FREIGHT MOBILITY RESEARCH INSTITUTE (FMRI)

A **USDOT** University Transportation Center

Identifying Critical and Vulnerable Freight Routes in Roadway Networks: A Game Theory Framework and Application in the State of Florida

Research Team

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FAU

Outline

- Introduction
- Problem Statement
- Project Benefits
- Project Objectives
- Literature review
- Methodology
- Case Study
- Results
- Future Research

Introduction

- Transportation networks are vulnerable
  - Natural disasters (flooding, bridge collapse landslide)

April 2010
Highway 3, Taiwan

Source: https://bit.ly/2mZNl5q

August 2018
Calicut, India

Introduction

- Transportation networks are vulnerable
  - Natural disasters (flooding, bridge collapse landslide)
  - Man-made disasters (dam collapse, flooding)

January 2019
Brumadinho, Brazil

Hurricane Harvey
August 2017
Houston, Texas

Introduction

- Transportation networks are vulnerable
  - Natural disasters (flooding, bridge collapse landslide)
  - Man-made disasters (dam collapse, flooding)
  - Incidents (accidents, mechanical problems)

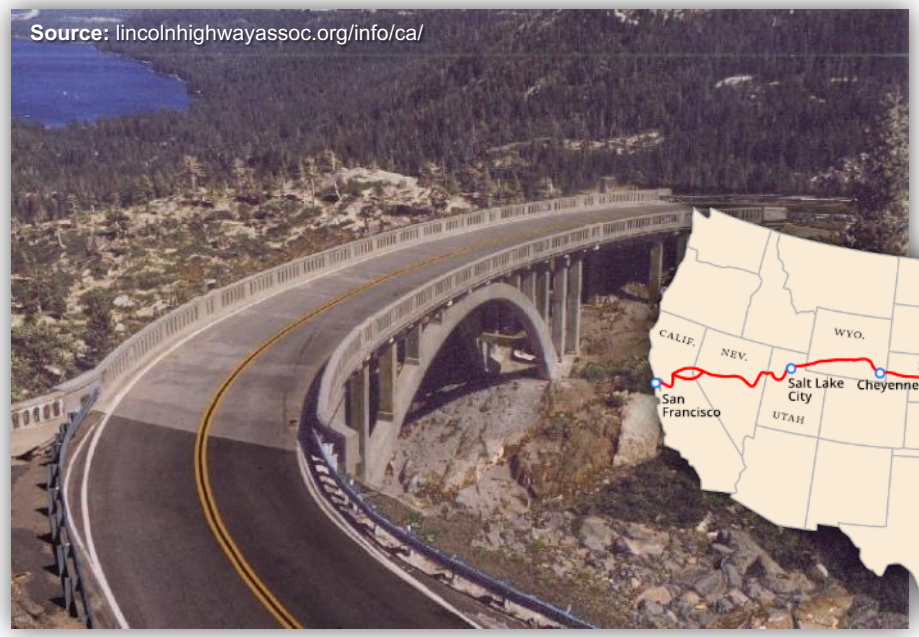
Uitvlugt, Guiana (West Coast Demerara)

Lansing, Michigan

Introduction

- Transportation networks are vulnerable
  - Natural disasters (flooding, bridge collapse landslide)
  - Man-made disasters (dam collapse, flooding)
  - Incidents (accidents, mechanical problems)
- Transportation network in the U.S. is the largest and oldest in the world

National Road
Year of 1811



Lincoln Highway
Year of 1913

Introduction

- Transportation networks are vulnerable
  - Natural disasters (flooding, bridge collapse landslide)
  - Man-made disasters (dam collapse, flooding)
  - Incidents (accidents, mechanical problems)
- Transportation network in the U.S. is the largest and oldest in the world
- Vulnerabilities and critical points
  - Identify
  - Take action
  - Protect and fortify
  - Focus on passenger, freight or combined movements

Problem Statement

- As traffic demand increases, decision-makers are faced with the important task of **identifying the vulnerable and critical links and routes in the transportation network** and take action on investments that will protect and fortify the network against attacks
- Addressing network vulnerabilities of transportation assets will
  - Minimize impacts of disruption
  - Reduce recovery time
  - Improve on the region's resilience.

