CLARUS Road-Weather Routing for Crash Risk Aversion

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CLARUS Monitoring Stations

CLARUS stations in Michigan’s U.P. as of 2009
A regression model was created

- Dependent Variable – A crash occurring within 50 miles of a weather station during a particular hour.
- Independent Variables
  - Temperature (Air, Road and Dew Point)
  - Precipitation Types
  - Precipitation Intensities
  - Visibility
  - Wind Speed (Average and Gust)
  - Atmospheric Pressure
## Linking Crashes and Weather

### First cut: What variables are significant?

<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>Directionality Tested</th>
<th>Odds of a Crash</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Speed</td>
<td>m/s</td>
<td>Higher Speed</td>
<td>1.023</td>
<td>0.0140</td>
</tr>
<tr>
<td>Ice Percent</td>
<td>%</td>
<td>Greater Percent</td>
<td>1.003</td>
<td>0.0288</td>
</tr>
<tr>
<td>Heavy Precipitation Intensity</td>
<td>present</td>
<td>1</td>
<td>1.753</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>No Precipitation Present</td>
<td>present</td>
<td>1</td>
<td>0.808</td>
<td>0.0052</td>
</tr>
<tr>
<td>Precipitation as Snow</td>
<td>present</td>
<td>1</td>
<td>2.174</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Atmospheric Pressure</td>
<td>mbar</td>
<td>Higher Pressure</td>
<td>0.993</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Dew Pt Temp</td>
<td>deg C</td>
<td>Higher Temperature</td>
<td>0.984</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>%</td>
<td>Greater Percent</td>
<td>0.996</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Precipitation Rate</td>
<td>cm/hr</td>
<td>Greater Rate</td>
<td>1.118</td>
<td>0.0478</td>
</tr>
<tr>
<td>Visibility</td>
<td>1000m</td>
<td>Greater Visibility</td>
<td>0.961</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Air Temperature</td>
<td>deg C</td>
<td>Higher Temperature</td>
<td>0.987</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Dry Road Surface</td>
<td>present</td>
<td>1</td>
<td>1.19</td>
<td>0.0004</td>
</tr>
<tr>
<td>Surface Ice Warning</td>
<td>present</td>
<td>1</td>
<td>1.747</td>
<td>0.0099</td>
</tr>
<tr>
<td>Surface Ice Watch</td>
<td>present</td>
<td>1</td>
<td>1.321</td>
<td>0.0010</td>
</tr>
<tr>
<td>Road Surface Temperature</td>
<td>deg C</td>
<td>Higher Temperature</td>
<td>0.995</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Wind Gust Speed</td>
<td>m/s</td>
<td>Higher Speed</td>
<td>1.042</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>
The regression model implies linear effects, but…
- Temperature changes may have greater effects around freezing
- What is the critical visibility level?
- Road temperatures are critical around freezing
- What about correlations between some of the variables?

Back to the raw data
- Where are the tipping points above or below which the regression modeling may be effective?
About 20% of the hours observed around the 4 stations had a crash.
Tipping Points

- Precipitation Rate and Visibility

6 cm/hr

16000 km

Average Crash Rate
Tipping Points

- Wind Speed (average and gust)

- Average Crash Rate

- Wind Gust Speed (m/s)

- Wind Avg Speed (m/s)

- 7 m/s

- 5 m/s
Decision Tree Construction

- A set of regression models applied under specific conditions.
  - Allows for evaluating continuous variables for regions of interest

- Evaluated subsets of data where crash risk was greater than 20% for all levels of other variables shown to be significant
  - i.e. the effect of dew pt, visibility, wind speed when air temperature is < 0 deg C.
Crash Risk Algorithm

1. Precipitation Rate > 0.6 cm/hr
   - Y: Average Wind Speed > 5 m/s
     - Y: Air and Dew Pt Temp < 0 deg C (Equation 1)
     - N: Air and Dew Pt Temp < 0 deg C (Equation 2)
   - N: Avg Wind Speed > 5 m/s
     - Y: Air and Dew Pt Temp < 0 deg C (Equation 3)
     - N: Air and Dew Pt Temp < 0 deg C (Equation 4)

2. Air and Dew Point Temperatures < 0 degrees C
   - Y: Crash Risk = 1
   - N: Crash Risk = 1
For each path on the tree, a regression model was created as done originally.

The exponential of the parameter estimate multiplied by the variable value yields the odds of a crash

\[
\text{CrashRisk}_{Eq1} = e^{(0.6025+0.1716+0.2189)}
\]

\[
\text{CrashRisk}_{Eq2} = e^{(0.6025+0.1716)}
\]

\[
\text{CrashRisk}_{Eq3} = e^{(0.6025+0.2189-1.6789(AirTemperature)+1.4417(DewPtTemperature))}
\]

\[
\text{CrashRisk}_{Eq4} = e^{(0.6025)}
\]

\[
\text{CrashRisk}_{Eq5} = e^{(0.1716+0.2189)}
\]

\[
\text{CrashRisk}_{Eq6} = e^{(0.1716-0.0245(DewPtTemperature))}
\]

\[
\text{CrashRisk}_{Eq7} = e^{(0.2189+0.0130(AirTemperature)+0.0438(AverageWindSpeed))}
\]
OpenStreetMap (OSM) data were loaded into a database to comprise the road network.

