Lateral driving behaviour
Victor L. Knoop
24-3-2014
Three phase traffic flow theory

Density (veh/km)

Driving direction

x (km)

Time (h)
Capacity drop

Fundamental Diagram

Capacity drop

Queue discharge rate

Flow (veh/h)

Density (veh/km)
1. A follower with a speed larger than the leader approaches with constant relative speed.

2. When the threshold is reached, the driver decelerates.

3. Deceleration until $\Delta v = 0$.

4. No notice that driver over-decelerates, so relative acceleration.

$Lateral driving behavior$

$V_{\text{follower}} < V_{\text{leader}}$

$V_{\text{follower}} > V_{\text{leader}}$
Agenda – After today, you can

• ... differentiate between courtesy, mandatory and desired lane changes
• ... explain gap acceptance theory and comment on measuring critical gaps
• ... comment on the principles of the Mobil lane change model (equations will be given)
• ... comment on lane selection theories
• ... comment an analyse lane distributions
• ... comment on merging
• ... describe the principle of relaxation
Driving tasks

microscopic
GAP ACCEPTANCE THEORY
Gap acceptance - concept

Histogram of critical gaps - crossing

Critical gaps - crossing
Gap acceptance for overtaking (1)

- If offered gap $g < g_1$, no overtaking.
- If offered gap $g > g_2$, 80% of drivers overtake.

Graph:
- $\Pr\{G \leq g\}$
- $g_1$: no overtaking if offered gap $< g_1$.
- $g_2$: 80% of drivers overtake if offered gap $> g_2$. 
Overtaking in time and space

Gap (time): interval between 2 successive meetings of passive vehicle and on-comers

\[ t_2 - t_1 = \text{rejected gap} \]
\[ t_4 - t_2 = \text{accepted gap} \]
Gaps – theory vs practice

• Gap in time is not completely usable for overtaking
  • nett gap starts at \( t_4 \), when oncomer meets overtaker
  • overtaker has to be back on right lane before \( t_3 \) to prevent a collision
Overtaking critical gap depends on....?
Critical gap distribution

- One measures gap-acceptance. Comparing the distribution of the accepted gaps to the critical gap distribution, one finds:
  A) The critical gaps are longer than the measured gaps
  B) The measured gaps are shorter than the critical gaps
  C) If one does enough measurements, they are equal
Application using the critical gap

• Model for ‘one driver at a time’ manoeuvres (e.g. a car crossing an intersection: single queue/server system)

• Simple model gap acceptance process for ‘fixed’ critical gap
  1. Draw critical gap $c_i$ from distribution $F(c)$
  2. Draw offered gap $g_i$ from offered gap distribution
  3. If $g_j > c_i$, then gap is accepted; go to 1
  4. If $g_i < c_j$, then gap is rejected; go to 2
MOTORWAY LANE CHANGING
Motorway Lane Changing

• 3 types of lane changing
  • Mandatory
  • Desired
  • Courtesy
Mandatory lane changes

In case of blockage, vehicle can speed up or decelerate.
Desired lane changes
Courtesy lane change
Gap acceptance for overtaking (2)

- Requirements for acceptance:
  - Gap
  - Speed
  - Speed of future follower
  - ...
LANE CHANGE MODELS
Models & observations

- Many lane changing models
- Problem in observation: no reasoning, only events
- Events: willingness x probability
- All models are wrong (but some are more wrong than others)
- Calibration?
One model in detail: MOBIL

- Model by Helbing, Treiber, Kesting
- Based on utility
Utility concept

- From economics
- People do whatever gives them highest payoff
- Include error in perception
- $\Rightarrow$ Compute utility $U_i$ for each option $i$
Example of utility

• Comparing apples and oranges:

• E.g.,
  \[ U = a \times \text{price [E]} + b \times \text{vitamins [g]} + c \times \text{age [days]} + \epsilon \]
  
  • \( a < 0 \)
  • \( b > 0 \)
  • \( c < 0 \)

• Buy product with highest utility
Mobil

- Minimising Overall Braking Induced by Lane changes
- Consider accelerations of 3 vehicles
Mobil: decision

- Acceleration trade-off

\[ \tilde{a}_c - a_c + p(\tilde{a}_n - a_n + \tilde{a}_o - a_o) > \Delta a_{th} \]

Own benefit  Benefit n  Benefit o  “Cost of changing lane”
Adding European driving rules

- Restrict acceleration in right lane:
  \[ a_{\text{eur right}} = \min(a_{\text{right}}, a'_{\text{left}}) \]

- Introduce a preference for the right lane:
  Threshold + bias towards right lane

- \( R \Rightarrow L \)
  \[ \tilde{a}_c - a_{\text{eur}} + p(\tilde{a}_n - a_n + \tilde{a}_o - a_o) > \Delta a_{\text{th}} + \Delta a_{\text{bias}} \]

- \( L \Rightarrow R \)
  \[ a_{\text{eur}} - a_c + p(\tilde{a}_n - a_n + \tilde{a}_o - a_o) > \Delta a_{\text{th}} - \Delta a_{\text{bias}} \]
How to calibrate

