Name:	First name:	Matrikel number:

Exam to the Lecture
Traffic Dynamics and Simulation
SS 2022

Total 120 points

Problem 1 (20 points)

(a) In microscopic models, the main dynamical elements are the vehicles and drivers (driver-vehicle unit) while, in macroscopic models, this is aggregated to locally averaged, mostly continuous spatiotemporal quantities.

- Variables micro: speed v_i, gap to the leader s_i, acceleration $\dot{v}_i$ of vehicle i
- Macro: Local density $\rho(x, t)$, speed $V(x, t)$, flow $Q(x, t)$

(b) Which class is better suited?

(i) Generating the surrounding traffic in driving simulators: Only micro because you need individual vehicles.

(ii) Traffic state estimation and short-term prediction: Macro, because you do not have the complete microscopic information to drive microscopic models.

(iii) Determining the efects of speed limits on the traffic flow: As in all situations concerning heterogeneous traffic (here, trucks and cars), microscopic models are better. (Though macromodels not principally impossible).

(iv) Real-time traffic-dependent navigation: Macro, because only the macroscopic quantities "travel times" are needed and microscopic information to drive micromodels generally is not given.

(v) Determining the efects of assisted or autonomous vehicles on the surrounding traffic flow: Micro, because the response to individual surrounding vehicles is needed.

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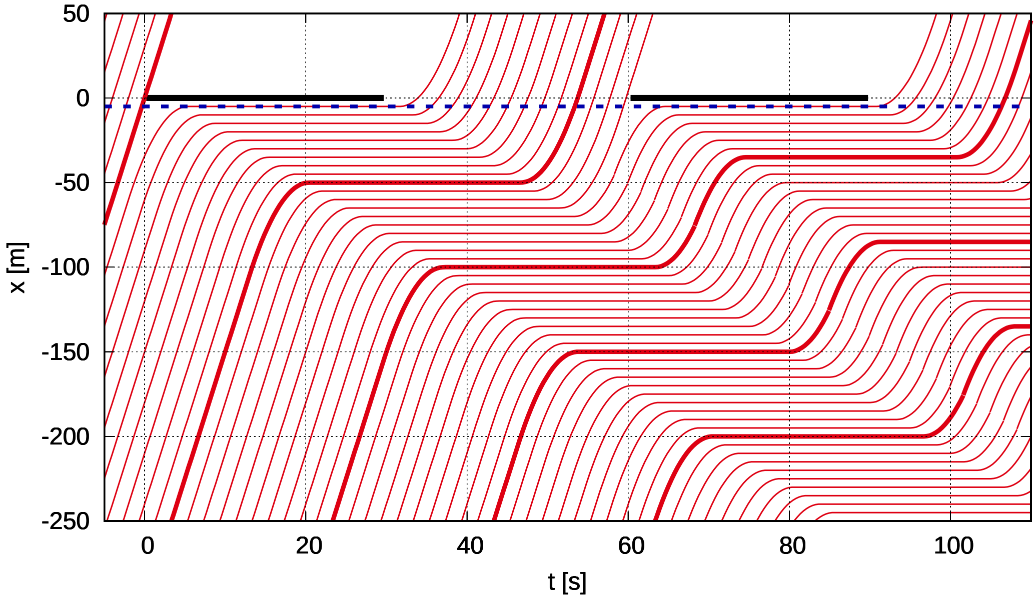
Problem 2 (40 points)



(a) Maximum density during queuing phases:

$$\rho_{\text{max}} = \frac{10\,\text{veh}}{50\,\text{m}} = 200\,\text{veh/km}$$

Outflow Q_{out} at $x = 50\,\text{m}$ during the interval $[40\,\text{s}, 60\,\text{s}]$:

$$Q_{\text{out}} = \frac{10\,\text{veh}}{20\,\text{s}} = 0.5\,\text{veh/s} = 1\,800\,\text{veh/h}$$

