FLOW BREAKDOWN LIKELIHOOD AND DURATION

Modeling the Effect of Weather

Jiwon Kim
Hani S. Mahmassani
Jing Dong

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5. PRE- and POST-Breakdown Flow Rate
6. Conclusions
Introduction

- Traffic breakdown and its stochastic nature
  - Largely recognized as a stochastic event, amenable to analysis using probabilistic and statistical approaches.

- Weather effects on traffic flow
  - Most traffic models and analyses are based on clear weather conditions.
  - *Adverse Weather*: one of the most common external changes that affect traffic stream behavior, occurrence and characteristics of flow breakdown.

- Understanding and quantifying the weather effect
  - Estimate the capacity and reliability of traffic facilities
  - Develop mitigation strategies for flow breakdown
Findings in literature

Free-flow speed reduction under rain was reported in Rakha et al. (2008), Lamm et al. (1990), Ibrahim et al. (1994) and Highway Capacity Manual (2000). The reduction varies in the range of 1.7 to 3.6% in light rain, and 4.4 to 9.0% in heavy rain.

Brilon et al. (2005) reported a reduction (around 11%) in breakdown capacity between dry and wet road surfaces.
Flow Breakdown Detection Criteria

- Two primary criteria
  - min. speed difference AND min. time duration
    - (10 mph)
    - (15 min)
  - $V_f$ : prevailing free mean speed
  - $V_{th}$ : Threshold speed ($V_f - 10$ mph)
Probabilistic Description of Flow Breakdown

$q_p$ (pre-breakdown flow rate): The flow rate observed immediately before the onset of traffic breakdown.

$q_b$ (post-breakdown flow rate): The average flow rate observed during breakdown.
Study Sites and Data Collection

- **Detector Locations**
  
<table>
<thead>
<tr>
<th>Route</th>
<th>Abs. Post Mile</th>
<th>Lanes</th>
<th>Location</th>
<th># of Breakdowns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 1</td>
<td>I280-N</td>
<td>45.14</td>
<td>4</td>
<td>South San Francisco</td>
</tr>
<tr>
<td>Section 2</td>
<td>I880-S</td>
<td>41.54</td>
<td>5</td>
<td>Oakland</td>
</tr>
<tr>
<td>Section 3</td>
<td>SR101-N</td>
<td>487.65</td>
<td>3</td>
<td>Santa Rosa</td>
</tr>
<tr>
<td>Section 4</td>
<td>SR101-S</td>
<td>420.21</td>
<td>4</td>
<td>Burlingame</td>
</tr>
<tr>
<td>Section 5</td>
<td>SR101-N</td>
<td>413.81</td>
<td>4</td>
<td>San Mateo</td>
</tr>
</tbody>
</table>

- **Traffic Data**
  - *Performance Measurement System (PeMS), California*
  - 5 min, Workdays (5AM-10PM), 100% observed data
  - Rainy season (November-April), 2000-2009

- **Weather Data**
  - *Automated Surface Observing System (ASOS) at airports*
  - 5 min, -RA(≤0.1 in/hr), RA(0.11-0.3 in/hr), +RA(>0.3 in/hr)
Probability of Breakdown Occurrence
RAIN vs. NO-RAIN
Probability of Breakdown Occurrence: RAIN vs. NO-RAIN

- \( q_p \) (pre-breakdown flow rate) is viewed as a random variable with distribution function \( F_{Q_p} (q_p) \).

- \( F_{Q_p} (q) \) : \( Pr(q_p \leq q) \), the probability that traffic breaks down at flow rates less than or equal to \( q \) (in the next time interval, for a given time discretization)

- \( 1 – F_{Q_p} (q) \) : the probability of flow rate sustaining at \( q \), indicating the travel reliability at flow rate \( q \) (i.e., survival function)
Probability of Breakdown Occurrence: RAIN vs. NO-RAIN

- **Survival Analysis** to obtain the pre-breakdown flow rate distribution
- Nonparametric method
  - Kaplan-Meier Product-limit (PL) method
- Parametric method
  - Weibull, Gaussian and Logistic distributions
  - Maximum Likelihood Estimation (MLE) method

\[
L = \prod_{i=1}^{n} f(q_i)^{\delta_i} \cdot [1 - F(q_i)]^{1-\delta_i}
\]

where

- \( n \): number of observations
- \( \delta_i \): 1, if uncensored (breakdown observed); 0, otherwise
- \( f(\cdot) \): probability density function
- \( F(\cdot) \): cumulative distribution function
**Estimation Results:**
Probability of breakdown under RAIN vs. NO-RAIN (Location: Burlingame)

