A GIS-Based Index for Estimating Road Vulnerability to Damage from Overweight Vehicles

Jeremy Scott
Research Associate
Institute for Transportation Research and Education

Greg Ferrara
Program Manager
Institute for Transportation Research and Education

Introduction

- Institute for Transportation Research and Education (ITRE) supports North Carolina State Highway Patrol (NCSHP) Motor Carrier Enforcement (MCE):
  - ➲ Helping to reduce Commercial Motor Vehicle (CMV) related crashes
  - ➲ preserving the states road and bridge infrastructure
- End goal: enable more data driven in their enforcement efforts

Why Develop a Road Vulnerability Index (RVI)?

- MCE planner has to figure out where to send S&W troopers to check on trucks

- Right now, He/she has to look at bridges, pavement condition, and estimated truck volume layers separately.

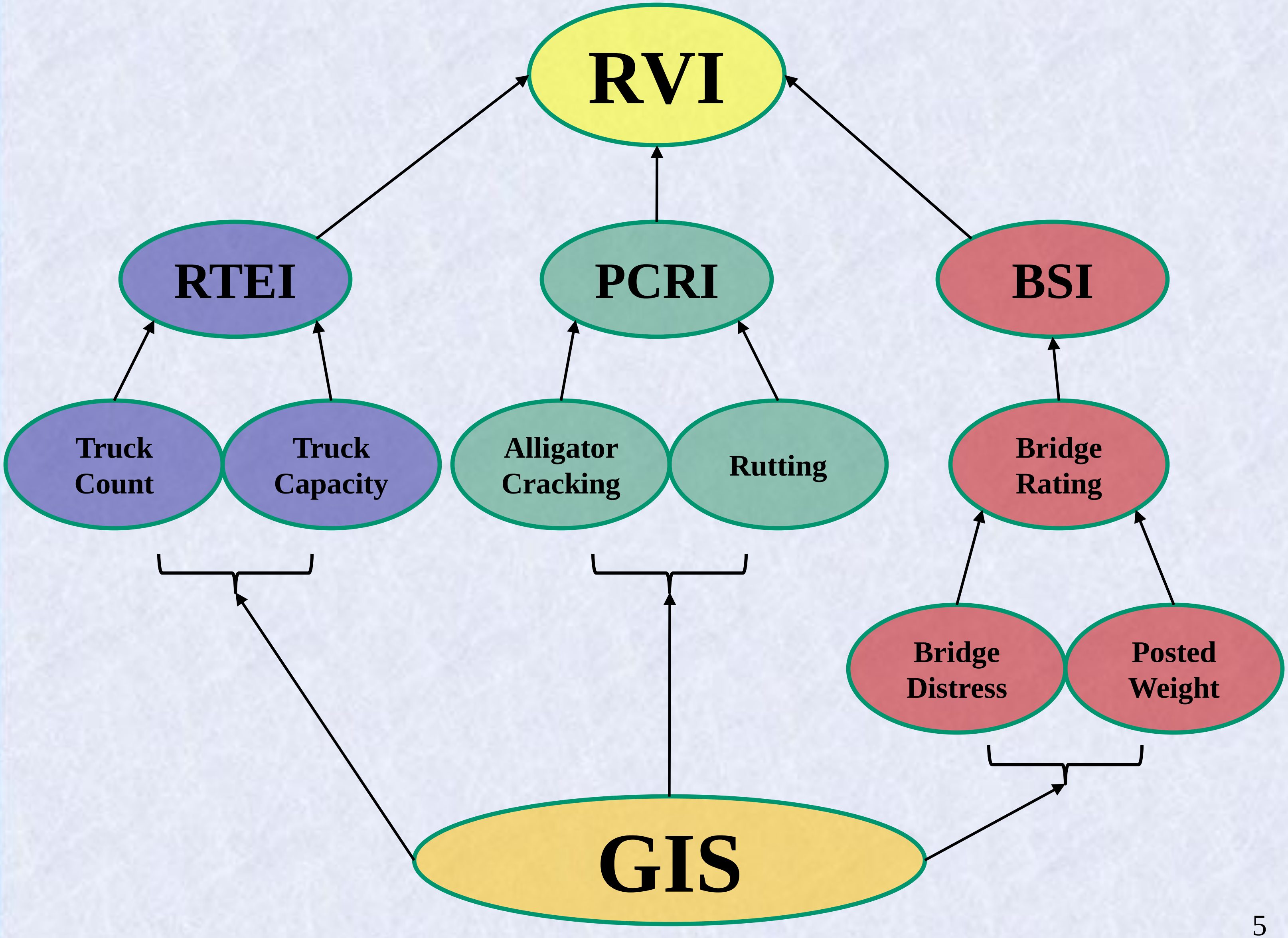
- RVI would give them a single simplified guide to focus enforcement resources

