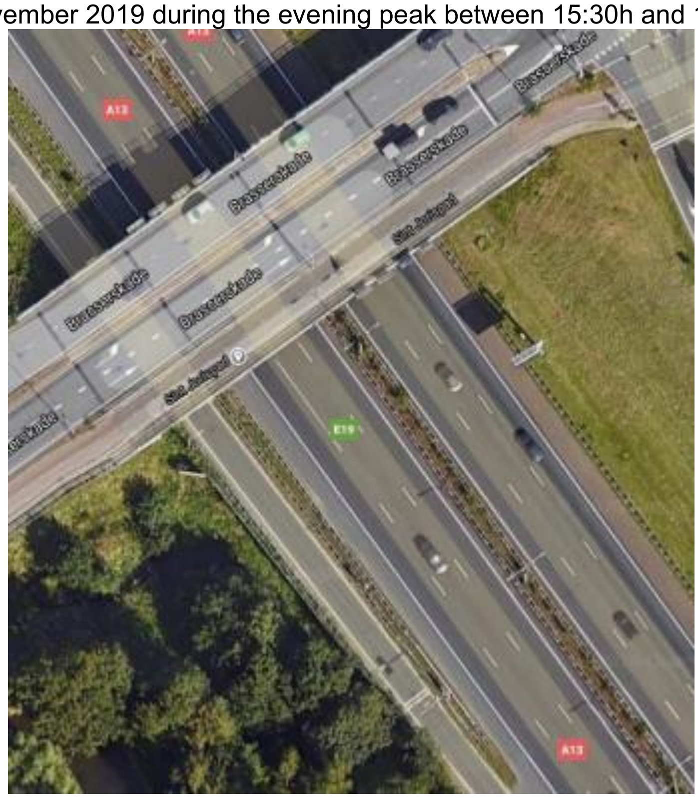
Readme acceleration data

This document will describe the data collected on the A13. This data is used to find the acceleration data used in the master thesis of Klomp (2020) and in the matching article (Klomp et al, 2021). Parts of the descriptions are taken from Klomp (2020).

