

Workload Patterns of Fast Charging Stations Along the German Autobahn

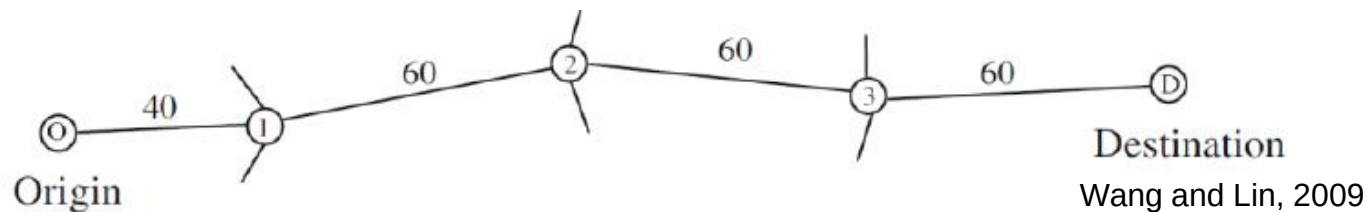
Patrick Jochem, Philipp Landes, Melanie Reuter-Oppermann, and Wolf Fichtner

Karlsruhe Service Research Institute (KSRI)



Agenda

- Significance of fast charging stations along the highway
- Optimised allocation (Jochem et al., 2016)
- Analysis of workload patterns on single charging stations
- Conclusions



Motivation

- Most charging happens at home or work (Mode 2-3¹).
- This charging strategy is sufficient for most EV applications today.
- Less than 10% of passenger car trips exceeds 100 km in Germany.
- Most of them take place (at least partly) on highways.
- The fast charging DC infrastructure (Mode 4) along the highway is
 - desired and needed,
 - frequently used, and
 - therefore, more profitable than other public charging stations.
- Mode 4¹ allows recharge (<150 km) in 15 minutes.



Combined Charging System (CCS)

¹ IEC 61851-1

Literature status

- Most literature is focusing on the optimal allocation of fast charging stations in the network:
 - OR based approaches (e.g. Chung und Kwon 2015; Li et al. 2016)
 - ... including the rollout pattern in several periods (e.g. MirHassani and Ebrazi 2013)
- Usage patterns of these stations are mostly neglected.

The applied model (Jochem et al., 2016)

- The maximum-covering formulation of the Flow Refueling Location Model (FRLM) is given by:

$$\text{Max} \sum_{q \in Q} f_q y_q \quad (1)$$

Subject to

$$\sum_{k \in K_{j,k}^q} z_i \geq y_q \quad \forall q \in Q, \quad a_{j,k} \in A_q \quad (2)$$

$$\sum_{i \in N} z_i = p \quad (3)$$

$$z_i, y_q \in \{0,1\} \quad \forall q \in Q, \quad i \in N \quad (4)$$

Notation:

Inputs

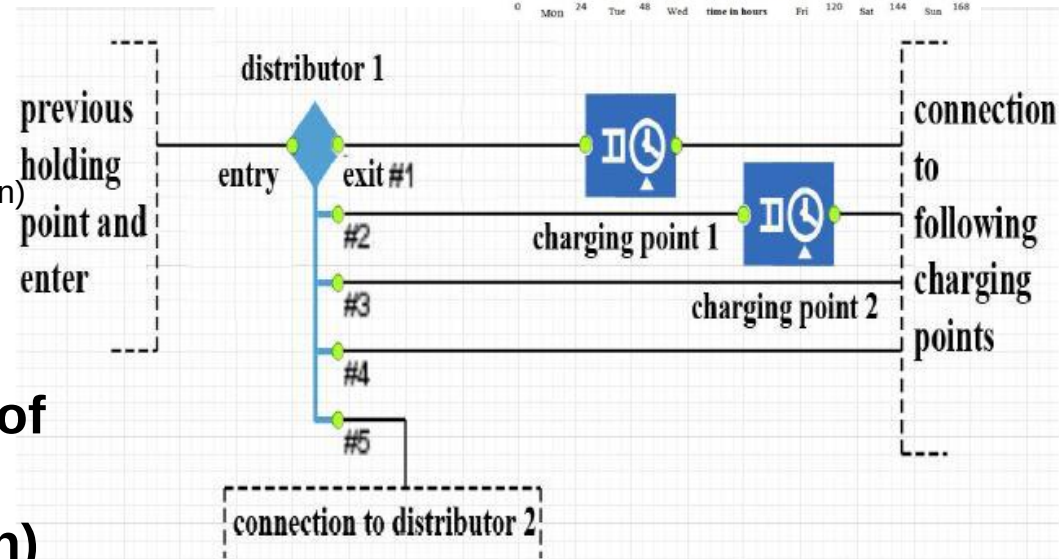
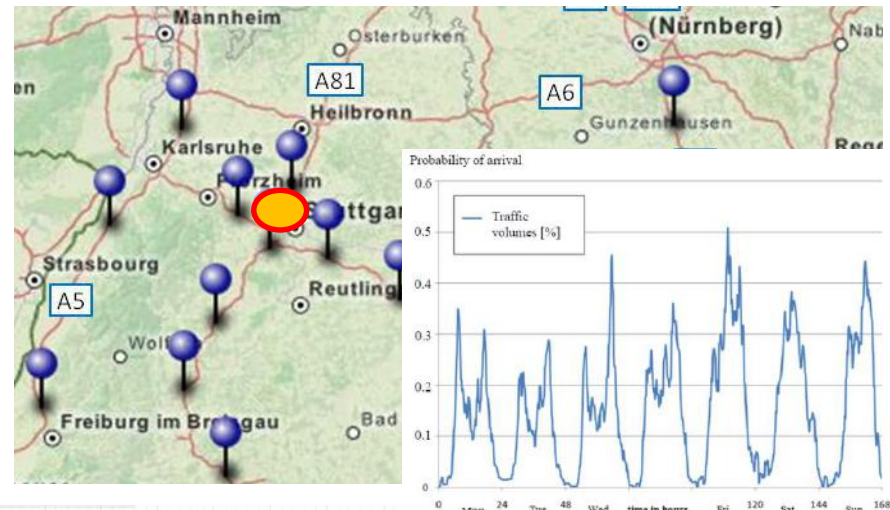
- $a_{j,k}$ = A directional arc starting from node j and ending at node k
- A_q = Set of directional arcs on path q , sorted from origin to destination and back to origin
- f_q = Volume of traffic flow on the shortest path between OD pair q
- i, j, k = Indexes for potential facilities
- $K_{j,k}^q$ = Set of candidate sites, which can refuel the directional arc $a_{j,k}$ in A_q
- M = Set of OD nodes where $M \subseteq N$
- N = Set of nodes which constitute the network, $N = \{1, 2, \dots, n\}$
- p = The number of stations to be located
- q = Index of OD pairs
- Q = Set of OD pairs

Decision variables

- y_q = 1 if the flow on path q is refueled
0 if not
- z_i = 1 if a service station is built at node i
0 if not

Our approach

- Optimized charging allocation in southern Germany (Jochem et al., 2016)
- Specifying time-dependent vehicle volumes over a representative week (MOP, 2014)
- Designing and implementing a simulation tool for a single charging location
- Defining “charging share”
- Probabilistic arrival time (Poisson)
- Individual charging time
- Analyzing the waiting time of the most frequently used charging station (Böblingen)



