Transportation System Vulnerability to Extreme Weather Events and Natural Hazards

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• Federal Highway Administration (FHWA) Order 5520:
  • State DOTs are directed to establish a policy on preparedness and resilience to climate change and extreme weather events.
  • Implement and evaluate risk-based and cost-effective strategies to minimize climate and extreme weather risks and protect critical infrastructure using the best available science, technology and information.

• Asset Management
  • Improve or preserve the condition of the assets and the performance of the system.
  • Transportation Asset Management Plan (TAMP) under development by KYTC
    • Risk-based assessment of the National Highway System (NHS)
• Perform a vulnerability assessment that identifies KYTC’s assets that are at risk to extreme weather events and other natural hazards
  • Quantitative (existing data)
  • Qualitative (local knowledge)
• Identify assets that are at greatest risk
  • National Highway System
  • All KYTC Districts
• Compile data and assessments into a GIS database
• Implement findings into KYTC’s risk based asset management plan required under MAP-21
Hybrid process:

1. Conduct a series of workshops at KYTC districts throughout the state to elicit local expert knowledge on transportation system vulnerabilities

2. Gather and analyze existing and available data on natural hazards, including meteorological hazards and geological hazards

3. Incorporate and process all data using FHWA’s Vulnerability Assessment Scoring Tool (VAST)
• Extreme weather events
  • Flooding: regional flooding, flash flooding
  • Severe thunder storm: wind, hail
  • Severe winter storm: snow, ice
  • Extreme temperature: heat, cold
  • Drought
  • Wildfire

• Other natural hazards
  • Seismicity (earthquakes)
  • Landslide (rockfalls, slips)
  • Karst (sinkholes)
KYTC survey results, Fall 2015

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District Workshops

KYTC divided into 12 districts
  • Workshop held at each district over the course of 18 months

Series of exercises:

1. Mapping exercise and discussion
   • Identify roads that have been impacted by natural hazards

2. Keypad exercises and discussion
   • Evaluate criticality and potential impacts of hazards to NHS
National Highway System Assets in District 5 to be assessed

- 334 Miles of NHS Roadway
  - 180 Interstate miles
  - 0 Parkway miles
  - 72 US Hwy miles
  - 75 KY Hwy miles
  - 6 Local road miles

- 72 Bridges

- 55 Culverts and pipes (greater than 20’)

- 380 Other NHS Structures

- Other National Highway System Assets
  - Lighting
  - Guardrail
  - Signals
  - Signage
### Kentucky National Highway System (NHS)

<table>
<thead>
<tr>
<th>Asset Type</th>
<th>KYTC Total</th>
<th>Earthquake</th>
<th>Flood</th>
<th>Sinkhole</th>
<th>Landslide</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PGA ≥ 60*</td>
<td>PGA ≥ 30 and &lt; 60</td>
<td>PGA ≥ 18 and &lt; 30</td>
<td>100 Yr Flood-plain</td>
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<tr>
<td>Total NHS Road Miles**</td>
<td>3,278</td>
<td>111</td>
<td>218</td>
<td>388</td>
<td>174</td>
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<tr>
<td>-Interstate</td>
<td>799</td>
<td>13</td>
<td>70</td>
<td>65</td>
<td>29</td>
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<tr>
<td>-Parkway</td>
<td>619</td>
<td>26</td>
<td>30</td>
<td>138</td>
<td>34</td>
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<tr>
<td>-US</td>
<td>1,187</td>
<td>70</td>
<td>75</td>
<td>170</td>
<td>78</td>
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<tr>
<td>-KY</td>
<td>647</td>
<td>2</td>
<td>43</td>
<td>15</td>
<td>32</td>
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<tr>
<td>-Local Road</td>
<td>26</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bridges</td>
<td>831</td>
<td>52</td>
<td>97</td>
<td>148</td>
<td>492</td>
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<tr>
<td>Culverts</td>
<td>390</td>
<td>12</td>
<td>25</td>
<td>33</td>
<td>190</td>
</tr>
<tr>
<td>Structures</td>
<td>1,494</td>
<td>56</td>
<td>111</td>
<td>180</td>
<td>95</td>
</tr>
</tbody>
</table>

* PGA refers to the maximum peak ground acceleration with 2% likelihood of exceedance in 50 years.

