Longitudinal Traffic model: The IDM

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In this simulation, we used the **Intelligent-Driver Model (IDM)** to simulate the longitudinal dynamics, i.e., accelerations and braking decelerations of the drivers.

The IDM is a "car-following model", i.e., the traffic state at a given time is characterized by the positions, velocities, and the lane index of all vehicles. The decision of any driver to accelerate or to brake depends only on his own velocity, and on the "front vehicle" immediately ahead of him. Lane-changing decisions, however, depend on all neighboring vehicles. Specifically, the acceleration dv/dt of a given driver depends on his velocity v, on the distance s to the front vehicle, and on the velocity difference Delta v (positive when approaching),

$$\frac{dv}{dt} = a\left[1 - \left(\frac{v}{v_0}\right)^{\delta} - \left(\frac{s^*}{s}\right)^2\right]$$

where

$$s^* = s_0 + \min\left[0,\ \left(vT + \frac{v\Delta v}{2\sqrt{ab}}\right)\right]$$

The acceleration is divided into a "desired" acceleration a $[1-(^{v}/_{v0})^{delta}]$ on a free road, and braking decelerations induced by the front vehicle. The acceleration on a free road decreases from the initial acceleration a to zero when approaching the "desired velocity" v0.

The braking term is based on a comparison between the "desired dynamical distance" s^*, and the actual gap s to the preceding vehicle. If the actual gap is approximatively equal to s^*, then the breaking deceleration essentially compensates the free acceleration part, so the resulting acceleration is nearly zero. This means, s^* corresponds to the gap when following other vehicles in steadily flowing traffic. In addition, s^* increases dynamically when approaching slower vehicles and decreases when the front vehicle is faster. As a consequence, the imposed deceleration increases with

- decreasing distance to the front vehicle (one wants to maintain a certain "safety distance")
- increasing own velocity (the safety distance increases)
- increasing velocity difference to the front vehicle (when approaching the front vehicle at a too high rate, a dangerous situation may occur).

Model Parameters

The IDM has intuitive parameters:

- desired velocity when driving on a free road, v0
- desired safety time headway when following other vehicles, T
- acceleration in everyday traffic, a
- "comfortable" braking deceleration in everyday traffic, b
- minimum bumper-to-bumper distance to the front vehicle, s0
- acceleration exponent, delta.

In general, every "driver-vehicle unit" can have its individual parameter set, e.g.,

- trucks are characterized by low values of v0, a, and b,
- careful drivers drive at a high safety time headway T,
- aggressive ("pushy") drivers are characterized by a low T in connection with high values of v0, a, and b.

Often two different types are sufficient to show the main phenomena. The standard parameters used in the simulations are the following:

Parameter	**Value Car**	**Value Truck**	**Remarks**
Desired velocity v_0	120 km/h	80 km/h	For city traffic, one would adapt the desired velocity while the other parameters essentially can be left unchanged.
Time headway T	1.5 s	1.7 s	Recommendation in German driving schools: 1.8 s; realistic values vary between 2 s and 0.8 s and even below.
Minimum gap s_0	2.0 m	2.0 m	Kept at complete standstill, also in queues that are caused by red traffic lights.
Acceleration a	0.3 m/s^2	0.3 m/s^2	Very low values to enhance the formation of stop-and go traffic. Realistic values are 1-2 m/s^2
Deceleration b	3.0 m/s^2	2.0 m/s^2	Very high values to enhance the formation of stop-and go traffic. Realistic values are 1-2 m/s^2

For more details, see the **scientific reference** for the IDM, or the **Wikipedia article**.

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The Lane-change Model MOBIL

Lane changes takes place, if

- the potential new target lane is more attractive, i.e., the **"incentive criterion"** is satisfied,
- and the change can be performed safely, i.e., the **"safety criterion"** is satisfied.

In our lane change model MOBIL, We base both criteria on the accelerations on the old and the prospective new lanes, as calculated with the longitudinal model, i.e., the IDM in our case.

Model equations:

- The safety criterion is satisfied, if the IDM braking deceleration $acc'=acc'_{IDM}$ imposed on the back vehicle B' of the target lane after a possible change does not exceed a certain limit b_{save}, this means, the **safety criterion**

$$acc'(B') > -b_{save}$$

- is satisfied. In this formula, the dash of the acceleration $acc'=acc'_{IDM}$ stands for "after a possible change", while the dash of the back vehicle label B' stands for "on the target lane".

