Transportation Resilience Planning with the Vermont Travel Model

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Introduction

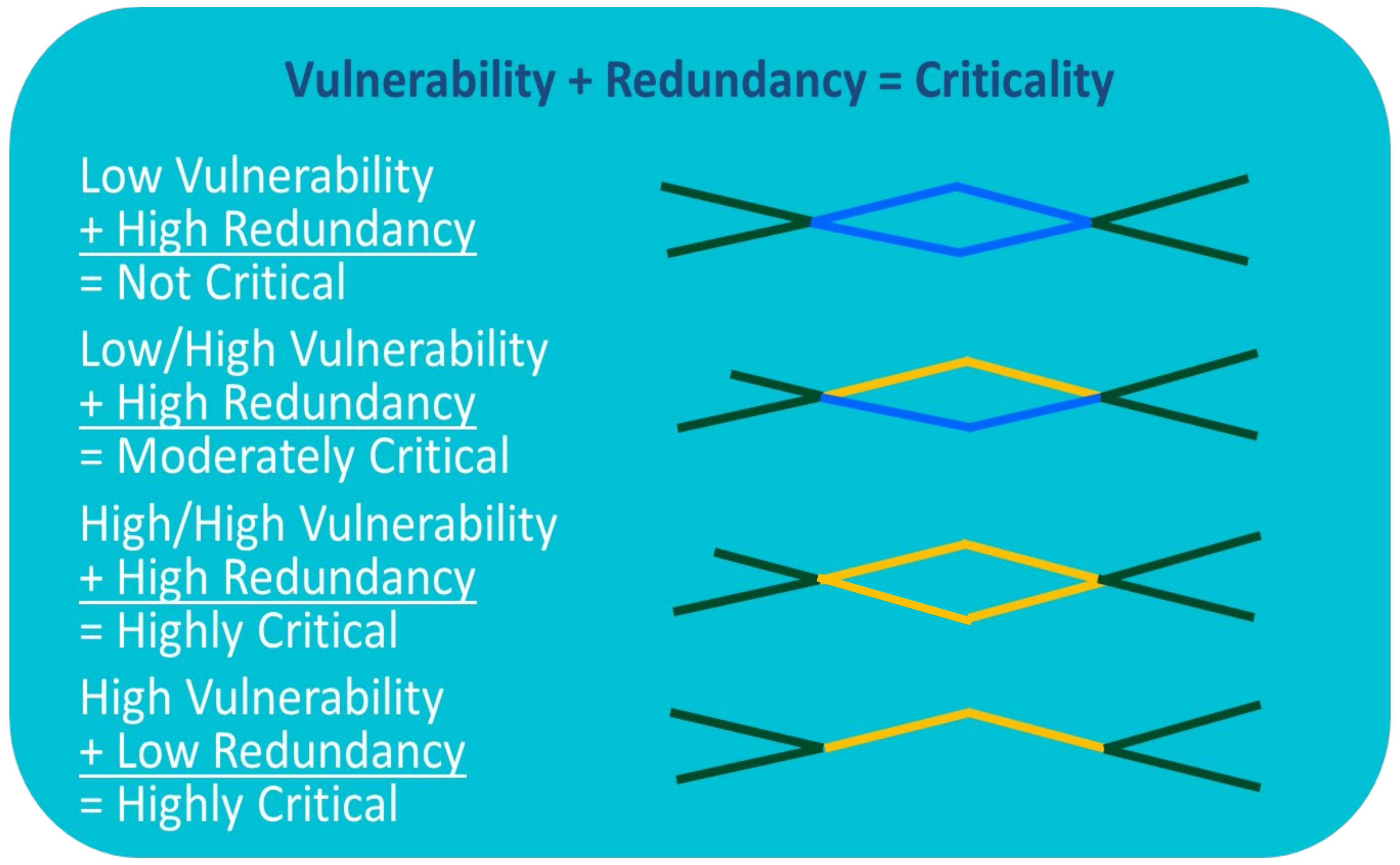
In 2019-2020, the Vermont Travel Model was used by UVM in cooperation with the Agency's consultant, Milone & MacBroom, Inc., to estimate a criticality index for each road segment in selected Vermont watersheds where flooding hazards exist and roadway damage is common. An innovative new approach was used to calculate the Network Criticality Index (NCI), which represents how vital a roadway is to regional travel and how vulnerable it is to flood-related damage.

Pertaining to the Vermont highway system, *vulnerability* measures how susceptible a roadway is to flood damage, and how severe that damage tends to be. It is represented as a vulnerability score, from 1 (not vulnerable) to 10 (extremely vulnerable).

Network Criticality Index (NCI)

The NCI measures the combined effects of redundancy and vulnerability on network criticality (Figure 1). Redundancy helps the system withstand the loss of a link, but vulnerability makes the loss more likely. The calculation of the NCI uses the vulnerability probability, *V*, which is a translation of a vulnerability score, to guide a set of *N* Monte Carlo simulations in which each link α disrupted n_α times:

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



Vulnerability + Redundancy = 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

Figure 1. Roadway bottleneck scenarios illustrating the contribution of vulnerability (low in blue, high in yellow) and redundancy to criticality

The NCI measures, for each link, the average increase in total statewide VHTs (c) over all N simulations:

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

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 ($N - n_\alpha$).

