RC.1: A Graph Neural Network Approach for Analyzing Urban Rail Transit System Threat Deterrence

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So What? Who Cares?

- **Space**: *Deter adversaries from targeting soft infrastructure network targets, such as rail transit systems*
- **Problem**: *Need to consider infrastructure network topology, dynamics, and cascading effects to assess holistic network-level threat risk and deterrence*
- **Solution**: *Graph Convolutional Network (GCN) learning with network data for dynamic node attractiveness prediction followed by cascading network failure and robustness simulation for network-level threat risk and deterrence assessment*
- **Results**: *GCN-based network threat deterrence analysis methodology, Boston T urban rail network data assimilation, prototype GCN software code development, invited 2024 and 2023 SRA annual meeting talks, 2022 IEEE-HST best paper award, engagements with DHS CISA, Boston MBTA, ICE, and SafeGraph*

Source: https://unsplash.com/

- **TRL**: *2*

Network Risk Example: July 2024 French Rail Sabotage

French high-speed rail sabotaged before Olympic ceremony

7 days ago

Share

Lipika Pelham and Paul Kirby
BBC News

"Paris Olympics had representatives from over 200 countries, millions of spectators, and a budget of over $9 billion"

"at least 250,000 passengers were expected to be impacted due to train cancellations and diversions"

"thousands of rail workers were distributed across the network to investigate damage and initiate repairs"

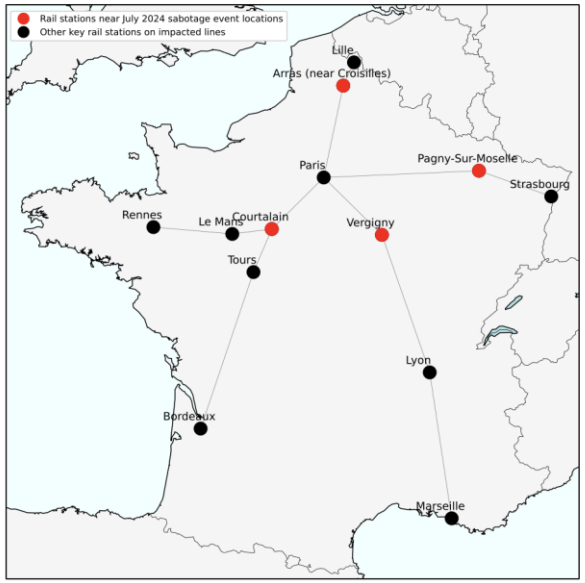
"presence of tens of thousands of security personnel in Paris"

"one foiled attack where presence of rail workers scared off individuals"

French PM Gabriel Attal:

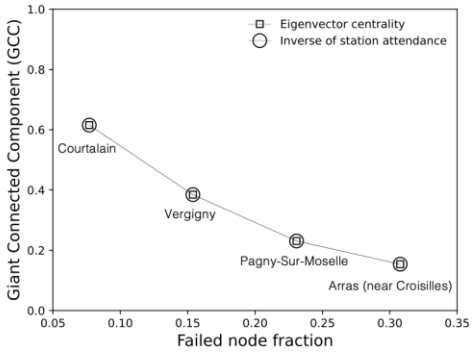
[the incidents were] "**prepared and organized**" [in a way that] "**shows a kind of knowledge of the network in order to know where to strike**"

Sources: https://www.bbc.com/news/articles/cv2gd9pqwlxo
https://www.cnn.com/2024/07/26/europe/france-rail-network-disruption-paris-olympics-intl-hnk/index.html

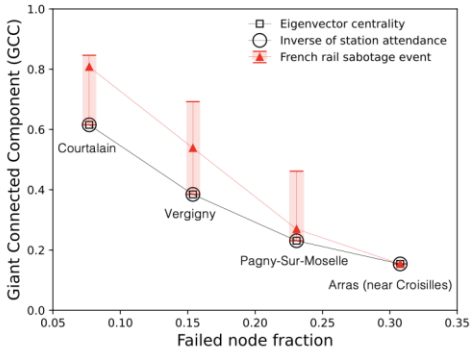


a. French high speed rail sub-network with key stations and impacted lines

Network robustness with French high speed rail sub-network



b. Network robustness (excluding Paris) with topology and flow-based failure sequences

