Exam CIE-4821-09
Traffic Flow Theory and Simulation

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The exam has 6 questions. 58 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	9
2	6
3	13
4	10
5	4
6	16
Total:	58

1. Short open questions

Total for Question 1: 9

(a) **Explain why Kerner claims that in his three phase theory there is no fundamental diagram (indication: 25 words)** (1)

(b) **What is a Macroscopic Fundamental Diagram (indication: 25 words)?** (1)

(c) **What are similarities and differences of a Macroscopic Fundamental Diagram compared to a normal fundamental diagram? Explain based on the underlying phenomena (indication: 75 words).** (2)

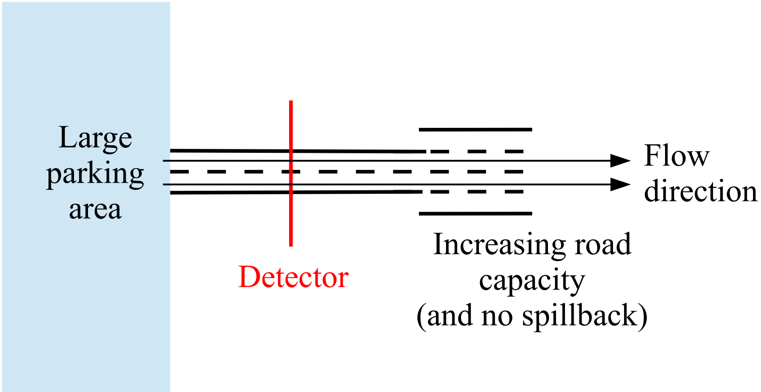
(d) **Explain in words the how the flow in from one cell to the next is calculated according to the Cell Transmission Model (indication: 100 words; equations can be useful, but need to be explained).** (2)

(e) **What do we mean with Lagrangian coordinates in macroscopic traffic flow simulation? Which variables are used? Why is this an advantage over other systems? (indication: total 100 words)** (3)

2. Leaving the parking lot

Total for Question 2: 6

Consider the situation where many cars are gathered at one place, and they can only leave over one road.



The above figure shows a simplified representation of the road layout. There is a detector at the red line, in the two-lane road stretch. Downstream of the detector the road widens and there are no further downstream bottlenecks.

(a) **Explain what the capacity drop is (be precise in your wording!).** (1)

(b) **How large is the capacity drop? Give a typical interval bound.** (1)

(c) **Sketch the traffic flow at the detector (indicated in the figure) as function of the demand (in veh/h, ranging from 0 to three times the road capacity) from the parking lot.** (2)

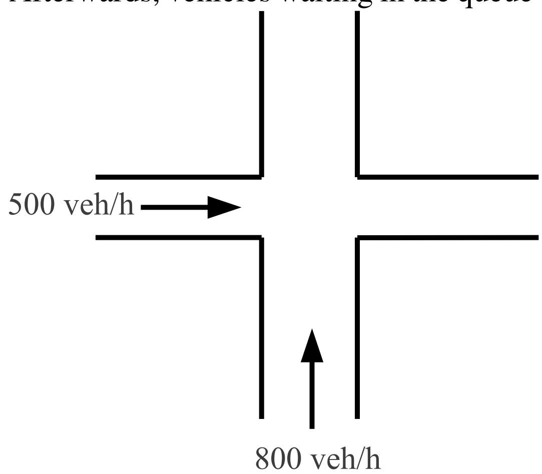
(d) **Explain the general shape you draw in the previous question.** (1)

(e) **Give some rough estimates for values in your graph.** (1)

3. Traffic lights

Total for Question 3: 13

Consider a junction with a traffic light with equal green time g, and a clearance time of 2 seconds (i.e., the time needed to clear the junction; during this time, both directions are red). If the traffic light turns green, the first vehicle needs 3 seconds to cross the line. Afterwards, vehicles waiting in the queue will follow this vehicle with a 2 second headway.



(a) **What is the fraction of time traffic is flowing over the stop line per direction as function of the cycle time c?** (2)

(b) **What is the maximum flow per direction as function of the cycle time? In your equation, what are the units for the variables?** (3)

Suppose traffic intensity from direction 1 is 500 veh/h and traffic from direction 2 is 800 veh/h, and suppose a uniform arrival pattern.

(c) **What is the minimum cycle time to ensure that no queue remains at the end of the cycle? Does an approach with vertical queuing models yield the same result as shockwave theory? Why?** (3)

This cycle time is fixed now at 120 seconds. We relax the assumption of uniform distribution to a more realistic exponential arrival pattern.

(d) **To which distribution function for the number of arrivals per cycle (N) does this lead? Name this distribution (1 pt).** (1)

The probability distribution function of X is given by:

$$f(k;\lambda) = \Pr(X = k) = \frac{\lambda^k e^{-\lambda}}{k!}, \tag{1}$$

with $e \sim 2.71828...$) and $k!$ is the factorial of k. The positive real number λ is equal to the expected value of X, which also equals the variance.
Assume there is no traffic waiting when the traffic light turns red at the beginning of the cycle.

