1 Replication of the HBS Autobahn with SUMO

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1.1 Abstract

This work seeks to prove the following hypothesis: SUMO can reproduce the fundamental diagrams put forward by the German handbook HBS to a certain degree. This is demonstrated by the particular example of what is known in Germany as the E1 ramp, which is a one-lane ramp connected to a two-lane freeway. A comparison of the simulation by SUMO with the HBS will show that SUMO can qualitatively reproduce some realistic scenarios, but not the full range of the fundamental diagram.

Keywords: HBS, on-ramp, capacity, autobahn, freeway, highway

1.2 Introduction

The German HBS [1] is a handbook and determined to plan inter alia highways. To this end it makes predictions about capacities of different highway elements. Traffic simulation is not well established in the planning process, as the skepticism towards the applicability of simulations is high. Selecting one highway element, the on-ramp of type E1, SUMO [2] should be adjusted to reproduce the predictions made by the HBS.
The on-ramp of type E1 consists of a main road with two lanes and a ramp with one lane. Obviously, the flow of the on-ramp is limited by the maximum flow of the two inflows. But also the capacity of the main road behind the ramp further limits the capacity of the entire on-ramp. As the ratio of the inflows can vary, the HBS describes the capacity by means of an elliptical function. This function is derived from four theoretical boundaries - the capacity of the main road before the ramp (C_{HO}), the capacity of the ramp (C_E) and the capacity of the main road behind the ramp (C_{HU}). The HBS adds a fourth boundary resulting from the merging of the arriving vehicles from the ramp to the main road (C_M). The flow of the merging area q_M is the sum of the ramp's flow q_E and the flow of the main road's right lane $q_{HO,r}$:

$$q_M = q_E + q_{HO,r}. \tag{1.1}$$

The HBS describes this boundary by the following function:

$$q_E = C_E \cdot \sqrt[a]{1 - \left(\frac{q_{HO}}{C_{HU}}\right)^a}, \tag{1.2}$$

with q_{HO} as the entire flow of the main road before the ramp and a, chosen such that the elliptical function touches the boundary C_M. This function is represented by the dashed line in Figure 1.1, which also shows the above-mentioned boundaries.
Assuming that the HBS describes the reality, a microscopic simulation such as SUMO should reproduce these characteristics. Figure 1.2 displays an enlarged detail of the simulation, showing the significant part of the on-ramp.

