MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY

MICHIGAN STATE UNIVERSITY

Electric Vehicle Charger Placement Optimization in Michigan: Urban Study

CITY PLANNERS GUIDE

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- Cherryland Electric Cooperative
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- ITC Transmission Company
- Lansing Board of Water and Light
- Michigan Electric Cooperative Association
- Michigan Municipal Electric Association
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Cities and Communities
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- City of Grand Rapids
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- City of Kalamazoo

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Electric Vehicle Drivers & Owners

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Introduction

The findings of this report are aimed to provide city planners and communities preliminary insights on required plug-in electric vehicles (EV) infrastructure development to support EV travels in their area, and for local authorities and state government units to develop policies and strategies to support investments into public charging infrastructures. Michigan Department of Environment, Great Lakes, and Energy (EGLE) has funded the development of a comprehensive study, including analytical models considering applied constraints, to find the optimum investment scenario for each urban area and has supported it through a series of stakeholders' meetings. This approach considers the urban trips of EV users, electric grid infrastructure, and costs associated with building a network of charging stations to find the optimum investment strategy, while ensuring the feasibility of urban trips for EVs in Michigan. The results of this study provide a perspective to local authorities on details of investment that they need to make to support EV trips in their communities.

This report presents the study approach and results of the proposed modeling framework for locating DC fast chargers in different urban areas in Michigan for the urban trips of EV users in the state by the year 2030. Note that level 2 chargers are not the focus of this study, however, the impact of these chargers, located at shopping centers or work places, is considered as an input to the optimization framework. The results for major urban areas in Michigan are presented in more detail, while the results for smaller urban areas are presented in a more aggregate manner, depending on the availability of data for these urban areas.

Approach

The first step of modeling framework and solution approach proposed in this study is data collection. Data required for this study includes origin-destination travel demand (OD demand), road network information, land use information, land cost, electricity provision cost, and charging station and charger costs and specifications. Users' trips are then simulated using a dynamic traffic simulation tool. Then, using the state-wide Michigan network, different information including the number of zones, generated demand, lane length, and estimated traveled miles are extracted for each candidate city. Among the candidate cities, those with sufficient network details and generated trips are selected for detailed EV charger placement analysis. In addition, Marquette with the highest generated demand in Upper-Peninsula is selected for the detailed analysis.

Then the entire trips within the state of Michigan are simulated, providing the ability to track each vehicle's trajectory. The next step is simulating the EVs' initial state of charge. Unlike the intercity trips, which are well-planned and begin with fully charged batteries, urban trips are not usually well-planned, and users might start with any state of charge. Therefore, a state of charge simulator is developed, which works based on the trip purpose, and land use at the trip origin. This simulator determines the initial state of charge for each trip trajectory. Then, all the above-mentioned information are used as inputs to the optimization model.

The optimization-based modeling framework proposed in this study considers the limited range of EVs and ensures that every EV trip is feasible by providing supporting charging infrastructure, while minimizing the total cost of charging infrastructures and the monetary value of delay experienced by EV users. The model differentiates between different candidate locations that can be equipped with charging stations based on land acquisition cost and electricity provision cost at each location. The constraints considered in this model include flow conservation equations, station allocation, tracking the state of fuel, trip feasibility, and delay at stations.

Results

The optimization-based modeling framework designed and proposed in this study finds the location of charging stations and number of chargers for the major urban areas (considering travel demand and size of the city) in the state of Michigan. This summary report presents the number of chargers and charging stations, as well as the associated costs. Specific location (latitude-longitude) and the number of chargers at each location can be accessed in the main urban study report. Separate reports are also available that present the required charging infrastructure for intercity/highway trips, as well as tourism travel, during the target year of 2030 in Michigan. Due to the limited data available, the analysis for the smaller urban areas is limited to the aggregate models finding the number of chargers, charging stations, and the investment costs. In case of requiring a more detailed analysis of smaller urban areas, please contact the authors.

Major Urban Areas

The optimization-based modeling framework provides the location of charging stations, number of chargers and estimated investment required for urban areas with largest travel demand and size in the state of Michigan, listed as Marquette, Muskegon, Ann Arbor, Kalamazoo, Flint, Saginaw, Lansing, Grand Rapids, and Detroit.

