Capacity drop in Belgium: empirical observations and implications

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TRAIL masterclass Mysteries on motorway traffic operations
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Overview

• Part 1: capacity drop on Belgian motorways
  ◦ R0 ring of Brussels
  ◦ empirical observations
  ◦ implications for potential impact control applications

• Part 2: capacity drop on Belgian intersections
  ◦ concept and definition
  ◦ empirical set-up
  ◦ empirical observations
Capacity drop on Belgian motorways

master thesis Thijs Van Tieghem
KU Leuven master Traffic & Logistics
Motivation and objective

- potential for traffic control claimed
  - literature
    - capdrop = one of two main degradation mechanisms
    - e.g. work Papageorgiou predicts ~50% TTS reduction by eliminating capacity drop and spillback
    - if even 20% of that were true…
  - field deployment
    - coordinated metering in Melbourne confirmed spectacular gains
    - e.g. John Gaffney (VicRoads)
  - this finally convinced Flemish road authority to support study into potential for ramp metering in Belgium
2. Why Ramp Metering?

Answer

\[ \Delta T_s = \frac{T_s^{nc} - T_s^{rm}}{T_s^{nc}} = \frac{q_{cap} - q_{con}}{q_{in} + d - q_{con}} \]

e.g. \( q_{con} = 0.95q_{cap} \); \( q_{in} + d = 1.2q_{cap} \)

\[ \rightarrow \Delta T_s \approx 20\% \]

prof. Markos Papageorgiou (TU Crete) is kindly acknowledged for sharing these slides!
Note: On-ramp queue should not interfere with surface street traffic.
6. Simulation Results

Amsterdam ring-road A10:
- 32 km (counterclockwise)
- 21 on-ramps
- 20 off-ramps
No-Control Case
TTS = 14167 veh\cdot h

Density profile
Ramp queue profile

Coordinated Ramp Metering Strategy HERO: Field Implementation at the Monash Freeway in Melbourne, Australia
Coordinated Ramp Metering Strategy HERO: Field Implementation at the Monash Freeway in Melbourne, Australia

ALINEA without Queue Control
TTS = 7563 veh\(\cdot\)h  -47%

Density profile

Ramp queue profile
Motivation and objective

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    • if even 20% of that were true…
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M1 Corridor – what are the traffic patterns?

John Gaffney (VicRoads) is kindly acknowledged for sharing these slides!
Getting Control of the Freeway

Before

2nd Bottleneck

1st Bottleneck

After

2nd Bottleneck Reduced

1st Bottleneck Removed
Empirical set-up

- R0 ring of Brussels
  - massive daily queuing on ring and connecting radial motorways, AM and PM
  - succession of on-off ramps with much exchange of traffic
    - many bottlenecks → capacity drop?
    - many blocked outflows
  - little support for capacity extension

- Research question:
  “can we quantify the drop in capacity during bottleneck activation, as an indicator for potential of managed motorway?”
Queues AM

1. E40 → Buitenring, Sint-Stevens-Woluwe
2. E19 → Binnenring, Machelen
3. Binnenring, Vilvoorde
4. Binnenring, Zellik
5. Binnenring, Huizingen/Halle
6. E411 → Buitenring, Leonardkruispunt
Queues PM

7. Buitenring, Wemmel

8. Buitrenring, Zaventem

9. Binnenring, Wezembeek-Oppem
Data availability and methodology

• double loop detector data
  ◦ 44 working days March & October 2015
  ◦ speed, occupancy + flow per lane
  ◦ 5-min aggregate

• methodology
  ◦ aggregation over lanes
  ◦ cumulative flow analysis
    • discharge just downstream, if needed aggregated main+off-ramp
    • bottleneck activation / de-activation by occupancy just upstream
Capacity drop

- occupancy 1st upstream detector
  - threshold site specific
  - determines discharge period
- average flow during discharge period = discharge rate
- longest “constant” flow period prior = pre-queue capacity
Result example: E40 (East) → R0 (outer - North)
Sint-Stevens-Woluwe AM peak

- weaving zone bottleneck
  - 3+2 lanes
  - activated 38 times
- pre-queue cap
  - 7970 veh/h
- discharge rate
  - 7528 veh/h
- drop
  - 5.52%
Examples special cases

- bottleneck in on-ramp before the merge (only on merge)
  - no downstream observation
  - detector on merge (i.e. just in queue) used
- E19 (North) → R0 (inner – South) Machelen AM peak
  - pre-queue: 3585 veh/h
  - discharge: 3303 veh/h
  - drop: 7.8%
- E411 (SE) → R0 (outer – N) Leonard interchange AM
  - pre-queue: 2604 veh/h
  - discharge: 1995 veh/h
  - drop: 23.3%
  - to be distrusted, instable discharge (no cause found)
### Overview results