Project Benefits

- From 1980 to 2011: 133 billion dollars disasters
  - Bridge collapses
  - Traffic accidents

August 2007
I-35W
Minneapolis
Minnesota

August 2019
Palm Bay, Florida

Project Benefits

- From 1980 to 2011: 133 billion dollars disasters
  - Bridge collapses
  - Traffic accidents
- Acknowledging the importance of freight networks
- Multimodal freight transportation networks under extreme conditions
- Improve the accuracy of freight fluidity measurement
- Evaluate and improve the resilience of freight networks

Project Objectives

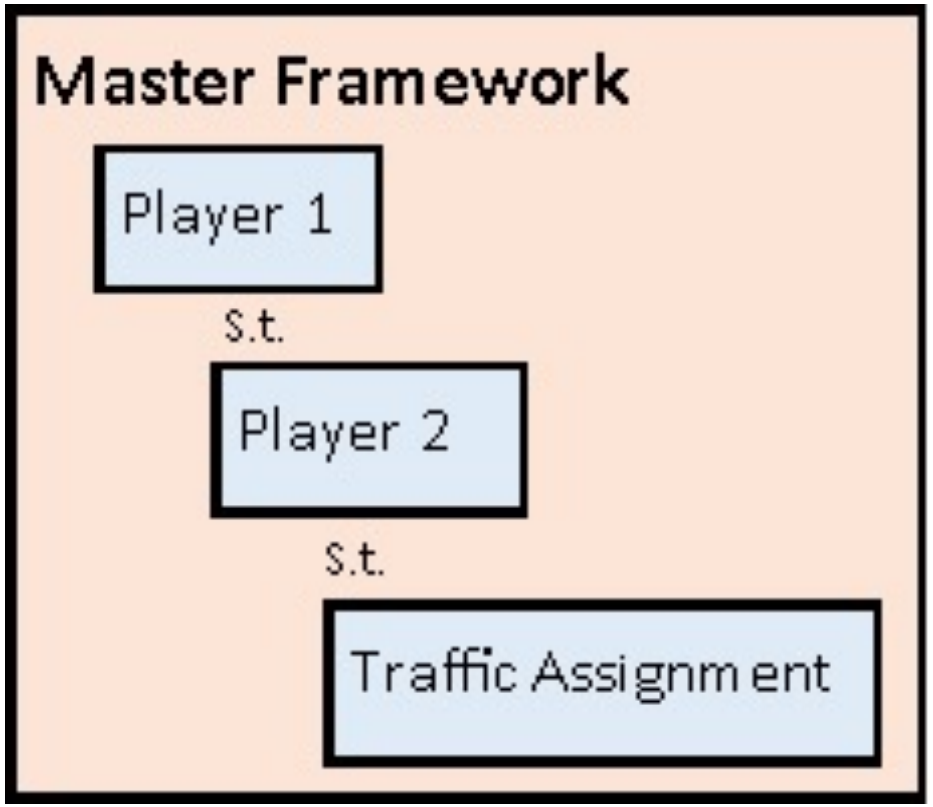
- Freight network vulnerability and resilience: models and tools
- Objectives
  - Long and medium range
  - Pre and post disruption network conditions
  - Route travel time
  - Impact on passenger, freight movement, and response/rescue teams
  - Access prevention to critical infrastructure, facilities, and equipment before, during and after the event