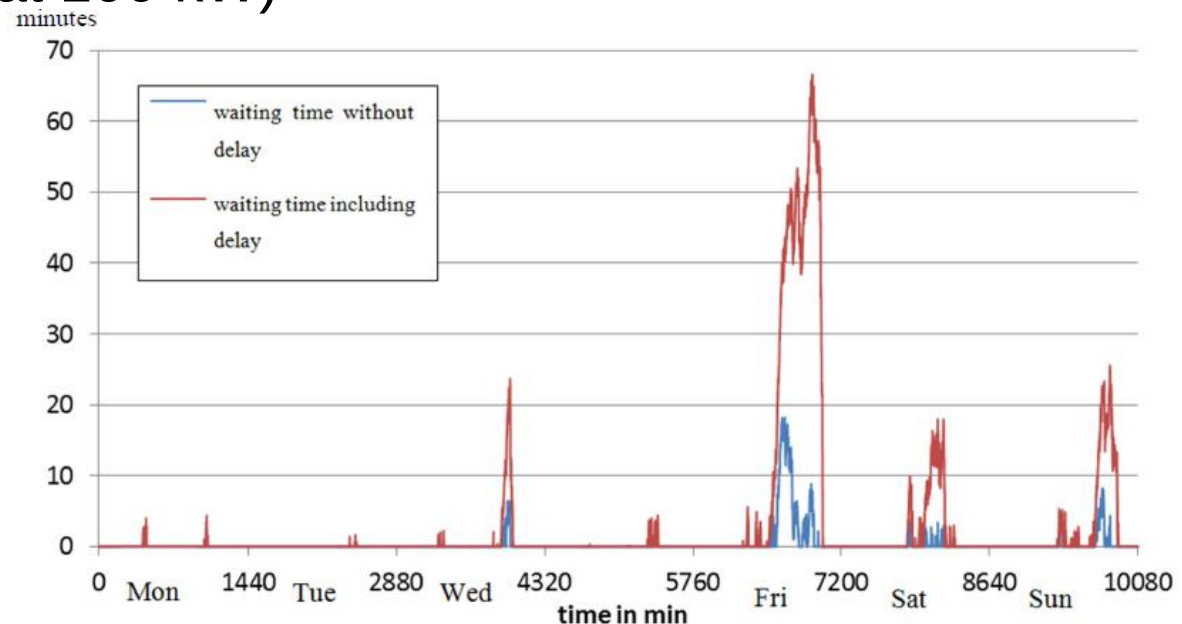
Results for exit Böblingen

Assumptions

- Only 20 fast charging opportunities in southern Germany
- 1062 charging events per day for 2020 (EV share: 2.25%)
- 20 charging points per charging location (2 MW)
- average gross charging time is 9.6 minutes per charge (demand of 16 kWh at 100 kW)

Results

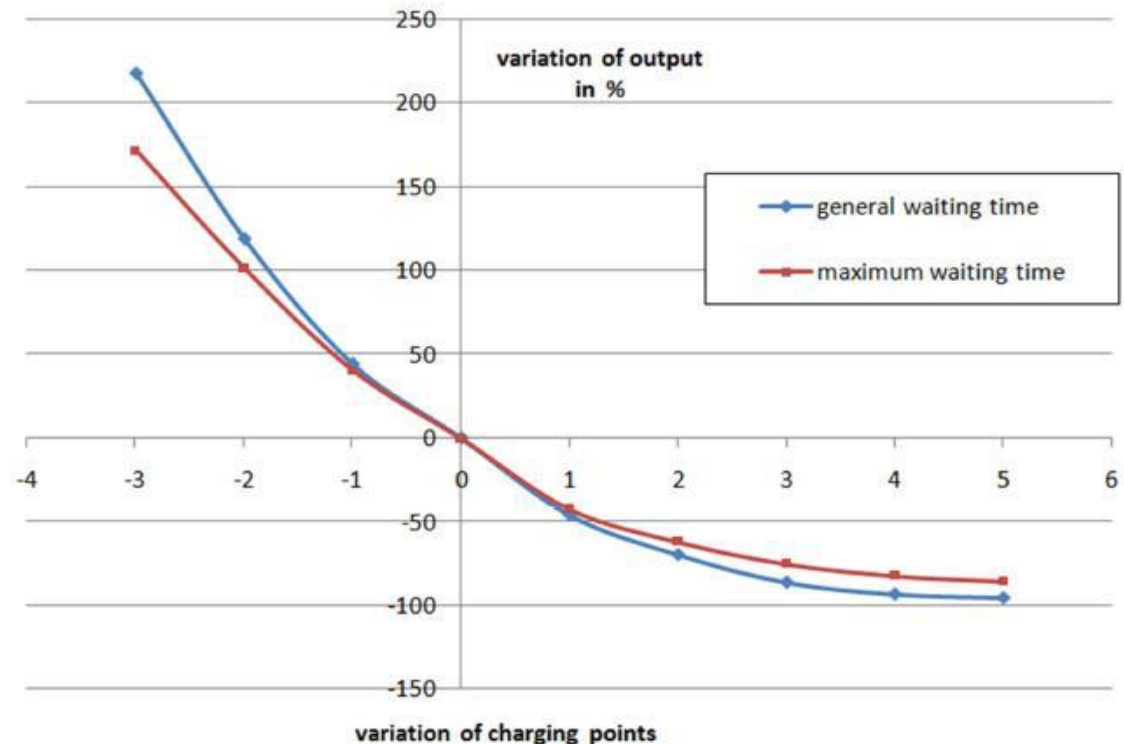
- Utilization hours are 75% → Profitability is high
- Waiting time exceeds 60 minutes on Friday afternoon



Sensitivity analysis

Main influences

- Traffic volumes (+10% → 150% average waiting time)
- Gross charging time (+10% → 150% average waiting time)
- Number of charging points per charging location
(one additional point leads to a decrease of maximum waiting time by 50%)



Conclusions

- There is a significant **need** for fast charging stations along highways.
- We analyzed the **waiting time** at the fast charging station with the highest traffic volumes in southern Germany for 2020 by developing a simulation model.
- Waiting time during **Fridays** is significant (trade-off between waiting time and costs).
- Electricity demand is high and exceeds **2 MW** on Fridays (grid!).
- The utilization hours are very high and a **profitable** operation of fast charging stations seems highly probable.
- The **sensitivity** is significant and we therefore propose an **individual** calculation for each charging station.

Outlook and further research

- Combination of both simulation and optimization seems to be very promising analysis.

Literature

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Thank you for your kind attention!

jochem@kit.edu