(b)
- Density: $\rho_{\text{in}} = 7\,\text{veh}/200\,\text{m} = 35\,\text{veh/km}$ (anything between $30\,\text{veh/km}$ and $35\,\text{veh/km}$ is OK; true density $33.3\,\text{veh/km}$)
- Flow: $Q_{\text{in}} = 10\,\text{veh}/20\,\text{s} = 0.5\,\text{veh/s} = 1\,800\,\text{veh/h}$
- Speed: $V_{\text{in}} = Q_{\text{in}}/\rho_{\text{in}} = 52\,\text{km/h}$ (anything between $50\,\text{km/h}$ and $55\,\text{km/h}$ is OK; true speed $15\,\text{m/s}$=$54\,\text{km/h}$)

(c) Between 30 s and 90 s, there is oversaturated traffic, so the cycle-averaged capacity is given by

$$C_{\text{TL}} = \frac{13\,\text{veh}}{60\,\text{s}} = 0.216\,\text{veh/s} = 780\,\text{veh/h}$$

Since the inflow $Q_{\text{in}} = 1\,800\,\text{veh/h}$, this is clearly not sufficient.

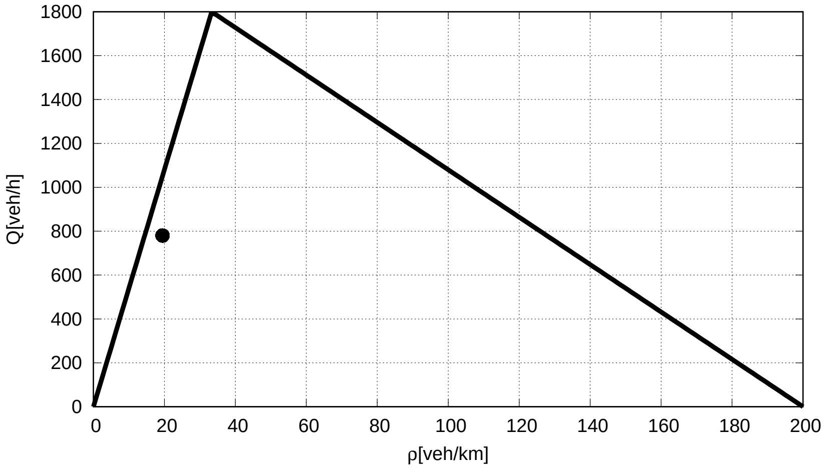
(d) Wave velocity from the transition congested-free, e.g., starting at $t = 30\,\text{s}$ and $x = 0$:

$$w = \frac{-200\,\text{m}}{96\,\text{s} - 30\,\text{s}} = -3\,\text{m/s}$$

(e) The fundamental diagram (FD) is determined by the already determined quantities V_0, Q_{max}, and w:

$$Q(\rho) = \min\left(V_0\rho, w(\rho - \rho_{\text{max}})\right)$$

or, intuitively, just a triangle with the corners $(0, 0)$, $(\rho_{\text{max}}, 0)$, and the free-flow and congested gradients v_0 and w, respectively



(f) We have $n = 13$ data points and an average speed (watch out - transform the speeds in m/s) of $V_{\text{data}} = \sum_i v_i/n = 11.1\,\text{m/s}$, so

$$Q_{\text{data}} = 13/60\,\text{veh/s} = 780\,\text{veh/h}, \quad \rho_{\text{data}} = Q_{\text{data}}/V_{\text{data}} = 0.0194\,\text{veh/m} = 19.4\,\text{veh/km}$$

Because this data point contains a mix of stopped and outflowing traffic, it does not lay on a homogeneous steady state, hence, not on the FD

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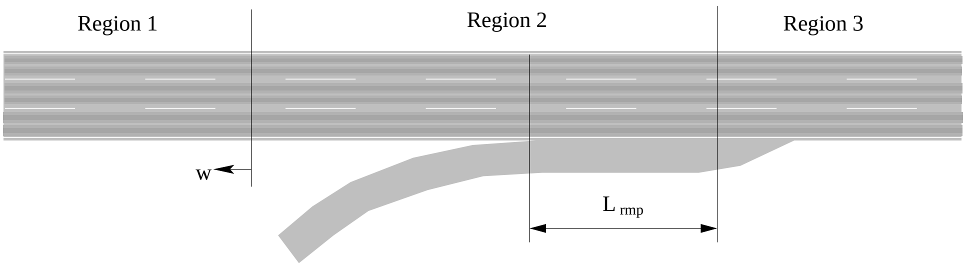
Problem 3 (40 points)