1) Data collection: type and location

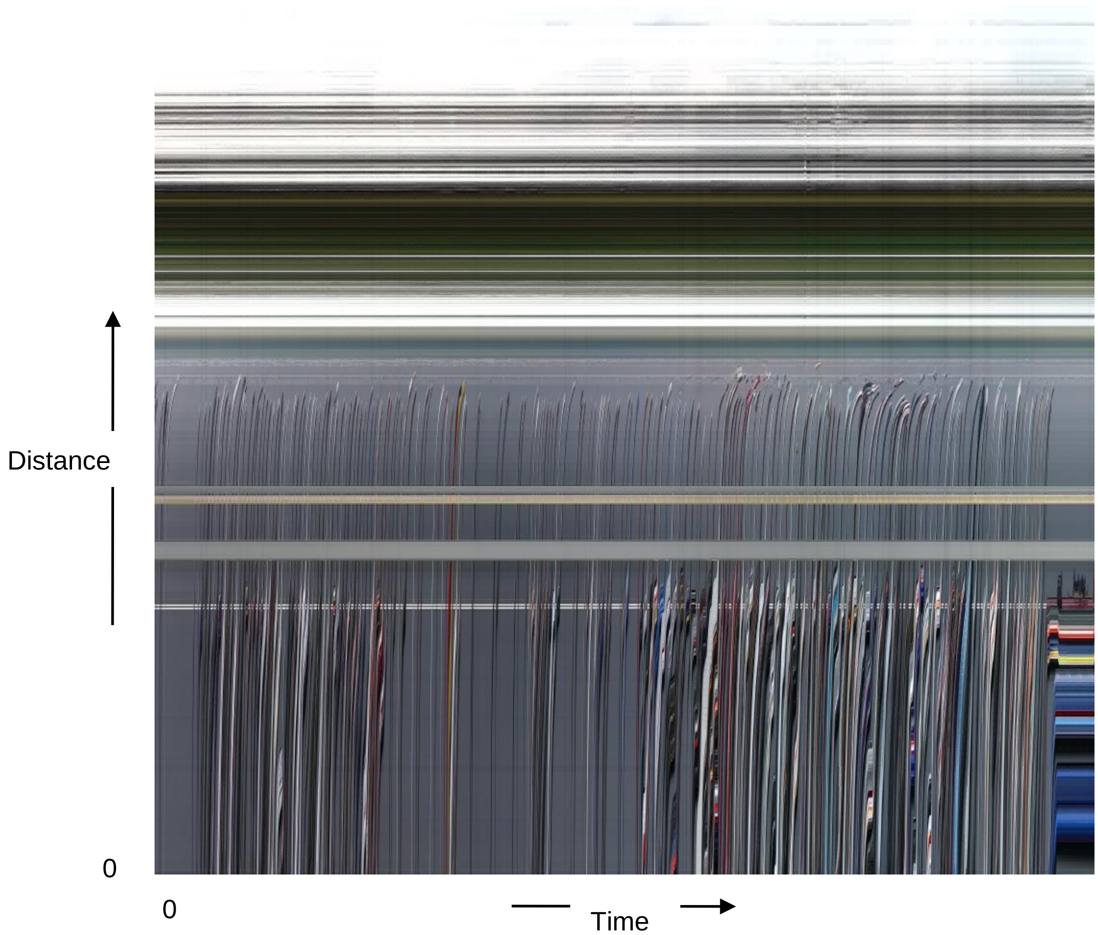
“Firstly, raw data on how vehicles accelerate has to be collected. This is done by filming the on-ramp of the A13 Delft-North in the direction of Rotterdam (southeast) with a stationary camera, placed on the Sint-Jorispad, near the Brasserskade bridge. This site was chosen, because it entails a single lane on-ramp downstream of the traffic light all the way to the end of the on-ramp, which makes sure that a filmed vehicle will not disappear behind another merging vehicles overtaking other the filmed vehicles. In other words, by making sure only one vehicle is accelerating at a time, it is ensured that individual vehicles will be more easily identified. Moreover, thanks to the bridge over the highway, it was fairly easy to film the accelerating vehicles. Furthermore, since the vehicles were filmed from behind and the drivers were unlikely to notice the filming installation from the other side of the bridge, the driver behavior was most likely not influenced by the presence of the filming camera. The moment of data collecting was on Tuesday the 5th of November 2019 during the evening peak between 15:30h and 18:00h.” (Klomp, 2020)



2) Raw data: video frames
There are 5 folders of video frames, each matching an uninterrupted video stream of 20 to 30 minutes each. Between each of the 5 videos, there is a short time in which the recording has been stopped and restarted. The videos are recorded in order of increasing number.
They were collected at 25 Hz, meaning each frame is 0.04s separated. For convenience of downloading, the frames even within one folder are split into folders containing 1000 images each.

3) Space-time plots
Next, these frames were combined into vehicles trajectories with a MATLAB-code. This is done by looking at a single line of pixels over time instead of at the entire frame. This line starts at the on-ramp, flowing towards the end of the merging area and then back through the tree tops (see yellow line). For a background of this method, see Knoop et al, 2009.
For this, we have used the enclosed series of a matlab script matching the paper of Knoop et al. This is called "transform_images.zip" and contains a readme for that program.