<table>
<thead>
<tr>
<th>Sec.</th>
<th>Best Fitting Model</th>
<th>Mean, $\mu_{nr}$</th>
<th>Mean, $\mu_{ra}$</th>
<th>$\mu_{nr} - \mu_{ra}$ (as % of $\mu_{nr}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Logistic</td>
<td>2175.7</td>
<td>2124.2</td>
<td>51.5 (2.4%)</td>
</tr>
<tr>
<td>2</td>
<td>Gaussian</td>
<td>1523.9</td>
<td>1438.2</td>
<td>85.7 (5.6%)</td>
</tr>
<tr>
<td>3</td>
<td>Gaussian</td>
<td>1674.6</td>
<td>1577.2</td>
<td>97.4 (5.8%)</td>
</tr>
<tr>
<td>4</td>
<td>Weibull</td>
<td>2024.3</td>
<td>1937.7</td>
<td>86.6 (4.3%)</td>
</tr>
<tr>
<td>5</td>
<td>Gaussian</td>
<td>2110.1</td>
<td>2015.7</td>
<td>94.4 (4.5%)</td>
</tr>
</tbody>
</table>
Summary

- The distribution providing the best fit to the data differs over study sections and weather conditions.
- The Gaussian distribution provides the best fit in six cases (three rain models and three no-rain models) out of ten.
- For all sections, the probability of breakdown at a given flow is higher under rain than the under no-rain.
- The effect of rain is shown to be statistically significant by performing likelihood ratio tests.
Breakdown Duration Analysis
Breakdown Duration Analysis

- Hazard-based duration model
  - hazard function:
    - the conditional probability that an event will occur in a time interval $t$ given that the event has not occurred up to time $t$.
    - the probability that breakdown will end at a duration $t$ given that breakdown has continued up to a duration length $t$.
    - Event $=$ End of breakdown
Breakdown Duration Analysis

- Cox proportional hazards Model

\[
h(t) = h_0(t) \cdot e^{(\beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k)}
\]

- $h(t)$ : hazard function at time $t$
- $h_0(t)$ : baseline hazard, assuming all independent variables are zero
- $x$ : independent variable
- $\beta$ : coefficient

\[
\frac{h(t)}{h_0(t)} = e^{(\beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k)}
\]

- This ratio captures the risk of the terminal event (i.e., end of breakdown) with respect to a particular independent variable
- $\exp(\beta) < 1 \rightarrow$ decrease hazard \rightarrow lengthen duration
# Breakdown Duration Analysis

## Variable Descriptions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Variable Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>Time period between occurrence and recovery of breakdown [dependent variable]</td>
</tr>
<tr>
<td>$q_p$</td>
<td>Pre-breakdown flow rate [continuous variable]</td>
</tr>
<tr>
<td>$q_b$</td>
<td>Post-breakdown flow rate (average flow rate during breakdown) [continuous variable]</td>
</tr>
<tr>
<td>$v_p$</td>
<td>Pre-breakdown speed(speed at pre-breakdown flow rate) [continuous variable]</td>
</tr>
<tr>
<td>$v_b$</td>
<td>Post-breakdown speed (average speed during breakdown) [continuous variable]</td>
</tr>
<tr>
<td>Pre-rain</td>
<td>1 if it rains prior to breakdown, 0 otherwise. [dummy variable]</td>
</tr>
<tr>
<td>Post-rain</td>
<td>1 if it rains during breakdown, 0 otherwise. [dummy variable]</td>
</tr>
</tbody>
</table>
## Breakdown Duration Analysis

### Parameters of Cox proportional hazard model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Section</th>
<th>( \beta )</th>
<th>S.E.</th>
<th>z-statistic</th>
<th>df</th>
<th>p-value</th>
<th>( \exp(\beta) )</th>
<th>95.0% CI for ( \exp(\beta) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( v_b )</td>
<td>1</td>
<td>0.144</td>
<td>0.014</td>
<td>10.054</td>
<td>1</td>
<td>0.000</td>
<td>1.155</td>
<td>1.123 to 1.187</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.107</td>
<td>0.010</td>
<td>10.268</td>
<td>1</td>
<td>0.000</td>
<td>1.113</td>
<td>1.090 to 1.136</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.086</td>
<td>0.011</td>
<td>7.635</td>
<td>1</td>
<td>0.000</td>
<td>1.090</td>
<td>1.069 to 1.114</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.243</td>
<td>0.023</td>
<td>10.445</td>
<td>1</td>
<td>0.000</td>
<td>1.275</td>
<td>1.218 to 1.334</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.053</td>
<td>0.006</td>
<td>8.682</td>
<td>1</td>
<td>0.000</td>
<td>1.055</td>
<td>1.042 to 1.067</td>
</tr>
<tr>
<td>Pre-rain</td>
<td>1</td>
<td>-0.004</td>
<td>0.240</td>
<td>-0.018</td>
<td>1</td>
<td>0.985</td>
<td>0.996</td>
<td>0.622 to 1.593</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.136</td>
<td>0.239</td>
<td>0.569</td>
<td>1</td>
<td>0.569</td>
<td>1.145</td>
<td>0.718 to 1.828</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.413</td>
<td>0.278</td>
<td>1.482</td>
<td>1</td>
<td>0.138</td>
<td>1.511</td>
<td>0.875 to 2.608</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.134</td>
<td>0.319</td>
<td>0.421</td>
<td>1</td>
<td>0.674</td>
<td>1.144</td>
<td>0.612 to 2.137</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>-0.057</td>
<td>0.180</td>
<td>-0.317</td>
<td>1</td>
<td>0.751</td>
<td>0.944</td>
<td>0.642 to 1.344</td>
</tr>
<tr>
<td>Post-rain</td>
<td>1</td>
<td>-0.990</td>
<td>0.241</td>
<td>-4.100</td>
<td>1</td>
<td>0.000</td>
<td>0.372</td>
<td>0.232 to 0.597</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-0.637</td>
<td>0.212</td>
<td>-3.000</td>
<td>1</td>
<td>0.003</td>
<td>0.529</td>
<td>0.349 to 0.802</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>-0.804</td>
<td>0.275</td>
<td>-2.922</td>
<td>1</td>
<td>0.003</td>
<td>0.448</td>
<td>0.261 to 0.768</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>-1.080</td>
<td>0.273</td>
<td>-3.962</td>
<td>1</td>
<td>0.000</td>
<td>0.339</td>
<td>0.199 to 0.579</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>-0.854</td>
<td>0.175</td>
<td>-4.887</td>
<td>1</td>
<td>0.000</td>
<td>0.426</td>
<td>0.302 to 0.600</td>
</tr>
</tbody>
</table>

