Exam CIE-4821-09
Traffic Flow Theory and Simulation

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18 April 2013

The exam has 5 questions. 53 points can be obtained, which are specified per question and subquestion. Some questions might require more time than others, so *use your time wisely*! The total time available for this exam is 3 hours.

Remarks:

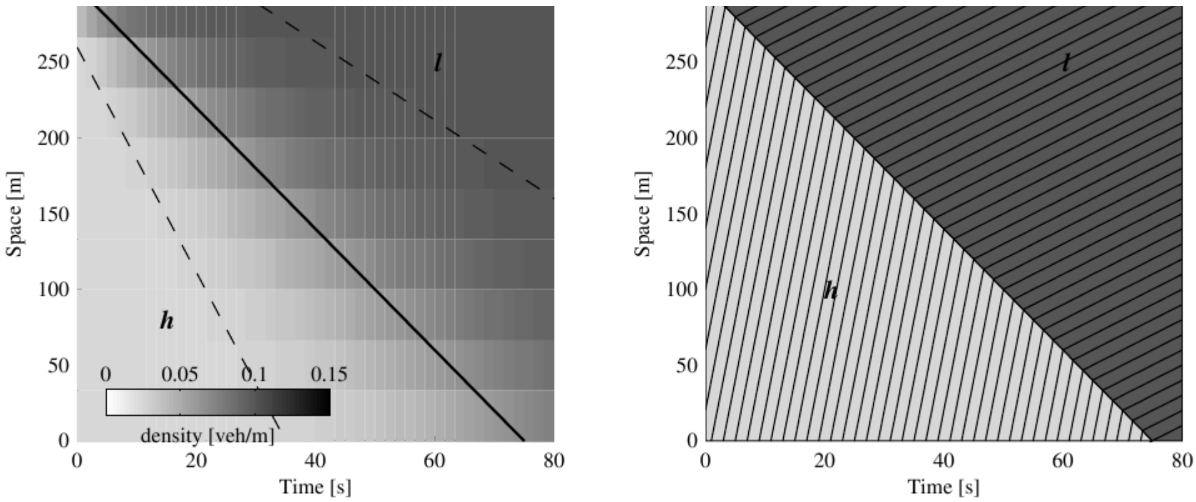
- Allowed: calculator (but no smartphones...), self-made equation sheet (1 double sided A4 max)
- Put labels at all your graph axes.
- If a *sketch* is asked, there is no need for an exact drawing. Do make sure, though, that it is clear whether points lie higher or lower or on one line, and that this is correct.
- Your answer will be judged on the good elements in there, but for all wrong answers points will be deducted.
- For some questions, an indicative number of words is given as guidance for the required level of detail. Your answer may be shorter or longer.
- Make sure you provide the calculus procedure as well as the result in order to get the maximum points.

Question	Points
1	6
2	6
3	19
4	12
5	10
Total:	53

1. Short open questions

Total for Question 1: 6

Below, two simulation results of a homogeneous congested area spilling back upstream are plotted. You see a high density, congested area, indicated with *h* downstream of x=0 at t=0, and a low density, uncongested area, indicated by *l*. The driving direction is up. One of the figures plots the results of a simulation in Eulearian coordinates and one of a simulation in Lagrangian coordinates.



(a) **Explain which of the two is Eulerian and which one Lagrangian.** (1)

(b) **Give the two main advantages of using Lagrangian coordinates.** (2)

(c) **Explain what a pce value is. (30 words)** (1)

(d) **How does the pce value of trucks depend on the speed, qualitatively (i.e., does it increase, decrease, ...). Give your reasoning** (2)

2. Multi-leader car-following models

Total for Question 2: 6

Consider the IDM car-following model, prescribing the following acceleration:

$$\frac{\mathrm{d}v}{\mathrm{d}t} = a_0 \left(1 - \left(\frac{v}{v_0}\right)^4 - \left(\frac{s^*(v, \Delta v)}{s}\right)^2\right) \tag{1}$$

In this equation, v is the speed of the following vehicle, v_0 a reference speed, s the distance headway and s^* a reference distance headway as function of speed v and the difference in speed with the leader, Δv:

$$s^*(v, \Delta v) = s_0 + v\,T + \frac{v\,\Delta v}{2\sqrt{a\,b}} \tag{2}$$

In this equation s_0 is a desired distance at standstill, and a is a reference acceleration and b is the maximum comfortable braking.