RVI Model Development

- Three components currently make up Road Vulnerability Index (RVI)
  - Relative Truck Exposure Index (RTEI)
  - Pavement Condition Ratings Index (PCRI)
  - Bridge Severity Index (BSI)

$$RVI = \frac{\alpha RTEI + \beta PCRI + \gamma BSI}{\alpha + \beta + \gamma}$$

Road Vulnerability Index



Relative Truck Exposure Index (RTEI)

- Measured as a ratio of Truck Count to Truck Capacity

$$RTEI = \frac{T}{v_t}$$

Truck Count

- Point layer obtained from Traffic Survey Unit at NCDOT
- Represent limited number of traffic monitoring stations on Interstates, US & NC Highways
- Only routes with truck count included in RVI
- NCDOT hopes to tag all routes with truck count in the future

Truck Count

- Two types of truck counts
  - ➲ Primary
  - ➲ Secondary
- Primary route supersedes secondary route
- If multiple truck count stations for a route exist, average was taken

Truck Capacity

- Derived from formula to determine passenger-car equivalent flow rate

$$v_p = \frac{V}{PHF * f_G * f_{HV}}$$

- Peak-hour factor (PHF) and grade adjustment (f_G) factor assumed to be one

- Heavy vehicle factor (f_{HV}) becomes $(E_T)^{-1}$, assuming proportion of trucks & buses equals 1

Truck Capacity

- After considering these assumptions, the formula to calculate truck capacity is

$$v_t = \frac{\lambda v_p}{E_T} * 24$$

- The passenger-car flow rates (v_p) and equivalent factors (E_T) for specified terrains are taken from the Highway Capacity Manual

- λ is the number of lanes and the value 24 translates the hourly truck capacity to a daily truck capacity

Relative Truck Exposure Index (RTEI)

- The values calculated using the formula in slide 5 are transformed to a scale of 0-100 using the formula

$$100 - \frac{RTEI}{\max(RTEI)} * 100$$

- Lower values represent higher vulnerability

Relative Truck Exposure Index (RTEI)

Pavement Condition Rating Index (PCRI)

- Two pavement distresses considered to be correlated with the vulnerability of a road to commercial motor vehicles
  - ➲ Alligator Cracking
  - ➲ Rutting

Alligator Cracking

- Alligator cracking is a load associated structural failure

Source: NCDOT

Alligator Cracking

- Method used to calculate Alligator Cracking based on formula obtained from PMU @ NCDOT

- Derived from fields contained in PCS layer
  - ALGTR_HGH_ – Severe Alligator Cracking
  - ALGTR_MDRT – Moderate Alligator Cracking
  - ALGTR_LOW_ – Low Alligator Cracking

- Calculated on a scale of 0-100

- Lower values represent more severe Alligator Cracking

Rutting

- Rutting is defined as having a surface depression in the wheel paths or at the edge of pavement

Source: NCDOT

Rutting

- Method to calculate *Rutting* score obtained from NCDOT
- Derived from field contained in PCS layer