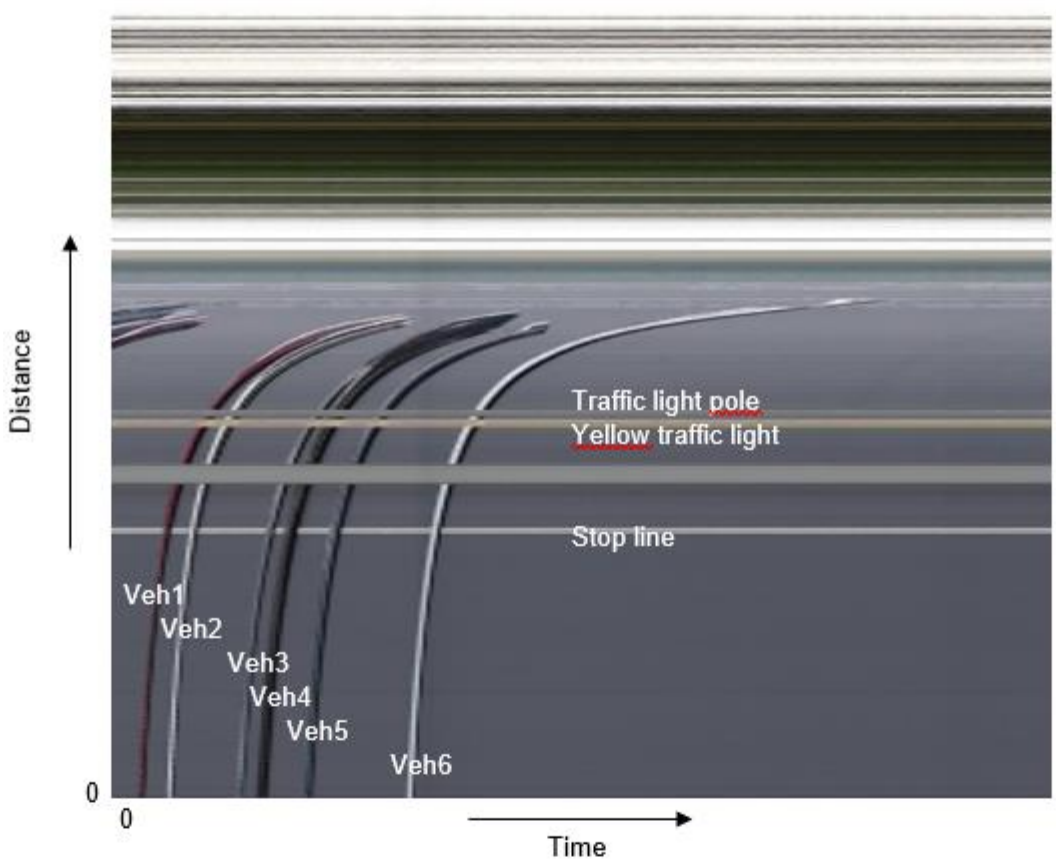
Merging the data of these lines over the frames results in pictures of moving vehicles and some stationary objects that are located on the yellow line, such as the yellow traffic light, the white stop line and the grey traffic light pole.



These files are called “Adjusted_FilmN_final_5.jpg”, in which N runs from 1 to 5.

4) Towards Trajectories

These axis on the pictures of the vehicle trajectories are time (unit **frames**) on the horizontal axis and distance (unit: **pixels**) on the vertical axis. Before acceleration data in meters per seconds squared can be determined, the dimension of the axis have to be in meters and seconds. The framerate of the video is 25 frames per second, so the time in seconds can be derived from the horizontal value of a point divided by 25.



Converting the distance from pixels to meters is a bit more challenging. This conversion is made possible by using the trajectory of a vehicle driven by a colleague, which was driven at a known constant speed. This vehicle is the 6th vehicle in the shown picture and it remained a speed of 66 km/h for the entire trajectory. By taking many data points of this trajectory in distance in pixels and time in seconds, various distance values in pixels can be calculated in meters, by firstly determining the starting time of the trajectory and assuming the starting distance as 0. Then, by using the speed of 66 km/h and the time of the data points, also assumed to be 0 when the vehicle trajectory begins, the distance in meters can be determined. So, for numerous data points, the time (unit: seconds) and distance (unit: meters) has been computed. For these frames, the distance in pixels is precisely converted to meters. For all intermediate distance pixels, a linear line between the two adjacent calculated data points is assumed to come up with the conversion of the distance values in pixels to meters. This conversion can be found in the 'ConversieMap.xlsx'. Herein, the first sheet ('Reference trajectory') lines out the derived datapoints of the reference trajectory (column A and B). Since the points originally start at 0 at the top and approach 1080 down at the bottom and the vehicles do drive bottom to top, the data points are inversed (column C). The difference in time, distance and inversed distance can be calculated from the second data point onwards (since that is the first data point with a predecessor) (columns D, E, F). The slope between two adjacent points in distance over time should not increase compared to the previous point, as can be derived from the original trajectory. Additionally it should not be 0 and it should not be negative. This column (G) serves as the slope check.