Given is a three-lane freeway section with an onramp:



Traffic flow is described by a LWR model with the tridiagonal fundamental diagram

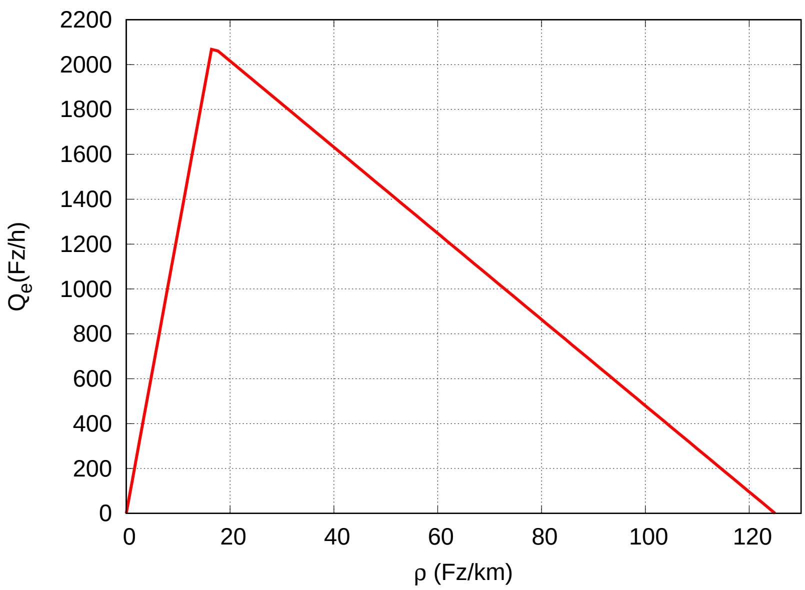
$$Q_e(\rho) = \min\left[V_0\rho, \frac{1}{T}(1 - l_{\text{eff}}\rho)\right].$$

(a) Ramp term of the continuity equations for the effective densitities and flows for 3 lanes:

$$\frac{\partial\rho}{\partial t} + \frac{\partial Q}{\partial x} = \eta_{\text{rmp}}, \quad \eta_{\text{rmp}} = \frac{Q_{\text{rmp}}}{3 * 0.3\,\text{km}} = 1\,333\,\text{veh/h/km}$$

(b) The corners of the triangular FD are $(0,0)$, $(\rho_{\max}, 0)$, and $(\rho_c, Q_{\max})$ where, for normal weather, we have

$$\rho_{\max} = \frac{1}{l_{\text{eff}}} = 125\,\text{veh/km}, \quad \rho_{\text{c}} = \frac{1}{v_0T + l_{\text{eff}}} = 16.5\,\text{veh/km}, \quad Q_{\max} = V_0\rho_c = 2\,083\,\text{veh/h}$$



(c) The total demand of the main road and the ramp flow realized in region 3 if there is no breakdown is given by the sum of the inflow Q_1^{tot} and the on-ramp flow,

$$Q_3^{\text{tot}} = Q_1^{\text{tot}} + Q_{\text{rmp}} = 4\,800\,\text{veh/h}$$

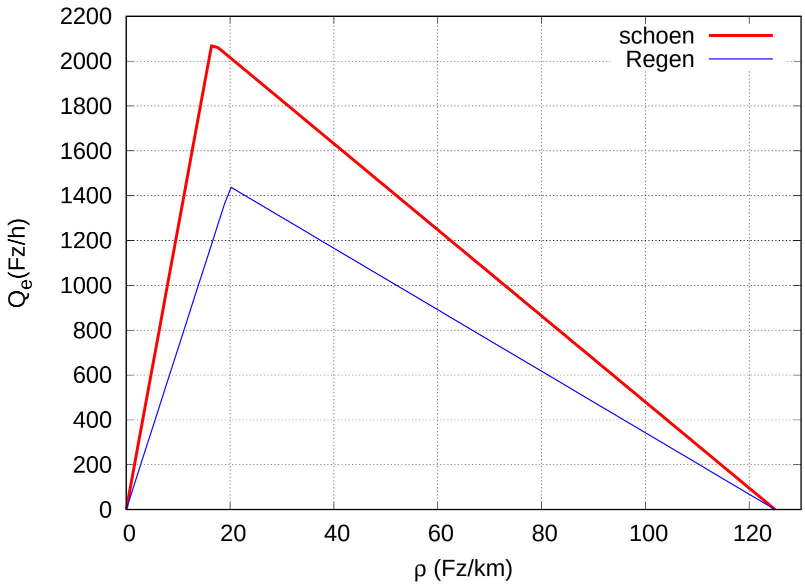
while the capacity of any main-road section is given by

