Modeling Bay Area Transportation Network Resilience

PEER Transportation Systems Research Program

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Motivation

Transportation networks are complex systems critical to functionality of communities. This work utilizes the concept of corridors to offer new insights for mitigating risk and assessing reliability of transportation networks.

A corridor is defined here as a set of network links with dependence on each other for delivering network services. The hypothesis of the work, is that corridors function as a unit, and that vulnerabilities to components of corridors should be mitigated simultaneously in order to reliably deliver network services. An idealized corridor would be a set of links connected in series, so that each link must be functioning in order for the path to exist.

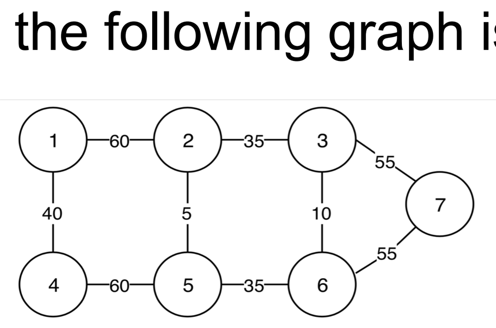
Corridors as a tool for resilience

We use the following approach to explore the concept of corridors as a tool for resilience:

- 1- Identify Corridors
  - a) Clustering Process
  - b) Area vs corridor clusters
- 2- Corridor Policies
  - a) Improve all elements
  - b) Improve worst element
  - c) Improve up to the best element
- 3- Optimize actions
  - a) L-Shaped Optimization
- 4- Evaluate Network Performance[1]
  - a) Generation of seismic scenarios
  - b) Damage maps computation
  - c) Network performance measure

Markov Clustering Algorithm[2]

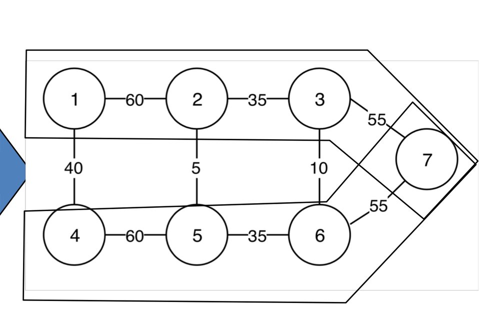
The Markov Clustering Algorithm is based on unsupervised random walks. It is used here for identification of corridors. As an example, the following graph is shown:



Original Graph

0	0.60	0	0.40	0	0	0
0.60	0	0.35	0	0.05	0	0
0	0.35	0	0	0	0.10	0.55
0.40	0	0	0	0.60	0	0
0	0.05	0	0.60	0	0.35	0
0	0	0.10	0	0.35	0	0.55
0	0	0.5	0	0	0.5	0

Transition Matrix



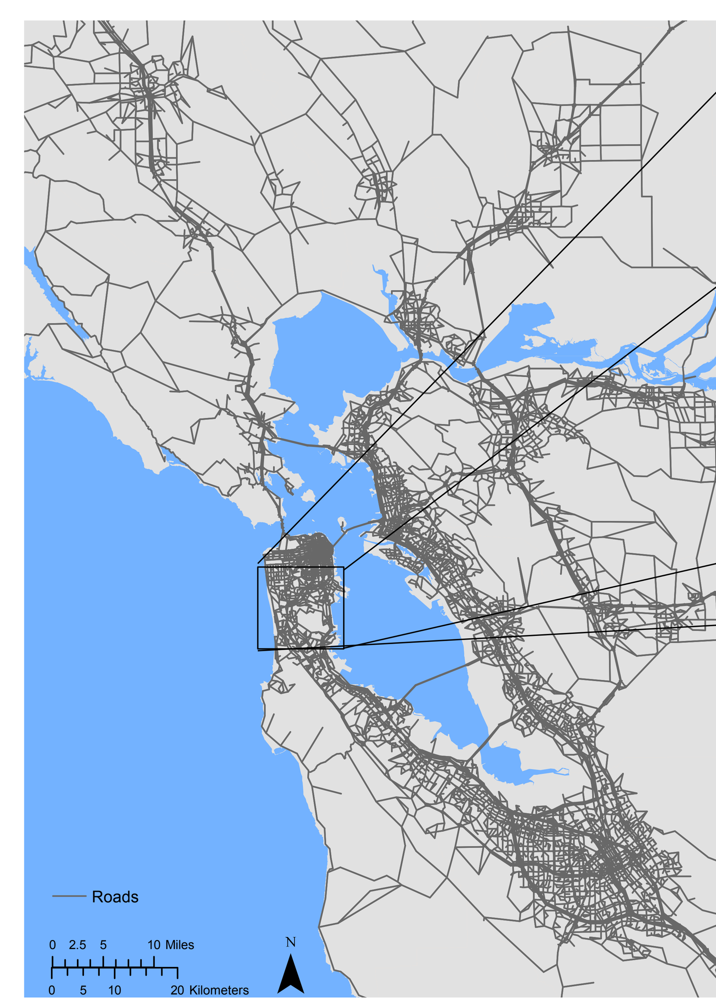
Clustering Results

In this case the probability of an agent to move from Node 1 to Node 2 is 40%. This process is repeated for each node to get the transition matrix of the system. A cluster, according to this algorithm will be sections of the cluster that concentrate several random walks.