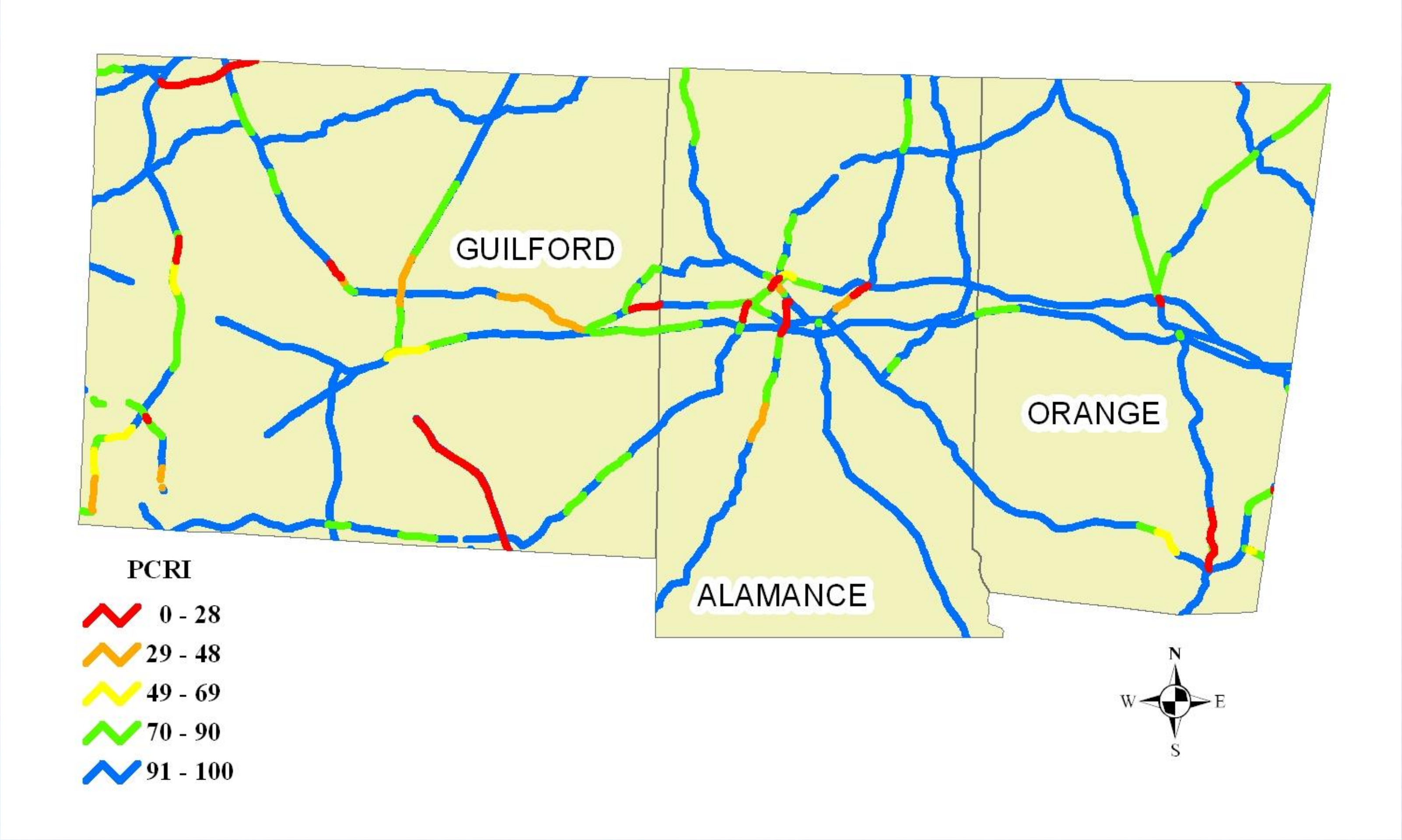
Rutting Code	Score
None (N)	100
Low (L)	90
Moderate (M)	40
Severe (S)	0