Literature Review

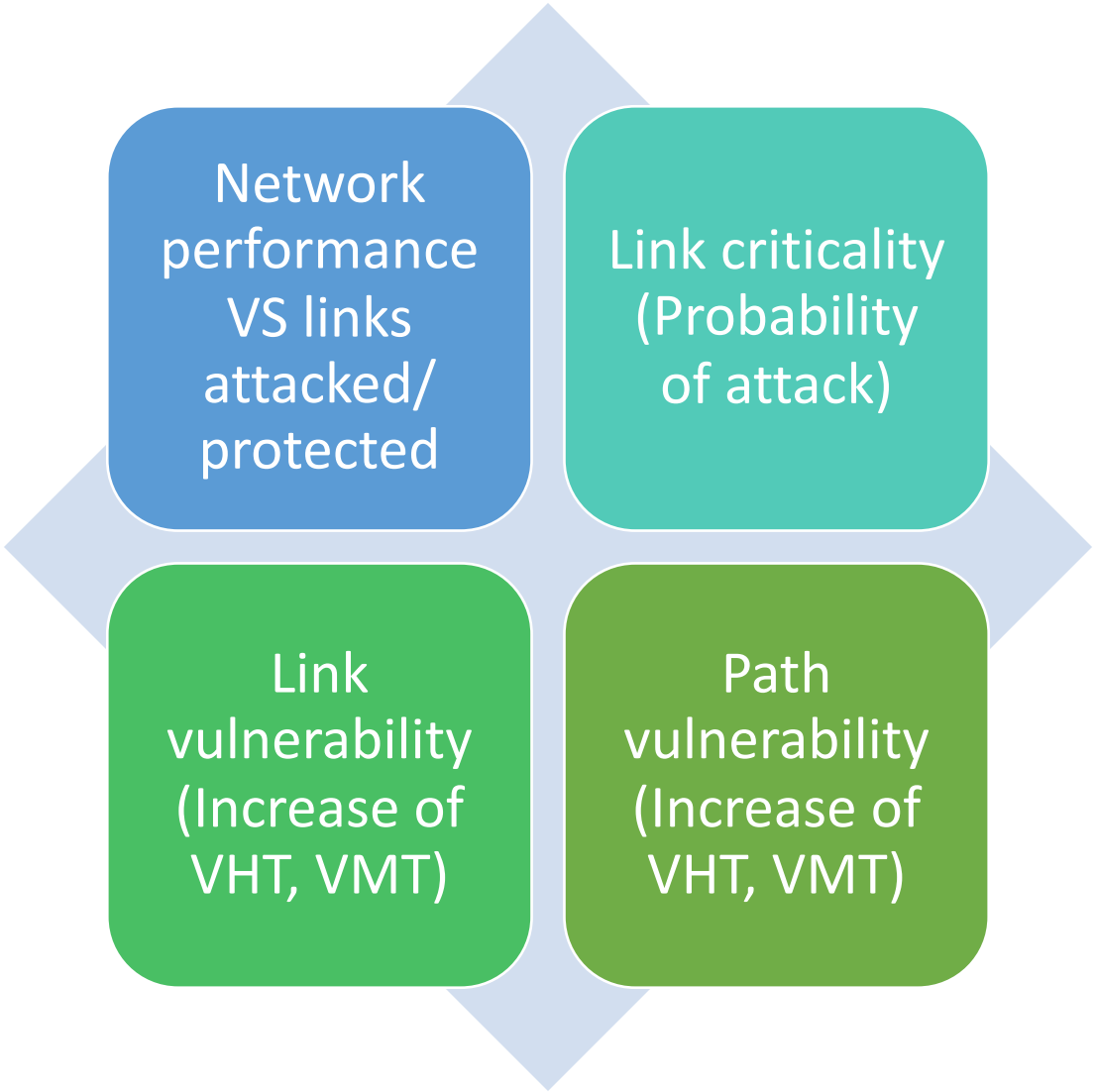
- Vulnerable VS Critical Links
  - Critical: Most likely to lose capacity
  - Vulnerable: Experience severe effects if a critical link loses capacity
- Link Vulnerability and Criticality Measures: Function of travel time change (delay, speed, accessibility)
- Link VS Path
- Single Link VS Sets of Links
- Approach: Topology, Demand/Supply (Traffic based analysis), Combination
- Solution: Optimization and/or Simulation
  - Most common approach: Removal of a single link

Modeling Framework

- Network Design Problem
- Hierarchical Optimization to capture interactions
- Unlike current practice we focus on sets of links



