Resiliency and Durability to Extreme Weather Pilot Study

Pramod Sambidi PhD
Houston-Galveston Area Council
May 12, 2020
Federal Highway Administration - Resilience Pilots

Study Lead
- State DOT
- Federal
- MPO
Study Goals

• Measure Criticality and Vulnerability of Regional Transportation Assets to Extreme Weather Events
Study Goals

• Develop Adaptation Strategy Decision Tool that Provide Recommendations for a Resilient Transportation Infrastructure

• Update H-GAC publications and future project selection criteria
Transportation Assets

- Freeways (83 segments)
- Major roads (7,696 segments)
  - major arterials
  - minor arterials
  - collectors
- Bridges (3,489) with waterway
### FEMA Disaster Declarations

<table>
<thead>
<tr>
<th>Threat</th>
<th>Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floods</td>
<td>13</td>
</tr>
<tr>
<td>Severe Storms</td>
<td>11</td>
</tr>
<tr>
<td>Hurricanes</td>
<td>6</td>
</tr>
<tr>
<td>Fires</td>
<td>3</td>
</tr>
<tr>
<td>Coastal Storms</td>
<td>2</td>
</tr>
</tbody>
</table>

**Extreme Weather Threats to Study:**

1) Inland Flooding
2) Coastal Flooding

**Work Group Feedback**
Study Overview

- **Phase 1 - Data Collection**
  - (Transportation Networks, Roads and Bridge Characteristics, Travel data, LiDAR data, Flood data)

- **Phase 2 – Criticality Assessment**
  - (measures the importance of road segments in the daily movement of people, goods and services)

- **Phase 3- Vulnerability Assessment**
  - (measures the exposure, sensitivity and adaptive capacity of road segments to flooding)

- **Phase 4- Criticality-Vulnerability Framework**
  - (combines results from criticality and vulnerability creates a C-V Matrix)

- **Phase 5-Economic Impact Analysis**
  - (Measures the economic impact of disruption in a road network)

- **Phase 6- Adaptivity Strategy Decision Tool**
  - (provides strategies and recommendations in developing a resilient transportation infrastructure)
Criticality
- **Socio-economic importance (20%)**
  - link to airport; link to port; service to activity population

- **Operational & usage importance (40%)**
  - AADT; AADT-truck; transit ridership

- **Health & safety importance (30%)**
  - link to hospitals; link to fire stations; service to vulnerable population

- **Emergency response importance (10%)**
  - evacuation route; link to shelters; link to EOCs; military access
Total 7,204 centerline miles

Freeways: 762 centerline miles (10.6%)  
Major Streets: 6,442 centerline miles (89.4%)
Vulnerability
Exposure Assessment: Harvey Flooding

BW 8 at IH-10 South

Post Harvey Aerial Imagery (2017)

Flight Timeline
- Aug. 30, 2017 - Sept. 8, 2017
Measuring Level of Exposure

- Ground Elevation
- Surface Elevation (Roadways and Bridges)
- Water Depth
Digital Elevation Model (DEM) from 2018 LiDAR

Digital Elevation Model (DEM) is a digital representation of a terrain's elevation data derived from 2018 LiDAR.
Digital Surface Model (DSM) from 2018 LiDAR

Digital Surface Model (DSM) represents the elevations of the reflective surfaces of roadways and bridges elevated above the ground.
Exposure Assessment: Harvey Flooding

BW 8 at IH-10 South

FEMA Harvey Flood Model (2017)

Water Depth Grid =
Modeled Flood Water Surface Elevation – Ground Elevation (DEM)
Exposure Assessment: Harvey Flooding
BW 8 at IH-10 South

Exposure Depth Grid

Exposure Depth = Flood Water Surface Elevation – Digital Roadway Surface Elevation