NCIs were calculated for selected watersheds in Vermont and provided to the relevant regional planning commissions so that they could take action in improving the resilience of the road network through future investment. NCIs will continue to be calculated for vulnerable watersheds as vulnerability scores become available.

Example NCI Calculation

In the schematic example of a road network shown in Figure 2, link 3 is highly vulnerable, with a V = 0.35, link 4 is moderately vulnerable, with V = 0.10, and roads shown in green are not vulnerable (V = 0.00).

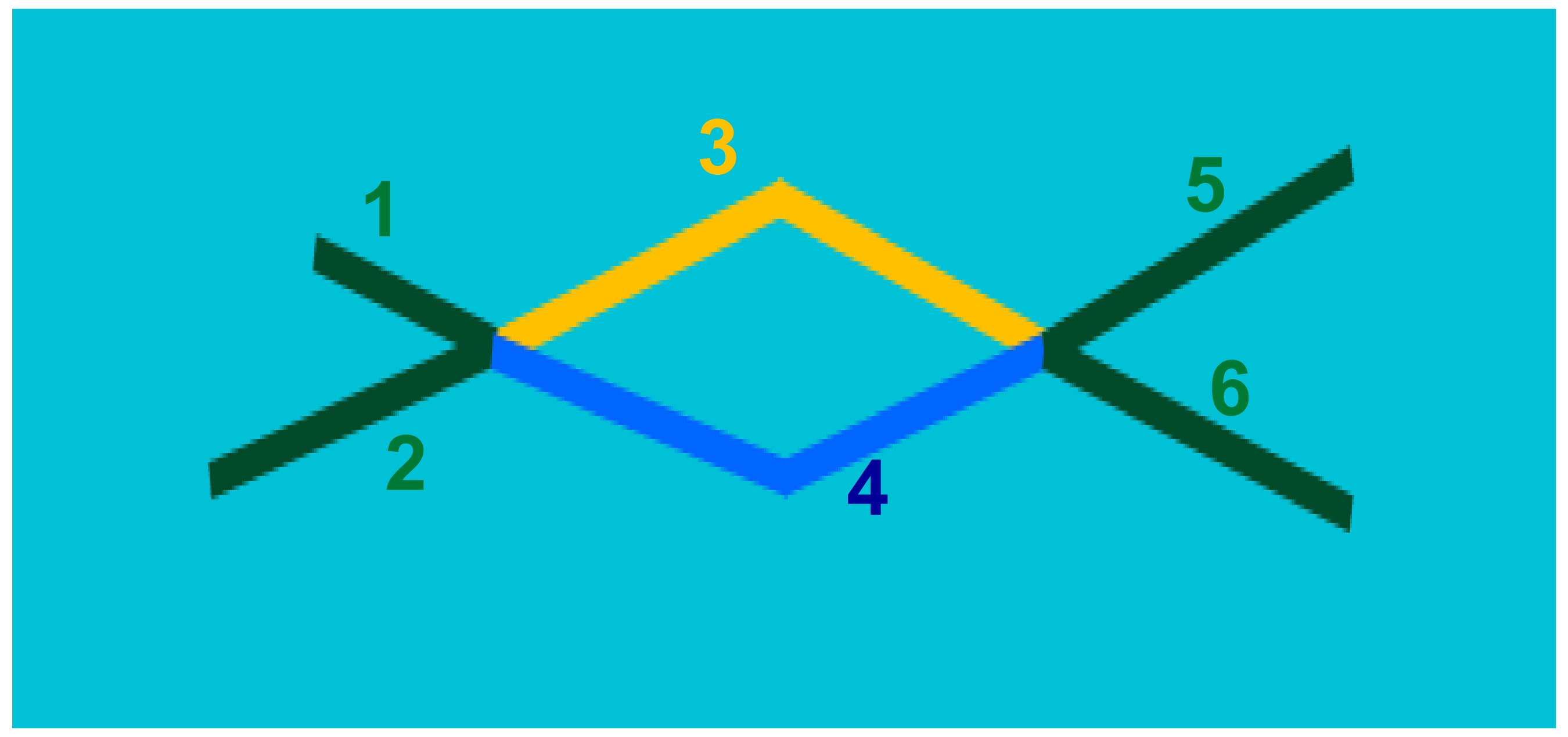


Figure 2. Schematic road network to illustrate the calculation of the Network Criticality Index

If we decide to use 100 simulations in our calculation of the NCI, then the yellow link will be disrupted 35 times, the blue link will be disrupted 10 times, and the green links will not be disrupted.

The Monte Carlo simulation process can then be envisioned by picturing that we have 6 hats, one for each link in the network (Figure 3). We put 100 pieces of paper in each of the hats:

- **The hats representing green links have "NO" written on all 100 pieces of paper**
- **The hat representing the blue link has "YES" written on 10 pieces of paper and "NO" written on 90 pieces of paper**
- **The hat representing the yellow link has "YES" written on 35 pieces of paper and "NO" written on 65 pieces of paper**

Figure 3. The Monte Carlo simulation process creates *N* link states, as if putting pieces of paper in a hat, and then randomly creates a system state, as if drawing one piece from each hat simultaneously

At each simulation, we draw one slip of paper out of each hat, and these represent the "system state", or which links will be disrupted ("YES") and which will be left intact ("NO").

We apply the disruptions and re-route all traffic in the network representing everyday travel and measure the increase in VHTs each time.

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