Through a series of stakeholder meetings, different scenarios with different battery and charger technologies are suggested and investigated for this study. The suggested EV battery energy levels are 70 kWh and 100 kWh, and charging station power levels of 50 kW and 150 kW are considered for chargers. Also, the winter scenario is selected for this study, as the number of urban trips is known to remain relatively constant seasonally, while the reduced battery performance during the cold seasons requires more chargers and charging stations. Table 1 shows a summary of the findings for different urban areas sorted by their travel demand.

Table 1. Summary of findings for major urban areas and different scenarios, sorted by travel demand

Urban Areas	Number of Stations	Number of Chargers	Total Infrastructure Cost (Million dollar)	Average Charging and Queuing Delay (min)
Marquette	4-5	8-19	1.13-1.39	4.24-15.63
Muskegon	6-9	18-48	2.27-2.72	3.94-15.13
Ann Arbor	3	10-29	1.74-2.02	4.01-15.35
Kalamazoo	7-12	19-57	2.47-3.26	3.79-14.63
Flint	8-14	26-73	3.47-4.62	3.85-14.90
Saginaw	17-27	45-123	5.70-7.17	4.11-15.82
Lansing	10-16	33-89	4.62-5.91	3.83-14.74
Grand Rapids	12-17	47-132	6.09-7.31	3.79-14.65
Detroit	42-62	233-636	30.09-38.41	3.97-15.40

The number of stations for the different scenarios for major urban areas ranges between 3-62 stations and 8-636 chargers. The charging infrastructure requirements of each major urban area for different scenarios are provided in Table 2.

Table 2. Scenario results for the major urban areas in the state of Michigan: charging stations, chargers, and required investment

City	Marquette				Muskegon				Ann Arbor			
Battery size (kWh)	70	100	70	100	70	100	70	100	70	100	70	100
Charging station power (kW)	50	50	150	150	50	50	150	150	50	50	150	150
Number of Stations	5	4	4	4	16	14	13	10	3	3	3	3
Number of Chargers	19	16	8	9	85	89	36	33	24	29	10	11
Station Cost (Million dollar)	0.7	0.56	0.68	0.68	2.52	2.21	2.47	1.88	0.81	0.8	0.9	0.9
Chargers Cost (Million dollar)	0.68	0.57	0.63	0.7	3.39	3.56	2.96	2.73	1	1.22	0.84	0.92
Total Infrastructure Cost (Million dollar)	1.37	1.13	1.31	1.39	5.91	5.78	5.43	4.62	1.81	2.02	1.74	1.82
City	Kalamazoo				Flint				Saginaw			
Battery size (kWh)	70	100	70	100	70	100	70	100	70	100	70	100
Charging station power (kW)	50	50	150	150	50	50	150	150	50	50	150	150
Number of Stations	12	11	8	7	14	12	12	8	27	23	23	17
Number of Chargers	55	57	21	19	71	73	31	26	123	122	54	45
Station Cost (Million dollar)	1.31	1.2	1.13	0.99	2.06	1.76	2.14	1.43	2.6	2.21	2.94	2.17
Chargers Cost (Million dollar)	1.95	2.02	1.64	1.48	2.56	2.63	2.43	2.04	4.4	4.36	4.23	3.52
Total Infrastructure Cost (Million dollar)	3.26	3.22	2.77	2.47	4.62	4.39	4.58	3.47	7	6.58	7.17	5.7
City	Lansing				Grand Rapids				Detroit			
Battery size (kWh)	70	100	70	100	70	100	70	100	70	100	70	100
Charging station power (kW)	50	50	150	150	50	50	150	150	50	50	150	150
Number of Stations	16	14	13	10	17	16	14	12	62	50	47	42
Number of Chargers	85	89	36	33	122	132	47	48	636	626	236	233
Station Cost (Million dollar)	2.52	2.21	2.47	1.88	2.79	2.63	2.74	2.35	15.37	12.39	13.14	11.74
Chargers Cost (Million dollar)	3.39	3.56	2.96	2.73	4.33	4.68	3.66	3.74	23.04	22.68	18.58	18.34
Total Infrastructure Cost (Million dollar)	5.91	5.78	5.43	4.62	7.12	7.31	6.41	6.09	38.41	35.07	31.72	30.09

