MUSTANSIRIYAH UNIVERSITY

COLLEGE OF ENGINEERING

HIGHWAY AND TRANSPORTATION ENGINEERING DEPARTMENT

POSTGRADUATE/MSC

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ADVANCED TRAFFIC ENGINEERING

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LECTURE 6:

MICROSCOPIC LANE CHANGE MODELS

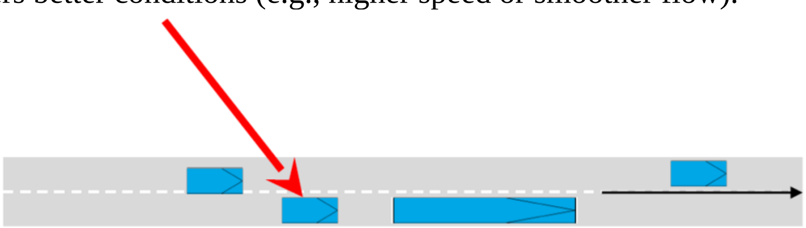
- This lecture mainly discusses lateral driving behaviour.
- Lane changing is emphasized as a major factor in traffic flow instability, particularly in multi-lane roads.

  – Psychological models for lane selection
  – Microscopic lane change model
  – Advanced integrated (lateral + longitudinal) models

TYPES OF LANE CHANGES

Three main categories of lane-change behavior are described:

1. **Desired Lane Change (Discretionary):** Performed when the driver believes another lane offers better conditions (e.g., higher speed or smoother flow).



(a) Desired lane changes

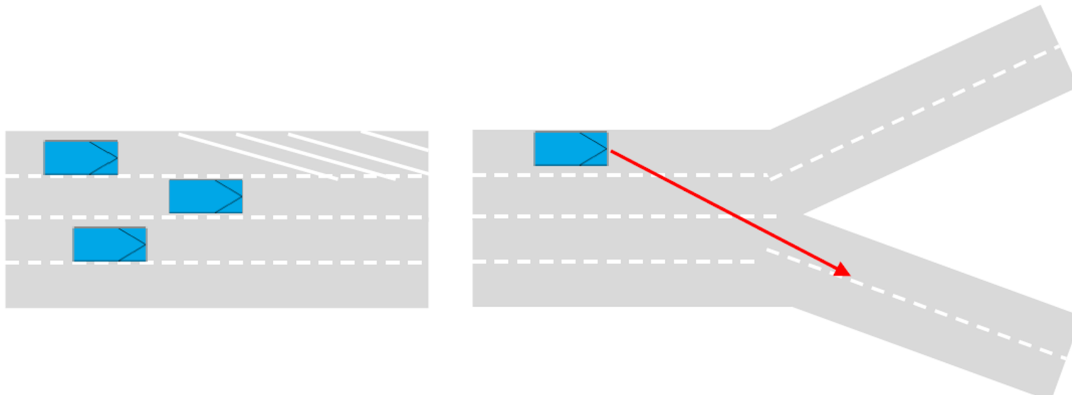
The vehicle (indicated by the red arrow) moves to an adjacent lane to improve its own travel condition—typically to reach a faster-moving lane or avoid slower traffic.

2. **Mandatory Lane Change:** Necessary due to road geometry or route requirements (e.g., lane ends, merges, exits, or diverging roadways).

   The driver must change lanes to remain on the correct route or to avoid an obstacle such as a lane drop, merge area, or diverging ramp.

   The red arrow shows a vehicle moving toward an exit or diverging section—a typical mandatory action to maintain the intended path.

   These lane changes are non-optional and often modeled with higher urgency and smaller accepted gaps.



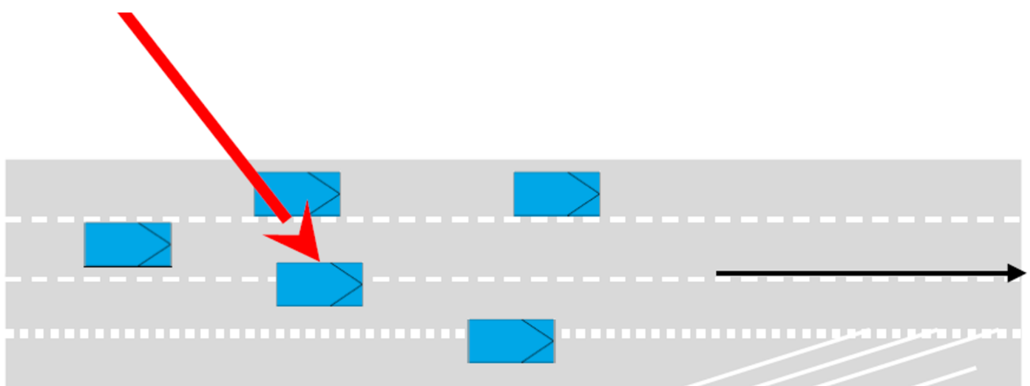
(b) Mandatory lane changes

3. **Courtesy Lane Change:** Executed to assist other drivers (e.g., yielding to merging traffic). There is no direct benefit for the driver that makes the lane change.

