A Spatial Evaluation of Nursing Home Vulnerability in the Southeastern United States

Matthew Wilson

Committee Members:
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Background

• Unequal Harm
• Older adults more likely to experience harm than their younger neighbors.
  • ~50% of post-Katrina deaths were adults aged 75+ (Rothman & Brown, 2007)
  • 12% of deaths from Katrina and Rita were nursing home residents (Brunkard, Namulanda, & Ratard, 2008)
  • +60% of deaths from Florence were adults aged 65+ (Goldsmith, 2018)

Image from Time (2017)
Research Objectives

Create a multivariate vulnerability index combining three sub-indices

- Underlying community characteristics
- Frequency of natural disasters
- Nursing home facility demographics

Internal Validation

- Brute Force Method
- Monte Carlo Simulation

External Validation

- Case-crossover
- Distributed lag non-linear model
Index Creation
Multivariate Nursing Home Vulnerability Index

Community Level Index (CLI)

Nursing Home Level Index (NHLI)

Hazard Level Index (HLI)

PCA

Variable Weight

Expert Rank

NHLI

PCA

1 2 3 5 6 8

1 2 3 5 6 8
Data
Community Level Variables

- 2015 Census 5-year estimates

- Percentage of each nationality
- Percent Hispanic
- Median age
- Median gross rent
- Median dollar value of owner occupied housing
- Per capita income
- Average people per household
- Percent unemployed
- Percent population over 25 with under 12 years education
- Percent population in poverty
- Percent renter-occupied housing units
- Percent unoccupied housing units
- Percent households receiving Social Security benefits
- Percent ESL
- Percent employed in extractive industries
- Percent children living in married couple families
- Percent female
- Percent female headed households
- Percent population living in mobile homes
- Percent housing units with no car
- Percent population living in nursing homes
- Percent families earning $200,000+ per year
- Percent employed in service occupations

Image from Cutter & Finch (2008)
Community Level Vulnerability PCA

- Poverty and Minority Population: 25.30%
- Age: 16.90%
- Income and Housing: 9.80%
- Hispanic Population: 6.60%
- Employment and Female Population: 4.90%
- Family Status: 4.90%
- Employment and Female Population Characteristics: 4.40%
- Nursing Facility Population: 3.75%
- Eigenvalues < 1: 28.35%

Total: 100.00%
Natural Hazard Variables

- Historic Tornado Tracks (1950 – 2013)
- Historic Tropical Storm Tracks (1851 – 2008)
- Tropical Depression Tracks (1851 – 2008)
- Tropical Storm Tracks (1851 – 2008)
- Hurricane Tracks (Categories 1 – 3)
- Large Hurricane Tracks (Categories 4 – 5)
- National Flood Hazard Layer (NFHL)
- Storm Surge (2017 Maximum of Maximum (MOM) SLOSH Model)
Hazard Level Vulnerability PCA

- Storm Surge: 43.77%
- Minor Hurricanes and Inland Flooding: 21.29%
- Eigenvalues < 1: 34.94%
Hazard Level Index

- Storm Surge
- Minor Hurricanes and Inland Flooding
- Eigenvalues < 1

Vulnerability:
- Very High
- High
- Average
- Low
- Very Low
Nursing Home Variables