Length or travel time the typical cost of a road segment.

<table>
<thead>
<tr>
<th>road_sid</th>
<th>length</th>
<th>precip</th>
<th>adt</th>
<th>dewpt</th>
</tr>
</thead>
<tbody>
<tr>
<td>53485902</td>
<td>0.1</td>
<td>2.1</td>
<td>375</td>
<td>15.2</td>
</tr>
</tbody>
</table>
Crash Risk Aversion Algorithm

- Origin & Destination
- Departure Date & Time
- Weather Observations
- Distance Weights
- Road Network Attributes
- Risk Modifier ($\alpha$)
- Spatial Buffering & Filtering
- Road Segment Weather
- Road Segment Crash Risk
- Cost Calculation
- pgRouting
- Path of least cost
Interpolate weather data for the road network using inverse distance weighting (IDW)

$$z(r) = \sum_{i=1}^{N} \left( \frac{w_i(s)z_i}{\xi} \right)$$

$$\xi = \sum_{i=1}^{N} w_i$$

$$w_i(s) = \frac{1}{\text{distance}(r, s)^p}$$

- \(z_i\): Weather observation at a given CLARUS station
- \(w_i\): Weight applied to the weather observation
- \(r\): Road segment centroid
- \(s\): Location of CLARUS station
- \(\xi\): Normalization factor
- \(p\): Power parameter (fixed at 2 in this application)

IDW not the most rigorous spatial interpolation method, but best choice with only 4 CLARUS stations

Inverse distance weights, calculated from road segment centroid, stored in the database for each road segment
Crash Risk & Cost Calculation

- Classical **shortest time problem**, but with crash risk considered as part of the cost

\[ f(p) = \text{cost}_{p,t} = \alpha \times \text{traveltime}_p + (1 - \alpha) \times \text{crashrisk}_{p,t} \]

- \( \text{cost}_{p,t} \): Cost of traversing edge \( p \) at time \( t \)
- \( \text{traveltime}_p \): Time required to traverse edge \( p \)
- \( \text{crashrisk}_{p,t} \): Crash risk associated with traversing edge \( p \) at time \( t \)
- \( \alpha \): Weighting factor between 0 and 1; shortest path and least crash risk

\[ \text{crashrisk}_{p,t} = \frac{\sum_{s \in S} \lambda_s \text{crashrisk}_{s,t}}{\sum_{s \in S} \lambda_s} \]

Crash risk for each nearby station by inverse distance weighting; in our problem, all four stations considered
**pgRouting**

**PostgreSQL**

Adds types to typical data stored by Postgres

**PostGIS**

Operates on spatial representations enabled by PostGIS

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**Find the nearest edge in PostGIS**

```sql
SELECT gid, source, target, the_geom,
       distance(the_geom, -83.69, 42.31, 4326) AS dist
FROM ways
WHERE the_geom && setsrid('BOX3D(-83.79, 42.21, -83.59, 42.41)::box3d, 4326)
ORDER BY dist LIMIT 1
```

---

**Find the least-cost path between edges**

```sql
SELECT rt.gid, rt.the_geom, length(rt.the_geom), ways.gid
FROM ways,
     (SELECT gid, the_geom FROM djikstra_sp_delta_crash_risk('ways', 650908, 643960, 0.1, '2009-01-01', 0.5)) AS rt
WHERE ways.gid=rt.gid
```
Routing Web Service

- Apache server programmed in **python** with the **django** framework (and RESTful and AJAX-compliant)
- Client application written in Javascript using GeoExt (ExtJS); web mapping powered by OpenLayers
- Routing data sent in Javascript Object Notation (JSON)
From State Highway 28, Covington, MI, USA:
1. Head **east** on M-28 E/US-41 S toward Old US Hwy 41 go 34.4 mi
2. Turn **right** onto Randall Dr go 302 ft
3. Take the 2nd right onto Co Rd 571/Co Rd Pl/Rd Pl/Stoneville Rd go 1.6 mi
4. Turn left onto Co Rd 581/Saginaw St go 36 ft
5. Turn **right** onto Co Rd Pl/Stoneville Rd go 1.4 mi
6. Turn left onto Co Rd Pq go 1.3 mi
7. Turn left onto Co Rd 476 go 0.8 mi
8. Turn **right** onto County Road Pn go 4.7 mi
9. Slight **right** onto Empire Mine Rd go 0.2 mi