Pavement Condition Rating Index (PCRI)

- If overall pavement rating <= 50, multiple distresses involved
- Factor in NCDOT’s overall pavement rating into PCRI
- PCRI calculated on scale of 0-100

$$PCRI = \begin{cases} \frac{A+R}{2} * \frac{RTG}{100} & \text{if } RTG \leq 50 \\ \frac{A+R}{2} & \text{if } RTG > 50 \end{cases}$$

Pavement Condition Rating Index (PCRI)



Bridge Severity Index (BSI)

- Bridge layer obtained from NCDOT
- Every bridge given a Bridge Rating (*BR*)
- Function of two components obtained from NCDOT bridge layer
  - Bridge distress (D_j)
  - Posted weight (W_j)

$$BR_j = 0.2D_j + 0.8W_j$$

Bridge Distress (D_j)

- Two bridge distresses defined in layer
  - Structurally Deficient (SD)

    "... if it is in relatively poor condition, or has insufficient load-carrying capacity. The insufficient load capacity could be due to the original design or to deterioration." (NCDOT)

    A bridge that is SD is given a Bridge Distress value of 100

  - Functionally Obsolete (FO)

    "... if it is narrow, has inadequate under-clearances, has insufficient load-carrying capacity, is poorly aligned with the roadway, and can no longer adequately service today's traffic." (NCDOT)

    A bridge that is only FO is given a Bridge Distress value of 33

  - A bridge that is neither SD nor FO is given a Bridge Distress value of 0

Posted Weight (W_j)

- Determined by how far below 45 tons a bridge's posted weight is
- 45 tons is the maximum weight allowable in the state without a permit
- Transformed to a scale of 0-100

$$100\frac{W_j}{\max(W_j)}$$

- The lower a bridge's posted weight, the more vulnerable it is to oversize/overweight trucks

Bridge Severity Index (BSI)

- Combine individual Bridge Ratings together to obtain a cumulative BSI
- Ensures all bridges included
- Want to ensure that segments with most vulnerable bridges designated as such