Legend

<table>
<thead>
<tr>
<th>Exposure Description</th>
<th>Exposure Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not exposed/ Less than 0 foot of flood water</td>
<td>No exposure or low risk</td>
</tr>
<tr>
<td>0 - 1 foot of flood water</td>
<td>Medium-low risk</td>
</tr>
<tr>
<td>1 - 2 feet of flood water</td>
<td>Medium risk</td>
</tr>
<tr>
<td>2 - 3 feet of flood water</td>
<td>Medium-high risk</td>
</tr>
<tr>
<td>More than 3 feet of flood water</td>
<td>High risk</td>
</tr>
</tbody>
</table>
Exposure Assessment: Harvey Flooding
BW 8 at IH-10 South

Exposure Depth Grid  $A = B - C$

Legend

<table>
<thead>
<tr>
<th>Exposure Depth Grid</th>
<th>Exposure Level</th>
<th>Exposure Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>No exposure or low</td>
<td>No exposure or low</td>
<td></td>
</tr>
<tr>
<td>risk</td>
<td>risk</td>
<td></td>
</tr>
<tr>
<td>Medium-low risk</td>
<td>0 - 1 foot of flood water</td>
<td>Medium-low risk</td>
</tr>
<tr>
<td>Medium risk</td>
<td>1 - 2 feet of flood water</td>
<td>Medium risk</td>
</tr>
<tr>
<td>Medium-high risk</td>
<td>2 - 3 feet of flood water</td>
<td>Medium-high risk</td>
</tr>
<tr>
<td>High risk</td>
<td>More than 3 feet of flood water</td>
<td>High risk</td>
</tr>
</tbody>
</table>

A = Exposure Depth
B = Flood Water Elevation
C = Roadway Elevation

Legend

- No exposure or low risk
- Medium-low risk
- Medium risk
- Medium-high risk
- High risk

0 0.035 0.07 Miles

Miles
Exposure Assessment: 500-Year Flooding

BW 8 at IH-10 South

Legend
Exposure Depth Grid
Exposure Level
- No exposure or low risk
- Medium-low risk
- Medium risk
- Medium-high risk
- High risk

Miles
0 0.25 0.5
Broken water line in east Houston disrupts city, forces boil order
Vulnerability Assessment

VAST Tool

• Exposure Assessment (70%)
  Flooding (100-year, 500-year, & Harvey)
  Storm Surge (Hurricane Category 1 - 5 and Ike)
  Sea-Level Rise (4 & 5 feet)

• Sensitivity Assessment (20%)
  Bridge Age
  Structural Evaluation
  Channel Conditions
  Scour Ratings
  Pavement Condition
  Past Closure

• Adaptive Capacity Assessment (10%)
  Detour Length
  Repair Cost
Vulnerability: Flooding (500-year flooding 50% + Harvey Flooding 50%)

Freeways: 762 centerline miles

Major Streets: 6,442 centerline miles

Vulnerability Assessment
Vulnerability: Storm Surge (Category 4 Storm Surge 50% + Ike Storm Surge 50%)

Freeways: 762 centerline miles

- Low: 84%
- Moderate: 8%
- High: 8%

Major Streets: 6,442 centerline miles

- Low: 91%
- Moderate: 5%
- High: 4%
Vulnerability Assessment

Vulnerability: Sea-Level Rise (5-ft Sea-Level Rise 100%)

Freeways: 762 centerline miles

- **High**: 3%
- **Moderate**: 1%
- **Low**: 96%

Major Streets: 6,442 centerline miles

- **High**: 0.1%
- **Moderate**: 0.4%
- **Low**: 99.5%

**Brazoria**

- High
- Moderate
- Low

**Chambers**

- High
- Moderate
- Low

**Fort Bend**

- High
- Moderate
- Low

**Galveston**

- High
- Moderate
- Low

**Harris**

- High
- Moderate
- Low

**Liberty**

- High
- Moderate
- Low

**Montgomery**

- High
- Moderate
- Low

**Waller**

- High
- Moderate
- Low

**Harris**

- High
- Moderate
- Low

**Galveston**

- High
- Moderate
- Low

**Fort Bend**

- High
- Moderate
- Low

**Chambers**

- High
- Moderate
- Low

**Brazoria**

- High
- Moderate
- Low

**Sea-Level Rise**

Vulnerability: Sea-Level Rise

- High
- Moderate
- Low
Vulnerability: Combined (Flooding 50% + Storm Surge 35% + Sea-Level Rise 15%)
Criticality-Vulnerability Matrix
Criticality (3 types)