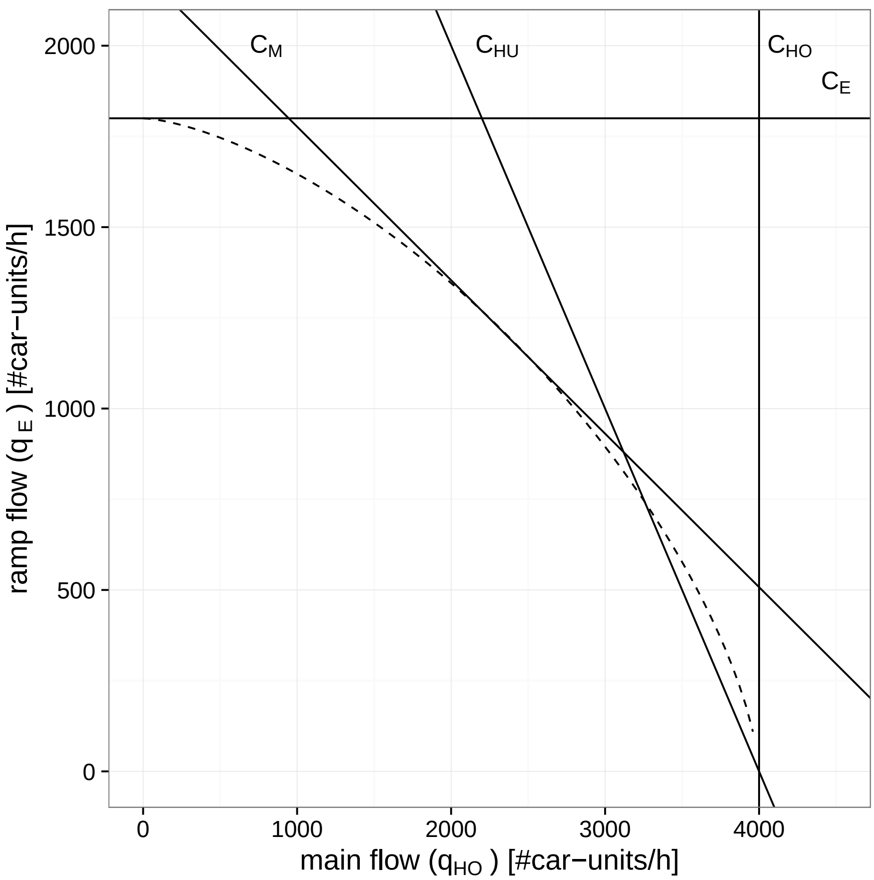

Figure 1.1: Construction of the capacity curve by the HBS for on-ramp E1

1.3 Methods

To determine the capacity of the on-ramp with SUMO, the simulation runs with slowly increasing flows. The capacity is reached briefly before the main flow breaks down. As the HBS makes no statement about breakdowns, it is not necessary to discuss the definition of breakdowns here. Important is that the capacity is defined as the maximum flow - in this scenario depending on the two inflows. With the current inflows, one gets one point of the capacity function predicted by the HBS.

The simulation measures the flows and speeds with induction loops aggregated for 5 minutes each. Each setup is repeated 10 times with a different set of random numbers. The HBS measures the number of vehicles in car-units, which adds a factor of 2 to the number of heavy traffic vehicles. Since the ratio of heavy traffic is chosen to be 10% in all simulations, the measured number of vehicles corresponds to the same number of car-units, but with a factor of 1.1 .

1.3.1 Implementation

Inflows

For the examination, it is necessary to choose some ratios of the two inflows leading to six realistic scenarios. These scenarios, named G1-G6, are defined with the following ratios q_E/q_{HO}:

G1 : 2/3 x 100%

G2 : 2/3 x 70%

G3 : 2/3 x 45%

Figure 1.2: Screen shot of the simulation for on-ramp E1

G4 : 2/3 x 30%

G5 : 2/3 x 20%

G6 : 2/3 x 10%

The measured ratios of the two inflows fluctuate, as there are an initial 4 km of main road and 500 m of ramp road to give the vehicles time to show a natural behavior. The scenarios always have an inflow ratio for heavy traffic of 10%.
To introduce as many vehicles as possible to the main road, some depart properties have to be observed. Property "departPos" is always set to "last." This introduces the vehicles with a minimum gap to the leading vehicle or at the end of the appropriate lane, if there is no other vehicle on this edge. The second important property to reach a high inflow is "departSpeed." Setting it to the critical speed determined previously, the vehicles already have the right speed to proceed with minimum headway.
Decreasing the time step of the simulation also increases the maximum flow of the main road. Since the other two properties already lead to a maximum flow of 4000 veh/h on the main road, which is the predicted capacity of the HBS, it is not necessary to change the default time step of 1 second.

Vehicle Types

According to the HBS scenario, at least two vehicle types have to be defined - a car type and a truck type. Only few properties of the vehicle types have a significant influence to the capacity of the on-ramp. One of them is the model parameter sigma. Using the default value of 0.5 leads to capacities around the predicted ones of the HBS, but this is insufficient, since the maximum inflow for the main road is 4800 veh/h instead of 4000 veh/h. That means the capacity of the main road is too high. A sigma of 1.0 makes the capacities describe a straight line above the HBS curve and decreases the maximum inflow to 3400 veh/h. Using values of around 0.7 for the car type and 0.9 for the truck type seems to be more reasonable. The maximum inflow of the main road is 4000 veh/h and the capacities follow a straight line. As the other properties have little impact to the capacity, they are set to realistic values shown in Table 1.1.

