIS should remain as the most effective algorithm.
- Assess the distribution geographically through analyzing maps created in ArcGIS.
  - We expect differences in the locations of the critical nodes through the results of the algorithms.

Project Timeline

- October 23, 2023
  - Capstone Project Proposal
- Late Summer 2024 – Fall 2024
  - Conduct the Analysis
- November 2024
  - Present at GIS Days 2024

Possible Presentation Venue

- GIS Days Conference 2024, potentially November 2024

Figure 5 – GIS Day Logo (ESRI, n.d.)

Works Cited

- Aman Ullah, Bin Wang, JinFang Sheng, Jun Long, Nasrullah Khan, ZeJun Sun. (2021). Identifying vital nodes from local and global perspectives in complex networks, Expert Systems with Applications, Volume 186
- Chen Dong, Guiqiong Xu, Lei Meng, Pingle Yang. (2022). CPR-TOPSIS: A novel algorithm for finding influential nodes in complex networks based on communication probability and relative entropy, Physica A: Statistical Mechanics and its Applications, Volume 603
- Esri, (n.d.). GIS Day logo [image]. ESRI. Obtained October 2, 2023, from https://www.gisday.com/en-us/resources
- Kizhakkedath, A. & Tai, K. (2021). Vulnerability analysis of critical infrastructure network, International Journal of Critical Infrasture Protection, Volume 35
- Lei Meng, Guiqiong Xu, Pingle Yang, Dengqin Tu. (2022). A novel potential edge weight method for identifying influential nodes in complex networks based on neighborhood and position, Journal of Computational Science, Volume 60
- Plachkinova, M., & Vo, A. (2021). A Taxonomy for Risk Assessment of Cyberattacks on Critical Infrastructure (TRACI). Communications of the Association for Information Systems