Longitudinal Traffic model: The IDM

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

Model Structure

The IDM is an *microscopic* traffic flow model, i.e., each vehicle-driver combination constitutes an active "particle" in the simulation. Such model characterize the traffic state at any given time by the positions and speeds of all simulated vehicles. In case of multi-lane traffic, the lane index complements the state description.

More specifically, the IDM is a *car-following model*. In such models, the decision of any driver to accelerate or to brake depends only on his or her own speed, and on the position and speed of the "leading vehicle" immediately ahead. Lane-changing decisions, however, depend on all neighboring vehicles (see the lane-changing model MOBIL).

The model structure of the IDM can be described as follows:

- The influencing factors (model input) are the own speed v, the bumper-to-bumper gap s to the leading vehicle, and the relative speed (speed difference) Delta v of the two vehicles (positive when approaching).
- The model output is the acceleration dv/dt chosen by the driver for this situation.
- The model *parameters* describe the driving style, i.e., whether the simulated driver drives slow or fast, careful or reckless, and so on: They will be described in detail below.

Model Equations

The IDM model equations read as follows:

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

where

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

The acceleration is divided into a "desired" acceleration a $[1-(v/v_0)^{\text{delta}}]$ 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 speed" 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 speed (the safety distance increases)
- increasing speed difference to the front vehicle (when approaching the front vehicle at a too high rate, a dangerous situation may occur).

The mathematical form of the IDM model equations is that of *coupled ordinary differential equations*:

- They are differential equations since, in one equation, the dynamic quantities v (speed) and its derivative dv/dt (acceleration) appear simultaneously.
- They are coupled since, besides the speed v, the equations also contain the speed v_l=v− Delta v of the leading vehicle. Furthermore, the gap s obeys its own kinematic equation,

  ds/dt=− Delta v

  coupling the gap s to the speeds of the two vehicles.

Model Parameters

The IDM has intuitive parameters:

- desired speed 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 apply 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 speed v_0	120 km/h	80 km/h	For city traffic, one would adapt the desired speed 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

Simulation of the Model

Simulation means to numerically "integrate", i.e., approximatively solve the coupled differential equations of the model. For this, one defines a finite *numerical update time interval* Δt, and integrates over this time step assuming constant accelerations. This so-called *ballistic method* reads

new speed:	$v(t+\Delta t)=v(t) + (dv/dt)\ \Delta t,$
new position:	$x(t+\Delta t)=x(t)+v(t)\Delta t+1/2\ (dv/dt)\ (\Delta t)^2,$
new gap:	$s(t+\Delta t) =x_l(t+\Delta t)- x(t+\Delta t)- L_l.$

where dv/dt is the IDM acceleration calculated at time t, x is the position of the front bumper, and L_l the length of the leading vehicle. For the Intelligent-Driver Model, any update time steps below 0.5 seconds will essentially lead to the same result, i.e., sufficiently approximate the true solution.

Strictly speaking, the model is only well defined if there is a leading vehicle and no other object impeding the driving. However, generalizations are straightforward:

- If there is no leading vehicle and no other obstructing object ("free road"), just set the gap to a very large value such as 1000 m (The limes gap to infinity is well-defined for any meaningful car-following model such as the IDM).
- If the next obstructing object is not a leading vehicle but a red traffic light or a stop-signalized intersection, just model the red light or the stop sign by a standing *virtual vehicle* of length zero positioned at the stopping line. When simulating a transition to a green light, just eliminate the virtual vehicle. (See the szenario "traffic Lights")
- If a speed limit (either directly by a sign or indirectly, e.g., when crossing the city limits) becomes effective, reduce the desired speed, if the present value is above this limit (scenario "Laneclosing"). Likewise, reduce the desired speed of trucks in the presence of gradients (scenario "Uphill Grade")

Special Case of Stopped Vehicles

For vehicles approaching an already stopped vehicle or a red traffic light, the ballistic update method as described above will lead to negative speeds whenever the end of a time integration interval is not exactly equal to the true stopping time (of course, there is always a mismatch). Then, the ballistic method has to be generalized to simulate following approximate dynamics:

If the true stopping time is within an update time interval, decelerate at constant deceleration (dv/dt) to a complete stop and remain at standstill until this interval has ended.

Furthermore, it may happen that the actual gap of a stopped vehicle s is slightly below the minimum gap s_0, in which case the unchanged IDM would give a negative acceleration, hence a negative velocity in the next time step. In most cases, however, real drivers will just keep that somewhat too low gap until the leader drives again rather than driving backwards. Both special cases can be implemented by following rules which are generally applicable to integrating any time-continuous car-following model, not just the IDM:

At least one of the above situations applies if:	$v(t) + (dv/dt)\ \Delta t < 0,$
new speed in this case:	$v(t+\Delta t)=0,$
new position in this case:	$x(t+\Delta t)=x(t) - 1/2\ v^2(t) / (dv/dt),$
new gap:	$s(t+\Delta t) =x_l(t+\Delta t)- x(t+\Delta t)- L_l.$

Notice that $- 1/2\ v^2(t) / (dv/dt)$ is greater than zero if the special cases apply.

Further information:

- the scientific reference for the IDM,
- a Wikipedia article,
- the book Verkehrsdynamik (German),
- or the book Traffic Flow Dynamics.

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