Road Network

It has already been mentioned that an on-ramp of type E1 is used, this is consisting of a main road with two lanes and a ramp with one lane. The main road has at least an initial 4 km and the ramp 500 m. The preceding edges are 1 km and 500 m respectively and are designed for the insertion of the vehicles. The merging area is 250 m followed by a 500 m road with two lanes.
As is standardly the case in Germany, trucks are not allowed to go faster than 80 km/h on the main road. The ramp is limited to 80 km/h for all vehicles.

Attribute	Value	Attribute	Value
id	car	id	truck
maxSpeed	50	maxSpeed	25
accel	3.5	accel	1.3
decel	4.5	decel	3.5
length	5	length	10
sigma	0.72	sigma	0.9
tau	1.2	tau	1.0
minGap	2.8	minGap	3.0
speedFactor	1.19	speedFactor	1.12
speedDev	0.1	speedDev	0.02
departLane	random	departLane	0
lcSpeedGain	1.0	lcSpeedGain	0.5

Table 1.1: Used vehicle types for the simulation with SUMO

1.3.2 Determining the Capacity from the Simulation

Figure 1.3 shows the measured fundamental diagram for three of the six simulated scenarios. The fundamental diagram consists of the mean speed depending on the entire flow, both referring to the main road before the ramp. Starting with free flow, the usual course of the fundamental diagram is a decreasing speed with an increasing flow; as soon as the capacity is reached, the flow decreases. As the state of maximum flow is not stable, there can be few measurements for that part of the state space and a determination of the capacity is not precise. To get around this problem, it is possible to choose a critical speed leading to maximum flows. Now the flows of the time intervals are used as the capacity where the speed falls below this critical speed.

1.4 Results

1.4.1 Evolution of the Simulated Flows

The mean speed evolution of the main road before the ramp has a similar course for all scenarios (as shown for example in scenario G4 in Figure 1.4). It starts with a value of around 40 m/s and decreases over time. At a certain point, the mean speed breaks down and fluctuates between the critical speed and 0 m/s. By construction, the mean flow of the main road before the ramp increases over time until it reaches a certain, mostly maximal value (Figure 1.5). Then it remaons constant or decreases marginally over the remaining time. Mostly, the time interval, where the speed falls below the critical speed, is also the interval with the highest flow. For the scenarios where the highest flow cannot exactly be extracted, the critical speed helps to determine a flow.

Smoothed Curves by Averaging per Scenario

Since the random number seeds of the individual scenarios show the same course, it is possible to average the speed and flow for each time interval to receive one smooth curve per scenario. The averaged values are plotted in Figure 1.6 and Figure 1.7. As expected, the speeds decrease and the flows increase with different slopes for the different scenarios.

