Research in Modelling Motorway Merging and Weaving

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with Thanks to:
Jiao Wang and Andyka Kusuma

SATURN UGM, 15 November 2013
• Part I: Motorway merge:
  – Current practice in modelling motorway merging
  – Research findings: empirical and microsimulation
  – Implications for modelling
• Part II: Motorway weaving
  – Specifications of motorway weaving
  – An empirical study of the traffic characteristics at a weaving
Modelling motorway merge - current practice

- Merging area modelled as a give-way node, via standard gap-acceptance model
- One fixed gap by time of day, by population
  - Cannot distinguish different user class/vehicle type
  - No difference in the 1st, 2nd, 3rd, … gap a driver accepts => underestimation of entry capacity
- Gaps are often inferred from average flow-delay functions
  - In SATURN, this is suggested to be the inverse of saturation flow
- Vertical queuing model
  - all vehicles wait by the stopline
- No explicit consideration of acceleration lanes
Correction methods in SATURN

• Cooperative lane choice: the use of parameter “Apresv”
  – To represent willingness of mainline traffic to accommodate merging
  – Moving a proportion of lane 1 traffic to lane 2

• Adding merge delay to post-merge traffic
  – To model delays to mainline traffic at merge
  – Insert a dummy node downstream of merge (up to 2km)
  – “Q-node” method: delay based on COBA delay function
  – “Stopping-node” method: delay due to capacity constraint
• Link speed-flow relationships

\[
V(q) = \begin{cases} 
V_F & \text{for } q \leq Q_B \\
V_B + \frac{(V_C - V_B)(q - Q_B)}{(Q_C - Q_B)} & \text{for } Q_B < q \leq Q_C \\
\frac{V_C}{1 + V_C(q - Q_C)/(8Q_C)} & \text{for } q > Q_C 
\end{cases}
\]

• Capacity at merge: \( Q = \frac{Q_0}{[1 + 0.01P_{HV}(F_{HV}-1)]} \text{ veh/hr/lane} \)
  – \( Q_0 = 2330 \text{ veh/hr} \) is capacity without heavy vehicles (HV)
  – Affected only by percentage HVs (\( P_{HV} \))
  – \( F_{HV} = 2.5 \) is the default pcu value of HV
• Merging area is modelled as a node with ‘no priority’

• Merge delay=$227(V/C - 0.75)$ sec/veh
  – Added on top of link speed-flow curve
  – To both mainline and merging vehicles

• Merge influence felt up to 2km downstream
### Comparison with HCM and HBS – capacity function

<table>
<thead>
<tr>
<th>Advice</th>
<th>Variable</th>
<th>Function</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>COBA</td>
<td>$f_{HV}$</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$Q_{C2}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$(\text{veh/hr/ln})$</td>
<td>$2330/[1+0.01P_{HV}(f_{HV}-1)]$</td>
<td>at speed limit 112kph</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$0.9*2330/[1+0.01P_{HV}(f_{HV}-1)]$</td>
<td>at speed limit = 96 kph</td>
</tr>
<tr>
<td>HCM</td>
<td>$f_{HV}$</td>
<td>1.5, 2.5 and 4.5 for flat, rolling and mountainous</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$Q_{C1}$</td>
<td>PHF*2300/[1+0.01P_{HV}(f_{HV}-1)]</td>
<td>default PHF=0.88</td>
</tr>
<tr>
<td></td>
<td>$Q_{C2}$</td>
<td>PHF*[2300+5*(V_{Fm}-100)]/[1+0.01P_{HV}(f_{HV}-1)]</td>
<td></td>
</tr>
<tr>
<td>HBS</td>
<td>$f_{HV}$</td>
<td>1.3 – 1.7 variable with flows</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$Q_{C1}$</td>
<td>2200 pcu/hr</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$Q_{C2}$</td>
<td>$1900/[1+0.01P_{HV}(f_{HV}-1)]$</td>
<td>at speed limit 120kph</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$1933/[1+0.01P_{HV}(f_{HV}-1)]$</td>
<td>at speed limits 80kph,100kph</td>
</tr>
</tbody>
</table>
### Comparison with HCM and HBS - overview

Concept of capacities and merge influence area

![Diagram showing capacity at merge and downstream link capacity](image)

<table>
<thead>
<tr>
<th>Concept</th>
<th>DMRB</th>
<th>HCM</th>
<th>HBS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merge influence area</td>
<td>2km</td>
<td>450m, 2 lanes</td>
<td>1 lane</td>
</tr>
<tr>
<td>Concept of capacity</td>
<td>$Q_{c1} = Q_{c2}$</td>
<td>$Q_{c1}, Q_{c2}$ separate</td>
<td>$Q_{c1}, Q_{c2}$ separate</td>
</tr>
<tr>
<td>Measurements</td>
<td>15-min peak flow</td>
<td>15-min peak flow</td>
<td></td>
</tr>
<tr>
<td>Peak flow profile correction</td>
<td>no</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>
An empirical Peak-Hour-Factor