Smaller Urban Areas

Aggregate level regression models are developed to find the number of charging stations and chargers in the smaller cities, with limited data availability, such as Menominee, Sault Ste. Marie, Escanaba, Houghton, Traverse City, Battle Creek, Jackson, Port Huron, and Holland. The models proposed in this study can be used for other cities based-on the availability of data as the need arises.[3] Considering an energy level of 70 kWh for batteries and 150 kW power for charging stations, Table 3 provides the result of this aggregate model for nine smaller urban areas in Michigan. The number of stations for the 150 kW charger and 70 kWh battery scenario for smaller urban areas ranges between 4-11 stations and 8-22 chargers.

Table 3. Number of charging stations and chargers for smaller urban areas in the state of Michigan

City	Menominee	Sault Ste. Marie	Escanaba
Battery Size (kWh)	70	70	70
Charging Station Power (kW)	150	150	150
Number of Stations	4	4	5
Number of Chargers	8	8	10
Station Cost (Million dollar)	0.32	0.32	0.40
Chargers Cost (Million dollar)	0.61	0.61	0.76
Total Infrastructure Cost (Million dollar)	0.93	0.93	1.16
City	**Houghton**	**Traverse City**	**Battle Creek**
Battery Size (kWh)	70	70	70
Charging Station Power (kW)	150	150	150
Number of Stations	6	5	5
Number of Chargers	12	10	10
Station Cost (Million dollar)	0.48	0.40	0.40
Chargers Cost (Million dollar)	0.92	0.76	0.76
Total Infrastructure Cost (Million dollar)	1.40	1.16	1.16
City	**Jackson**	**Port Huron**	**Holland**
Battery Size (kWh)	70	70	70
Charging Station Power (kW)	150	150	150
Number of Stations	6	11	6
Number of Chargers	12	22	12
Station Cost (Million dollar)	0.48	0.88	0.48
Chargers Cost (Million dollar)	0.92	1.68	0.92
Total Infrastructure Cost (Million dollar)	1.40	2.56	1.40

[3] Detailed analysis can be performed per request for smaller urban areas based on availability of data.

The major findings of this study are listed below:

- The battery energy level **(driving range) is not a significant factor in electric vehicles charger placement to support the urban trips (intracity)** of EV users, unlike intercity trips. This is due to the shorter distance of the trips in urban areas, compared to that of the intercity trips.
- The **150 kW chargers reduce the charging and waiting time**, compared to that of the 50kW chargers
- It is **less costly to build a network of 150 kW chargers** than 50 kW chargers. Building these chargers also reduces the charging and waiting time. However, if the vehicles cannot accept the 150-kW power level, longer delays would be experienced, while all the trips still would remain feasible.
- The number **of generated trips and the total length of the roadways affects the number of chargers in the network**, with the latter being the main factor.
- The **vehicle battery size does not affect the number of chargers**, as the length of the urban trips is significantly lower than the range of the EVs.

Communities are encouraged to pursue sustainable transportation systems. EVs are the key to help communities to move toward sustainable transportation. An enabling DC fast charging infrastructure network not only meets the charging demand of EVs but also promotes their adoption. Full construction of the suggested charger and charging stations from this report will make all urban trips of EV users in Michigan feasible by the year 2030, assuming a predicted 6 percent EV market share. However, to ensure efficient and progressive infrastructure development, city planners are advised to deploy the proposed EV infrastructure incrementally. Development by phases should prioritize locations with higher charging demand to be constructed first[4]. The utilization of implemented chargers should then be monitored as an indicator for charging demand, to be used for planning of the subsequent phases accordingly.

The models proposed in this study can also be adopted for other non-listed urban areas (large or small) based on the availability of data as the need arises.

[4] Detailed analysis for the annual increments can be done for each urban area per request.