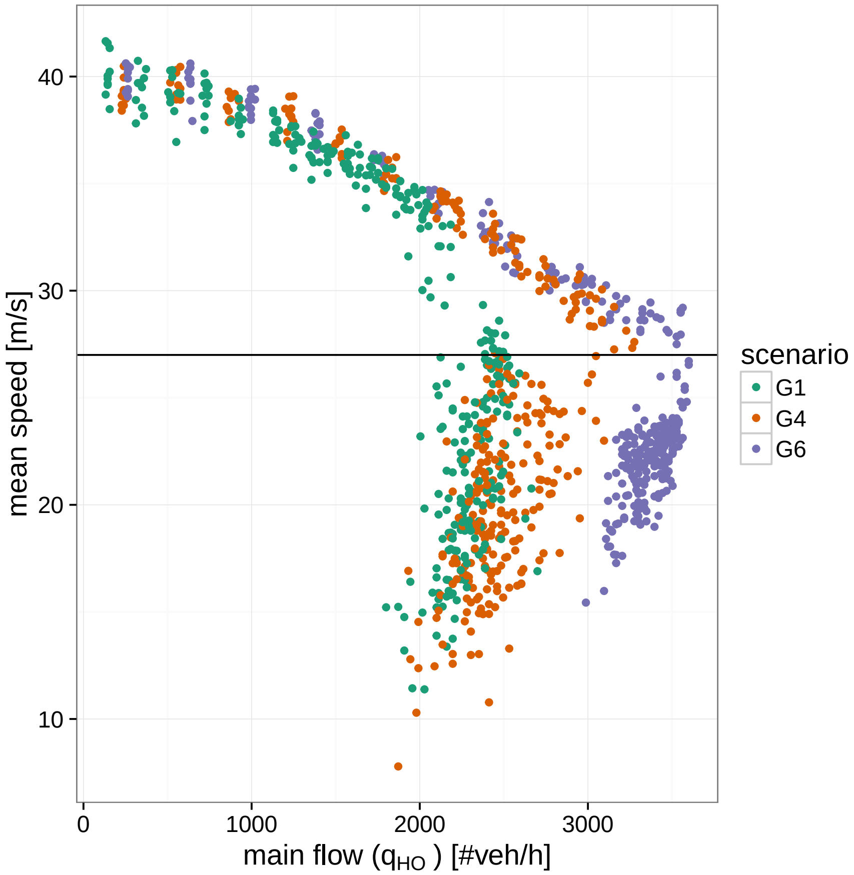

Figure 1.3: Fundamental diagram for three of the measured scenarios

1.4.2 Measured Capacities

Considering the extracted capacities in Figure 1.8, it is not clear whether they follow the HBS curve. They could also follow the capacity of the main road behind the ramp (boundary C_{HU}). To investigate the upper left part of the capacity, three additional "unrealistic" scenarios G0, G-1 and G-2 with higher ramp flows are executed. Although they mostly show no breakdown within the considered time range, the ramp inflow has a maximum value of around 1700 veh/h ($\approx$ 1850 car-units/h), which corresponds to the limit C_E given by the HBS.
Figure 1.9 shows all averaged flow evolutions over all random number seeds for each scenario. The possible flows seem to be limited by two straight boundaries - a maximum value for the flow of the ramp and a boundary similar to the capacity of the main road behind the ramp.

1.5 Discussion

SUMO can reproduce the capacity boundaries C_E and C_{HU}, as the capacities in Figure 1.8 and the larger values for the flow in Figure 1.9 show. The courses of the flows for scenario G-1 and G0 indicate that the simulation does not noticeably observe the limitation by the merging area C_M. This could be an issue of the way the vehicles interact while merging. A change of the lane change parameter "lcCooperative," which is responsible for the willingness to perform cooperative lane changing, does not achieve a better behavior. It alters the position of the maximum flows, but they still describe a straight line with almost the same slope. As well, the calibration of the other considered parameters does not change the qualitative behavior of the flows. There is always an upper boundary for the flow of the ramp and a boundary following a line such as C_{HU} with the same slope.