(e) **Express the probability p that there are vehicles remaining in the queue for direction 2 when the traffic light turns red at the end of the cycle in an equation ($p = ...$). Write your answer as mathematical expression in which you specify the variables. Avoid infinite series. There is no need to calculate the final answer as a number** (3)

(f) **Argue whether this probability is higher or lower than if a uniform arrival process is assumed** (1)

4. Car-following model

Total for Question 4: 10

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

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

with the desired distance s^* as function of speed v and speed difference Δv:

$$s^*(v,\Delta v) = s_0 + v\,T + \frac{v\,\Delta v}{2\sqrt{a\,b}} \tag{3}$$

(a) **Explain in words the working of this car-following; i.e. comment on the acceleration.** (3)

Another car-following model is the relatively simple car-following of Newell.

(b) **How does the Newell car-following model work? (indication: 50 words)** (1)

(c) **Name two weak points of both car-following models (IDM and Newell)** (2)

(d) **Give two reasons to choose the IDM model over Newell's model** (2)

(e) **Give two reasons to choose Newell's model over the IDM model** (2)

5. Pedestrians in a narrow tunnel

Total for Question 5: 4

We consider a pedestrian flow through a narrow tunnel, which forms the bottleneck in the network under high demand. The tunnel is 4 meters wide and 20 meters long. You may assume that the pedestrians are distributed evenly across the width of the tunnel. The pedestrian flow characteristics are described by a triangular fundamental diagram, with free speed v_0 = $1.5 m/s$, critical density k_c = $1 P/m^2$ and jam density $k_j = 6 P/m^2$ (P stands for pedestrian).

(a) **Draw the fundamental diagram for the tunnel. What is the capacity of the tunnel expressed in P/min?** (2)

Between 11-12 am, the average flow through the tunnel is q = 180 P/min.

(b) **Assuming stationary conditions, what is the density in the tunnel expressed in P/m^2 ?** (2)

6. Moving bottleneck with different speeds

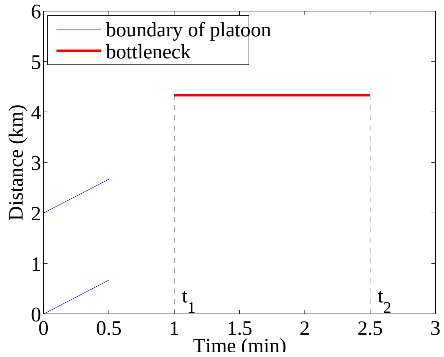
Total for Question 6: 16

Consider a two-lane road with traffic in opposing directions. Assume a triangular fundamental diagram with a free speed of 80 km/h, a critical density of 20 veh/km and a jam density of 120 veh/h. At t=0 there is a platoon of 30 vehicles on the road with equal spacing in the section x=0 to x=2km. There are no other vehicles on the road. In this question, we will consider the effect of a speed reduction to 15 km/h.

(a) **What is the density on the road in the platoon? Indicate the conditions in the fundamental diagram. Make a clear, large drawing of the fundamental diagram such that you can reuse it for indicating states in the remaining of the question.** (1)

In each of the following subquestions, consider these initial conditions and no other bottlenecks than introduced in that subquestion – i.e., there never is more than one bottleneck.

Suppose there is a local, stationary bottleneck where drivers have to pass at 15 km/h from time $t1$ to $t2$. The figure below shows the position and the duration compared to the platoon in the space time plot.



(b) **Sketch the resulting traffic operations in a space-time plot. Also sketch some trajectories in the plot, using a different color or style. *Indicate how you construct the diagram* (i.e., indicate how you get the lines, angles, and distances in the plot). There is no need to calculate the exact traffic states. Additional information: the combination of speeds and the fundamental diagram will lead to congestion.** (4)

Suppose there is a temporal speed reduction to 15 km/h for a short period of time over the whole length of the road at the same time. You may assume the platoon to be completely on the road.

(c) **Sketch the resulting traffic operations in a space-time plot. Also sketch some trajectories in the plot, using a different color or style. *Indicate how you construct the diagram* (i.e., indicate how you get the lines, angles, and distances in the plot).** (2)

Suppose there is a large tractor moving in the opposite direction of the traffic at 5 km/h from x1 to x2. This wide vehicle causes vehicles that are next to it to reduce speed to 15 km/h. The speed (5 km/h) is lower than the speed of the shock wave at the tail of the queue in question b

(d) **Sketch the resulting traffic operations in a space-time plot. Also sketch some trajectories in the plot, using a different color or style. *Indicate how you construct the diagram* (i.e., indicate how you get the lines, angles, and distances in the plot).** (4)

Suppose there is a large tractor moving in the opposite direction of the traffic at 50 km/h. This wide vehicle causes vehicles that are next to it to reduce speed to 15 km/h. The tractor speed (50 km/h) is higher than the speed of the shock wave of the tail of the queue in question b.

(e) **Sketch the resulting traffic operations in a space-time plot. Also sketch some trajectories in the plot, using a different color or style. *Indicate how you construct the diagram* (i.e., indicate how you get the lines, angles, and distances in the plot). (Hint: it can help to consider a finite tractor length, but it is not necessary)** (5)