Integrating the effects of adverse weather conditions on traffic:

Methodology, empirical analysis and simulation

Romain Billot
I. Problem Statement
II. Methodology
III. Results from real world data
IV. Online traffic state estimation
V. Concluding remarks

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I. Problem Statement

- Proactive real-time traffic management systems involve a comprehensive knowledge of all elements impacting traffic conditions.
- Adverse weather conditions are well recognized as one important event which can severely impact traffic in terms of traffic operations and safety.
- What are adverse weather conditions? The presented work focuses only on the effects of rain on traffic.
How does adverse weather impact traffic?

<table>
<thead>
<tr>
<th>DRIVERS’ BEHAVIOUR</th>
<th>Speed and acceleration</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Time Headways</td>
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<tr>
<td></td>
<td>Spacing</td>
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<td></td>
<td>Lane Changing</td>
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<td>Platooning ?</td>
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<table>
<thead>
<tr>
<th>TRAFFIC OPERATIONS</th>
<th>Capacity</th>
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<tbody>
<tr>
<td></td>
<td>Traffic Volume</td>
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<tr>
<td></td>
<td>Speed</td>
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<td></td>
<td>Speed Variation</td>
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<td></td>
<td>Congestion Severity</td>
</tr>
</tbody>
</table>
Precipitation impacts the driver’s safety by degrading the state of the pavement, reducing the visibility as well as light,

Increase of the crash frequencies and above all crash severity,

Lagged effect of precipitations across days: the effect of rain is higher if many days have passed since the last precipitation.
II. Methodology

• Relevant datasets

• Multi-level assessment

• Integration of weather effects into traffic models

• Online weather-responsive decision support systems (DSS)

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Methodology

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Methodology (II): data selection & data mining

DATA FUSION & DATA SELECTION

Traffic data → Selection of relevant data subsets with similar characteristics (traffic composition, type of day, lane) → Weather data

- Dataset 1: No rain
- Dataset 2: Light rain
- Dataset 3: Medium rain
- ... Dataset N: Heavy snow

DATA MINING

- MESOSCOPIC ANALYSIS (Platoons)
- MICROSCOPIC ANALYSIS (Time headways, Spacing, Individual Speeds)
- MACROSCOPIC ANALYSIS (Free Flow Speed, Capacity, Critical Density)

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III. Results from real world data: 118 national road

- Two-lane freeway section near Paris with high traffic volume
- Traffic data collected from 2005 to 2007 from 9 double-trap loop sensors.
- First traffic data selection from 3 out of 9 sensors located on a homogeneous section (same topography)
Datasets construction

TRAFFIC DATA

• Same day category (regular weekday) and same time periods (morning/evening peak hours)

• Similar traffic composition & significant amount of vehicles (>10 000 vehicles per lane).

• Speed limit = 110 km/h (68.3 mph). Only the southbound direction towards Paris is considered.

WEATHER DATA

• Hourly weather data provided by a consistent weather station located near the section.

• Then, traffic data were divided into 3 datasets according to the rain intensity:
  • No rain: rainfall= 0 mm/h
  • Light: up to 2 mm/h
  • Medium: from 2 to 3 mm/h

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Results: speed and spacing distributions

- Clear decrease for the slow lane of the frequencies of speeds > 90 km/h under rainy conditions. Primary adaptation to rain = speed reduction.

- Frequency of short spacing decreases during inclement weather conditions -> Drop of about 10% of the spacing <50m under medium rain conditions.
Results: Time headways (TH) distributions

- Frequency of TH <3s higher under dry conditions.
- Good fit of the log normal distribution with our TH distribution.
- The higher the intensity of rain is, the lower the density of short TH is.

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Results: Macroscopic level

- Calibration of Van Aerde Model.
- Drop in free-flow speed: 8% under light rain conditions and of about 12.6% under medium rain conditions.
- Roadway capacity decreases by 18.5% vs 21% under light & medium rain conditions.