$$BSI = \max_{j}(BR) + \sum_{j \neq \max} \frac{BR_j}{10}$$

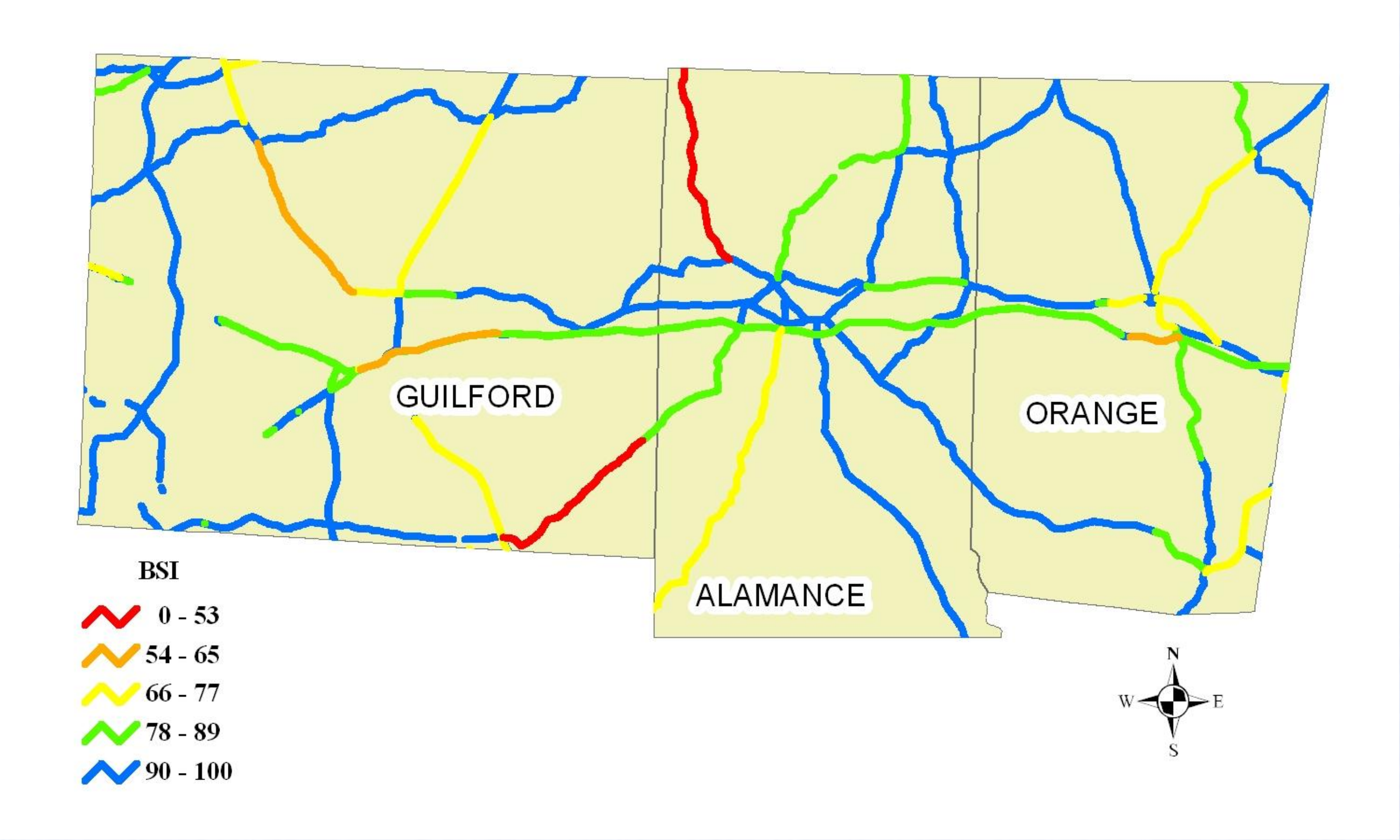
Bridge Severity Index (BSI)