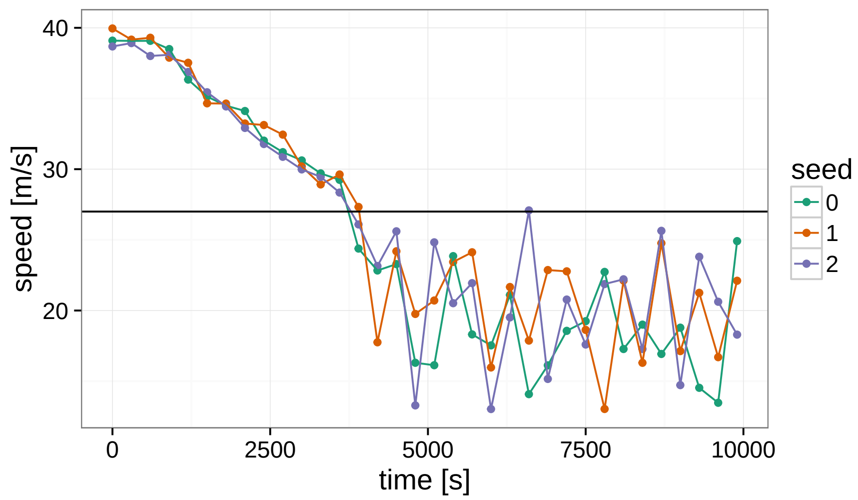

Figure 1.4: Speed evolution for scenario G4 (main road)

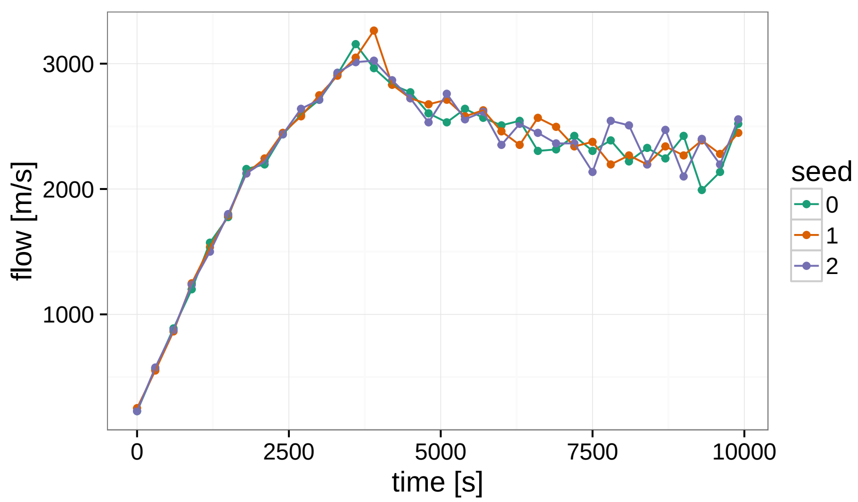

Figure 1.5: Flow evolution for scenario G4 (main road)

Overall, SUMO can reproduce the course of the capacity in a realistic range. Fine-tuning is necessary to shift the capacities of the ramp and the main road to the capacities given by the HBS. That however does not mean SUMO behaves realistically. As the capacities with higher ramp flow shows, the merging should be revised. As well, the influence of the other parameters needs to be clarified, since these parameters do not affect the capacity, but, rather, the microscopic behavior of the vehicles.
As a next step, real life data should be used to calibrate a SUMO simulation. This will show whether the found parameters will also reproduce other scenarios and could help to understand the problems of merging in this context.
Additionally, further freeway elements such as off-ramps and weaving sections should be investigated to get an overall overview of the freeway simulation.

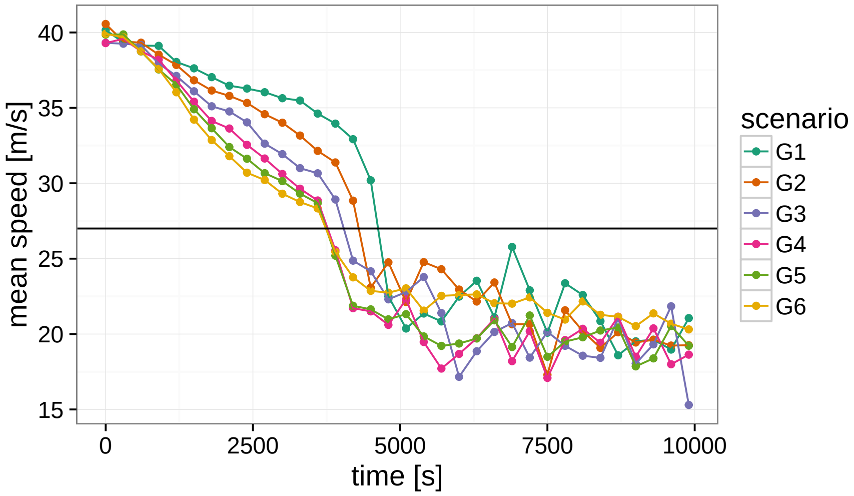

Figure 1.6: Speed evolution for all averaged scenarios (main road)