- Observation:
  - J10 – J11 (clockwise) on M25 motorway in England, 8am-9am
  - 19 MIDAS detector data on 15-min and 1-hr averaged flow

- Average observed PHF on M25 is 0.9 (HCM default 0.88)
- M25 congested most of the day; its peak period demand profile might be more uniform than other motorway networks in the UK
A microsimulation model of merge

• **MergeSim** developed by Jiao Wang (2006, ITS)
  - Designed to model the microscopic behaviour at merge:
    • Merge vehicle C follows leaders L, and PL
    • Veh C takes smaller gaps as it gets closer to the end of acceleration lane
    • Cooperative lane-change at merge: Lane 1 traffic (PF) moves to Lane 2
    • Courtesy yielding: Lane 1 traffic (PF) slows down for merging vehicle
Capacity at merge, and extend of merge influence

- Simulated speed-flow relationships

- Max. throughputs along road section

- Capacity higher at vicinity of merge

- Merge influence confined within 500m downstream
### Impact of traffic composition on merge capacity

- **Test scenario:** seven levels of $P_{HV}$ at 0, 5, 10, ..., 30%  

<table>
<thead>
<tr>
<th>$P_{HV}$ (%)</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capacity</strong></td>
<td>DMRB(2.5)</td>
<td>2300</td>
<td>2167</td>
<td>2026</td>
<td>1902</td>
<td>1792</td>
<td>1694</td>
</tr>
<tr>
<td></td>
<td>Simulated $Q_{c1}$</td>
<td>2190</td>
<td>2104</td>
<td>2080</td>
<td>2044</td>
<td>2026</td>
<td>1976</td>
</tr>
<tr>
<td></td>
<td>Simulated $Q_{c2}$</td>
<td>2088</td>
<td>2055</td>
<td>2021</td>
<td>1984</td>
<td>1965</td>
<td>1924</td>
</tr>
<tr>
<td></td>
<td>DMRB(1.5)</td>
<td>2200</td>
<td>2113</td>
<td>2089</td>
<td>2053</td>
<td>2035</td>
<td>1985</td>
</tr>
<tr>
<td><strong>Pcu values</strong></td>
<td>DMRB</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Simulated</td>
<td>1.82</td>
<td>1.53</td>
<td>1.48</td>
<td>1.4</td>
<td>1.43</td>
<td>1.38</td>
</tr>
</tbody>
</table>

- $Q_{c1}$ higher than $Q_{c2}$ by 60 veh/hr (3%), similar to HCM estimates at 70mph  
- With $F_{HV} = 2.5$, DMRB capacity decreases more rapidly than simulated  
- With $F_{HV} = 1.5$, DMRB capacity similar to simulated $Q_{c1}$
Summary

- Current UK method was based on studies of traffic data 20 years ago; new interpretation need to take into account:
  - Effect of peak flow profiles
  - Impacts of HVs
  - Differences between junction capacity and link capacity
  - Differences in delays to mainline and to merging traffic

- Suggestions for quick fixes:
  - An empirical PHF of 0.9 is found for M25 -> reduces capacity by 10%
  - Merge capacity higher than motorway link capacity (by 3% at 70mph)
  - DMRB capacity with $F_{HV}=2.5$ is overly sensitive to $P_{HV}$; a $F_{HV}=1.5$ is found a better fit the simulated result
  - Merging turbulences confine within 500m downstream

- Further empirical and detailed microsimulation analysis to help develop better (macroscopic) traffic models
Motorway weaving

- DMRB (2006):
  - *the distance between a successive merge and diverge where vehicles have to cross the paths of vehicles that have joined the mainline at the merge*
  - the distance between merge and diverge < 2000m
Study site 1

- A weaving section on a four-lane dual carriageway on A5103

- The distance between those measurement location is 50m.
- Traffic is recorded by video camera
- The extraction focuses on the highest 5 minutes period, 15.35-15.40
Traffic Characteristic

Data Extraction Result (5 Minutes Period)

• Vehicle Composition
  – 524 vehicles passing through the A5103, during the 5min period
  – Car (79.8%), MPV (7.1%), Van (6.7%), LGV (3.1%), HGV (1.9%), Bus/Coaches (1%) and MC (0.6%).

