Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 41 (2019) 146–149

Transportation Research Procedia

www.elsevier.com/locate/procedia

International Scientific Conference on Mobility and Transport
Urban Mobility – Shaping the Future Together
mobil.TUM 2018, 13-14 June 2018, Munich, Germany

GIS-based modelling of fast-charging infrastructure at city-regional level

Tamer Soylu[a,*], Michael Heilig [a], Lars Briem [a], Patrick Plötz [b], Martin Kagerbauer [a], Peter Vortisch [a]

[a]*Institute for Transport Studies (IfV), Karlsruhe Institute of Technology (KIT), Kaiserstrasse 12, 76131 Karlsruhe, Germany*
[b]*Fraunhofer Institute for Systems and Innovation Research ISI, Breslauer Strasse 48, 76139 Karlsruhe, Germany*

Keywords: Electric vehicles; GIS modelling; Agent-based simulation

1. Problem Statement and Research Objective

The development of electric mobility has a substantial role in mitigating the negative effects of fossil fuels, given the fact that around 14% of global greenhouse gas emissions result from transport sector (IPCC, 2014). However, despite developments in battery technology and charging infrastructure, desired acceptance of electric mobility by the masses has not been realized yet. Beside the well-known arguments against electric vehicles like limited range, higher costs and lack of charging infrastructure, political willingness and interventions at different administrative levels also affect the expansion of electric mobility. Whereas some communities are highly motivated to develop their charging infrastructure, others, do not even have an agenda on electric mobility. Financing public charging infrastructure could be a heavy burden on municipal budgets, therefore lacking interest in promoting them is understandable. Consequently, assessing the real demand for charging infrastructure and their optimal allocation is an important task for local authorities to prevent malinvestments.

* Corresponding author. Tel.: +49-721-608-43048; fax: +49-721-608-48031.
E-mail address: tamer.soylu@kit.edu

2352-1465
10.1016/j.trpro.2019.09.026

The objective of this paper is to provide a methodology to determine and assess the optimal areas to allocate fast-charging infrastructure at a city-regional level. We developed a geospatial analysis tool to assess the optimal allocation of fast-charging infrastructure within a city-region. Our approach enables to determine possible locations for fast-charging infrastructure and evaluate the economic feasibility based on simulation of the demand for infrastructure under different market diffusion scenarios of electric vehicles. We integrated our approach in a GIS-tool for the region of Stuttgart, Germany, enabling policy makers and possible investors to apply the model for planning purposes.

2. Methodology

Site analysis and allocation are common tasks in infrastructure planning. Sound methods have been developed and been implemented as tools among others in GIS software. These methods have been also inherited for the analysis of EV charging infrastructure. Previous studies have addressed the problem of optimal location allocation by using complex mathematical models, such as discrete, graph theory based methods (Wang and Wang, 2010; Wang and Lin, 2013), diverse location models (Sathaye and Kelly, 2013; He et al., 2013) and capturing models (Lim and Kuby, 2010). The main difficulty in location allocation problem is in the contradiction that spatially detailed complex models are time and cost inefficient.

Our method focuses on a flexible and easy to compute modelling approach, which consists of three parts. First, we determine the optimal locations for possible fast-charging infrastructure. Then, we simulate the charging demand for each location using an agent-based microsimulation for travel demand. Finally, we assess each location and calculate the necessary charging points based on different criteria and structural characteristics by using the GIS-based assessment tool. The main emphasis in this paper is on the first and third part of the approach.

2.1. Allocation of charging locations

Our methodology is based on the analysis of road network, travel times and build-up environment for the optimal location of fast-charging infrastructure. We used an existing travel demand model for the region of Stuttgart in Germany, which has a population of around 2.7 million and a total area of 3.654 km^2. Road networks, travel demand and travel times are imported into GIS from this demand model for further analysis. A GIS-based network analysis of travel times on a weekday with the typical demand for the given weekday and time intervals delivers a solution for the accessible charging locations. This is a location-allocation kind of network analysis problem, solved in ArcGIS®. Basically, the location-allocation network analysis allocates a given number of demand points on the network to an optimal number of service points or vice versa. Criteria such as accessibility to service points within a given time or minimum number of demand points that should be served are user-defined parameters for the calculation. In our approach, we set accessibility times for service points (charging infrastructure) from each demand point (residential areas) as such parameter. For the identification of demand points on the network some additional spatial analysis are undertaken. Since the population of a zone in the travel demand model is saved as an attribute of the zone, a spatially precise and disaggregated localization of population within the zone is not possible. We used open source data (OpenStreetMap) of building footprints in the region and calculated a weighted distribution of population in residential areas as demand points within zones.

Depending on the calculated travel times on the network, locations for fast-charging points were then determined under the condition that these points would be accessible within five or ten minutes and yet the smallest possible number of points have to be installed. Specific areas such as natural reserves, tracks for rail traffic etc. were not considered as potential locations and are excluded from the analysis. The defined locations are then used as input for the simulations in the microscopic demand model.