<table>
<thead>
<tr>
<th>Bottleneck 1: complex Zaventem-Henneaulaan</th>
<th>Stroom voor</th>
<th>Stroom na</th>
<th>CD [%]</th>
<th>Stdev(CD)</th>
<th>n</th>
<th>Starttijd</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7970</td>
<td>7528</td>
<td>5.52%</td>
<td>2.61</td>
<td>38</td>
<td>7u51</td>
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</table>

<table>
<thead>
<tr>
<th>Bottleneck 2*: complex Machelen (E19 → binnenring)</th>
<th>Stroom voor</th>
<th>Stroom na</th>
<th>CD [%]</th>
<th>Stdev(CD)</th>
<th>n</th>
<th>Starttijd</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>3585</td>
<td>3303</td>
<td>7.81%</td>
<td>3.65</td>
<td>28</td>
<td>6u48</td>
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<table>
<thead>
<tr>
<th>Bottleneck 3: knooppunt Machelen (binnenring)</th>
<th>Stroom voor</th>
<th>Stroom na</th>
<th>CD [%]</th>
<th>Stdev(CD)</th>
<th>n</th>
<th>Starttijd</th>
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<tr>
<td></td>
<td>6105</td>
<td>5919</td>
<td>3.03%</td>
<td>0.99</td>
<td>21</td>
<td>7u30</td>
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</table>

<table>
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<tr>
<th>Bottleneck 4: complex UZ-Jette (binnenring)</th>
<th>Stroom voor</th>
<th>Stroom na</th>
<th>CD [%]</th>
<th>Stdev(CD)</th>
<th>n</th>
<th>Starttijd</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6454</td>
<td>6119</td>
<td>5.16%</td>
<td>2.43</td>
<td>31</td>
<td>6u33</td>
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</table>

<table>
<thead>
<tr>
<th>Bottleneck 6a: complex Hoeilaart (Leonardkruispunt)</th>
<th>Stroom voor</th>
<th>Stroom na</th>
<th>CD [%]</th>
<th>Stdev(CD)</th>
<th>n</th>
<th>Starttijd</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3924</td>
<td>3710</td>
<td>5.38%</td>
<td>2.43</td>
<td>33</td>
<td>7u33</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Bottleneck 6b*: Leonardkruispunt (E411 → buitenring)</th>
<th>Stroom voor</th>
<th>Stroom na</th>
<th>CD [%]</th>
<th>Stdev(CD)</th>
<th>n</th>
<th>Starttijd</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2604</td>
<td>1995</td>
<td>23.34%</td>
<td>4.72</td>
<td>39</td>
<td>6u37</td>
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<tr>
<th>Bottleneck 7: complex UZ-Jette (buitenring)</th>
<th>Stroom voor</th>
<th>Stroom na</th>
<th>CD [%]</th>
<th>Stdev(CD)</th>
<th>n</th>
<th>Starttijd</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>6728</td>
<td>6449</td>
<td>4.17%</td>
<td>2.18</td>
<td>15</td>
<td>13u47</td>
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<tr>
<th>Bottleneck 8: knooppunt Machelen (buitenring)</th>
<th>Stroom voor</th>
<th>Stroom na</th>
<th>CD [%]</th>
<th>Stdev(CD)</th>
<th>n</th>
<th>Starttijd</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7185</td>
<td>7009</td>
<td>2.56%</td>
<td>1.99</td>
<td>6</td>
<td>14u20</td>
</tr>
</tbody>
</table>
Conclusion and implication

- Some bottlenecks allow for CD estimation, which reproduces reliably
  - 2.5 – 5.5% (range over sites)
  - 0 – 16% (range over days and sites)
- Others give unreliable estimates
- Others exhibit no noticeable drop

- Implication:
  “Does not seem like a sound basis to recommend CD-avoiding traffic control operations like ramp metering or MTFC?”

- Would you agree or am I missing something?
Capacity drop on Belgian intersections

Master thesis Martin Camerman
KU Leuven master Traffic & Logistics
“Capacity drop is the reduction in throughput for a movement over the intersection, caused by conflicts that were underestimated during design of the traffic control, or that were supposed to be excluded by traffic control but still activate due to problems in evacuating the intersection.”
Let’s go back 10 years…

• my presentation at masterclass November 2006 – PhD Francesco Viti
Application
Modelling the network
Simulation results: reference without hindrance

- averaged over 50 15’ runs for each gridpoint
- other demands 500 veh/h
Monte-Carlo simulation of capacity drop at intersections

95% confidence interval and composition

14.30 veh/h
Simulation results: capacity drop!