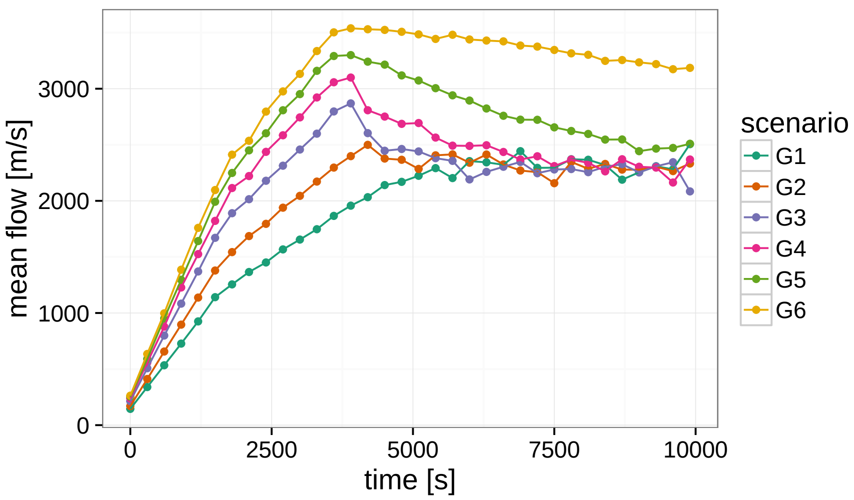

Figure 1.7: Flow evolution for all averaged scenarios (main road)