• Weaving movements
  – 81 weaving movements observed
  – 48% weaving between lanes 1 and 2
  – More weaving out (26% lane-changing from lane 1 to exit slip road), than weaving in (15% from entry slip road to lane 1)
Gap Acceptance

- The leading vehicles critical gaps are 4.03 sec (current lane) and 1.36 sec (target lane) in average.
- The following vehicles critical gaps are 2.61 sec (current lane) and 4.88 sec (target lane).
- Based on Type of Vehicle (in Seconds)

Table. Predicted critical gap (unit: seconds)

<table>
<thead>
<tr>
<th>Leading Vehicle</th>
<th>Gap Event</th>
<th>Following Vehicle</th>
<th>Gap Event</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current Lane</td>
<td>Target Gap</td>
<td>Current Lane</td>
</tr>
<tr>
<td>Heavy</td>
<td>0.81</td>
<td>0.62</td>
<td>Heavy</td>
</tr>
<tr>
<td>Heavy</td>
<td>1.78</td>
<td>1.15</td>
<td>Small</td>
</tr>
<tr>
<td>Small</td>
<td>5.07</td>
<td>2.82</td>
<td>Heavy</td>
</tr>
<tr>
<td>Small</td>
<td>4.04</td>
<td>1.30</td>
<td>Small</td>
</tr>
</tbody>
</table>
Study site 2:

• Site
  – M1 between J42 and J43
  – A dual carriageway, five lanes each direction
  – Section length ~1400m (a weaving section)

• Observation
  – N-bound traffic merge at J42
  – Video recording of PM peak (16:00-18:30, 15 June 2013), taken over footbridge 900m downstream from J42
  – MIDAS loop detector data
Observation and Data Extraction...

Video data extraction locations

MIDAS Loop detector locations

1375m
Observation and Data Extraction…

• The Data Extraction Process

Video data extraction:
• Type of Vehicle
• The passage time of the $n^{\text{th}}$ vehicle at the measurement location
• Time and Location for lane-changing

Figure: The Data Extraction Interface (Software: Semi-Automated Video Analyser, KTH)
Traffic Characteristic – video observations

• Traffic Flow between 16:30-17:30 over the first 200m from J42:

<table>
<thead>
<tr>
<th>Time</th>
<th>Type of Vehicle (PCU value)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Car (1.0)</td>
<td>MPV (1.0)</td>
</tr>
<tr>
<td>16:30-16:45</td>
<td>979</td>
<td>54</td>
</tr>
<tr>
<td>16:45-17:00</td>
<td>944</td>
<td>23</td>
</tr>
<tr>
<td>17:00-17:15</td>
<td>1083</td>
<td>40</td>
</tr>
<tr>
<td>17:15-17:30</td>
<td>1202</td>
<td>29</td>
</tr>
</tbody>
</table>

(The pcu value is based on the HCM 2010)

• Traffic speed (kph) for the highest 5 minutes between 17:15-17:20

<table>
<thead>
<tr>
<th>Type of Vehicle</th>
<th>Statistic Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>All</td>
<td>68.1</td>
</tr>
<tr>
<td>Car</td>
<td>68.2</td>
</tr>
<tr>
<td>MPV</td>
<td>69.1</td>
</tr>
<tr>
<td>Van</td>
<td>68.1</td>
</tr>
<tr>
<td>LGV</td>
<td>61.5</td>
</tr>
<tr>
<td>HGV</td>
<td>55.2</td>
</tr>
</tbody>
</table>
• 42.9% of lane changing occurs in the first 50m (from M to N), of which
• 37.4% are weaving between Lane 1 and the two Auxiliary lanes
On-going research:

- Incorporate MIDAS loop detector data into analysis
- Capacity analysis at weaving
- Car-following, gap-acceptance and lane-changing at weaving
- Microscopic analysis of weaving => simpler (macroscopic) models of weaving
Thank you

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with Thanks to:
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Example analysis: consequence of changing the value of capacity

- Test scenarios:
  - 1km section with 500 merge influence area and 500 downstream
  - 3 levels of total traffic flow, 3 capacity values
  - Travel time estimated from DMRB speed-flow and queuing delay

<table>
<thead>
<tr>
<th>Flow/Capacity (veh/hr)</th>
<th>Link travel time (sec/veh)</th>
<th>Queuing delay (sec/veh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Qc=2024</td>
<td>Qc=2112</td>
</tr>
<tr>
<td>Low flow (1600)</td>
<td>11.4</td>
<td>11.2</td>
</tr>
<tr>
<td>Medium (2000)</td>
<td>14.1</td>
<td>13.5</td>
</tr>
<tr>
<td>High flow (2400)</td>
<td>22.2</td>
<td>22.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total</th>
<th>Total travel time (sec/veh)</th>
<th>Difference relative to that at Qc=2330</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low flow</td>
<td>20.6</td>
<td>12.9</td>
</tr>
<tr>
<td>Medium flow</td>
<td>68.1</td>
<td>58.2</td>
</tr>
<tr>
<td>High flow</td>
<td>121.1</td>
<td>109.9</td>
</tr>
</tbody>
</table>
Impact of traffic composition on merge delays

- Journey times increase with $P_{HV}$

- Journey time of the mainline traffic different to that of merging traffic

- Mainline to merging journey time difference steadily increases with $P_{HV}$

- Perhaps, with more HVs, more platoons forming, making merge easier?