- Cumulative BSI scaled to 0-100 using linear transformation

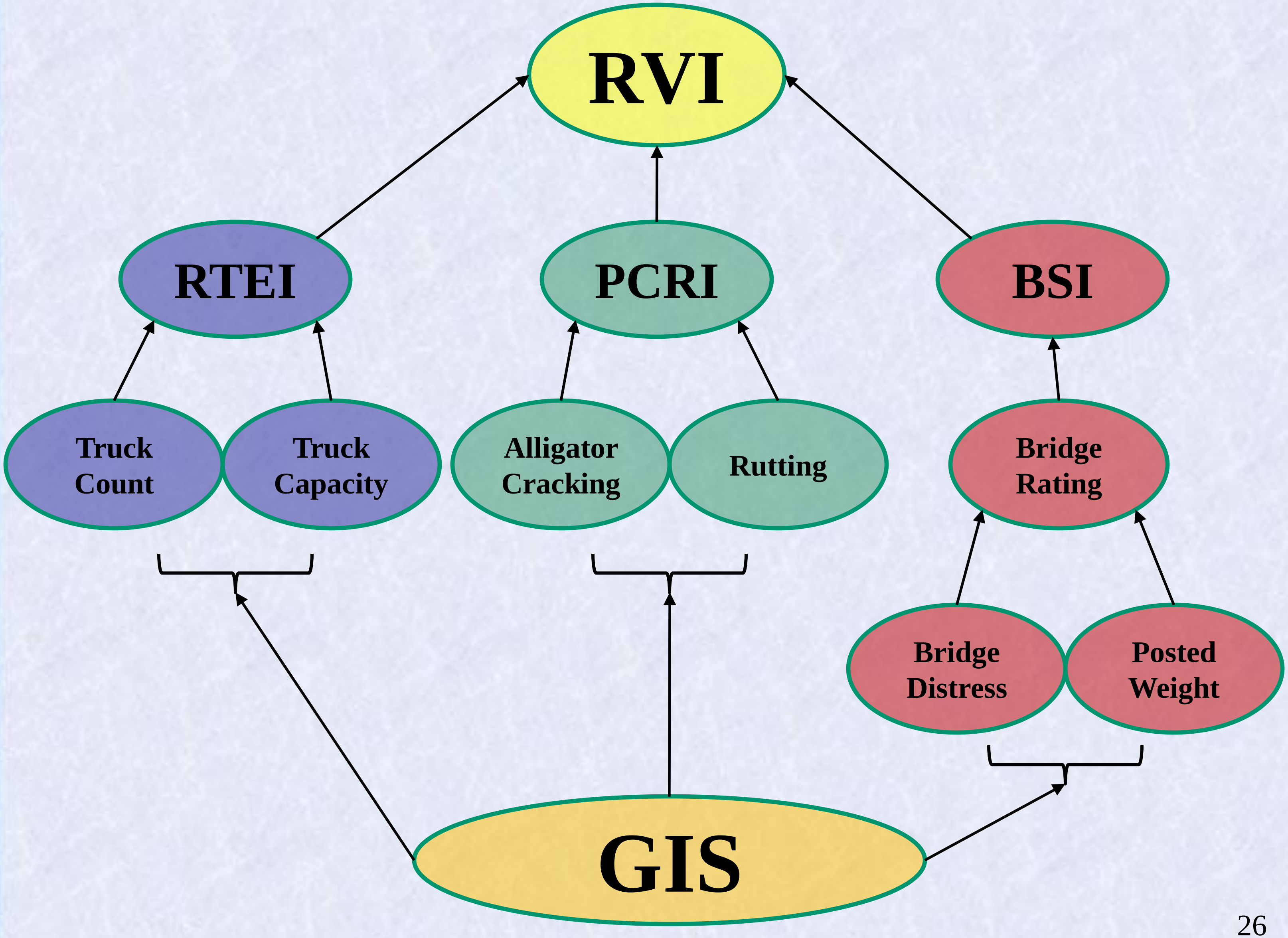
$$100 - \frac{BSI}{\max(BSI)} * 100$$

- Lower values represent higher vulnerability

Bridge Severity Index (BSI)