$$C = 3Q_{\text{max}} = 6\,249\,\text{veh/h}$$

This is sufficient, hence no breakdown.

(d) Behavioural change during a strong thunderstorm: $v_0 = 72\,\text{km/h}$, $T = 2.1\,\text{s}$, $l_{\text{eff}} = 8\,\text{m}$, so

$$\rho_{\text{max}} = \frac{1}{l_{\text{eff}}} = 125\,\text{veh/km}, \quad \rho_c = \frac{1}{v_0 T + l_{\text{eff}}} = 20\,\text{veh/km}, \quad Q_{\text{max}} = V_0 \rho_c = 1\,440\,\text{veh/h}$$



(e) During the thunderstorm, the main-road capacity is given by $C = 3 * 1\,440\,\text{veh/h} = 4\,320\,\text{veh/h}$ which is greater than the demand $Q_1^{\text{tot}} = 3\,600\,\text{veh/h}$ but less than the traffic $Q_3^{\text{tot}} = 4\,800\,\text{veh/h}$ which the downstream segment must take if there is no breakdown. hence, there is a breakdown soemwhere along the onramp merge section. The resulting lane-average density in the congested region is given by (watch out that congested branches are always calculated for the effective quantities in SI units; anything else is too error prone!)

$$Q_2 = Q_{\text{max}} - \frac{1}{3} Q_{\text{rmp}} = 0.289\,\text{veh/s}, \quad \rho_2 = \rho_{\text{cong}}(Q_2) = \rho_{\text{max}}(1 - Q_2 T) = 0.0491\,\text{veh/m}$$

We also have

$$Q_1 = \frac{Q_{\text{in}}}{3} = 0.333\,\text{veh/s}, \quad \rho_2 = \rho_{\text{free}}(Q_1) = \frac{Q_1}{v_0} = 0.0167\,\text{veh/m}$$

resulting in a propagation velocity of the upstream front of the jam

$$c_{12} = \frac{Q_2 - Q_1}{\rho_2 - \rho_1} = -1.37\,\text{m/s}$$

Problem 4 (20 points)

Consider the decision situation where the driver of a stopped vehicle wants to enter a priority road at an unsignalized intersection.

(a) The safety criterion is satisfied if the nearest follower f on the main road has to brake at a smaller deceleration than b_{safe} in the case of a positive (enter) decision,

$$\dot{v}_f(s_f, v_f, v_l = 0) > -b_{\text{safe}}.$$

The incentive criterion is always satisfied because, without incentive, the entering driver would wait forever.

(b) Minimum gap to an arriving upstream vehicle at speed v assuming $a = b = b_{\text{safe}} = 2\,\text{m}$: Here, the arriving vehicle is the subject vehicle and the entering vehicle the leading vehicle at speed $v_l = 0$. The IDM+ only decelerates if $v > v_0$ (excluded) or if the interaction regime is active. Hence, the safety criterion (with respect to the approachiung vehicle) reads

$$\dot{v} = -a\left(\frac{s^*}{s}\right)^2 = -a\left(\frac{s_0 + vT + v^2/(2\sqrt{ab})}{s}\right)^2 \stackrel{!}{=} -b_{\text{safe}}$$

With $a = b = b_{\text{safe}}$, this simplifies to

$$-b\left(\frac{s_0 + vT + v^2/(2b)}{s}\right)^2 \stackrel{!}{=} -b$$

or

$$s = s_0 + vT + \frac{v^2}{2b}$$

$s - s_0$ is the stopping distance consisting of the reaction distance vT and the braking distance $v^2/(2b)$ provided that the reaction time is assumed to be equal to the desired time gap