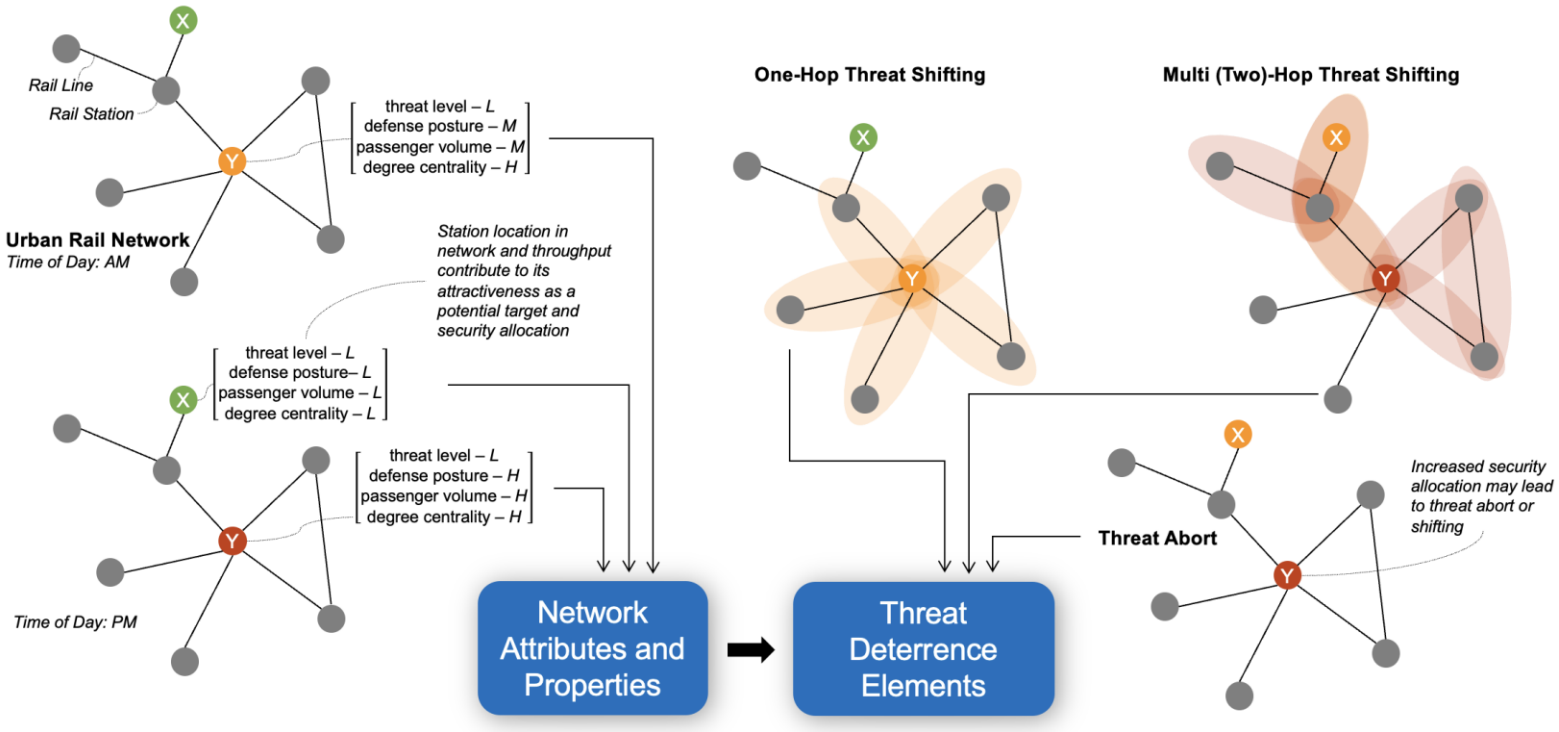


c. Network robustness (excluding Paris) with French rail sabotage event sequence uncertainties

- Network topology and flow-based failures provide a worst-case scenario for the July 2024 event sequence
- Node level risk and deterrence analysis is *necessary*, but not *sufficient*, to fully understand and mitigate soft target threats in surface transportation networks