(a) **Explain in words the working of this car-following model; i.e. comment on the acceleration. Only comment on equation 1. (indication: 50 words)** (2)

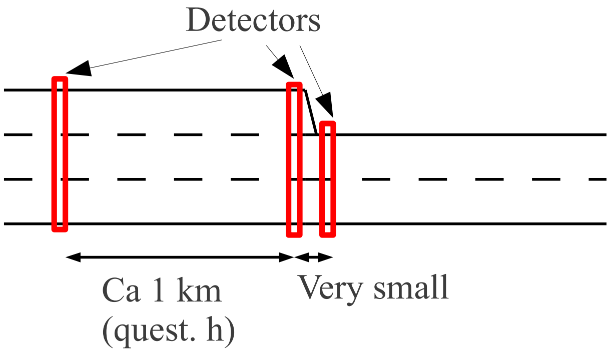
(b) **Explain in words what is meant with multiple-leader car-following models. Only comment on the multi-leader part. (indication: 50 words)** (1)

(c) **Reformulate the IDM model into a multiple-leader car-following model by including two leaders. Give your reasoning, and, for all points, formulate those reasonings into equations.** (3)

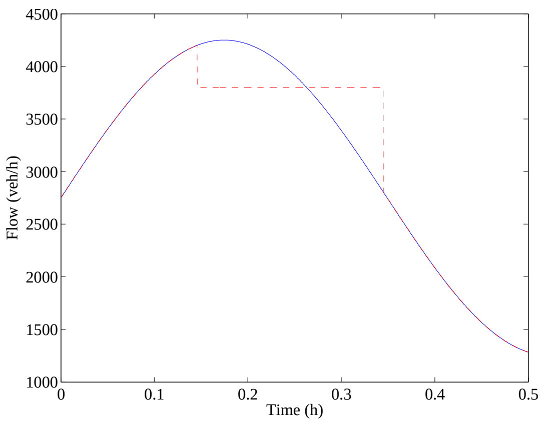
3. Measuring the speed at a cross section

Total for Question 3: 19

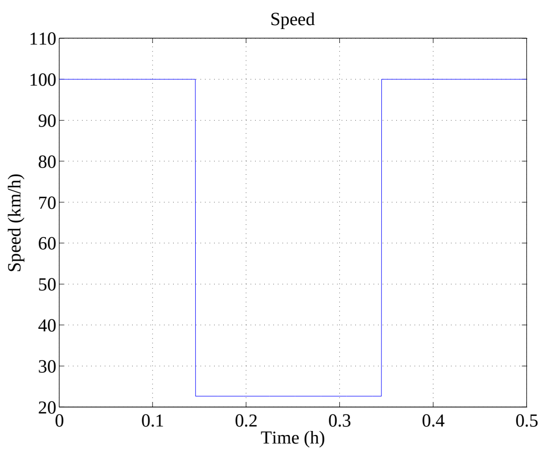
Consider the following road layout with a lane drop from 3 to 2 lanes; traffic is flowing left to right.



The demandm as well as the flow at the downstream detector, is given in the figure below. The speed at the detector, located just upstream (you may assume no spacing between the bottleneck and the detector) of the bottleneck, is as follows.



(a) Flow and demand



(b) Speed

In the question, you might need values from the graph. Slightly misreading the graph is not a problem, but *mention the values you directly read from the graph and where you find these*.