- Number of lane changes?
- Lane distributions?
- Travel times?
Mandatory lane changes

- We do not know
- Engineers find a solution: Adapt the model!
- Usually: change model parameters until it looks OK

Photo by Breana Cronk
Problems of simulation programs

- Cars stuck: possible solutions
  - Stop cars until gap is there
  - Remove cars
  - Other direction (in case of wrong decision)
- Cars stuck at the on-ramp
- Low-speed merging creating congestion
Implications of lateral behaviour

- Lane changes are important for traffic flows
  - Lane distribution
  - Disturbances
- But it is very difficult to model them correctly
After this hour, you can

• … differentiate between courtesy, mandatory and desired lane changes
• … explain gap acceptance theory and comment on measuring critical gaps
• Comment on the principles of the Mobil lane change model (equations will be given)
Coffee question....

• Lane changes are discrete events (i.e.,...) What is the best way to express the number of lane changes (and what is the most constant?)

• Different formulation: What would your reply be to my question: how many lane changes are there?
Dependencies

Selected trajectories no bounds

Space (m)

Time (h)
Parallelograms / Rhomboid

Selected trajectories

Space (m)

Time (h)

10 10.02 10.04 10.06 10.08 10.1 10.12
Setup of analysis

- Separate densities in origin lane and destination lane
Guess – what is the influence of
Guess – what is the influence of

constant density lane 3

Number of lane changes per km per h

Dens lane 3 (veh/km/lane)

Dens lane 2 (veh/km/lane)
Lane changing lane 2 => 3

Experimental average number of lane changes from lane 2 to 3

Number of lane changes per km per h

Dens lane 3
(veh/km/lane)

Dens lane 2
(veh/km/lane)
Explanations

- Future conditions not included (drivers anticipate)
- Lane changes are induced by lane changes from the target lane (place swapping), which occur more frequently with higher target lane density
- Separation origin lane density and target lane density artificial
- Daganzo’s theory of slugs and rabbits...
Number of observed aggregation intervals

Dens lane 3 (veh/km/lane)

Dens lane 2 (veh/km/lane)
Flow distribution

Question: which lane corresponds with the blue line in the graph?
LANE SELECTION THEORIES
Slugs and Rabbits (Daganzo, 2002)

- **Slugs:**
  - lower free speed
  - right lane(s)

- **Rabbits**
  - higher free speed
  - left lane if that is faster than the right lane(s)
Two different regimes

- **Two-pipe regime:** slugs and rabbits separated

- **One-pipe regime:**
  slugs right lane and rabbits on both lanes
  equal speed (≈Kerner: synchronised flow)
Slugs and rabbits – start of congestion

- Rabbits and slugs enter on-ramp
- Rabbits will not merge immediately into left lane
Consequences of merging

- Oversaturation on left lane after lane change

- Start congestion on left lane, downstream of ramp
Impact and consequences

- Capacity drop
- Congestion start downstream of merge (“boomerang”)
- Lane distribution uneven

- All seen in practice!
Observed phenomena in traffic flow
Lane Distribution

Average lane distribution km 38.125 - Speed Limit 120kph

- Lane 1
- Lane 2
- Lane 3

Density (veh/km)

Fraction of the flow
Influence of speed limit

Average lane distribution km 38.125 - Speed Limit 120kph

Average lane distribution km 38.125 - Speed Limit 60kph
MERGING
Merging

- Helicopter observations
- Gap acceptance theories are wrong
- Current research => gap selection theory?
- Relaxation present

283 (m)
Available gaps (1)

Merging vehicle at $x = 0.08 \text{ m}$, $t = 1270.87 \text{ s}$

Merging vehicle at $x = 63.73 \text{ m}$, $t = 1276.00 \text{ s}$
Realised speed merging vehicle: 44.64 km/h
Realised speed PF: 28.71 km/h  ;  Realised speed PL: 28.25 km/h
Available gaps (2)

Merging vehicle at $x = 132.60 \text{ m}$, $t = 1281.13 \text{ s}$
Realised speed merging vehicle: 48.30 km/h
Realised speed PF: 28.17 km/h ; Realised speed PL: 35.52 km/h

Merging vehicle at $x = 201.95 \text{ m}$, $t = 1286.20 \text{ s}$
Realised speed merging vehicle: 49.27 km/h
Realised speed PF: 32.57 km/h ; Realised speed PL: 49.02 km/h
Trajectories, merging in congestion

- Acceleration lane
- Right lane (mg)
- Middle Lane (mg)
- Left lane (mg)
- Right lane (mn)
- Middle Lane (mn)
- Left lane (mn)
After this lecture, you are able to...

• ...differentiate between courtesy, mandatory and desired lane changes
• ...explain gap acceptance theory and comment on measuring critical gaps
• ...comment on the principles of the Mobil lane change model (equations will be given)
• ...comment on lane selection theories
• ...comment on analyse lane distributions
• ...comment on merging
• ...describe the principle of relaxation
Mobil: safety criterion

- Always safety first:
  \[ a_{\text{new follower}} > -b_{\text{safe}} \]
- \( b_{\text{safe}} \) is safe deceleration (not max!)

Photo by AutoYim