A Stochastic Delay Prediction Model for Real-Time Incident Management

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Motivation

Effective incident management is vital for urban freeway performance.

This requires real-time prediction of incident severity.
Motivation

How do we measure incident severity?

<table>
<thead>
<tr>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total delay caused</td>
</tr>
<tr>
<td>Property damage</td>
</tr>
<tr>
<td>Number of responders</td>
</tr>
<tr>
<td>Injuries</td>
</tr>
<tr>
<td>Number of blocked lanes</td>
</tr>
<tr>
<td>Duration/clearance time</td>
</tr>
</tbody>
</table>

In this research, this is the metric we use.

Motivation

Total delay can be calculated, with the right information:

Traffic demand → Traffic flow theory → Incident delay

Incident duration
General Incident Management Framework

Motivation

**Uncertainty** and **limited information** are very characteristic of incident management. Ignoring them will **always** create error.

<table>
<thead>
<tr>
<th></th>
<th>Incident A</th>
<th>Incident B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>5 or 25</td>
<td>17</td>
</tr>
<tr>
<td>Expected duration</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>Delay using expected duration</td>
<td>225</td>
<td>289</td>
</tr>
<tr>
<td>True expected delay</td>
<td>325</td>
<td>289</td>
</tr>
</tbody>
</table>
Outline

1. Why do we need stochastic delay prediction models?
2. How can we model uncertainty?
3. What about complicated real-world situations?
4. Conclusion; what is the practical impact?

Jensen’s Inequality

A fundamental result in probability guarantees that using average incident duration will underestimate incident delay.

Motivation  ❖  Theory  ❖  Simulation  ❖  Conclusion
Classical Delay Formulas

There are standard formulas for calculating delay caused by changes in capacity.

\[
D_n = \frac{1}{2n} \left( q_1 - q_1 \right) \left( q_n - q_1 \right)
\]

Estimating Incident Duration

These rely on predicted incident duration. For stochastic models, we need a probability distribution.

**Single predicted duration**

Example:

Incident involves two vehicles and one injury, predict duration will be 25.3 minutes

**Probability distribution**

Incident duration will be:

- <15 minutes with 35% probability
- 15-30 minutes with 40% probability
- 30-45 minutes with 15% probability
- >45 minutes with 10% probability
Stochastic Formulas

Knowing the probability distribution, we can adapt the traditional formulas:

\[
D_n = \frac{1}{2} \times \frac{(q_1 - q_0)(q_n - q_1)}{q_1 - q_0}
\]

\[
E[D_n] = \frac{(q_1 - q_0)(q_n - q_1)}{2(q_1 - q_0)} \sum_{i=1}^{3} \left( \xi_i^2 + \xi_i \xi_{i-1} + \xi_{i-1}^2 \right)
\]

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Dynamic Demand

In the real world, these formulas don’t apply exactly. Traffic flow is not uniform, but changing and dynamic.

Simulation can be used for more complicated scenarios.
Simulation Framework

Mesoscopic simulation was applied to a fictitious freeway segment with a variety of demand profiles.

Simulation Results

Incident impacts depend greatly on how demand is changing.

<table>
<thead>
<tr>
<th>Profile</th>
<th>Average delay</th>
<th>Standard deviation</th>
<th>Skewness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform</td>
<td>179.60</td>
<td>247.93</td>
<td>1.69</td>
</tr>
<tr>
<td>Rising</td>
<td>122.30</td>
<td>137.07</td>
<td>1.04</td>
</tr>
<tr>
<td>Falling</td>
<td>343.58</td>
<td>524.22</td>
<td>1.95</td>
</tr>
<tr>
<td>Peak</td>
<td>206.67</td>
<td>281.69</td>
<td>1.65</td>
</tr>
</tbody>
</table>
Simulation Results

Failing to account for uncertainty leads to substantial underprediction of incident impacts.

<table>
<thead>
<tr>
<th>Profile</th>
<th>True average delay</th>
<th>Estimated delay</th>
<th>Underestimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform</td>
<td>179.60</td>
<td>106.22</td>
<td>41%</td>
</tr>
<tr>
<td>Rising</td>
<td>122.30</td>
<td>95.49</td>
<td>22%</td>
</tr>
<tr>
<td>Falling</td>
<td>343.58</td>
<td>159.04</td>
<td>54%</td>
</tr>
<tr>
<td>Peak</td>
<td>206.67</td>
<td>119.63</td>
<td>42%</td>
</tr>
</tbody>
</table>

Motivation ◇ Theory ◇ Simulation ◇ Conclusion
Conclusions

1. Accounting for uncertainty is vital for accurate prediction of incident impacts
2. Dynamic demand also plays a key role: theoretical results are insufficient by themselves
3. Incorporating real-time flow measurements and incident information is feasible (e.g., at TMCs)

Questions?