The absolute timestamp (unit: seconds) of the data point in the video can be determined by dividing the time in pixels (column A) by 25 (fps) (column H). Assuming the trajectory starts at a distance of 0, the absolute distances in meters can be computed by multiplying the time of the considered data point relative to the start of the trajectory times the speed of the vehicle, either in m/s or in m/frame (column I). Then, assuming a linear increase between two adjacent data points, the increase in distance in meters per frame can be calculated. The increase in distance in meters between data points x-1 and x is posted in the row of data point x, meaning the first data point does not have such an increase.

In the 'Reference trajectory' datasheet, graphs with the original reference trajectory (as retrieved from the pictures), actual trajectory and conversion of the distance in pixels to distance in meters are provided.

Example, the fourth data point of the first considered trajectory (see the second Excel sheet 'Trajectorydata') entails a distance in pixels of 755. The closest determined data point of the reference trajectory with a larger distance in pixels has a distance of 760 in pixels and is equal to a distance of 21,63 in meters. The remaining 5 distance in pixels can be calculated by 5*(x(m)/x(frames)), which comes down to 0,73 meters. So the distance in meters of the distance of 755 pixels is equal to 22,37.

5) Trajectories

We extracted 19 trajectories of vehicles of which 16 were used in the research since three of them proved to yield unrealistic acceleration values. The space-time coordinates can be found in the 'trajectory data' sheet of the 'ConversieMap.xlsx'. The method to convert the data points in distance and time in pixels and frames to meters and seconds can be found in the previous section.

The retrieved data points and relative distance in meters and time in seconds (assuming every vehicle starts at a distance and time of 0 just as it is about to accelerate) of the 19 considered trajectories can be found in the 'trajectorydata' sheet. The distance in meters is computed similarly to the provided example above.

The 'VehicleData' sheet is the cleaned up version of the 'trajectorydata' sheet with merely the relative distance in meters and relative time in seconds.

6) Acceleration profiles

To calculate the acceleration, we have considered the collected data points start at the stop line. When the vehicle starts to drive (seen by a vertical increase in the trajectory), the distance in meters is assumed to be 0,the time in seconds is assumed to be 0 and the speed is assumed to be 0 as well.

Using the retrieved data points of a singular vehicle trajectory, the acceleration parameters (a_{max} and p_{used}) of that vehicle can be found by minimizing the difference between the acceleration formula, including the acceleration parameters and retrieved data points (see the two pages of Appendix B, Klomp (2020)).

For optimizing the acceleration parameters, the function fitTrajectory.m can be used. It iteratively creates synthetic trajectories for various parameters (via getTrajectory.m) and thus finds the best one. TX.mat provides an example trajectory to test the method.

B DETAILED ACCELERATION MATHEMATICS

In this appendix all mathematical steps to get to the computation of the position and speed for every time step of an individual vehicle are outlined. An overview of all used variables, their units and a short description regarding these variables can be found in Appendix A.