Problem Illustration

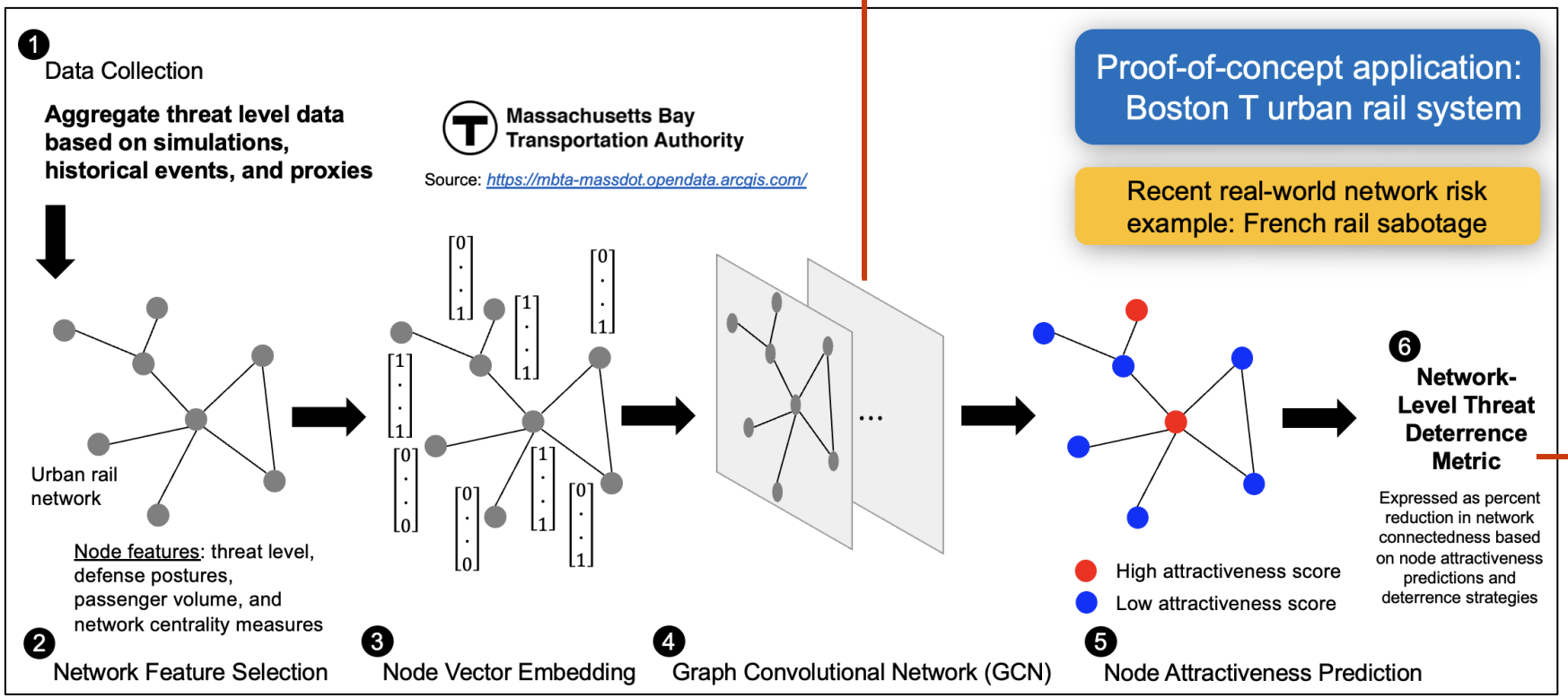
- Network perspective is key for effective allocation of scarce defensive resources
- Methods for machine learning with graphs are promising for target attractiveness score predictions
- Visualizing time-varying attractiveness scores as spatial heat maps with hotspots will inform situational awareness



- Need to incorporate cascading network effects due to target failures
- Need to dynamically update target location attractiveness based on evolving threat and defense postures, and operational conditions

