To queue or not to queue
Interesting phenomena from traffic flow theory

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Introduction: traffic

- Traffic jams: €1.5 bil/yr
- Queuing due to too many vehicles on the road
- Queuing on vehicle level, patterns on higher levels
- What are these levels, and what are the patterns?
## Relationships

<table>
<thead>
<tr>
<th>Microscopic (vehicle-based)</th>
<th>Macroscopic (flow-based)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space headway (s [m])</td>
<td>Density (k [veh/km])</td>
</tr>
<tr>
<td>Time headway (h [s])</td>
<td>Flow (q [veh/h])</td>
</tr>
<tr>
<td>Speed (v [m/s])</td>
<td>Average speed (u [km/h])</td>
</tr>
</tbody>
</table>

- Fundamental relation between q and k and v
- Behavioral relation between k and u (or s and v)
Scales

- Microscopic: vehicle level
- Macroscopic: road level
- New level: network level
Microscopic description
To queue or not to queue?

- On a microscopic scale, (average) relations can be given for the accelerations of a driver
- Full system description is possible (but time intensive, dependent on models used)
To queue or not to queue?

- But: when is traffic congested??
- How to observe as individual driver?
Macroscopic description
Relationships variables

• Given $q = ku$
• Given a relationship, e.g. $u = u(k)$ (does that make sense?)
the traffic state is determined by one variable

Flow

Density
Points characterising the FD

- Up and down in flow-density (often: triangular)
- Critical speed: 100 km/h
- Jam density: 125 veh/km (8 m/veh)
- Capacity: $\frac{1}{1.5} \times 3600 = 2400$ veh/h/lane
  ($=\text{min time headway 1.5 s}$)
Traffic dynamics

- Fundamental diagram represents equilibrium conditions
- What happens to disturbances?

![Graph showing traffic dynamics](chart.png)
Traffic dynamics

- Fundamental diagram is equilibrium
- What happens to disturbances?

\( v_0 = 5 \text{mps} \)

\( v_0 = 18 \text{mps} \)
To queue or not to queue

- But: when is traffic congested??
- How to observe as individual driver?

Diagram:
- High speed
  - Space
  - Time
  - Speed copied downstream
- Low speed
  - Space
  - Time
  - Speed copied upstream

Congestion
Network Level
Fundamental diagram

- Network Fundamental Diagram
- Average fundamental diagram for an area

Density

Fig: (Geroliminis and Daganzo)
Simple road

- Road with bottleneck
- Outflow increases with demand and then remains constant
Network Fundamental Diagram

- What happens to the flow if the density increases?
Build up of congestion
Fitting a functional form

\[ P(A) = A*(c_1 + c_2A + c_3A^2) - c_4\sigma \]

Homogeneous traffic situation

Inhomogeneous traffic situation
Fitting a functional form

\[ P(A) = A \cdot (c_1 + c_2 A + c_3 A^2) - c_4 \sigma \]
Fitting a functional form

Different traffic conditions

![Graph showing different traffic conditions](image-url)
Empirical evidence

GMFD top view fit

Inhomogeneity (veh/km/lane)

Accumulation (veh/km/lane)
Suitable for any queuing application?
Impact of pedestrians
Background

• Known: capacity of the road under one single (fixed timing) pedestrian crossing

• Pedestrian crossings: determine capacity by allowing capacity flow between the pedestrians

• Calculate microscopically: how often do gaps occur which are larger then $n$ times the required time for one vehicle to pass, $g_{crit}$

$$q_{enter} = q_{ped} \sum_{n=1:inf}^{(n+1) \times g_{crit}} \int_{n \times g_{crit}} P(h)dh$$
Vehicular capacity with pedcrossings

- More crossings help
- No interaction effects taken into account
Spreading pedestrian load

- Spreading pedestrian load over more pedestrian crossings benefits drivers and pedestrians

- Extreme case: infinite number of pedestrian crossings, i.e. pedestrians can cross anywhere (but still have priority)
Simulation

Interaction effects
Capacity = shortest path

- Flow overtaking moving observer maximized by fundamental diagram
- Capacity minimum overtakings via several paths
- Variational theory: Daganzo, 2005
Analytical boundaries – lower bound

- Given peds,
- Given optimal path = least “cost” = capacity determining path
- Cost for traveling no on ped fixed
- \( q/q_{\text{max}} = \frac{\text{sum}(Y)}{\text{sum}(Y)+\text{sum}(o)} < q(\text{ped flow } f) \)

\[
\frac{1}{q_0^L} = 1 + \left[ \frac{2f}{\pi e^{4f}} \right]^{1/2} \left[ \Phi(2\sqrt{f}) \right]^{-1}
\]
Analytics

• Capacity decreases with pedestrian flow and duration
  \[ f = q_{\text{ped}} T_{\text{cross}}^2 \]
• Upper and lower bound analytical
• Capacity estimated (0.2% off)
Simulation and estimation

• Various levels of pedestrian load

• Simulation and estimation

• Very accurate estimation

$f = \{0.001, 0.002, 0.005, 0.01, 0.02, 0.05, 0.1, 0.3\}$
Conclusions
To queue or not to queue?

- Traffic operates at different levels
- Queuing patterns can be described at macroscopic and network level
- Queues attract queues
- Interaction effects relevant, and solvable
  - **Spatial extent is essential**
References and acknowledgement