Performance Measures

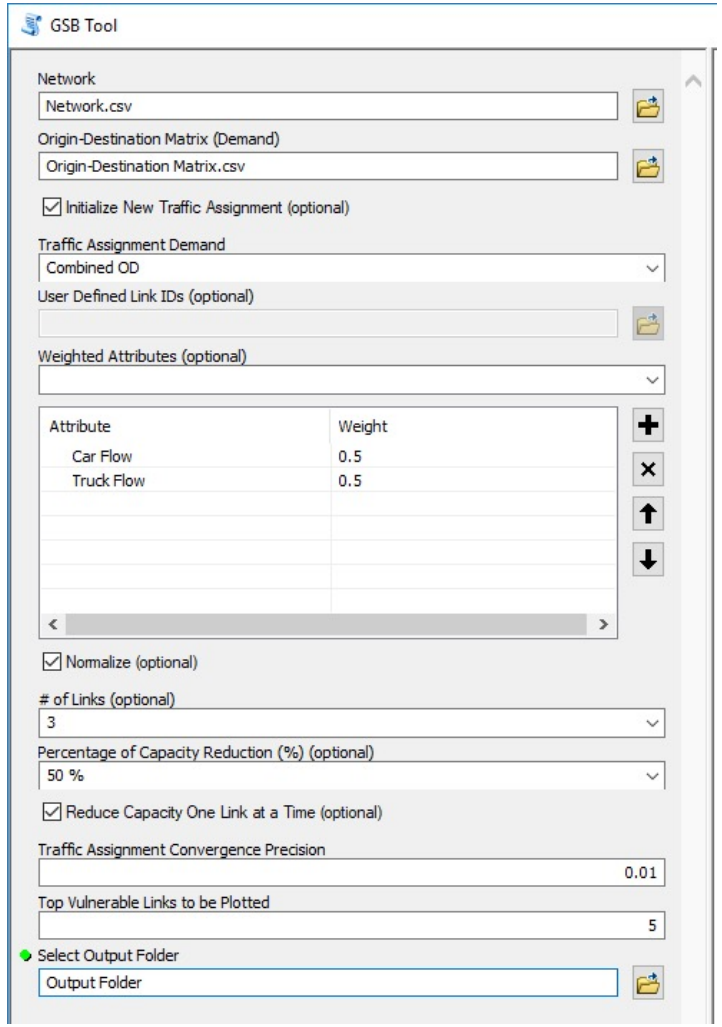


Solution Heuristics

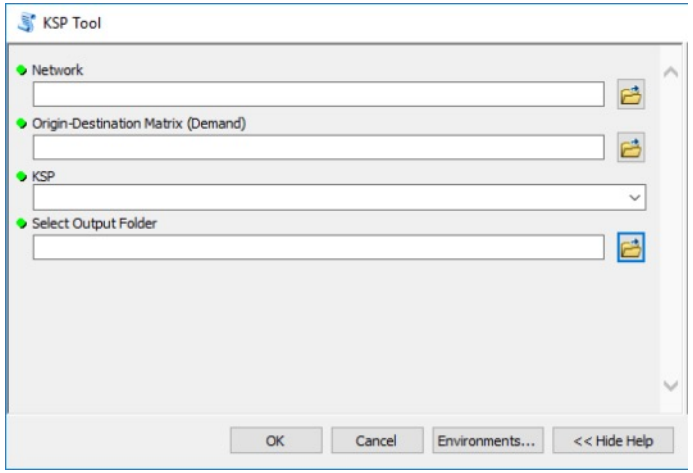
- Greedy Search Based heuristic
  - Each link is assigned a criticality measure based on weighted combination of user-defined attributes (e.g., car flows, truck flows, capacity, Volume to Capacity (VC) Ratio etc.)
  - In this research we ranked based on hybrid link measures proposed by Takhtfiroozeh et al. (2021)
  - A User Equilibrium (U.E.) traffic assignment is performed with a reduced capacity (defined by the user) for the top n links (n is provided by the user)
- K-shortest Path
  - Basis: Importance of link depends on the number of k-shortest path
  - Link ranking is based on the k-shortest paths a link belongs to
  - Attacker that has no knowledge on traffic data and/or network attributes that may affect traffic conditions
- Random Search Heuristic
  - Intelligent attacker
  - Solve the three-level problem
  - Custom heuristic developed by the research team