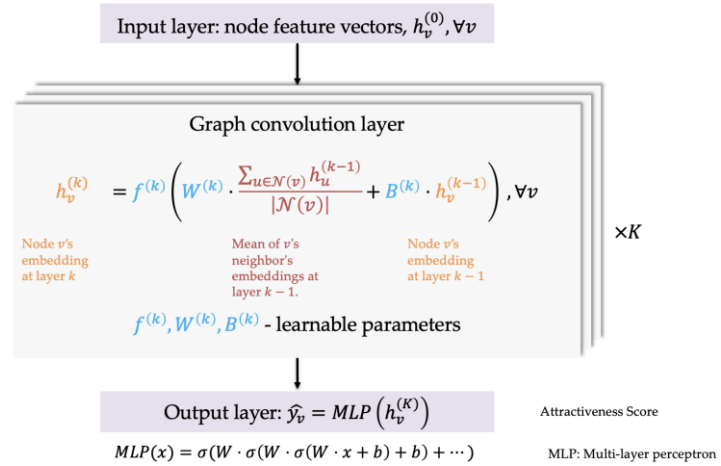
Methodological Approach

Step 4: GCN overview

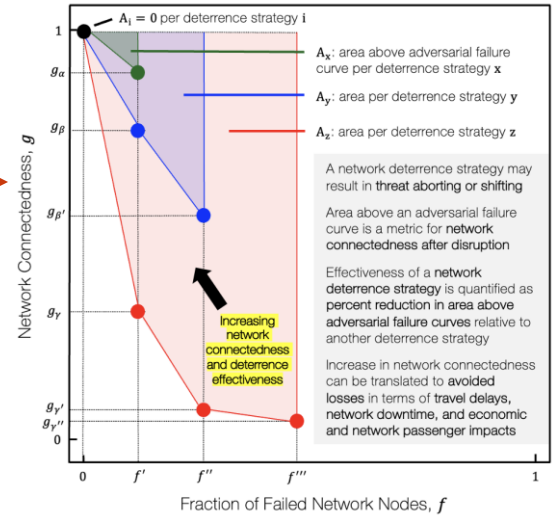


Proof-of-concept application: Boston T urban rail system

Recent real-world network risk example: French rail sabotage



Step 6: Network failure curves



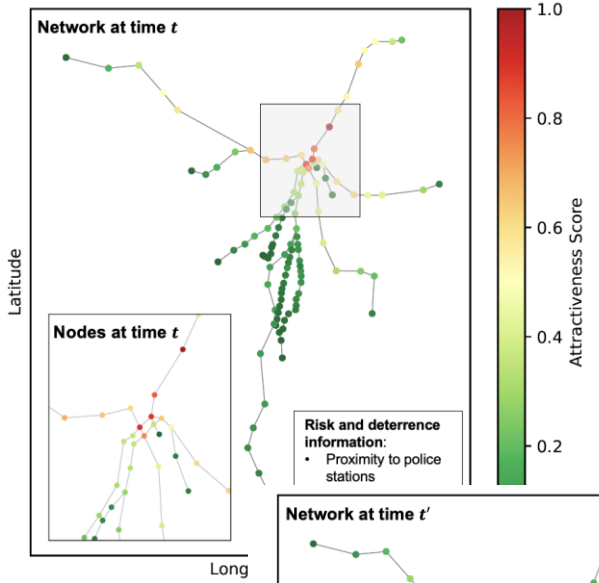
- Node attractiveness predictions based on GCN and network deterrence strategies inform network path analysis to generate plausible adversarial scenarios and simulated network failure curves
- Quantify scenario-based relative network deterrence effectiveness from network failure curves

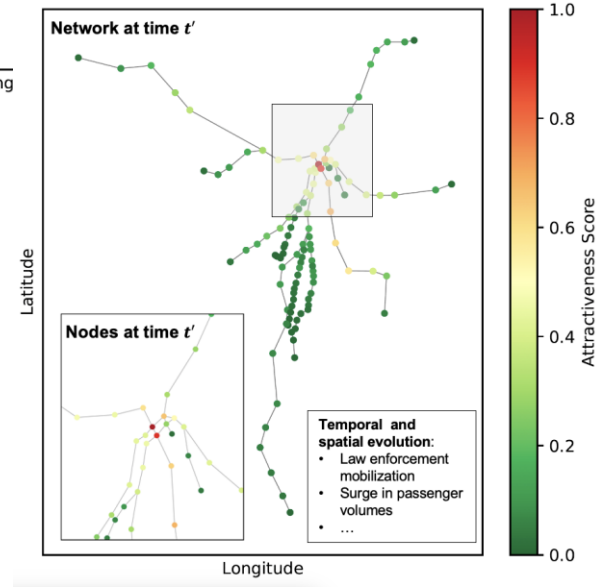
Proof-of-Concept: Boston T Urban Rail Network