\( \exp(\beta) < 1 \) (47.1 to 66.1 % reduction in hazard function w.r.t. the baseline hazard)
Observations of breakdown duration under different weather conditions (data from Section 1 located in South San Francisco on Thursdays in January, 2008)

(a) No-rain (top),
(b) Pre-rain =1 (middle)
(c) Post-rain =1 (bottom)
Summary

- A Cox proportional hazard model is used to study the factors that affect the duration of breakdown episodes.
  - Rain during the breakdown episode increases breakdown duration significantly.
  - Rain before breakdown does not significantly affect breakdown duration for the locations tested.
  - The increase in breakdown duration of actual observations due to rain ranges from 34.8 to 43.8%.
  - The lower the average speed during breakdown, the longer the breakdown episode.
Pre- and Post-breakdown Flow Rate
Under RAIN vs. NO-RAIN
**Pre- and Post-breakdown Flow Rate Under RAIN vs. NO-RAIN**

- Comparison based on actual breakdown observations (uncensored data only)

<table>
<thead>
<tr>
<th>Section</th>
<th>Mean flow quantities (vphpl)</th>
<th>% Average increase in breakdown duration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>No-Rain</td>
<td>$q_{p,nr}$</td>
<td>$q_{b,nr}$</td>
</tr>
<tr>
<td>Rain</td>
<td>$q_{p,ra}$</td>
<td>$q_{b,ra}$</td>
</tr>
<tr>
<td>Section 1</td>
<td>1950</td>
<td>1797</td>
</tr>
<tr>
<td></td>
<td>149*</td>
<td>118</td>
</tr>
<tr>
<td>Section 2</td>
<td>1103</td>
<td>1012</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>86</td>
</tr>
<tr>
<td>Section 3</td>
<td>1349</td>
<td>1182</td>
</tr>
<tr>
<td></td>
<td>117</td>
<td>86</td>
</tr>
<tr>
<td>Section 4</td>
<td>1723</td>
<td>1571</td>
</tr>
<tr>
<td></td>
<td>156</td>
<td>122</td>
</tr>
<tr>
<td>Section 5</td>
<td>1295</td>
<td>1132</td>
</tr>
<tr>
<td></td>
<td>133</td>
<td>117</td>
</tr>
</tbody>
</table>

* The italicized number is a standard deviation
** The value in ( ) is % reduction with respect to the former term
Summary

- The average values of service flow rates before and after (during) breakdown were compared between rain and no-rain for each section.
  - Mean flow drop before and after breakdown with respect to pre-breakdown flow rate ranges from 7.8 to 12.7% under no-rain, and from 3.9 to 12.0% under rain.
  - The pre-breakdown flow rate under rain is lower than under no-rain for all sections; the mean reduction for actual breakdown instances is found to be 8.1 to 15.3%.
Contributions and Future Research

Contributions of this study

- This is among the few studies that focus on weather effects specifically on flow breakdown, and possibly the first to do so using data from the U.S.
- It is also the first to conduct formal statistical tests of significance of these effects, and to study breakdown duration using hazard-based techniques.

Further research suggestions

- Consider different types and levels of weather conditions (e.g., snow, fog, heavy rain) and other factors (e.g., visibility) for a more complete understanding of the interaction between weather and flow breakdown phenomena.
- Additional observations at different locations are also required.
Thank you

Q&A