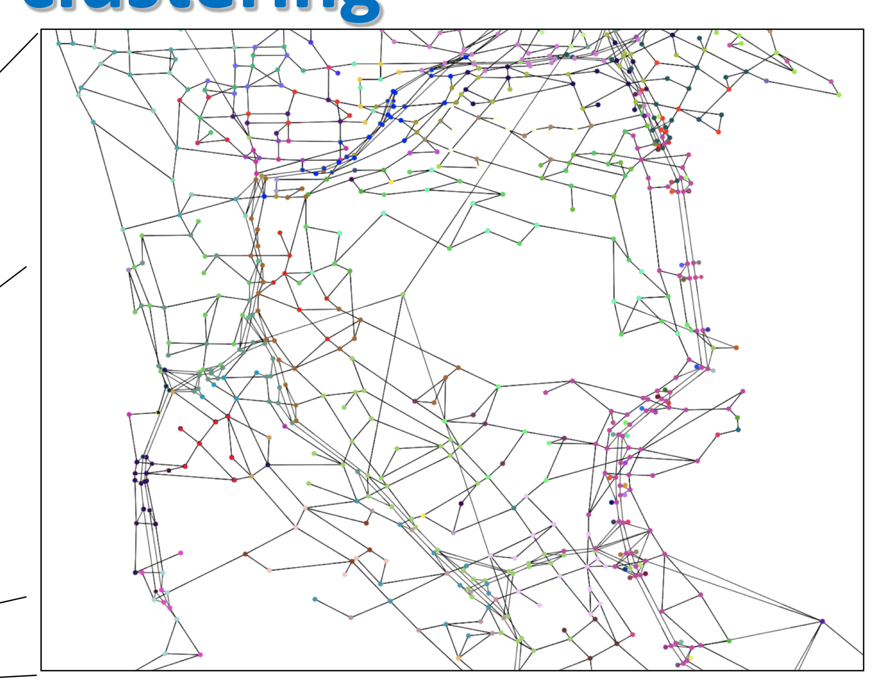
Bay Area Transportation Network: Our testbed.

The San Francisco Bay Area road network is used as a testbed for this study. Our model contains 11,921 nodes, 32,858 edges (road links) and 1743 bridges.

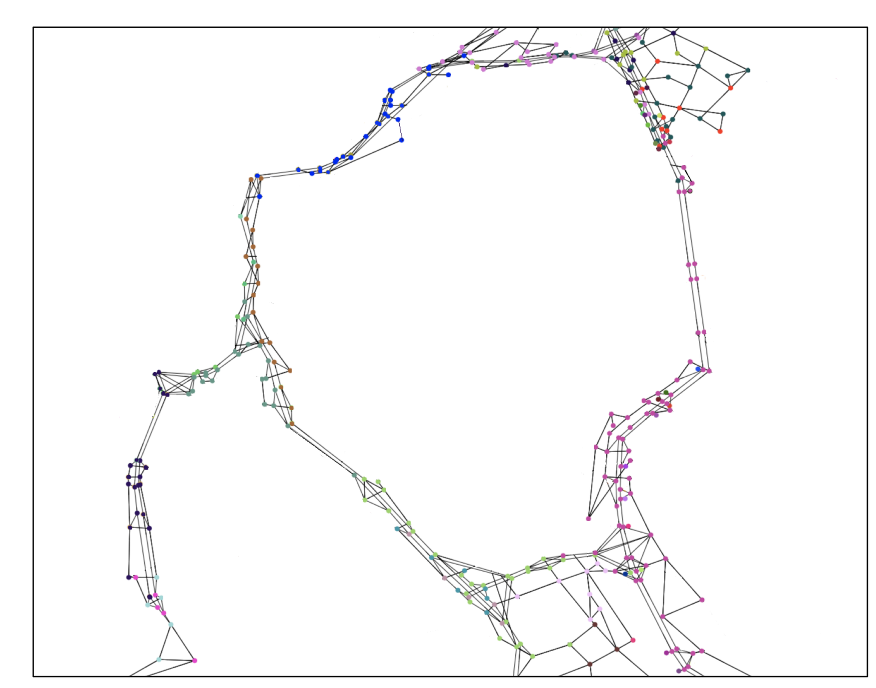
Preliminary results of clustering



Road Network [1]



Global Clustering



Identified Corridors

Optimization of decision making process[3]

The decision over which actions have to be taken over bridges in the road network come as a result of the following optimization problem:

$$\min\left(\sum_{b\in C_{path}} c_{retrofit}x_b + E_\xi\left[\sum_{b\in path} c_{repair}y_{\xi,b} + \omega_\xi\right]\right)$$

Subject to a time performance constraint:

$$\sum_{a\in p} t_{a,\xi} < t_p^*(1+\epsilon), \qquad \forall p \in P, \forall \xi \in \Xi$$

where

c_{action} = Cost of specific action. x_b = Binary indicator for retrofitting a corridor,
$y_{\xi,b}$ = Binary indicator for repair under specific scenario ξ, ω_ξ= Consequences for specific scenario. t_p^*= Time for path before the event. ϵ = Acceptable increase in time.
C_{path} = Set of corridors within paths. $t_{a,\xi}$= Time for arch a in scenario ξ, P = Set of specific paths, Ξ = set of scenarios

Next research steps and expected outcome

We will next optimize decisions (e.g., retrofits) to maximize resilience. Optimization will be implemented in the whole transportation network, in order to analyze the utility of corridor-oriented decision strategies.

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References

(1) Miller, M. K. (2014). *Seismic risk assessment of complex transportation networks* (PhD dissertation, Stanford U.).
(2) Dongen, S. (2000). A cluster algorithm for graphs.
(3) Gomez, C., and Baker, J. W. (2018). “An optimization-based decision support framework for coupled pre- and post-earthquake infrastructure risk management.” Structural Safety, in press.

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