(a) **In figure a with the flow and the demand, which line is the demand and which line the flow. Argue why** (1)

(b) **Give the free flow capacity (and the reasoning how you find it)** (2)

(c) **Give the queue discharge rate. (and the reasoning how you find it)** (2)

Assume the fundamental diagram per lane is the same for all lanes, at all locations in this setting.

(d) **Explain why can this situation not be described with a triangular fundamental diagram.** (1)

(e) **Draw the simplest fundamental diagram possible for the three lane section (aggregated over all lanes). Explain how you find the values for the relevant points, and give calculate them.** (5)

Now the delay is analysed by slanted cumulative curves.

(f) **Explain the offset you choose.** (1)

(g) **Sketch the slanted cumulative curve of the flow and the demand for the situation at hand.** (2)

(h) **Indicate in the figure how you can determine the delay.** (1)

Now a second detector is constructed approximately 1 km upstream of the bottleneck.

(i) **Sketch the demand as function of time (i.e., copy the second figure of this question, indicate the times of speed change in the graph - no points given) and in the same graph, sketch the resulting flow at this second detector. Pay attention to the times at which the flow changes compared to the time of the speed changes.** (2)

We now relax the assumption of all traffic states at the fundamental diagram to a more realistic situation (i.e., including demand and supply variations). In this situation, We measure the one-minute aggregated (harmonically averaged) speeds during one month.

(j) **Sketch a probability distribution or histogram of these speeds. Explain the shape** (2)

4. Moving bottleneck

Total for Question 4: 12

Consider a two-lane motorway. Assume a triangular fundamental diagram with a free flow speed of 80 km/h, a critical density of 25 veh/h/lane and a jam density of 150 veh/km/lane. The inflow is stationary at 2000 veh/h.

(a) **Draw the fundamental diagram and calculate the capacity of the road stretch** (2)

Consider a wide vehicle (special transport) driving slowly is entering the road. There are no overtaking possibilities. This creates congestion, *of which the tail happens to stay at the same position*.

(b) **Calculate the flow in the jam. (Hint: you can use the speed of the shockwave at the tail of the queue)** (1)

(c) **Calculate the density in the jam.** (2)

(d) **Calculate the speed of the special transport.** (2)

After 5 km, the truck leaves the road.

(e) **Construct the space-time diagram of this situation, from before the moment the truck enters the road to after the moment the traffic situation is stationary. Explain how you find the speed of the solving of congestion; you may re-use the figure you created in a.** (4)

(f) **At the maximum queue length, how many vehicles are in congestion** (1)

5. Multi-lane traffic flow

Total for Question 5: 10

(a) **Give the names of two regimes according to Daganzo's theory of slugs and rabbits (only names are required).** (1)

Below, you find a Google Earth image of the A1 motorway near Bathmen. Consider the right to left (east to west) direction

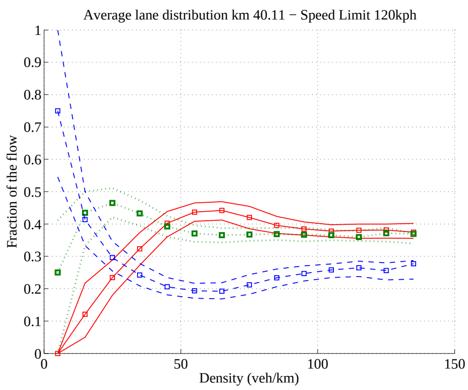
(b) **To which of the regimes of question a) does the situation in the figure resemble most. Explain why** (2)

There are 4 trucks and 7 passenger cars (including one delivery van) in the image. The fraction of passenger cars in the density is hence 7/11.

(c) **What would you expect from the fraction of passenger cars in the flow: is this higher, lower or equal to 7/11. Motivate your answer** (2)

(d) **Calculate the fraction of the is passenger cars in the flow. Assume reasonable speeds for the different vehicle types in your answer – state your assumptions clearly.** (4)

Below, a figure of a lane flow distribution for a three lane road in the Netherlands is given.



(e) **In the figure, which color matches which lane. Argue why** (1)