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Optimization of novel charging Infrastructures using linear programming[⋆]

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Abstract: Future traffic that will be accompanied by higher alternative drive concepts will pose as a challenge when it comes to corresponding energy systems. Whereas today's conventional energy supply infrastructure (in form of gas stations) has not been optimized for the integration of charging processes into vehicle operation, the inevitable development of alternative energy supply systems and infrastructures will pose as a chance to reevaluate and optimize them accordingly. This paper will show that with currently available charging powers charging processes can be integrated into urban traffic operations without the need for explicit charging halts or detours (e. g. at traffic lights) and present a method for the analysis of microscopic traffic scenarios and the optimal placement of corresponding charging stations.

Keywords: Road traffic, electric vehicles, optimization problems, urban systems, linear programming.

1. INTRODUCTION

The prospective post-oil era and rising fuel prices have lately resulted in several global trends towards alternative drive technologies. Main advantage of oil over many other energy carriers is not only its high energy density of up to $45,4\,\mathrm{MJ/kg}$ but also the immensely high charging power of over $51,6\,\mathrm{GW}$ (assuming a pumping rate of $80\,\mathrm{l/min}$). In consideration of these parameters, alternative drive concepts will be accompanied by drawbacks that can not only be compensated by vehicle optimizations. Infrastructural optimization will be required to make vehicles with alternative drive concepts attractive for potential buyers and their successful market penetration.

Main drawback of electric vehicles today is their limited driving range and the low charging powers. Analyses show that both disadvantages can be countered by optimizing the location of energy supply infrastructure components and integrating the process into traffic operation, such that explicitly designated halts for charging will become unnecessary.

The German Federal Ministry of Transport and Digital Infrastructure is therefore funding the project *emilia*, the German acronym of *electric mobility with inductive charging in automobiles* (*Elektromobilität mittels induktiver Ladung im Automobil*). The pursued method in project *emilia* for optimizing charging station locations consists of (1) modelling urban traffic scenarios using the microscopic traffic simulation tool SUMO [Krajzewicz et al. (2012)] and (2) evaluating vehicle routes. SUMO's development was initiated by the Institute of Transportation Systems of the German Aerospace Center (DLR), in 2001. It has evolved into a simulation tool, high in features, functionality and interfaces. It was chosen in project *emilia*, since none of the available microscopic traffic simulation tools supports the calculation of vehicle energy consumptions and due to its open source character and its license under GPL. This has allowed the extension of its functionalities for the definition of vehicles along with energy consumption relevant parameters and the implementation of energy consumption calculations as well as charging stations [Kurczveil et al. (2014)].

Using SUMO or any other microscopic traffic simulation tool requires a valid and representative traffic scenario, whose creation will be outlined in section 2. Using the microscopic traffic simulation results, the method for optimizing charging station locations will be presented in section 3 and interpreted in section 4.

2. BUILDING AN URBAN TRAFFIC SCENARIO

For the creation of representative traffic scenarios in the regarded urban area, *eNetEditor* [Kurczveil and Lopez (2015)] was used. It has previously been developed at the institute for traffic safety and automation engineering and allows the rapid creation of microscopic traffic scenarios with energy relevant parameters. Using traffic data and measurements from different sources, such as flows measurements from induction loops, *eNetEditor* allows the generation of traffic demand for microscopic traffic simulations. The goal is a simulation output in form of a structure that can be used to represent energy consumption of individual vehicles over time and vehicle position or along individual lanes of a road network over time. An example urban traffic scenario has been created that

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represent a section of Brunswick's urban road transport.

Primary data source for the traffic demand is the city's traffic intensity map [Stadt Braunschweig (2015)], which was used to generate routes. The general problem of solely using routers is that vehicle instances are assigned a route under static conditions, e.g. by searching for the *shortest* path through the network. Prevailing traffic conditions are not regarded. This task can be compared to that of finding a/the short/est way through a traffic-intense urban area, only by knowledge about the nodes and edges in its network, in hope that the chosen route will be the fastest or the one with the least amount of energy required. It is obvious that prevailing traffic conditions can have a high impact on these optimization criteria. In real traffic, participants without (sometimes also with) assistance usually need a few tries, where the iterative variation of departure time and/or route choice ultimately yields the optimal perceived route for a recurring trip.