   The vehicle performs a cooperative maneuver to facilitate another driver’s movement, such as yielding to merging traffic or making room for an entering vehicle.

   The red arrow shows the driver changing lanes to assist others, not for self-benefit.

   These are less frequent.



(c) Coutesy lane changes

PSYCHOLOGICAL MODELS

Psychological models

Slugs and Rabbits — Lane Selection Theory (Daganzo, 2002a,b)

THEORY

Daganzo proposed that drivers can be categorized into two behavioral groups: Slug and Rabbit

Category	Free Speed	Lane Choice
Slug	Low	Always drives in the right (slow) lane
Rabbit	High	Always selects the fastest lane

- **Slugs** prefer comfort and stability — they remain in the right lane even when other lanes are faster.
- **Rabbits** prefer speed — they continuously seek the lane with the highest speed (usually the left lane).
- Therefore, lanes can operate at different speeds and even under different traffic flow regimes, especially during varying traffic demand levels.

TRAFFIC OPERATIONS (AT CONTINUOUS MOTORWAY STRETCH)

At low demand condition:

- Slugs drive at their own desired (low) speed in the right lane.
- Rabbits drive faster and occupy the left lane(s).
- This condition results in two independent flows — known as the "two-pipe regime."

As density increases:

- The left lane slows down due to congestion….> less than FFS of the right lane.
- Rabbits begin to move into the right lane to seek higher speeds.
- This increases the right-lane density, reducing speed there, while left-lane speed slightly improves.
- Eventually, lane speeds equalize — the flow transitions into a **"**one-pipe regime**,"** meaning uniform speed across lanes.

LOADING EFFECTS AT ON-RAMPS

At merging areas (on-ramp):

- Vehicles entering from ramps always merge into the right lane.
- Rabbits (Who are not in their desired lane) must later change lanes again to reach their desired left lanes.
- If the left lane is already congested, this movement may cause it to become overcritical**,** leading to speed reduction downstream of the merge point.

MICROSCOPIC LANE CHANGE MODEL

Utility Model (MOBIL) (Minimizing Overall Braking Induced by Lane Changes,

MODEL IDEA

The MOBIL model builds upon the Slugs and Rabbits theory but formalizes lane-changing decisions through a utility-based framework.

Each lane is assigned a utility value (U_l) — representing how "desirable" that lane is for the driver. The driver evaluates possible decisions:

- Change left
- Change right
- Stay in the current lane

and selects the one with the highest utility gain.

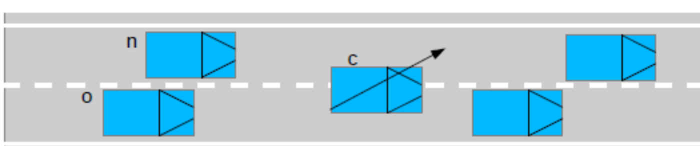
Utility Components

Utility depends on three factors:

1. Driver's own acceleration: The greater the acceleration achievable in a lane, the higher its utility.
2. Acceleration of other vehicles: Drivers prefer not to force others to decelerate significantly. Hence, the model penalizes lane changes that cause others to brake hard.
3. Keep-right rule (for European roads): Adds a bias to encourage staying in the right lane unless overtaking.

MODEL EQUATIONS

The total **utility (U_{tot})** for a driver combines personal benefit and the effect on surrounding vehicles:



In this figure, the symbols identify each vehicle's role in the lane-changing maneuver as used in the MOBIL utility model:

- **c** → the lane-changing vehicle (the driver evaluating whether to change lanes).
- **n** → the new follower in the target lane (the vehicle behind the lane changer after moving).
- **o** → the old follower in the original lane (the vehicle behind after the lane changer leaves).