ArcGIS Toolboxes

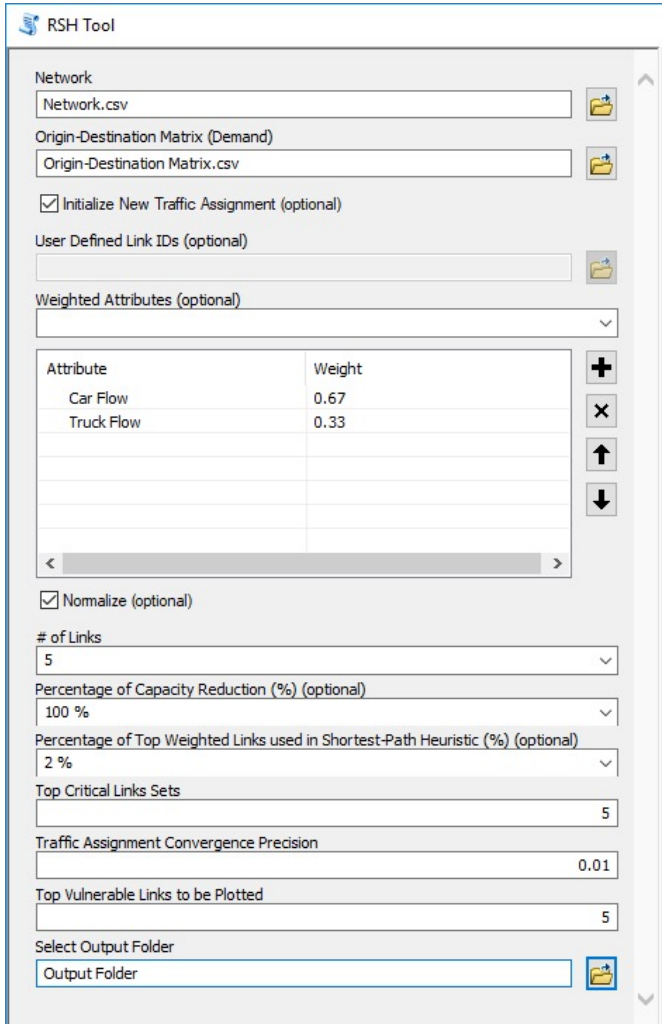
Greedy Search Heuristic



K shortest path

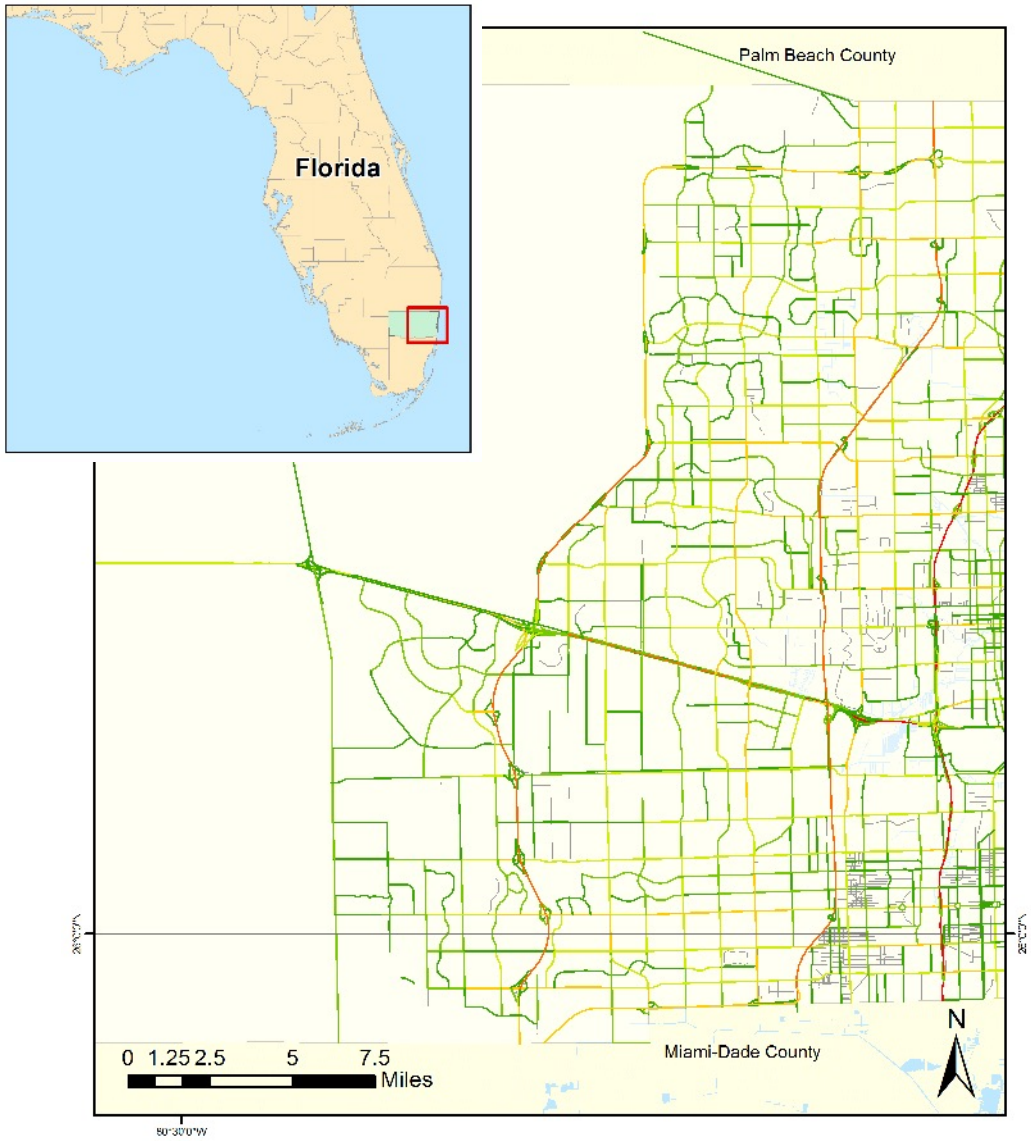


Random Search Heuristic



Case study

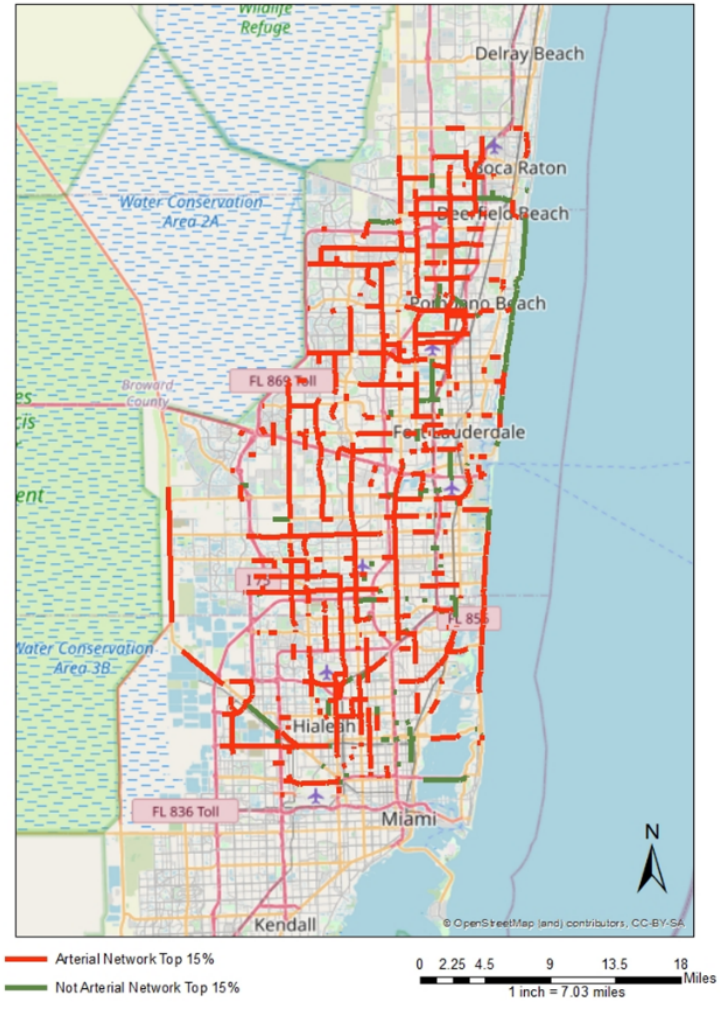
- Testbed location: Broward County, FL
- Significance in the freight scenario
  - Port Everglades
  - I-95, Florida Turnpike, I-595
  - Fort Lauderdale International Airport
- Southeast Florida Regional Planning Model Version 8 (SERPM 8)
  - Road network
  - Road capacity, free flow speed
  - Origin/Destination
  - Traffic Analysis Zones
  - Demand