Power equals force times the speed.

$$P = Fv \tag{B.1}$$

Moreover, the force is equal to the acceleration times the mass of an object.

$$F = ma \tag{B.2}$$

Additionally, the produced power at top speed can be calculated by multiplying the effective power at top speed with the horse power of the vehicle at top speed. Then, this outcome is divided by the top speed, resulting in the produced power. The effective power of a vehicle at top speed is normally equal to 0.9. This is due to the fact that the wheel resistance is approximately 10% at top speed for vehicles.

$$P = \frac{P_{\text{eff}} P_{\text{horse}}}{v_{\text{top}}} \tag{B.3}$$

The force that can be used for the acceleration of a vehicle is the force produced by the engine minus the force that is 'wasted' with the resistance.

$$F_a = F_e - F_{\text{res}} \tag{B.4}$$

In other words, the effective force for the acceleration of the vehicle is equal to the powered force minus the resistance force.

$$F_{\text{eff}} = F_p - F_{\text{res}} \tag{B.5}$$

The resistance force that applies to the vehicle at time t can be calculated by the formula for calculating the air resistance (or drag).

$$F_t^r = \frac{1}{2} C_d \rho A v_t^2 \tag{B.6}$$

In order to make the calculations a bit more clear, a new variable is introduced. This variable stands for the combined air resistance components that applies to the vehicle, without the speed.

$$\phi = \frac{1}{2} C_d \rho A \tag{B.7}$$

With this component, the resistance force that applies to the vehicle at time t can be calculated. Namely, this force is equal to the air resistance component times the squared speed at time t.

$$F_t^r = \phi v_t^2 \tag{B.8}$$

The force delivered by the engine at time t can be calculated by dividing a used power value by the speed at time t. The used power is kept the same for the entire acceleration distance. For every vehicle trajectory, this used power is fitted by means of the least square method as explained in Section 3.4.

$$F_t^e = \frac{p^{used}}{v_t} \tag{B.9}$$

Knowing both the resistance force at time t and the force delivered by the engine, the force that remains for the acceleration at time t can be computed. This is done by subtracting the resistance force at time t from the force delivered by the engine at time t.

$$F_t^a = F_t^e - F_t^r \tag{B.10}$$

Combining this equation with Equation B.2 enables the calculation of the acceleration of the vehicle at time t. Namely, this is equal to the acceleration force at time t divided by the mass of the vehicle. The mass of the vehicle is kept constant for the entirety of the acceleration trajectory.

$$a_t^f = \frac{F_t^a}{m} \tag{B.11}$$

However, the computed acceleration is not supposed to be higher than a certain maximum accepted acceleration by the driver. Therefore, an effective acceleration at time t is introduced. This effective acceleration is equal to the minimum of the calculated acceleration at time t and a maximum acceleration. This maximum acceleration is fitted for every individual vehicle. For the individual vehicles, this maximum acceleration is kept constant for the entire trajectory.

$$a_t^{eff} = \min\left(a_t^f, a_{\max}\right) \tag{B.12}$$

All this leads to the final to equation which calculate the speed at time $t+1$ and the position of the vehicle at time $t+1$. The speed can be calculated by adding the speed of the current time step (t) to the calculated effective acceleration at time t. This effective acceleration is equal to the calculated effective acceleration at time t times the time step.

$$v_{t+1} = v_t + a_t^{eff} dt \tag{B.13}$$

When the speeds at t and $t+1$ are known, the position of the vehicle at $t+1$ can be determined. This position is equal to the position at time t added to the average speed between t and $t+1$ times the time step.

$$x_{t+1} = x_t + \frac{v_t + v_{t+1}}{2} dt \tag{B.14}$$

These formulae and variables are used to fit the individual used power and maximum acceleration for the various observed vehicles.

Klomp, S.R. (2020) A microscopic approach to ramp metering. A case study in the Netherlands. *TU Delft.* pp. 19-23 and pp. 121-122 https://repository.tudelft.nl/islandora/object/uuid%3Ad756a787-9194-410c-9e4b-899915f06fc6

Klomp, S.R., Knoop, V.L., Taale, H, Hoogendoorn, S.P. (2021). Ramp Metering With Microscopic Gap Detection: Algorithm Design And Empirical Acceleration Verification. Transportation Research Records: Journal of the Transportation Research Board. In press.

Knoop, V.L., Hoogendoorn, S.P. and Van Zuylen, H.J. (2009) Processing Traffic Data collected by Remote Sensing. Transportation Research Records: Journal of the Transportation Research Board, No. 2129, pp. 55-61