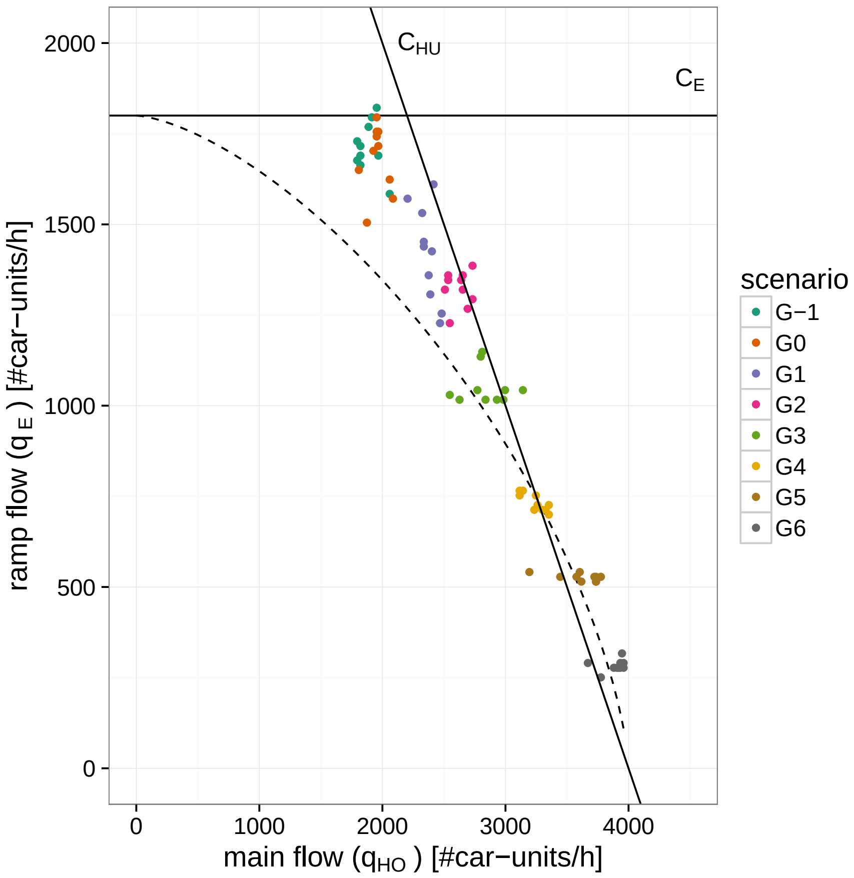

Figure 1.8: Capacities for all scenarios and seeds (dots), prediction by HBS (dashed line), capacity of the ramp C_E and the main road behind the ramp C_{HU}

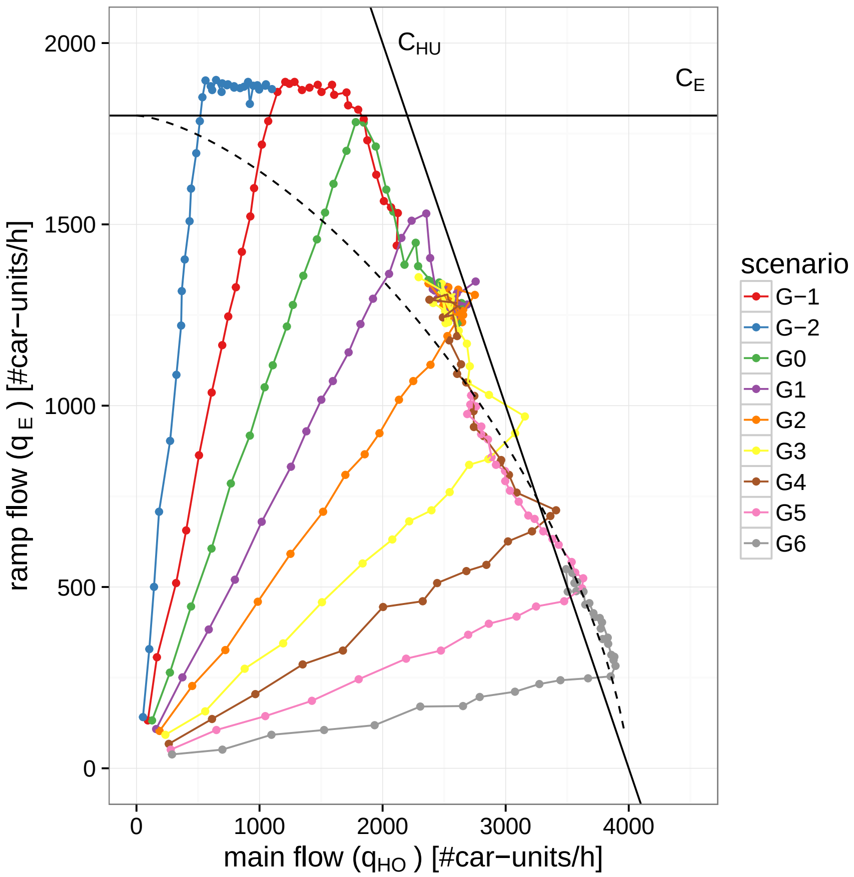

Figure 1.9: Flow courses for all scenarios (dots with lines), prediction by HBS (dashed line), capacity of the ramp C_E and the main road behind the ramp C_{HU}

References

[1] *HBS – Handbuch für die Bemessung von Straßenverkehrsanlagen*, volume Autobahnen, Landstraßen, Stadtstraßen. FGSV Verlag – Der Verlag der Forschungsgesellschaft für Straßen- und Verkehrswesen, 2015.

[2] Behrisch, Michael, Laura Bieker, Jakob Erdmann and Daniel Krajzewicz: *SUMO – Simulation of Urban MObility: An Overview*. In *Proceedings SIMUL 2011, The Third Conference on Advances in System Simulation*, pages 63 – 68, 2011.