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Consistency with other studies

Light rain conditions: reductions coefficient of two key parameters on freeways: free-flow speed and capacity:

<table>
<thead>
<tr>
<th>Country</th>
<th>Road type</th>
<th>Free-flow speed</th>
<th>Capacity</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>interurban area</td>
<td>8% – 12.5%</td>
<td>18.5% – 21%</td>
<td>Previous study</td>
</tr>
<tr>
<td>France</td>
<td>urban ring road</td>
<td>9%</td>
<td>15.5%</td>
<td>Billot et al. (2008)</td>
</tr>
<tr>
<td>Canada</td>
<td>urban freeway</td>
<td>10%</td>
<td>15.5%</td>
<td>Andrey et al. (2006)</td>
</tr>
<tr>
<td>USA</td>
<td>3 metropolitan areas</td>
<td>6% – 9%</td>
<td>10% – 11%</td>
<td>Rakha et al. (2008)</td>
</tr>
<tr>
<td>Japan</td>
<td>metropolitan expressway</td>
<td>5%</td>
<td>6 – 9%</td>
<td>Chung et al. (2006)</td>
</tr>
</tbody>
</table>

• Results are context-dependent (urban/interurban area).

• Regarding other world-wide studies, traffic parameters reductions are slightly higher.

• Regional differences need to be analyzed.
IV. Toward online weather-responsive estimation

- Goal: to show how the new knowledge about the rain effects would be useful from a simulation point of view.

- Tools: Bayesian framework with the use of Monte Carlo observer-based traffic flow estimations.

- Simulation case from real world data: eastern part of Lyon’s ring road (urban motorway)
Macroscopic traffic model

- Discretized version of conservation equation:
  \[ k_i(t + \Delta t_N) = k_i(t) + \frac{\Delta t_N}{\Delta x_i} \left( q_{i-1}(t) - q_i(t) \right) \]

- Gudunov balance equation:

\[
\begin{align*}
\text{Cell } i \text{ demand: } & \Gamma_i(t) = Q_{e,i,t} \left( \min(k_i(t), k_{c,i}(t)) \right) \\
\text{Cell } i+1 \text{ supply: } & \Omega_{i+1}(t) = Q_{e,i+1,t} \left( \max(k_{i+1}(t), k_{c,i+1}(t)) \right) \\
\text{Resulting flow: } & q_i(t) = \min(\Gamma_i(t), \Omega_{i+1}(t))
\end{align*}
\]

- State Vector:
  \[ x_t = (k_1(t), k_2(t), \ldots, k_n(t), q_0(t), q_1(t), \ldots, q_n(t))^T \]

\[ x_{t+1} = f(x_t) \]
Observation equation and state estimation

- The measured quantities (vector $y_t$) are flows and densities in certain cells, i.e. components of the state vector $x_t$:

  $$y_t = Cx_t$$

- Bayesian framework: the dynamic state estimation is carried out through the construction of the posterior probability density of the state.

- Tools: sequential Monte Carlo (SMC) State Estimation

  deriving an estimate of:

  $$P(x_t | x_{t-1}, u_{t-1}, y_t)$$

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Integration of weather in a observer-based model

- A day-long scenario under adverse weather conditions is created.
- Without any knowledge about rain effects => overestimation of traffic volume during peak hours.
- By introducing the new knowledge about rain impacts into the fundamental diagram => new simulation leads to correct estimations.

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Perspectives & current works

• Analysis of weather impact on platooning: does a platooning phenomenon raise more often under adverse weather conditions?

• Wider range of rain and snow intensities -> analysis of Swiss and Japanese data enabling also comparison of regional differences.

• Effect of weather on travel times: French regional project TPTEO with road operator AREA

• Adaptative traffic modelling according to prevailing weather conditions.

• Vlasov Fokker Planck traffic modelling taking into account platooning and the weather parameter
Conclusion

• Standardized methodology for weather impact integration into DSS.

• Work undertaken within an european project enabling data and knowledge sharing:
  COST ACTION TU0702 (http://tu0702.inrets.fr)

• Goal: Provide the road operators with weather-sensitive management tools (DSS)
Thank you for your attention!

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