• Centers for Medicaid and Medicare Services – Nursing Home Compare Database:
  • Quality Measures
  • Staffing
  • Other measures:
    • Long-stay residents who lose too much weight
    • Low risk long-stay residents who lose control of their bowels or bladder
    • Long-stay residents who have depressive symptoms
    • Long-stay residents who received an antianxiety or hypnotic medication
<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Average Rank</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of long-stay residents whose need for help with daily activities has increased</td>
<td>7.6</td>
<td>9.66%</td>
</tr>
<tr>
<td>Percentage of long-stay residents whose ability to move independently worsened</td>
<td>7</td>
<td>8.90%</td>
</tr>
<tr>
<td>Percentage of high risk long-stay residents with pressure ulcers</td>
<td>6.4</td>
<td>8.14%</td>
</tr>
<tr>
<td>Percentage of long-stay residents who received appropriate medication</td>
<td>6.2</td>
<td>7.88%</td>
</tr>
<tr>
<td>Percentage of long-stay residents who have depressive symptoms</td>
<td>6</td>
<td>7.63%</td>
</tr>
<tr>
<td>Percentage of long-stay residents experiencing one or more falls with major injury</td>
<td>6</td>
<td>7.63%</td>
</tr>
<tr>
<td>Percentage of long-stay residents who lose too much weight</td>
<td>5.4</td>
<td>6.87%</td>
</tr>
<tr>
<td>Percentage of long-stay residents who self-report moderate to severe pain</td>
<td>5.2</td>
<td>6.61%</td>
</tr>
<tr>
<td>Percentage of long-stay residents with a catheter inserted and left in their bladder</td>
<td>5.2</td>
<td>6.61%</td>
</tr>
<tr>
<td>Percentage of low risk long-stay residents who lose control of their bowels or bladder</td>
<td>5</td>
<td>6.36%</td>
</tr>
<tr>
<td>Percentage of long-stay residents who were physically restrained</td>
<td>4.8</td>
<td>6.10%</td>
</tr>
<tr>
<td>Staffing (CNA, LPN, RN, Total Staff)</td>
<td>4.5</td>
<td>5.66%</td>
</tr>
<tr>
<td>Percentage of long-stay residents with a urinary tract infection</td>
<td>4.4</td>
<td>5.59%</td>
</tr>
<tr>
<td>Percentage of long-stay residents who received appropriate vaccines</td>
<td>3.2</td>
<td>4.07%</td>
</tr>
<tr>
<td>Organization type (For-Profit, Non-Profit, Government)</td>
<td>1.8</td>
<td>2.29%</td>
</tr>
</tbody>
</table>
Nursing Home Level Index

- Percentage of long-stay residents whose need for help with daily activities has increased
- Percentage of long-stay residents whose ability to move independently worsened
- Percentage of high risk long-stay residents with pressure ulcers
- Percentage of long-stay residents who received appropriate medication
- Percentage of long-stay residents who have depressive symptoms
- Percentage of long-stay residents experiencing one or more falls with major injury
- Percentage of long-stay residents who lose too much weight
- Percentage of long-stay residents who self-report moderate to severe pain
- Percentage of long-stay residents with a catheter inserted and left in their bladder
- Percentage of low risk long-stay residents who lose control of their bowels or bladder
- Percentage of long-stay residents who were physically restrained
- Percentage of long-stay residents with a urinary tract infection
- Percentage of long-stay residents who received appropriate vaccines
- Organization type (For-Profit, Non-Profit, Government)
Multivariate Nursing Home Vulnerability Index
Multivariate Nursing Home Vulnerability Index

Community Level Index (CLI)

Nursing Home Level Index (NHLI)

Hazard Level Index (HLI)
Multivariate Nursing Home Vulnerability Index

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Variable Weight

Expert Rank

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PCA

1 3 6 5

1 2 3 6 9

6 5 4

1 2 5 4

3 6 9

2 7 6 3

9 4 6 3

6 5 4
Multivariate Nursing Home Vulnerability Index

- Community Level Index (CLI)
- Nursing Home Level Index (NHLI)
- Hazard Level Index (HLI)
Tract Level MNHVI

County Level MNHVI

Vulnerability Scores
- Very High
- High
- Average
- Low
- Very Low

Tracts containing nursing home locations retain their crisp color. Tracts without nursing homes have increased transparency.

Source: United States 2015 Census 5-year estimates, NOAA, HIFLD, FEMA, CMMIS-MDS

Vulnerability Scores
- Very High
- High
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Counties containing nursing home locations retain their crisp color. Counties without nursing homes have increased transparency.