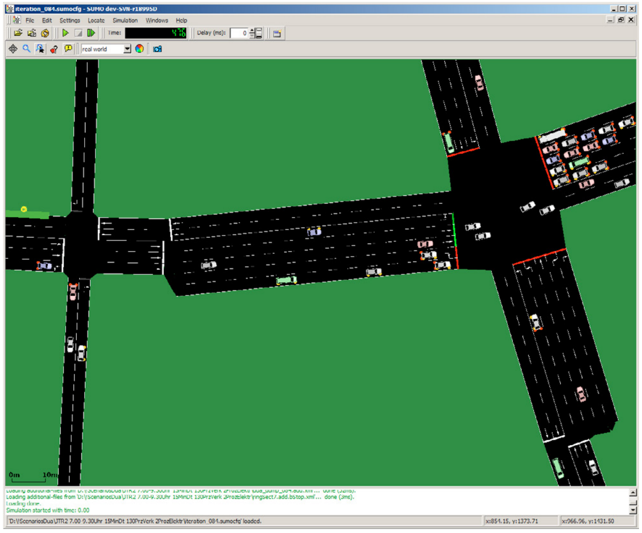
A variety of methods exist for traffic simulations that aim to minimize a cost function to find an optimum route distribution among participants (vehicles) in a similar manner as described above. In the scope of this work, demand calibration refers to the adaption of these route assignments. A comparison between different traffic demand assignment methods can be found in [Behrisch et al. (2010)]. eNetEditor provides an interface to two established implementations for SUMO that aim to optimize the route assignment for vehicle instances: *DUAROUTER* [Gawron (1999)]and *cadyts* [Flötteröd et al. (2011)]. The basis for both is a validated set of vehicle trips, each consisting of origin, destination, and departure time. These parameters are taken from the route definitions that were stochastically determined previously by routers. The subsequent calibration of traffic demand in eNetEditor is implemented as a 2-phase process:

(1) DUAROUTER: Vehicle routes are distributed by creating alternative routes and evaluating the resulting edge-based weights for specified vehicle trips, until no vehicle can modify its route choice without increasing its travel cost. One of the outputs is a vehicle route file for vehicles containing alternative route probabilities and corresponding travel costs.
(2) cadyts: cadyts itself performs no routing. The alternative routes created by DUAROUTER are evaluated and vehicle route choices adapted, such that the chosen routes comply with detector measurements passed as an input to cadyts.

Whereas the result of DUAROUTER is the so-called *dynamic user equilibrium*, cadyts aims at redistributing vehicle routes in compliance with traffic measurements, while minimizing vehicle travel durations.

A screenshot of the resulting traffic scenario can be found in Fig. 1. Next to calibrated routes, the traffic demand includes a realistic distribution of vehicle types.

The remaining sections of this contribution assume that a calibrated traffic scenario exists for the regarded urban road traffic system. The considerations and optimizations, which will be carried out, will not affect the determined vehicle routes.



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Loading additional-files from 'D:\\ScenariosDua\JTR2 7.00-9.30Uhr 15MinDt 130PrzVerk 2ProzElektr\ringSect7.add.bStop.xml'... done (3ms).
Loading done.
Simulation started with time: 0.00
'D:\\ScenariosDua\JTR2 7.00-9.30Uhr 15MinDt 130PrzVerk 2ProzElektr\iteration_084.sumocfg' loaded.
x:854.15, y:1373.71
x:966.96, y:1431.50
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Fig. 1. .The regarded traffic scenario as represented in SUMO's GUI.

3. CHARGING STATION OPTIMIZATION

First analyses have indicated that with currently available charging powers, only a fraction of urban road networks would have to be equipped with charging stations in order to supply all of its vehicles with the adequate amount of energy required to complete their routes. Many vehicle halts in current prevailing traffic, such as at red lights, could be used for charging, *if* it could be allowed at the corresponding locations. Especially the inductive charging technology seems very promising, when it comes to the integration of these charging process into traffic. Most inductive systems require vehicles to be standing still, before a secondary coil can be lowered into the proximity of a primary coil and the energy transfer can be initiated. This process usually takes only a few seconds, and does not involve the driver handling any charging cables. Newer systems have also been developed and successfully tested, where energy is transferred into moving vehicles over longer road segments that are equipped with primary coils. The optimal placement of charging stations for the supply of urban road traffic shall be covered in this chapter and a corresponding model be formulated. It will be assumed that vehicles need to halt to receive energy from a charging station and that the energy transfer begins only after a regarded vehicle has stopped for the duration $t_{s,\mathtt{min}}$.

The facility-location problem for the optimal placement of charging stations is not entirely new. Existing algorithms have therefore been studied that optimize charging station locations to provide a maximum amount of vehicles with adequate energy for their chosen routes. These are referred to in literature as flow capture location allocation (Hodgson (1990)), discretionary service facility location (Berman et al. (1992)), and flow refueling location [Kuby and Lim (2005)] problems.