During a lane change:

- The MOBIL model accounts for all three drivers' utilities using **a** politeness factor **(p)** to represent how much the lane changer considers others' comfort.

$$U_{\text{tot}} = U_c + \mathcal{P} \sum_{i \in \text{other drivers}} U_i = U_c + p\,(U_o + U_n)$$

where:

- U_c = utility of the current driver
- U_o, U_n = utilities of the follower and new follower after lane change
- P = politeness factor (how much a driver values others' comfort)

<u>Utility Expression</u>

The instantaneous utility for a vehicle i is linked to its acceleration a_i (from the IDM car-following model):

$$U_i = a_i = a_0 \left(1 - \left(\frac{v}{v_0}\right)^{\delta} - \left(\frac{s^*(v, \Delta v)}{s}\right)^2\right)$$

- a_0 = maximum acceleration
- v_0 = desired speed
- s^* = desired spacing (function of speed and relative speed)
- s = actual spacing

A lane change occurs only if the utility in the target lane exceeds the current lane's utility by at least a threshold a_{th}:

$$U_{new} - U_{current} \geq a_{th}$$

<u>European Driving Rules (Right-Keep Bias)</u>

To model continental European driving, two adjustments are made:

1. **No overtaking on the right:**
   Utility of the right lane cannot exceed that of the left lane when overtaking.
2. **Right-lane bias (a_{bias})**:
   Adds a preference to stay right unless the left lane clearly offers better conditions

   A lane change to the right is performed if:

   $$U^{right} - U^{left} \geq a_{th} - a_{bias} \quad \text{(for right change)}$$

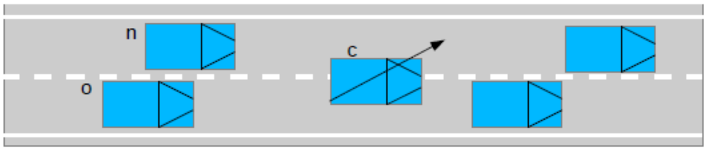
   A lane change to the left is performed if:

   $$U^{left} - U^{right} \geq a_{th} + a_{bias} \quad \text{(for left change)}$$

a_{th} acts as a threshold or inertia parameter — representing the "cost" of lane changing.
If the gain is smaller than a_{th}, no change is made.

EXAMPLE (1)

Should vehicle c change lane to the left?



Given / assumed data

- **Politeness factor**: p=0.3
- **Lane-change threshold (cost)**: a_{th}=0.2 m/s^2

Current accelerations (before lane change):

- Vehicle **c** in current lane:
  $a_c^{\text{now}} = 0.5\ \text{m/s}^2$ (it can accelerate a bit)
- Vehicle **o** (follower behind c in the current lane):
  $a_o^{\text{now}} = 1.0\ \text{m/s}^2$ (comfortable)
- Vehicle **n** (follower in target lane, behind the gap):
  $a_n^{\text{now}} = 0.8\ \text{m/s}^2$

Predicted accelerations **if c moves to the left lane**:

- Vehicle **c** after lane change (in faster lane):
  $a_c^{\text{new}} = 1.2\ \text{m/s}^2$ (benefits from faster lane)
- Vehicle **n** after c cuts in front of it:
  $a_n^{\text{new}} = 0.2\ \text{m/s}^2$ (has to brake a bit)
- Vehicle **o** after c leaves its lane (more space):
  $a_o^{\text{new}} = 1.3\ \text{m/s}^2$

MOBIL criterion

$$U_i = U_c + p(U_o + U_n)$$

and for each vehicle U=a (utility = its IDM acceleration)

So for the lane-changing vehicle we write the *incentive* as

$$\underbrace{(a_c^{new} - a_c^{now})}_{\text{gain of c}} + p\Big[\underbrace{(a_n^{new} - a_n^{now})}_{\text{effect on new follower}} + \underbrace{(a_o^{new} - a_o^{now})}_{\text{effect on old follower}}\Big] \geq a_{th}$$

Plug in numbers.

2.1 Gain of c

$$a_c^{new} - a_c^{now} = 1.2 - 0.5 = 0.7 \text{ m/s}^2$$

2.2 Effect on new follower n

$$a_n^{new} - a_n^{now} = 0.2 - 0.8 = -0.6 \text{ m/s}^2$$

(negative → n is penalized)

2.3 Effect on old follower o

$$a_o^{new} - a_o^{now} = 1.3 - 1.0 = +0.3 \text{ m/s}^2$$

(positive → o is happier after c leaves)

2.4 Weighted effect on others

$$p\big[(-0.6) + (0.3)\big] = 0.3 \times (-0.3) = -0.09 \text{ m/s}^2$$

2.5 Total incentive

$$\text{Incentive} = 0.7 + (-0.09) = 0.61 \text{ m/s}^2$$

Compare with threshold

Incentive = **0.61 m/s²** **,** Threshold = **0.20 m/s²**

0.61 ≥ 0.20 ⇒ LANE CHANGE IS PERFORMED

So, **"yes, change lane."**

<u>if the driver is more "polite"?</u>

Keep all numbers, but increase **p** to **0.8**.