** Road miles refers here to centerline miles; for divided highways, centerline miles are doubled.

Notice that along with the qualitative terms there is an associated scale of 1 to 9, this is so serve as a facilitation tool for some people who may find it useful to think in terms of a numerical scale – although the scoring by each individual is of course subjective. The scale is a generic scale of criticality where “1” is very low (least critical) and “9” is very critical.
# Keypad rating: impacts Scale

<table>
<thead>
<tr>
<th>Reduced Capacity</th>
<th>Temporary Operational Failure</th>
<th>Complete Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>9</td>
</tr>
</tbody>
</table>

## Workshop Impact Rating Scale

Notice that along with the qualitative terms there is an associated scale of 1 to 9, this is so as serve as a facilitation tool for some people who may find it useful to think in terms of a numerical scale – although the scoring by each individual is of course subjective. The scale is a generic scale of impact where “1” is very low (least impactful) and “9” is very high (most impactful).

### Reduced Capacity

Results in little or negligible impact to asset. Asset would be available with full use within 10 days and has immediate limited use still available.

Typically involves:
- Less convenient travel
- Occasional brief lane closures, but roads remain open
- Some vehicles may move to alternate routes

### Temporary Operational Failure

Results in minor damage and/or disruption to asset. Asset would be available with either full or limited use within 60 days.

Typically involves:
- Temporary road closures, hours to weeks
- Reduced access to destinations served by the asset
- Stranded vehicles

### Complete Failure

Results in total loss or ruin of asset. Asset may be available for limited use after at least 60 days and would require major repair or rebuild over an extended period of time.

Typically involves:
- Immediate road closure
- Travel disruptions
- Vehicles forced to reroute to other roads
- Reduced commerce in affected areas
- Reduced or eliminated access to some destinations
Keypad rating of NHS

• NHS divided into 287 segments (avg. of 24 segments per district)

• Segmentation based on route number, county, functional class, and asset type (major bridges scored individually).

• Workshop participants provided with keypads to rate each NHS segment.

• Scoring is anonymous, real-time, and transparent.

• Participants can see the results immediately after scoring

• Discussions often ensued to identify why segments rated certain ways
KY 155 (Taylorsville Rd)
What are the worst case impacts?

1. Reduced Capacity
2. ...
3. ...
4. ...
5. Temporary Operational Failure
6. ...
7. ...
8. ...
9. Complete Failure
Vulnerability Assessment Scoring Tool (VAST)

• Indicator-based approach

• 287 NHS segments assessed for vulnerability to flooding, landslides, sinkholes, and earthquakes

• 22 data sets incorporated into dataset, divided into categories of:
  • Exposure
  • Sensitivity
  • Adaptive Capacity