Road Vulnerability Index



RVI Integration

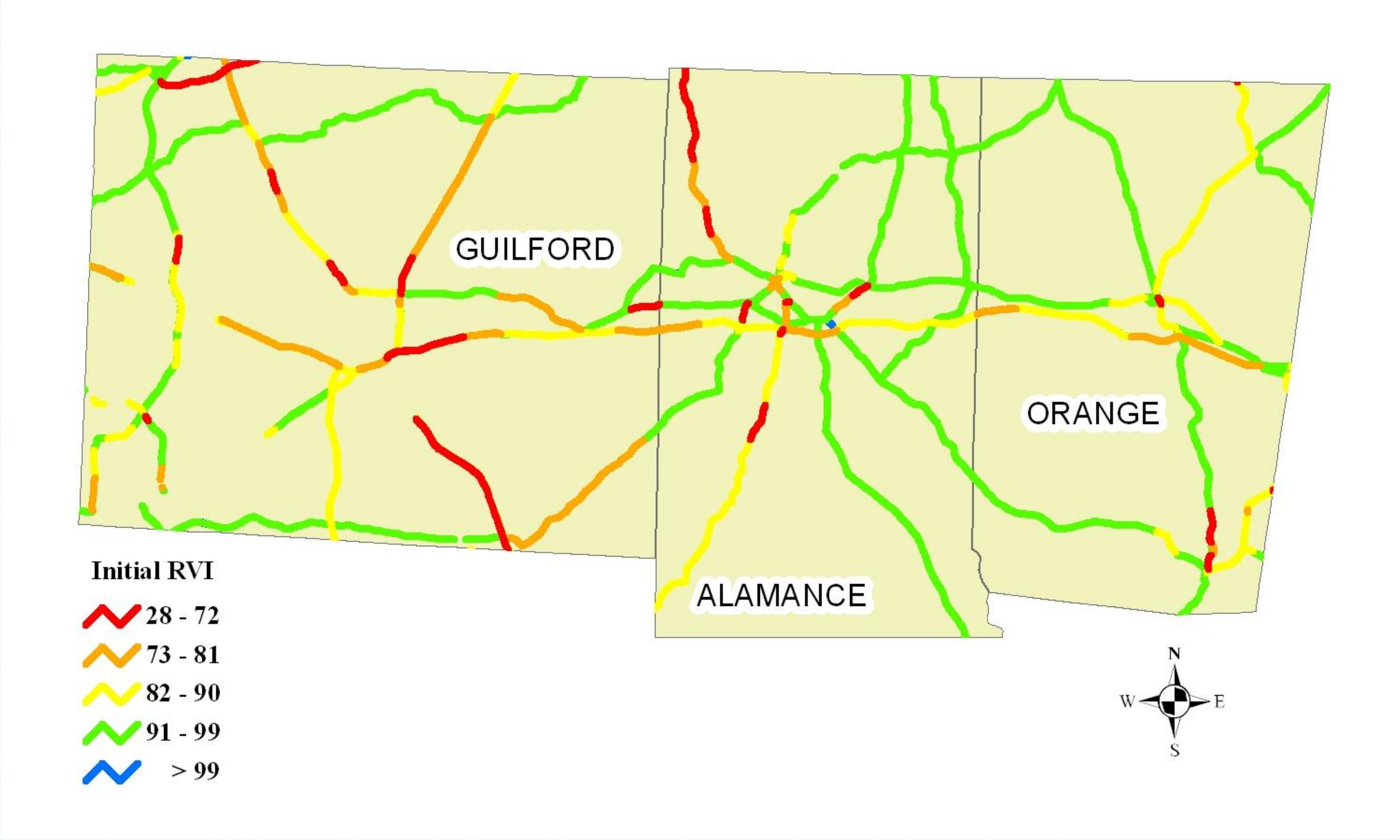
- Components described are combined to obtain RVI using following formula

$$RVI = \frac{\alpha RTEI + \beta PCRI + \gamma BSI}{\alpha + \beta + \gamma}$$

- Initial RVI, coefficients assumed to be 1

- Lower values represent higher vulnerability

Initial RVI



GUILFORD
ALAMANCE
ORANGE
Initial RVI
28 - 72
73 - 81
82 - 90
91 - 99
> 99
N
W
E
S

Baseline RVI

- Before determining weights of individual components, bias needs to be removed
- Goal was to ensure percent variation in RVI equally explained by each of the individual component indices