- To asses the incentive criterion, we weight the **own advantage** on the target lane, measured by the increased acceleration (or reduced braking deceleration), against the **disadvantage imposed to other drivers**, again measured by the decrease acceleration or increased braking deceleration for these drivers. Since we tend to be egoistic, we weight the disadvantage imposed on other drivers with a**politeness factor p** whose values are typically less than 1, resulting in following **incentive criterion**:

$$acc'(M') - acc(M) > p\left[acc(B) + acc(B') - acc'(B) - acc'(B') \right] + a_{thr}$$

-

- As above, *acc* mean the actual IDM accelerations while *acc'* mean the accelerations after a possible change. The car labels *M* and*M'* mean "Me" before and after a possible change, respectively, while *B* and *B'* mean the back vehicle before and after a possible change, respectively.

- The own advantage is measured by "my" acceleration difference *acc' (M') - acc (M)* after the change, compared to the actual situation.

- The combined disadvatage to the new and old back vehicles is given by the sum *[acc (B) + acc (B')]* of the accelerations of both vehicles before the change, minus the acceleration sum *[acc' (B) + acc' (B')]* of these vehicles after the change.

- *Note on implementation:* In the actual version, we did not consider the disadvantage acc(B) - acc'(B), that the driver of the "old" back vehicle may suffer due to a lane change. In fact, acc(B) - acc'(B) nearly always is negative since changing to another lane generally gives an advantage to the driver of B. This means, we ignored "pushy" people urging us to change lanes for their own benefit. This definitely is a correct strategy for drivers on the right-hand lane while the "full" MOBIL should be considered for drivers on the left-hand lane.

- To avoid lane-change maneoeuvres triggered by marginal advantages which can lead to frantic lane hopping, an additional lane-changing threshold a_{thr} has been added to the balance of the above equation.

Model Parameters and Typical Values

Parameter	**Typical Value**	**Remarks**
Politeness factor p	0 ... 0.5	For details, see below
Maximum safe deceleration b_{save}	4 m/s^2	Must be lower than maximum deceleration of about 9 m/s^2
Threshold a_{thr}	0.2 m/s^2	Must be below the lowest acceleration ability (IDM parameter a) of any vehicle type

Bias to the right laneDelta b	0.2 m/s^2	Only for European traffic rules (see below)

The lane-change model MOBIL has the following main features:

- While other lane-change models typically assume purely egoistic behaviour, i.e., p=0, we can model different behaviours by varying this factor:
    - $p > 1$ => a very altruistic behaviour.
    - p in]0, 0.5] => a realistic behaviour: Advantages of other drivers have a lower priority, but are not neglected: Notice that this feature means that yielding to "pushy" is included into MOBIL.
    - p=0 => a purely selfish behaviour. Notice that also selfish drivers do not ignore the safety criterion!
    - p<0 => a malicious personality who takes pleasure in thwarting other drivers even at the

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    - *p*<0 => a malicious personality who takes pleasure in thwarting other drivers even at the cost of own disadvantages. This may have some interesting game-theoretic consequences. Of course, even those mischief makers do obey the safety criterion!

- A special case is given by p=1 and $a_{thr}=0$. In this case, lane changing takes place whenever the sum of the accelerations of all affected drivers increases after the change, or, equivalently, the overall decelerations are minimized. This effect gave birth to the acronym for this model:

MOBIL = Minimizing Overall Braking decelerations Induced by Lane changes

Variants of MOBIL for asymmetric traffic rules or situations

The model defined by the two equations above describes more or less symmetric lane usage where overtaking on the right is not explicitely forbidden. If traffic rules or situations are asymmetric, one needs modifications. In the following, there are some typical situations:

- In many European countries, the lane usage rules are explicitely asymmetric, particularly,
    - one should keep to the right,
    - overtaking to the right is forbidden unless traffic is congested.

  For some countries such as Thailand, Britain or Australia, swap "left" and "right". To incorporate the keep-right directive, we added to the incentive criterion an additional bias a_{bias} in favour of the right lane.

- If there are forced lane changes such as
    - entering a freeway *via* an onramp,
    - exiting a freeway,
    - lane changes as a reaction of a closing of the actual lane ahead,

  the lane-usage bias introduced above can be used to treat this situation: Of course, the bias is in favour of the target lane(s):
    - For on-ramp traffic, a_{bias} is negative (modelling a bias to the left)
    - For the lane closing szenario 3, a_{bias} is positive for vehicles on the left lane that is about to be closed.

- Implementing the overtaking rule is more difficult and requires a so-called "longitudinal-transversal coupling", see **this reference (in German)** for details.

References

- The original publication (in German):
M. Treiber and D. Helbing, ***Realistische Mikrosimulation von Straßenverkehr mit einem einfachen Modell*** , 16. Symposium "Simulationstechnik ASIM 2002" Rostock, 10.09 -13.09.2002, edited by Djamshid Tavangarian and Rolf Gr\"utzner pp. 514--520.

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