2.2. Agent-based microsimulation

The evaluation of potential locations for fast-charging points is based on simulations of the travel demand model mobiTopp (Mallig et al., 2013) in the Stuttgart Region. mobiTopp is a multi-agent travel demand model, which models every person and household as well as cars and charging points of the planning area. People are modelled as individual agents, who are grouped together into households. Each agent is assigned an activity program for a whole week. This activity program is created in the first of two stages of mobiTopp, the long term model. In the second stage, all agents are simulated simultaneously. During the simulation, every agent selects the location and mode for their trips.

When using electric cars, the agent decides when the car has to be charged. The decision depends on the remaining capacity and the availability of charging facilities inside the destination zone. Charging facilities are assigned to each zone based on the simulated scenario. All charging events were then extracted from the simulation results and local demand for fast-charging infrastructure at the determined location was derived using queuing models. The simulation results include the number of charging events and the amount of energy consumed for each point and for each market penetration scenario for an average weekday.

2.3. Assessment tool

The most important part of our developed method is the assessment tool and its results. Aim of the scalable assessment tool is to calculate the number of necessary charging points for each location, evaluate and rank them based on different criteria and structural characteristics (number of electric vehicles, number of charging activities, economic efficiency). The tool allows the user to weight these criteria and characteristics individually, depending on the preferences of the user (for example, economic aspects could be more important than structural characteristics for the ranking of locations). Each location will be ranked differently.

For the economic efficiency, total costs were calculated, which took into consideration the purchase and sales prices for electricity as well as the estimated costs for construction, connection to power supply and operation for each location individually.

As structural characteristics, the total population in the investigation area of fast-charging location (areas that can be reached in 5 or 10 minutes from the location), the number of jobs within the investigation area, the number of POIs and private parking space in the area as well as the distance to the next junction with a non-built-up road (motorway of federal highway) were considered.

The number of potential charging points was evaluated depending on the demand. For each location an individual regression and queuing model (M/G/c model with 5 minutes waiting time) was set up. For each of these characteristics, an independent quantitative ranking was set up, resulting in a value between 0% and 100% for each variable – 100% being the best and 0% the worst value. The total ranking was then calculated using a weighted sum for the different variables.

The assessment tool is implemented in a GIS-environment using ModelBuilder in ArcGIS®, which offers a user interface for entering the input parameters interactively by the user. The results of the model, i.e. number of charging events and individual rankings, can also be visualized geographically in thematic maps.

4. Results and Conclusion

Based on an aspired accessibility of fast-charging points for all inhabitants in the Stuttgart Region within five minutes, 218 potential locations were determined, against 58 potential locations for an accessibility within ten minutes. Each location includes several charging points in order to minimize waiting times. The number of potential charging points was evaluated depending on the demand; however, a minimum of four charging points should be available at each location to ensure comfortable customer service.

Results of the tool for a market penetration of 300,000 electric vehicles and assuming 0.1 €/kWh buying and 0.3 €/kWh selling electricity show that the most profitable location is near to a highway and in the middle of a large commercial area. The amortization will take less than two years. The less profitable location will never redeem and is located in a rural area, where most electric vehicle users are able to charge their car at home anyway.

We created a tool for the assessment of predetermined locations for fast charging infrastructure, which is effortless to use and has brief computational times. It allows for individual weighting factors, which makes it suitable to be used for decision-making processes.

It is well suited for future tasks of assessing possible locations of fast charging infrastructure. Most assumptions can also be adopted and having the travel demand model applied, it can also be adapted to other regions.

Acknowledgements

We thank the “Verband Region Stuttgart (VRS)” for the permission to use the results of the project “Masterplan Schnellladeinfrastruktur Region Stuttgart” for scientific publication.

References

He, F., D. Wu, Y. Yin, and Y. Guan. Optimal deployment of public charging stations for plug-in hybrid electric vehicles. Transportation Research Part B: Methodological, Vol. 47, 2013, pp. 87-101. DOI: 10.1016/j.trb.2012.09.007.

IPCC (2014). Climate Change 2014: Mitigation of Climate Change . Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Lim, S., Kuby, M. (2010) Heuristic algorithms for siting alternative-fuel stations using the flow-refueling location model. European Journal of Operational Research, 204 (1), 51-61, 2010.

Mallig, N., Kagerbauer, M., Vortisch, P., 2013. mobiTopp – A Modular Agent-based Travel Demand Modelling Framework. Procedia Computer Science 19, 854–859. 10.1016/j.procs.2013.06.114.

Sathaye, N., and S. Kelley. An approach for the optimal planning of electric vehicle infrastructure for highway corridors. Transportation Research Part E: Logistics and Transportation Review, Vol. 59, 2013, pp. 15-33. DOI: 10.1016/j.tre.2013.08.003.

Wang, Y.-W., and C.-R. Wang. Locating passenger vehicle refueling stations. Transportation Research Part E: Logistics and Transportation Review, Vol. 46, No. 5, 2010, pp. 791-801. DOI: http://dx.doi.org/10.1016/j.tre.2009.12.001.

Wang, Y.-W., and C.-C. Lin. Locating multiple types of recharging stations for battery-powered electric vehicle transport. Transportation Research Part E: Logistics and Transportation Review, Vol. 58, 2013, pp. 76-87. DOI: 10.1016/j.tre.2013.07.003.