Vulnerability (3 types)

Criticality-Vulnerability Matrix (9 types)
Freeways: 762 centerline miles

<table>
<thead>
<tr>
<th>Matrix Summary</th>
<th>Matrix</th>
<th>Miles</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>762.2</td>
<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>High Criticality -High Vulnerability</td>
<td>9.5</td>
<td>1.2%</td>
<td></td>
</tr>
<tr>
<td>Moderate Criticality -High Vulnerability</td>
<td>23.2</td>
<td>3.0%</td>
<td></td>
</tr>
<tr>
<td>High Criticality -Moderate Vulnerability</td>
<td>20.2</td>
<td>2.6%</td>
<td></td>
</tr>
<tr>
<td>Low Criticality -High Vulnerability</td>
<td>66.2</td>
<td>8.7%</td>
<td></td>
</tr>
<tr>
<td>High Criticality -Low Vulnerability</td>
<td>61.5</td>
<td>8.1%</td>
<td></td>
</tr>
<tr>
<td>Moderate Criticality -Moderate Vulnerability</td>
<td>18.3</td>
<td>2.4%</td>
<td></td>
</tr>
<tr>
<td>Low Criticality -Moderate Vulnerability</td>
<td>113.7</td>
<td>14.9%</td>
<td></td>
</tr>
<tr>
<td>Moderate Criticality -Low Vulnerability</td>
<td>63.1</td>
<td>8.3%</td>
<td></td>
</tr>
<tr>
<td>Low Criticality -Low Vulnerability</td>
<td>386.5</td>
<td>50.7%</td>
<td></td>
</tr>
</tbody>
</table>

Vulnerability – Criticality Matrix

Freeways Details (excerpt)

<table>
<thead>
<tr>
<th>Matrix</th>
<th>Name</th>
<th>Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Criticality – High Vulnerability</td>
<td>I-45</td>
<td>3.11</td>
</tr>
<tr>
<td></td>
<td>IH 10 E</td>
<td>6.37</td>
</tr>
<tr>
<td>High Criticality -Moderate Vulnerability</td>
<td>GULF FWY/IH 45</td>
<td>8.05</td>
</tr>
<tr>
<td></td>
<td>IH 10 E</td>
<td>6.68</td>
</tr>
<tr>
<td></td>
<td>IH 69</td>
<td>5.45</td>
</tr>
<tr>
<td></td>
<td>IH 10 E</td>
<td>6.62</td>
</tr>
<tr>
<td></td>
<td>IH 10 W</td>
<td>5.66</td>
</tr>
<tr>
<td></td>
<td>IH 69</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>SOUTH FWY/SH 288</td>
<td>3.89</td>
</tr>
<tr>
<td></td>
<td>SOUTH LOOP E</td>
<td>6.14</td>
</tr>
<tr>
<td>Low Criticality – High Vulnerability</td>
<td>IH 10 W</td>
<td>19.50</td>
</tr>
<tr>
<td></td>
<td>IH 45</td>
<td>2.39</td>
</tr>
<tr>
<td></td>
<td>IH 69</td>
<td>7.84</td>
</tr>
<tr>
<td></td>
<td>NORTH FWY/IH 45</td>
<td>21.01</td>
</tr>
<tr>
<td></td>
<td>NORTH LOOP</td>
<td>4.90</td>
</tr>
<tr>
<td></td>
<td>SOUTH LOOP E</td>
<td>5.83</td>
</tr>
<tr>
<td></td>
<td>GULF FWY/IH 45</td>
<td>21.07</td>
</tr>
<tr>
<td></td>
<td>SH 146</td>
<td>16.18</td>
</tr>
<tr>
<td></td>
<td>SH 288</td>
<td>28.94</td>
</tr>
</tbody>
</table>
**Major Streets:** 6,442 centerline miles