GCN inputs: urban rail network features

	Features	Description	Source
Static	Centrality metrics		Python NetworkX
	Degree	Connectivity strength	https://networkx.org/documentation/stable/tutorial.html
	Betweenness	Importance in network flow	
	DomiRank	Influence in network structure	
	Distance metrics		OpenRouteServices
	To fire stations	Response times to/from critical facilities	https://openrouteservice.org/
	To police		
	To hospitals		
Dynamic	Ridership	Passenger exposure over time	MBTA
	Passenger flow over time		https://mbta-massdot.opendata.arcgis.com/datasets/
	Crime	Crime landscape around rail stations	Boston PD [4]
	Crime influence by type		https://data.boston.gov/dataset/
	Threat levels and resource allocation strategies	Defense postures at rail stations	SME Inputs

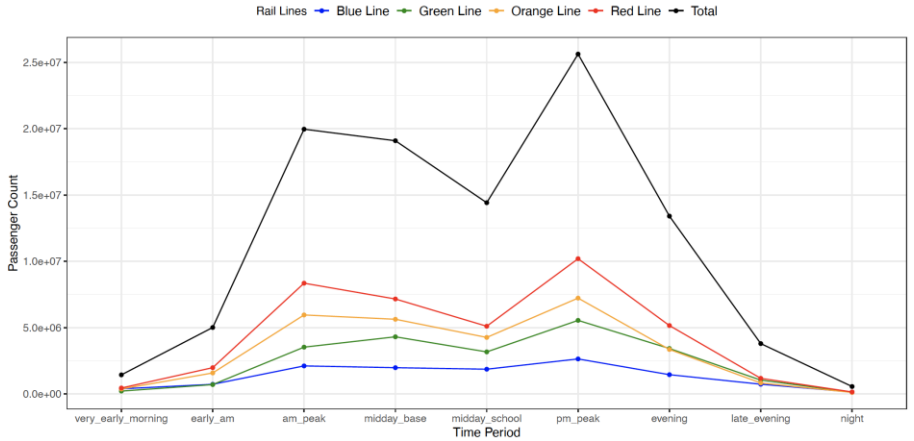
Ongoing and future plans include continued development of prototypes, generalization of case studies, and scenario-based evaluation with SME inputs and stakeholder participation



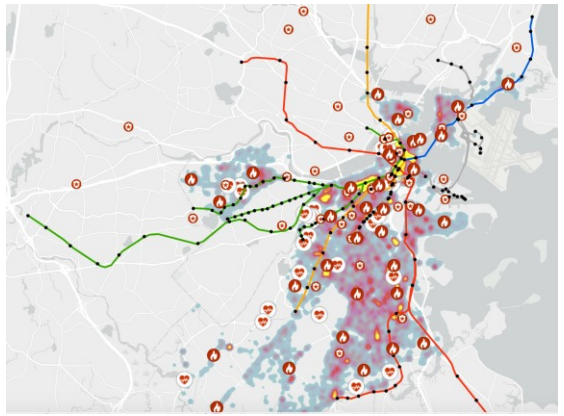


Time-varying spatial heat maps based on risk and deterrence dynamics

Urban rail network ridership patterns



Spatial overlay of network features



Chatterjee, S., R. Sahastrabuddhe, S. Dey, and A. Ganguly. (2023) "A Graph Neural Network Approach for Analyzing Urban Rail Transit System Threat Deterrence." **Society for Risk Analysis (SRA) Annual Meeting**, December 2023, Washington, D.C.

Watson J, Chatterjee S, Ganguly A. (2022) "Resilience of Urban Rail Transit Networks under Compound Natural and Opportunistic Failures." **Best Paper Award (Climate and Homeland Resilience Track), IEEE–Homeland Security Technologies (HST) Conference**, Link: https://ieeexplore.ieee.org/document/10025456.