$$\varepsilon = (\rho_{BSI} - \rho_{RTEI})^2 + (\rho_{RTEI} - \rho_{PCRI})^2$$

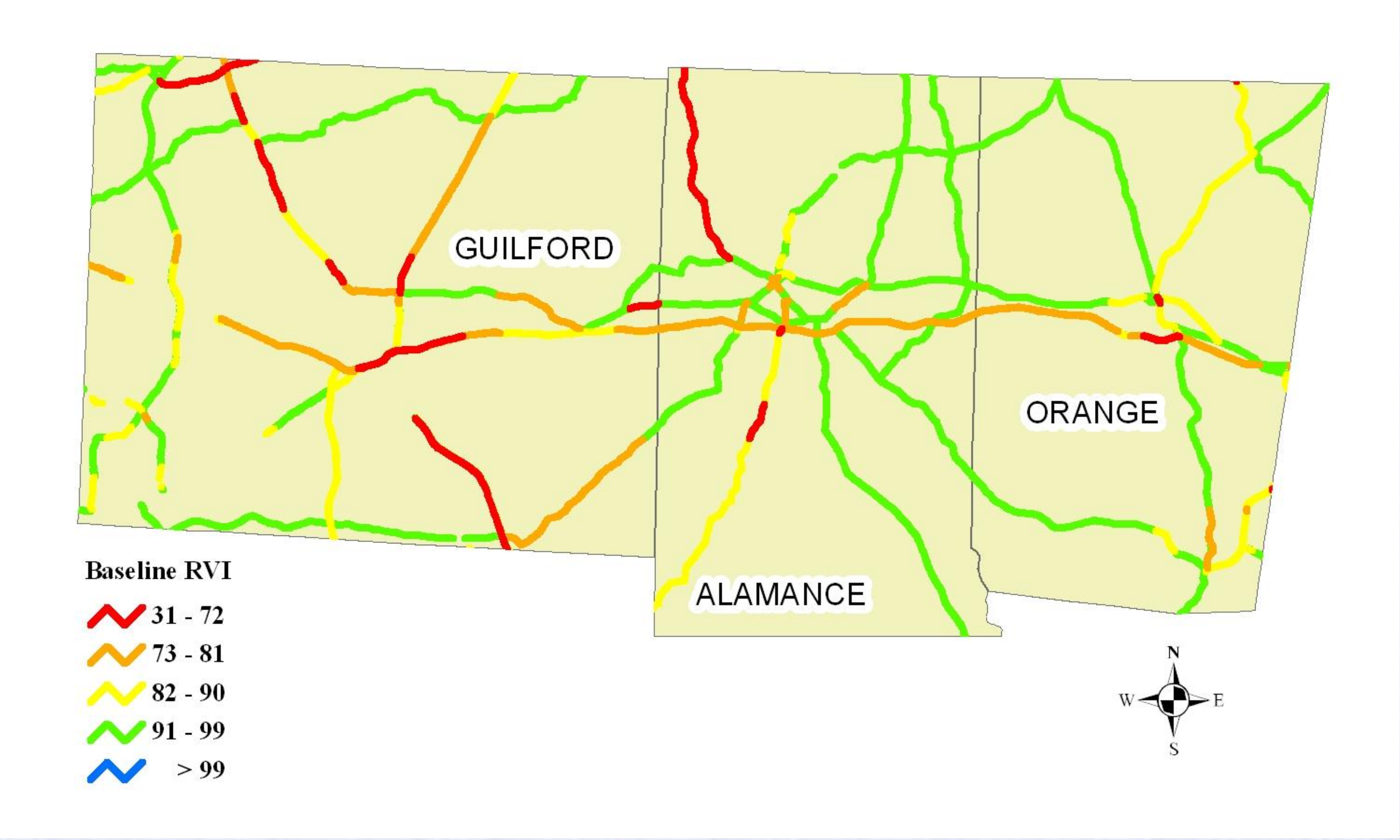
Baseline RVI

- Minimizing equation on previous slide results in baseline model

$$RVI = \frac{2.05 * RTEI + 1.39 * PCRI + 1.96 * BSI}{5.40}$$

  - Relative Truck Exposure Index (RTEI)
  - Pavement Condition Ratings Index (PCRI)
  - Bridge Severity Index (BSI)

Baseline RVI



Sensitivity Analysis

- Sensitivity analysis performed to determine how stable the model is
- Average of each component perturbed by 5%

	RTEI	PCRI	BSI	RVI	Percent Difference
μ	91.52	89.92	89.06	90.22	
$\mu_{[RTEI]}$ + 5%	96.10	89.92	89.06	91.95	**1.93%**
$\mu_{[PRCI]}$ + 5%	91.52	94.42	89.06	91.37	**1.28%**
$\mu_{[BSI]}$ + 5%	91.52	89.92	93.51	91.83	**1.79%**

Summary

- Developed methodology that shows how to combine disparate datasets to produce a single layer for operational planning
- Framework for building when data is more complete
- The model is portable
- Additional components?
  - Geometric design
  - Grade
  - Lane width

Questions?

Contact: jscott@ncsu.edu

Website: http://itre.ncsu.edu/vams