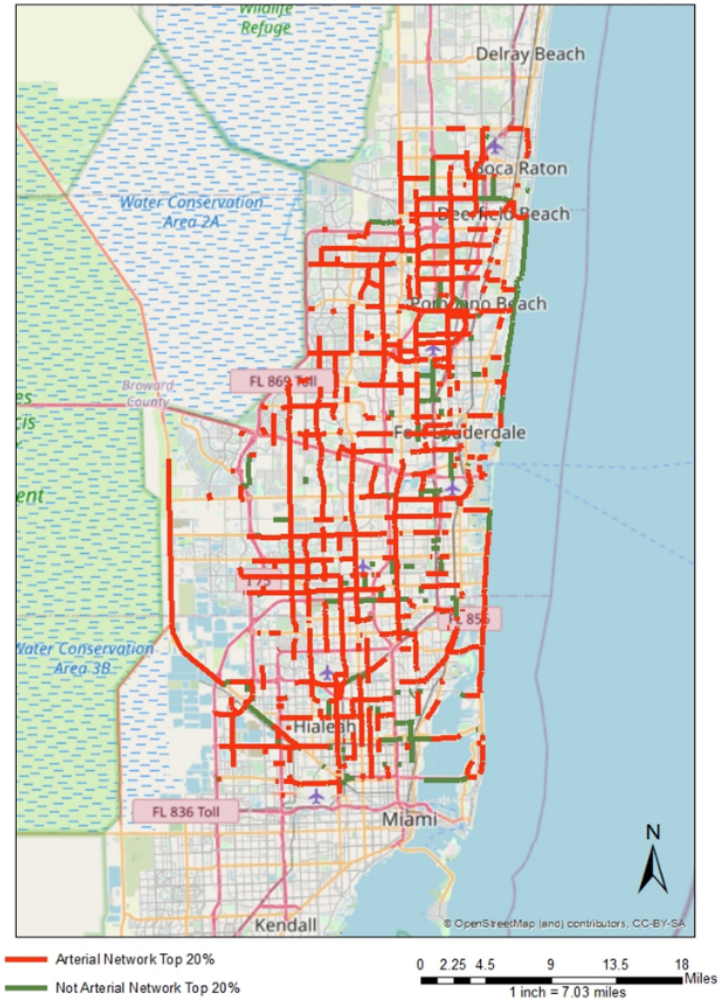
Critical Links: Individual Measures

Top 10% Critical Links

Top 15% Critical Links



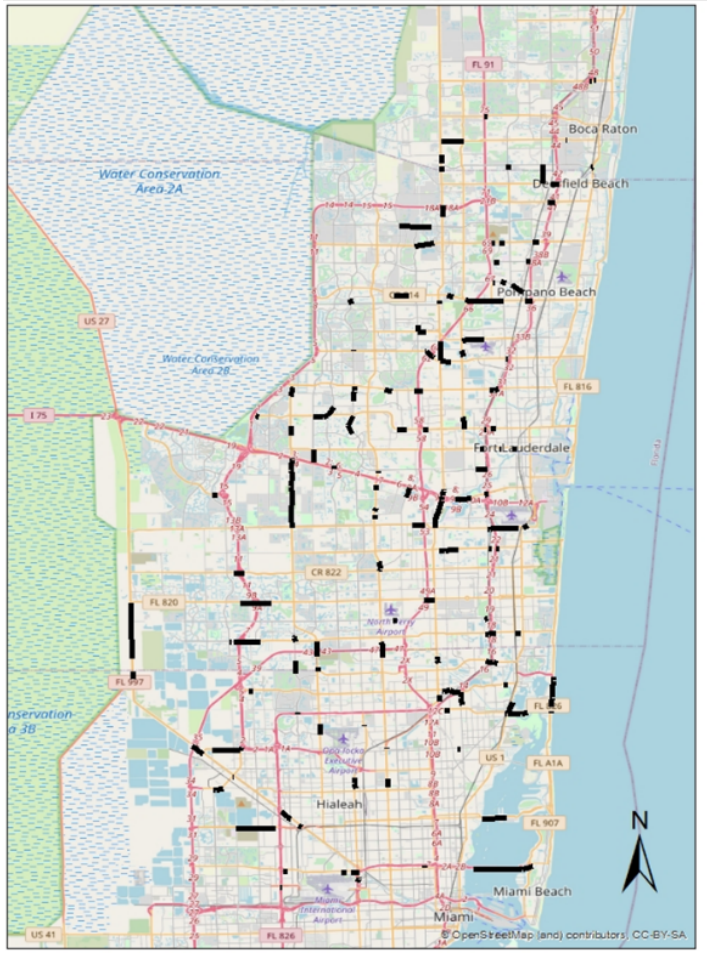
Top 20% Critical Links



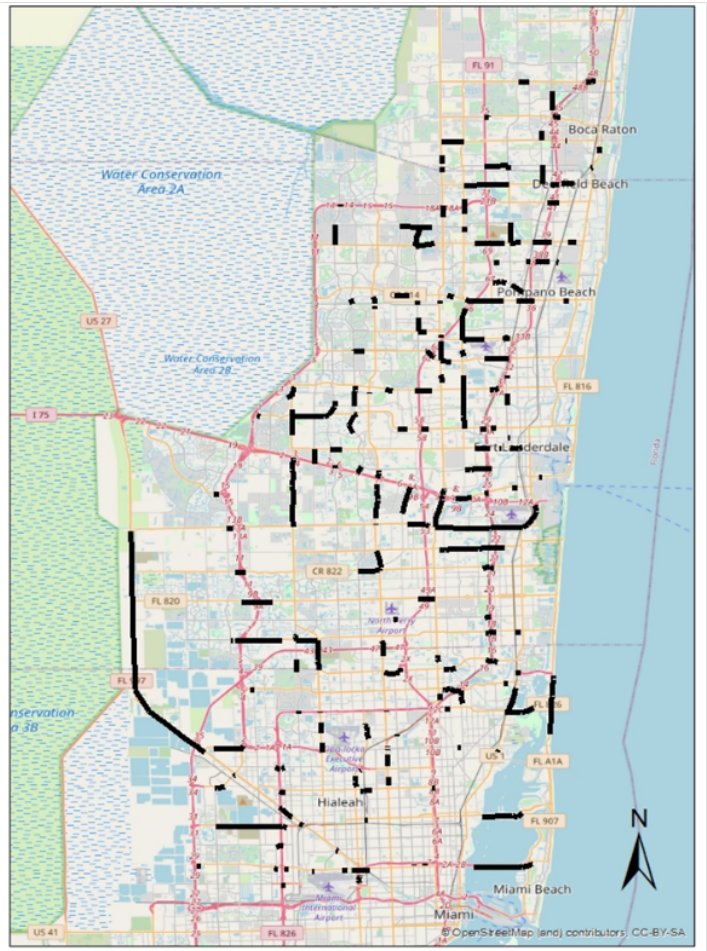
Critical Links: Combined Measures

Top 10% Common Critical Links

Top 15% Common Critical Links

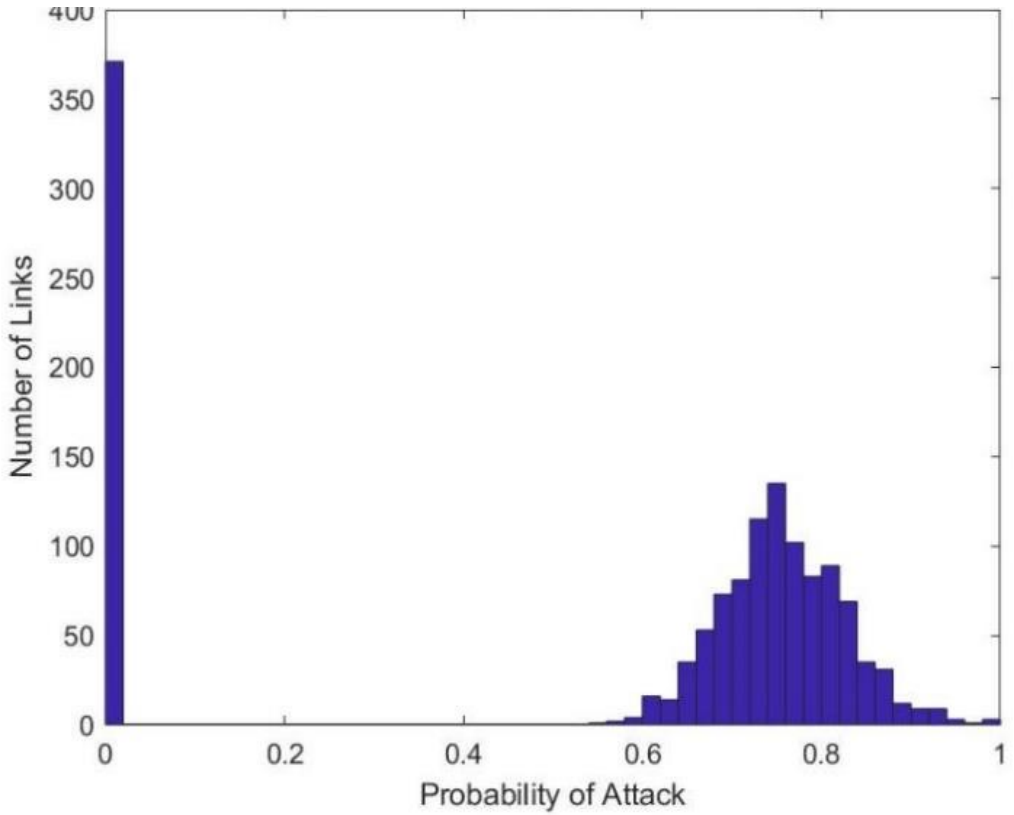


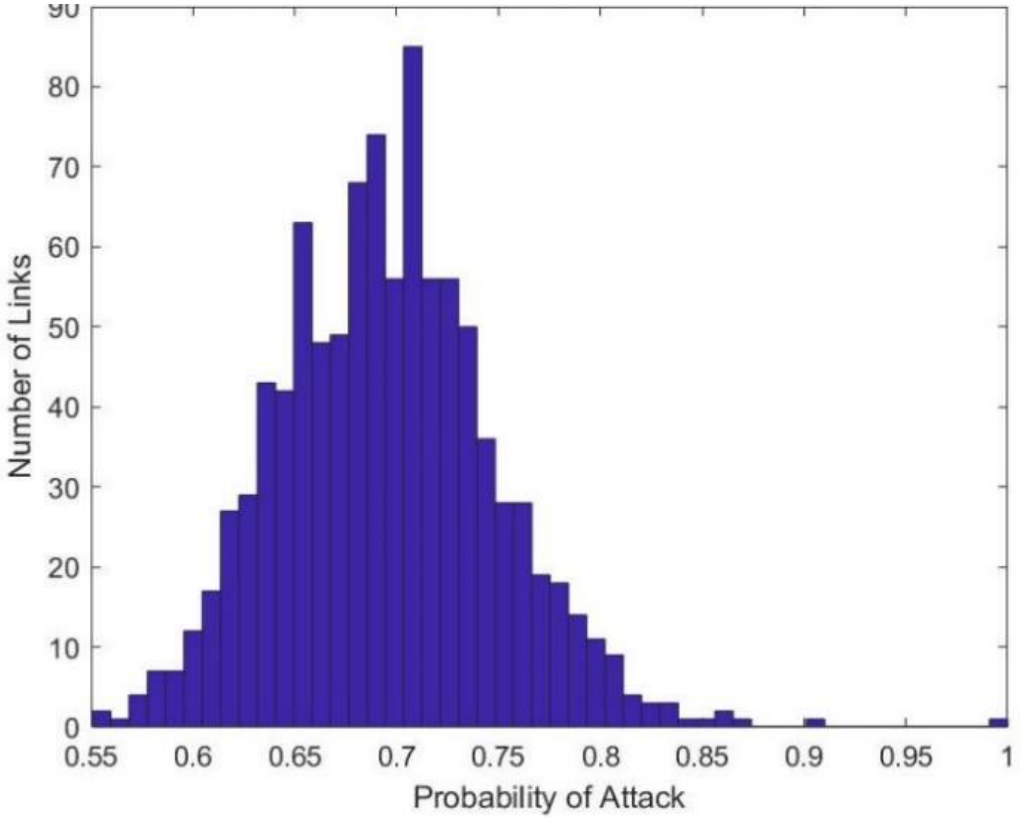
Top 20% Common Critical Links



Results

Critical Links: Probability of attack





Results

Vulnerable Paths by OD

Future research

- Different objective functions for defender/attacker
- Multiple attackers with different objectives
- Multiple objectives for decision maker
- Include investment for fortification and/or increased capacity

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Thank you!

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