Figure credit: FHWA
<table>
<thead>
<tr>
<th>Indicator Type</th>
<th>Hazard Type</th>
<th>Description</th>
<th>Measure</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure</td>
<td>Earthquake</td>
<td>Peak Ground Acceleration</td>
<td>Max PGA of asset</td>
<td>USGS</td>
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<tr>
<td>Exposure</td>
<td>Flood</td>
<td>Historical Precipitation</td>
<td>Average annual # of days precip. &gt;3&quot;</td>
<td>MRCC</td>
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<tr>
<td>Exposure</td>
<td>Flood</td>
<td>Projected Precipitation</td>
<td>Average annual # of days precip&gt;1&quot;</td>
<td>Kunkel et al</td>
</tr>
<tr>
<td>Exposure</td>
<td>Flood</td>
<td>KGS Flood Hazard layer</td>
<td>Segments intersecting this layer</td>
<td>KGS</td>
</tr>
<tr>
<td>Exposure</td>
<td>Flood</td>
<td>Location via 100-yr floodplain</td>
<td>Percent of asset located in flood zone</td>
<td>FEMA</td>
</tr>
<tr>
<td>Exposure</td>
<td>Landslide</td>
<td>USGS Landslide susceptibility</td>
<td>Percent of asset located in High landslide zone</td>
<td>USGS</td>
</tr>
<tr>
<td>Exposure</td>
<td>Landslide</td>
<td>Max slope</td>
<td>Maximum slope along NHS segment</td>
<td>KTC GIS analysis</td>
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<tr>
<td>Exposure</td>
<td>Landslide</td>
<td>KGS Slope Stability/Landslide layer</td>
<td>Segments intersecting this layer</td>
<td>KGS</td>
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<tr>
<td>Exposure</td>
<td>Landslide</td>
<td>KGS Landslide Inventory</td>
<td>Landslides within 500 feet of NHS per centerline mile</td>
<td>KGS</td>
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<tr>
<td>Exposure</td>
<td>Landslide</td>
<td>KGS Karst Potential</td>
<td>Percent of asset located in high karst zone</td>
<td>KGS</td>
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<tr>
<td>Exposure</td>
<td>Landslide</td>
<td>KGS Karst Hazard layer</td>
<td>Segments intersecting this layer</td>
<td>KGS</td>
</tr>
<tr>
<td>Exposure</td>
<td>Landslide</td>
<td>KGS Sinkhole database</td>
<td>Acres sinkholes/centerline miles</td>
<td>KGS</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>Flood</td>
<td>Workshop mapping results</td>
<td>NHS assets identified in workshops as having flooded</td>
<td>KYTC district workshops</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>Flood</td>
<td>FEMA flood event</td>
<td>NHS assets that experienced FEMA response flood events</td>
<td>FHWA/KYTC/FEMA</td>
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<tr>
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<td>Landslide</td>
<td>Workshop landslide results</td>
<td>NHS assets identified in workshops as having landslides</td>
<td>KYTC district workshops</td>
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<td>Landslide</td>
<td>FEMA slide event</td>
<td>NHS assets that experienced FEMA response landslide events</td>
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<td>Sinkhole</td>
<td>Workshop sinkhole results</td>
<td>NHS assets identified in workshops as having sinkholes</td>
<td>KYTC district workshops</td>
</tr>
<tr>
<td>Adaptive Capacity</td>
<td>ALL</td>
<td>AADT</td>
<td>Average annual daily traffic per NHS segment</td>
<td>KYTC HIS</td>
</tr>
<tr>
<td>Adaptive Capacity</td>
<td>ALL</td>
<td>Criticality Rating</td>
<td>Workshop keypad criticality rating of NHS asset</td>
<td>KYTC district workshops</td>
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<td>Adaptive Capacity</td>
<td>ALL</td>
<td>Functional Class</td>
<td>Functional classification of NHS asset</td>
<td>KYTC HIS</td>
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<td>Adaptive Capacity</td>
<td>ALL</td>
<td>Impacts Rating</td>
<td>Workshop keypad impacts rating of NHS asset</td>
<td>KYTC district workshops</td>
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</tbody>
</table>
Average annual number of days with three or more inches of rainfall; 1981-2015. Source data provided by MRCC.
Floodplain
Floodplain
Floodplain
Acres of sinkholes per centerline miles
Sinkholes
Sinkholes
VAST analysis

• All data parameterized into categories of 1 to 4
• Exposure 33%
• Sensitivity 33%
• Adaptive Capacity 33%

• VAST analysis results in a score from 1 to 4 for every NHS segment to each of the four hazard types
Of the 287 NHS segments,

- 83 were found to have high vulnerability to either earthquake, flood, landslide, or sinkhole.
- Of these 83 segments, 13 were had high vulnerability to two hazard types, and one other segment had high vulnerability to three hazard types.
- 4 segments vulnerable to earthquake,
- 27 segments vulnerable to flood
- 45 segments vulnerable to landslide
- 22 segments vulnerable to sinkhole.
Other Findings, Next Steps

- Local knowledge was key
- Worst case scenario
- External factors affecting vulnerability

- Risk register
- Continued refinement of VAST analysis
- Incorporate results into KYTC processes
  - FHWA pilot project
  - TAMP
  - SHIFT