- 48 miles (0.7%)
- 190 miles (2.4%)
- 959 miles (14.9%)
- 1,473 miles (22.9%)
- 3,512 miles (54.5%)
- 260 miles (4.0%)

**Matrix Summary**

<table>
<thead>
<tr>
<th>Matrix</th>
<th>Miles</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>6,442.0</td>
<td>100.0%</td>
</tr>
<tr>
<td>High Criticality - High Vulnerability</td>
<td>48</td>
<td>0.7%</td>
</tr>
<tr>
<td>Moderate Criticality - High Vulnerability</td>
<td>119</td>
<td>1.9%</td>
</tr>
<tr>
<td>High Criticality - Moderate Vulnerability</td>
<td>140</td>
<td>2.2%</td>
</tr>
<tr>
<td>Low Criticality - High Vulnerability</td>
<td>595</td>
<td>9.2%</td>
</tr>
<tr>
<td>High Criticality - Low Vulnerability</td>
<td>364</td>
<td>5.7%</td>
</tr>
<tr>
<td>Moderate Criticality - Moderate Vulnerability</td>
<td>191</td>
<td>3.0%</td>
</tr>
<tr>
<td>Low Criticality - Moderate Vulnerability</td>
<td>861</td>
<td>13.4%</td>
</tr>
<tr>
<td>Moderate Criticality - Low Vulnerability</td>
<td>611</td>
<td>9.5%</td>
</tr>
<tr>
<td>Low Criticality - Low Vulnerability</td>
<td>3,512</td>
<td>54.5%</td>
</tr>
</tbody>
</table>

**Principal Arterials Details (excerpt)**

<table>
<thead>
<tr>
<th>Matrix</th>
<th>Name</th>
<th>Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Criticality - High Vulnerability</td>
<td>BROADWAY (Galveston)</td>
<td>2.617</td>
</tr>
<tr>
<td></td>
<td>SH 3</td>
<td>1.537</td>
</tr>
<tr>
<td></td>
<td>BROADWAY (Houston)</td>
<td>0.777</td>
</tr>
<tr>
<td></td>
<td>COLLEGE</td>
<td>1.199</td>
</tr>
<tr>
<td></td>
<td>CULLEN</td>
<td>0.735</td>
</tr>
<tr>
<td></td>
<td>FAIRMONT PKWY</td>
<td>1.021</td>
</tr>
<tr>
<td></td>
<td>FEDERAL</td>
<td>0.462</td>
</tr>
<tr>
<td></td>
<td>FM 1960</td>
<td>0.142</td>
</tr>
<tr>
<td></td>
<td>KIRBY DR</td>
<td>0.635</td>
</tr>
<tr>
<td></td>
<td>LOCKWOOD DR</td>
<td>0.620</td>
</tr>
<tr>
<td></td>
<td>MEMORIAL DR</td>
<td>0.637</td>
</tr>
<tr>
<td></td>
<td>MONROE</td>
<td>0.134</td>
</tr>
<tr>
<td></td>
<td>NASA RD 1</td>
<td>1.237</td>
</tr>
<tr>
<td></td>
<td>OLD SPANISH TRAIL</td>
<td>0.102</td>
</tr>
<tr>
<td></td>
<td>SH 35</td>
<td>0.794</td>
</tr>
<tr>
<td></td>
<td>SH 146/LOOP 201</td>
<td>0.239</td>
</tr>
<tr>
<td></td>
<td>SHAVER</td>
<td>0.437</td>
</tr>
<tr>
<td></td>
<td>SPENCER HWY</td>
<td>0.463</td>
</tr>
<tr>
<td></td>
<td>LOOP 336</td>
<td>0.119</td>
</tr>
</tbody>
</table>
Economic Impact Analysis
Economic Impact Analysis

Scenario 1: IH 10 San Jacinto Bridge

Scenario 2: Gulf Freeway Galveston Causeway

Scenario 3: SH 146 Fred Hartman Bridge

Scenario 4: SH 225/Lawndale St.