Source: United States 2015 Census 5-year estimates, NOAA, HIFLD, FEMA, CMMIS-MDS
Research Question 1:

Is the MNHVI externally valid?
External Validation
Preliminary Results

• Age-adjusted death rates were calculated using the CDC Wonder database at the monthly scale.
  • External Causes and All Causes of Death

• Raw death counts for each county were transformed by the age-adjusted population:

• Presence vs. absence of rates for each county were then compared with MNHVI scores.
### Percentage of Death per Vulnerability Class

<table>
<thead>
<tr>
<th>Hurricane Matthew (2016)</th>
<th>Very Low</th>
<th>Low</th>
<th>Average</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aged 65+</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Causes of Death</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>August</td>
<td>16.9</td>
<td>22.1</td>
<td>18.8</td>
<td>20.4</td>
<td>21.7</td>
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<tr>
<td>October</td>
<td>17.4</td>
<td>23.0</td>
<td>18.6</td>
<td>19.8</td>
<td>21.2</td>
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<tr>
<td>November</td>
<td>17.5</td>
<td>20.4</td>
<td>18.6</td>
<td>21.3</td>
<td>22.2</td>
</tr>
<tr>
<td>December</td>
<td>18.4</td>
<td>21.6</td>
<td>18.2</td>
<td>21.2</td>
<td>20.6</td>
</tr>
<tr>
<td><strong>Aged 85+</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>August</td>
<td>12.6</td>
<td>22.8</td>
<td>19.3</td>
<td>21.3</td>
<td>24.0</td>
</tr>
<tr>
<td>October</td>
<td>14.7</td>
<td>22.3</td>
<td>19.4</td>
<td>20.5</td>
<td>23.1</td>
</tr>
<tr>
<td>November</td>
<td>14.5</td>
<td>21.9</td>
<td>17.2</td>
<td>22.1</td>
<td>24.3</td>
</tr>
<tr>
<td>December</td>
<td>16.0</td>
<td>24.3</td>
<td>17.8</td>
<td>21.3</td>
<td>22.3</td>
</tr>
<tr>
<td><strong>External Causes of Death</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Aged 65+</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>August</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>October</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
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<tr>
<td>November</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>December</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11.1</td>
<td>88.9</td>
</tr>
<tr>
<td>Aged 85+</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>August</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<tr>
<td>December</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14.3</td>
<td>85.7</td>
</tr>
</tbody>
</table>
Percent of Death per Vulnerability Class

<table>
<thead>
<tr>
<th>Vulnerability</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High</td>
<td>46%</td>
</tr>
<tr>
<td>High</td>
<td>30%</td>
</tr>
<tr>
<td>Average</td>
<td>15%</td>
</tr>
<tr>
<td>Low</td>
<td>11%</td>
</tr>
<tr>
<td>Very Low</td>
<td>0%</td>
</tr>
</tbody>
</table>

Counties with Deaths in Nursing Homes due to External Causes 2011
Counties with Deaths in Nursing Homes due to External Causes 1999 – 2016

Percent of Death per Vulnerability Class

<table>
<thead>
<tr>
<th>Vulnerability Class</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High</td>
<td>41%</td>
</tr>
<tr>
<td>High</td>
<td>23%</td>
</tr>
<tr>
<td>Average</td>
<td>23%</td>
</tr>
<tr>
<td>Low</td>
<td>11%</td>
</tr>
<tr>
<td>Very Low</td>
<td>2%</td>
</tr>
</tbody>
</table>
Future Directions for External Validation

• Case-crossover study for **North Carolina**
  • Compare age-adjusted death rates following specific hazard events to baseline death rate.

• **Distributed lag non-linear model** to examine the relative risk of death over time.
  • ICD09 and ICD10 codes relating to:
    • Natural disasters deaths
    • Stress related deaths
    • Deaths associated with socioeconomic conditions
Research Question 2 and 3:

Is the MNHVI internally valid?

