Transportation Resilience Planning

Link Criticality Calculations

Link Criticality Calculation

- Network Criticality Index (NCI)
  - Considers how critical a roadway is for normal everyday travel by all Vermonters
- Critical Closeness Accessibility (CCA)
  - Considers how critical a roadway is for access to/from emergency service facilities

Network Criticality Index (NCI)

Vulnerability + Redundancy = Criticality

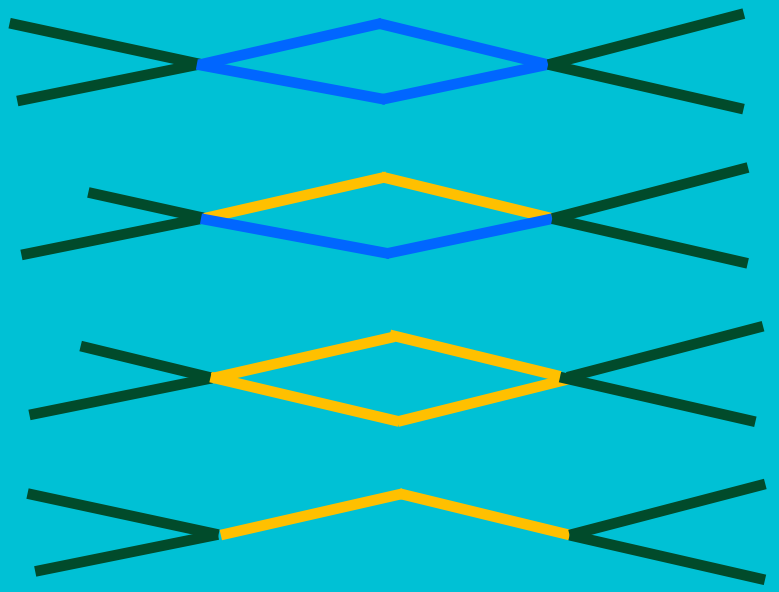
The NCI method measures the combined effects of redundancy and vulnerability on network criticality:

Low Vulnerability
+ High Redundancy
= Not Critical

Low/High Vulnerability
+ High Redundancy
= Moderately Critical

High/High Vulnerability
+ High Redundancy
= Highly Critical

High Vulnerability
+ Low Redundancy
= Highly Critical



Network Criticality Index (NCI)

The calculation of the NCI uses the vulnerability probability (0 to 1) which is a translation of the vulnerability scoring to guide a set of Monte Carlo simulations whereby each link α is disrupted n_α times:

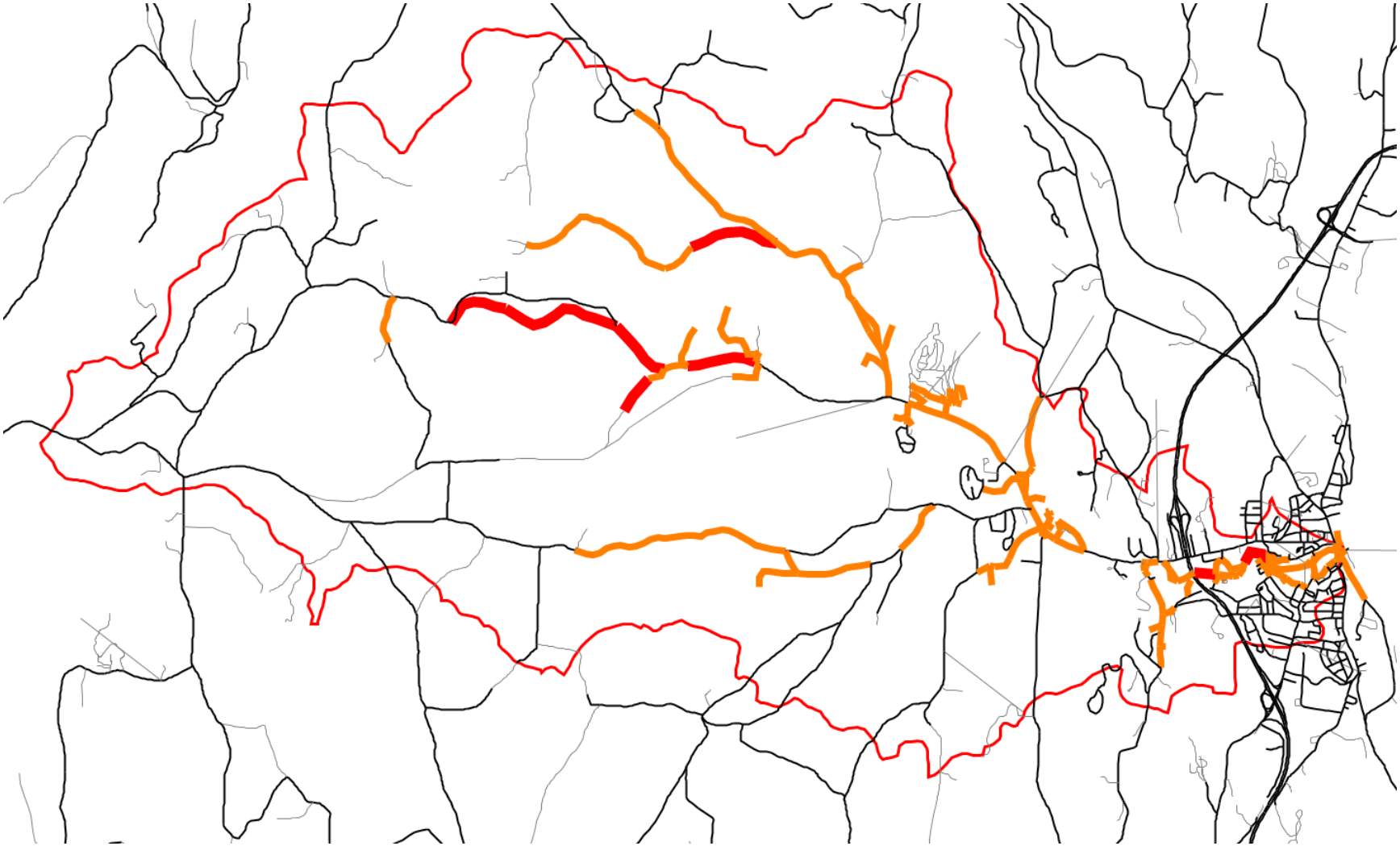
$$n_\alpha = N \times V_\alpha$$

Where N is the number of simulations and V_α is the vulnerability probability of link α. The NCI measures, for each link, the increase in total system-wide VHTs (c) over the set of N simulations:

$$NCI_\alpha = \frac{\sum_N c_\alpha}{n_\alpha} - \frac{\sum_N c}{n}$$

Where c_α is the VHTs with link α disrupted, n_α is the number of simulations with α disrupted, c is the VHTs with α intact, and n is the number of simulations with α intact ($N - n_\alpha$).

Network Criticality Index (NCI)



Network Criticality Index (NCI)

- Example
  - Link 1 is highly vulnerable ($V_1 = 0.35$)
  - Link 2 is moderately vulnerable ($V_2 = 0.10$)
  - Link 3 is not vulnerable ($V_3 = 0.00$)
  - We decide to do 100 simulations
    - Link 1 will disrupt 35 times
    - Link 2 will disrupt 10 times
    - Link 3 will disrupt 0 times
  - We put in 3 hats:
    - For link 1, 35 “yes” and 65 “no”
    - For link 2, 10 “yes” and 90 “no”
    - For link 3, 100 “no”

Network Criticality Index (NCI)

- Example
  - At each simulation, we draw one slip of paper out of each hat and disrupt the links accordingly
  - We then re-route all of the traffic in the network representing everyday travel
  - We measure the increase in VHTs each time

Network Criticality Index (NCI)

- Example
  - Then apply the formula:
    - $NCI_{\alpha} = \frac{\sum_N c_{\alpha}}{n_{\alpha}} - \frac{\sum_N c}{n}$
    - Where c_{α} is the VHTs with link α disrupted, n_{α} is the number of simulations with α disrupted (e.g., 35 for link 1), c is the VHTs with α intact (e.g., 65 for link 1)

Critical Accessibility (CA)

- The NCI doesn't consider access to emergency services
- For emergency services, we don't have everyday travel information
- So we need to develop a separate index, based on "closeness"

Critical Accessibility (CA)

- To implement this method, first the shortest paths from the critical destination in question (*i*) to all other destinations in the network (J) are calculated, and the residual closeness is calculated:
  - $C_i = \sum_{j \in J} 1/2^{d(i,j)}$
  - where d(i,j) is the shortest-path (in minutes) between node *i* and all other nodes in the network (set J) with link *a* removed.
- Residual critical closeness, $CC_{a,i}$, of link *a* is
  - $CC_{a,i} = \sum_{j \in J} 1/2^{da(i,j)}$
  - where $d^a(i,j)$ is the shortest-path (in minutes) between node *i* and all other nodes in the network (set J) with link *a* removed.
- Subtracting this value from the original closeness calculated with link *a* intact provides a measure of the change in closeness between a critical node and all other nodes in the network:
  - $\Delta CC_{a,i} = CC_{i} - CC_{a,i}$
- A higher value implies an increasingly important relationship between link *a* and critical node *i.* This process is repeated for each critical destination in the network and taking the sum of these measures and subtracting it from the same value with link *a* intact yields the critical accessibility of link *a:*
  - $CA_a = \sum_{i \in I} CC_i - \sum_{i \in I} CC_{a,i}$

Critical Accessibility (CA)

- The CCA measures how the "closeness" of ESFs to all inhabitable structures would change if the roadway was disrupted
  - First, we find the locations of all 751 ESFs in Vermont
    - Ambulance Service - 50
    - Fire Station - 282
    - Health Clinic - 348
    - Hospital / Medical Center - 7
    - Law Enforcement - 64
  - Then we find the location of all inhabitable structures in Vermont – approximately 350,000

Critical Accessibility (CA)

- The CA measures how the "closeness" of ESFs to all inhabitable structures would change if the roadway was disrupted
  1. Then we find the shortest time paths between all of them, convert that number to "closeness", and sum all of them to get the CC
  2. One at a time, we remove each link in the network and repeat step 1
  3. The decrease in the CC when link *a* is removed is its CA_a

Criticality Screening

TABLE 4-1
Variables and Scoring for the Criticality Screen

SCORE	Network Criticality Index		Critical Closeness Accessibility		Locally Important	Combined Criticality
10=	High or Medium	AND	High	AND	y	HIGH (RED)
9=	High or Medium	AND	Medium	AND	y	
8=	High or Medium	AND	High or Medium	AND	n	
7=	High or Medium	AND	Low	AND	y	
6=	Low	AND	High	AND	y	
5=	Low	AND	Medium	AND	y	
4=	High or Medium	AND	Low	AND	n	MEDIUM (YELLOW)
3=	Low	AND	High or Medium	AND	n	
2=	Low	AND	Low	AND	y	
1=	Low	AND	Low	AND	n	LOW (GREEN)