- averaged over 50 15’ runs for each gridpoint
- other demands 500 veh/h
Sensitivity analysis: Influence service time increase when obstructed
Boomsesteenweg – L1
Boomsesteenweg – L2
Boomsesteenweg – L3
Boomsesteenweg – R1
Mortsel – R2
Dynamische effecten - block
Dynamische effecten - push
Dynamische effecten - squeeze
Conflict ‘linksaf’ - referentiecapaciteit

~ CAPCAL methode

\[
P_{AEi,unsat} = \frac{G_{eff}}{T_{cyclus}} \cdot P_{AEi,tot}
\]

\[
G_{i,sat} = \frac{3600(s/h)}{1800(PAE/h)} \cdot P_{AEi, sat}
\]

\[
Flow_{i,unsat} = \frac{P_{AEi,unsat}}{G_{i,unsat}}
\]

\[
Cap_{ref} = Cap_s \cdot \min(G_{i, unsat})
\]
Conflict ‘linksaf’ – gemeten vs. referentie
Conflict ‘link saf’ – regressie totaal

<table>
<thead>
<tr>
<th></th>
<th>Constante</th>
<th>$c_{block}$</th>
<th>$c_{Squeeze}$</th>
<th>$c_{Push}$</th>
<th>$c_{Spill}$</th>
<th>$c_{PAE_{left}}$</th>
<th>$c_{Flow_{unsat}}$</th>
<th>$c_{Opstel}$</th>
<th>$R^2$</th>
<th>$R_A^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>8.876</td>
<td>-0.066</td>
<td>nvt.</td>
<td>-2.589</td>
<td>180.532</td>
<td>nvt.</td>
<td></td>
<td></td>
<td>78.32</td>
<td>75.72</td>
</tr>
<tr>
<td>L2</td>
<td>7.420</td>
<td>-0.053</td>
<td>3.691</td>
<td>nvt.</td>
<td>-8.271</td>
<td>nvt.</td>
<td></td>
<td></td>
<td>65.52</td>
<td>60.35</td>
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<tr>
<td>L3</td>
<td>5.611</td>
<td>-0.055</td>
<td>1.389</td>
<td></td>
<td>-2.929</td>
<td>nvt.</td>
<td></td>
<td></td>
<td>77.51</td>
<td>73.02</td>
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<tr>
<td>Totaal</td>
<td>3.820</td>
<td>-0.069</td>
<td>0.343</td>
<td>0.755</td>
<td>-2.867</td>
<td></td>
<td></td>
<td></td>
<td>69.89</td>
<td>67.60</td>
</tr>
</tbody>
</table>

- $T_{block} = A + c_{PAE} \cdot P_{AE} + c_{PAE_{left}} \cdot P_{AE_{left, tot}}$

<table>
<thead>
<tr>
<th></th>
<th>Constante</th>
<th>$PAE$</th>
<th>$PAE_{left, tot}$</th>
<th>$R^2$</th>
<th>$R_A^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>47.623</td>
<td>-8.812</td>
<td>2.593</td>
<td>77.82%</td>
<td>76.11%</td>
</tr>
<tr>
<td>L2</td>
<td>0.627</td>
<td>-3.613</td>
<td>6.010</td>
<td>70.51%</td>
<td>67.70%</td>
</tr>
<tr>
<td>L3</td>
<td>-26.076</td>
<td>-1.383</td>
<td>8.512</td>
<td>63.42%</td>
<td>58.84%</td>
</tr>
<tr>
<td>Totaal</td>
<td>19.086</td>
<td>-5.876</td>
<td>4.924</td>
<td>68.09%</td>
<td>67.17%</td>
</tr>
</tbody>
</table>

- Dynamic effects (Squeeze, push) influence significantly but not predicted themselves
Conclusions of this first exploration

• Literature: unrealistic performance of saturated intersections → need for theory and observations of capacity drop of intersections
• Proposed definition of capacity drop intersections
• Exploration of role of 3 dynamic effects
  ○ Block
  ○ Push
  ○ Squeeze
• Some empirical results prove their influence on intersection discharge, along with
  ○ (time blocked)
  ○ volumes of conflicting flows
Can I consult you?

• Do you think my conclusion about capacity drop on R0 Brussels is justified?

“Empirical results do not appear to be a sound basis to recommend CD-avoiding traffic control operations like ramp metering or MTFC?”

• Do you think capacity drop at intersections is a topic worth further consideration?
  ○ if so, which aspects? how?
Questions?