What are the sources of uncertainty in MNHVI creation?
Internal Validation
Brute Force and Monte Carlo Simulation

- Where are sources of uncertainty and variability found within the model?
- Each iteration creates a unique version of the MNHVI
- The study will run 7,392 iterations (N) since the base sample size (B) is 924 and the number of input parameters (k) is 3:
  \[ N = 2B(k + 1) \]
- Uncertainty is measured by calculating the deviation from the baseline index:
  \[ D_{\text{Base}} = \frac{1}{M} \sum_{i=1}^{M} [\text{MNHVI}_{\text{Base}}(CU_i) - \text{MNHVI}(CU_i)] \]
- Where \( M \) = # of census units, \( CU_i \) = census unit i, and \( D_{\text{Base}} \) = average deviation from the baseline score
Brute Force and Monte Carlo Simulation

- Indicator Set
- Model Structure
- Analysis Scale
- Transformation
- Normalization
- Weighting
- Aggregation
- Uncertainty and Sensitivity Analysis

Number of Iterations (n)

- Brute Force
  - n = 8
- Monte Carlo
  - n = 7,382

Variance
Model Structure

• How should the sub-indices and the composite index be created?

• Inductive:
  • Principal Components Analysis:
    • Allows for a high level of statistical robustness

• Hierarchical:
  • Analytical Hierarchy Process:
    • Allows for a well-defined theoretical organization and input from experts at each stage of index development
Which variables are most important for this analysis?

- Community Level Index (CLI)
  - Inductive
- Hazard Level Index (HLI)
  - Inductive
- Nursing Home Level Index (NHLI)
  - Hierarchical
Analysis Scale

How does the scale at which the data are aggregated change the vulnerability scores?

- Census Tract
  - 16,284

- County
  - 924
Normalization

- How does rescaling the data impact the vulnerability scores?
- Z-Score Normalization, where $\mu = \text{mean}$ and $\sigma = \text{standard deviation}$:
  \[
  z = \frac{x - \mu}{\sigma}
  \]
- Min-Max Value Linear Scaling:
  \[
  \frac{x - \min(x)}{\max(x) - \min(x)}
  \]
Weighting

- How important is each variable compared to one another?

- Equal Weights, where \( n \) = the number of indicators

\[
W_{ew} = \left( \frac{1}{n} \right) \times 100
\]

- Expert Ranks
  - Survey
  - Analytical Hierarchy Process (AHP) using ranks given through a survey taken by experts within the field, where \( V \) = variable and \( W \) = weight:

\[
w_{er} = \{(V_1) \times (W_1)} + \{(V_2) \times (W_2)} + \ldots \{(V_k) \times (W_k)}\]
Transformation

• Should data be transformed based on population, area, or left to raw counts?
  • Population
  • Raw Counts

Aggregation

• How does way the sub-indices are combined alter the final output?
  • Hierarchical
    • Creates the MNHVI
Analysis Scale

Indicator Set

Model Structure

Transformation

Normalization

Weighting

Aggregation

Uncertainty and Sensitivity Analysis

Images from Tate (2013)
Conclusion

• Once validated, the MNHVI can:

  • Assist nursing home administrators and emergency management personnel in their required annual risk assessment planning.
Conclusion

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  • Assist nursing home administrators and emergency management personnel in their required annual risk assessment planning.
  
  • Identify regions where the index is misidentifying so that updates can be made.
Conclusion

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  • Assist nursing home administrators and emergency management personnel in their required annual risk assessment planning.
  
  • Identify regions where the index is misidentifying so that updates can be made.
  
  • Add to the existing hazards and vulnerability literature by synthesizing multiple recommending internal and external validation methods.
Survey

• Used for the weighting and aggregation for the internal validation.

• Your opinion on the importance of each sub-index as it relates to the vulnerability of nursing home facilities in the southeastern United States.
Questions?
References


Goldsmith, T. (2018). Nearly half of tar heels killed by hurricane Florence were 70 or older. North Carolina Health News. https://www.northcarolinahealthnews.org/2018/10/08/nearly-half-of-tar-heels-killed-by-hurricane-florence-were-70-or-older/ (last accessed 26 October 2018)