P [(−0.6) + 0.3] = 0.8 × (−0.3) = −0.24

Incentive=0.7−0.24=0.46 m/s2

Still

0.46 ≥0 .2 ⇒ still change

<u>When would it not change?</u>

Suppose cutting in front of **n** is much worse:

$a_n^{new} = -0.6 \text{ m/s}^2$ (n must brake hard)

Then

$$a_n^{new} - a_n^{now} = -0.6 - 0.8 = -1.4$$

Weighted effect on others (with p=0.3):

0.3[(−1.4) +0.3] =0.3× (−1.1) =−0.33

Total incentive:

$0.7 - 0.33 = 0.37 \geq 0.2 \rightarrow$ still yes

But if the **threshold** were higher, say $a_{th}=0.4$, then:

$0.37 < 0.4 \Rightarrow$ NO lane change

HOMEWORK

Vehicle	Before	After
c	$a_c^{now} = 0.4$	$a_c^{new} = 1.2$
n	$a_n^{now} = 0.9$	$a_n^{new} = 0.1$
o	$a_o^{now} = 1.0$	$a_o^{new} = 1.3$

$p=0.3$(driver cares somewhat about others),

Lane-change threshold (cost): $a_{th}=0.25$ m/s^2

1. Should vehicle c change lane to the left?
2. If European right-keep bias is added, is lane change allowed? $a_{bias}=0.15$ m/s^2.

EXAMPLE (2)

Given:

- Maximum accel: $a_0 = 1.2\ \mathrm{m/s}^2$
- Desired speed: $v_0 = 30\ \mathrm{m/s}$ (≈108 km/h)
- Exponent: $\delta = 4$
- Minimum gap: $s_0 = 2\ \mathrm{m}$
- Desired time headway: $T = 1.5\ \mathrm{s}$
- Comfortable decel: $b = 2\ \mathrm{m/s}^2$
- Lane-change threshold: $a_{th} = 0.3\ \mathrm{m/s}^2$
- Current Speed: 20 m/s
- leader in current lane: **18 m/s** → **approaching** → $\Delta v = v - v_{lead} = 20 - 18 = 2$ m/s
- actual spacing in current lane: **s=20 m** (a bit short)
- leader in target lane: 22 m/s → leader is pulling away → $\Delta v = 20 - 22 = -2$ m/s
- spacing available in target lane: s=30 m

Solution

$$s^*(v, \Delta v) = s_0 + vT + \frac{v\Delta v}{2\sqrt{a_0 b}}$$

$$2\sqrt{a_0 b} = 2\sqrt{1.2 \times 2} = 2\sqrt{2.4} \approx 2 \times 1.549 = 3.10$$

$$s^* = 2 + 20 \times 1.5 + \frac{20 \times 2}{3.10} = 2 + 30 + \frac{40}{3.10} \approx 2 + 30 + 12.9 = 44.9 \text{ m}$$

$$U_i = a_i = a_0 \left(1 - \left(\frac{v}{v_0}\right)^\delta - \left(\frac{s^*(v\Delta v)}{s}\right)^2\right)$$

$$\left(\frac{v}{v_0}\right)^\delta = \left(\frac{20}{30}\right)^4 = (0.6667)^4 \approx 0.1975$$

$$\left(\frac{s^*}{s}\right)^2 = \left(\frac{44.9}{20}\right)^2 = (2.245)^2 \approx 5.04$$

$$U_{\text{current}} = a_0\Big(1 - 0.1975 - 5.04\Big) = 1.2 \times (1 - 5.2375) = 1.2 \times (-4.2375) \approx -5.1 \text{ m/s}^2$$

Desired gap in target lane

$$s^* = 2 + 20 \times 1.5 + \frac{20 \times (-2)}{3.10} = 2 + 30 - \frac{40}{3.10} = 32 - 12.9 \approx 19.1 \text{ m}$$

$$\left(\frac{s^*}{s}\right)^2 = \left(\frac{19.1}{30}\right)^2 = (0.6367)^2 \approx 0.405$$

$$\left(\frac{v}{v_0}\right)^4 \approx 0.1975$$

$$U_{\text{new}} = 1.2\Big(1 - 0.1975 - 0.405\Big) = 1.2 \times (1 - 0.6025) = 1.2 \times 0.3975 \approx 0.48 \text{ m/s}^2$$

in the target lane we can **accelerate a bit → positive utility**.

$$U_{\text{new}} - U_{\text{current}} = 0.48 - (-5.1) = 5.58 \text{ m/s}^2$$

$$5.58 \geq 0.3 \quad \Rightarrow \quad \text{lane change is clearly worthwhile.}$$

References

1. Knoop, V. L. (2017). Introduction to traffic flow theory: An introduction with exercises. *Delft University of Technology: Delft, The Netherlands*.

2. Manual, H. C. (2000). Highway capacity manual. *Washington, DC*, *2*(1), 1.

3. Traffic engineering / Roger P. Roess, Elena S. Prassas, William R. McShane. -4th ed.