Scenario 5: US 59

Scenario 6: FM 723 & FM 359

Scenario 7: IH 10

Scenario 8: North-South Connecters along Buffalo Bayou between Memorial Dr and Briar Forest

Scenario Segment
### Economic Impact Analysis

#### GDP Loss (Million of Fixed Dollars in 2020) by Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Annual</th>
<th>Month</th>
<th>Week</th>
<th>Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>IH 10 San Jacinto Bridge</td>
<td>206.9</td>
<td>17.2</td>
<td>4.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>Gulf Freeway Galveston Causeway</td>
<td>599.2</td>
<td>49.9</td>
<td>11.5</td>
<td>1.7</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>SH 146 Fred Hartman Bridge</td>
<td>205.6</td>
<td>17.1</td>
<td>4.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>SH 225/Lawndale St.</td>
<td>191.5</td>
<td>16.0</td>
<td>3.7</td>
<td>0.5</td>
</tr>
<tr>
<td>Scenario 5</td>
<td>US 59</td>
<td>182.5</td>
<td>15.2</td>
<td>3.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Scenario 6</td>
<td>FM 723 &amp; FM 359</td>
<td>173.6</td>
<td>14.5</td>
<td>3.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Scenario 7</td>
<td>IH 10</td>
<td>215.3</td>
<td>17.9</td>
<td>4.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Scenario 8</td>
<td>North-South Connecters along Buffalo Bayou between Memorial Dr and Briar Forest</td>
<td>494.8</td>
<td>41.2</td>
<td>9.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Scenario 1+3+4</td>
<td></td>
<td>431.0</td>
<td>35.9</td>
<td>8.3</td>
<td>1.2</td>
</tr>
<tr>
<td>Scenario 1-8</td>
<td></td>
<td>1,407.5</td>
<td>117.3</td>
<td>27.1</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Source: H-GAC Travel Demand Data and REMI Transight
How can one utilize the data from this study?

- Road Segment Elevation Data
- Criticality of Road Segment based on individual criteria
- Location Specific Exposure Depth
- Network Redundancy (Detour Length)
- Project Prioritization
Resilience Tools
Acknowledgements

- H-GAC Staff
- Texas Transportation Institute
- TxDOT Houston District
- Federal Highway Administration
- Harris County Flood Control District
- Rice University SSPEED Center
- Regional Stakeholders
Contact and Links

Resilience Tool
https://datalab.h-gac.com/resilience/

Contact Information

Pramod Sambidi, Ph.D.
Manager, Modeling & GIS
Houston-Galveston Area Council
Ph. No.: 713-993-2451
Email: psambidi@h-gac.com
Bridge Exposure

Bridge Exposure Classification Criteria

<table>
<thead>
<tr>
<th>Exposure Description</th>
<th>Exposure Category</th>
<th>Exposure Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water level 6+ feet below bridge deck</td>
<td>Not exposed/low risk</td>
<td>0</td>
</tr>
<tr>
<td>Water level 4-6 feet below bridge deck</td>
<td>Medium-low risk</td>
<td>1</td>
</tr>
<tr>
<td>Water level 2-4 feet below bridge deck</td>
<td>Medium risk</td>
<td>2</td>
</tr>
<tr>
<td>Water level within 2 feet below bridge deck</td>
<td>Medium-high risk</td>
<td>3</td>
</tr>
<tr>
<td>Water level above bridge deck</td>
<td>High risk</td>
<td>4</td>
</tr>
</tbody>
</table>
Bridge ID: 121020050801222
Feature Intersect: SAN JACINTO RIVER
Name: IH 10 WB
Year Built: 1971
Operational Status: Open
Type Service Under Bridge: Waterway

Waterway: Bridge deck and roadway approaches above flood water elevations (high water).

Exposure: 100YR
- Medium risk of exposure

Exposure: 500YR
- Medium risk of exposure

Exposure: Harvey
- Medium risk of exposure

Exposure: Category 1
- Low risk of exposure

Exposure: Category 2
- Medium risk of exposure

Exposure: Category 3
- Medium-high risk of exposure

Exposure: Category 4
- Medium-high risk of exposure

Exposure: Category 5
- Medium-high risk of exposure

Exposure: Ike
- Medium risk of exposure