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Electric Vehicle Charger Placement Project

Meeting with Lansing Board of Water and Light

01-07-2020

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This study is commissioned and funded by the Michigan Department of Environment, Great Lakes, and Energy.

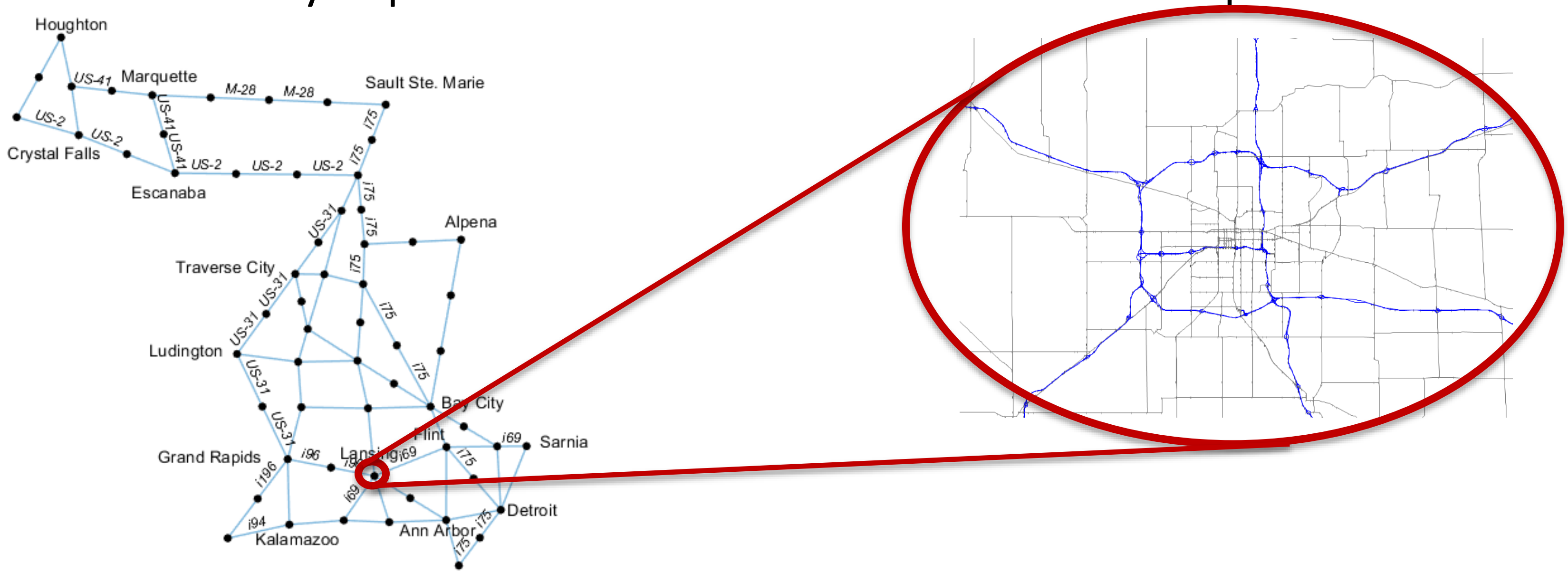
EGLE

MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY

Problem Statement

Phase I- Intercity Trips of EV Users

Phase II- Urban Trips of EV Users



Macroscopic Traffic Simulation

Optimization Model

(Aggregate O/D Demand)

Meso/Microscopic Traffic Simulation

Optimization Model

(Trip Trajectories)

Regression Model(s)

(MNL)

Outline

- Selected Cities
- Modeling Framework
- Data Collection
  - Candidate points
- Preliminary Results

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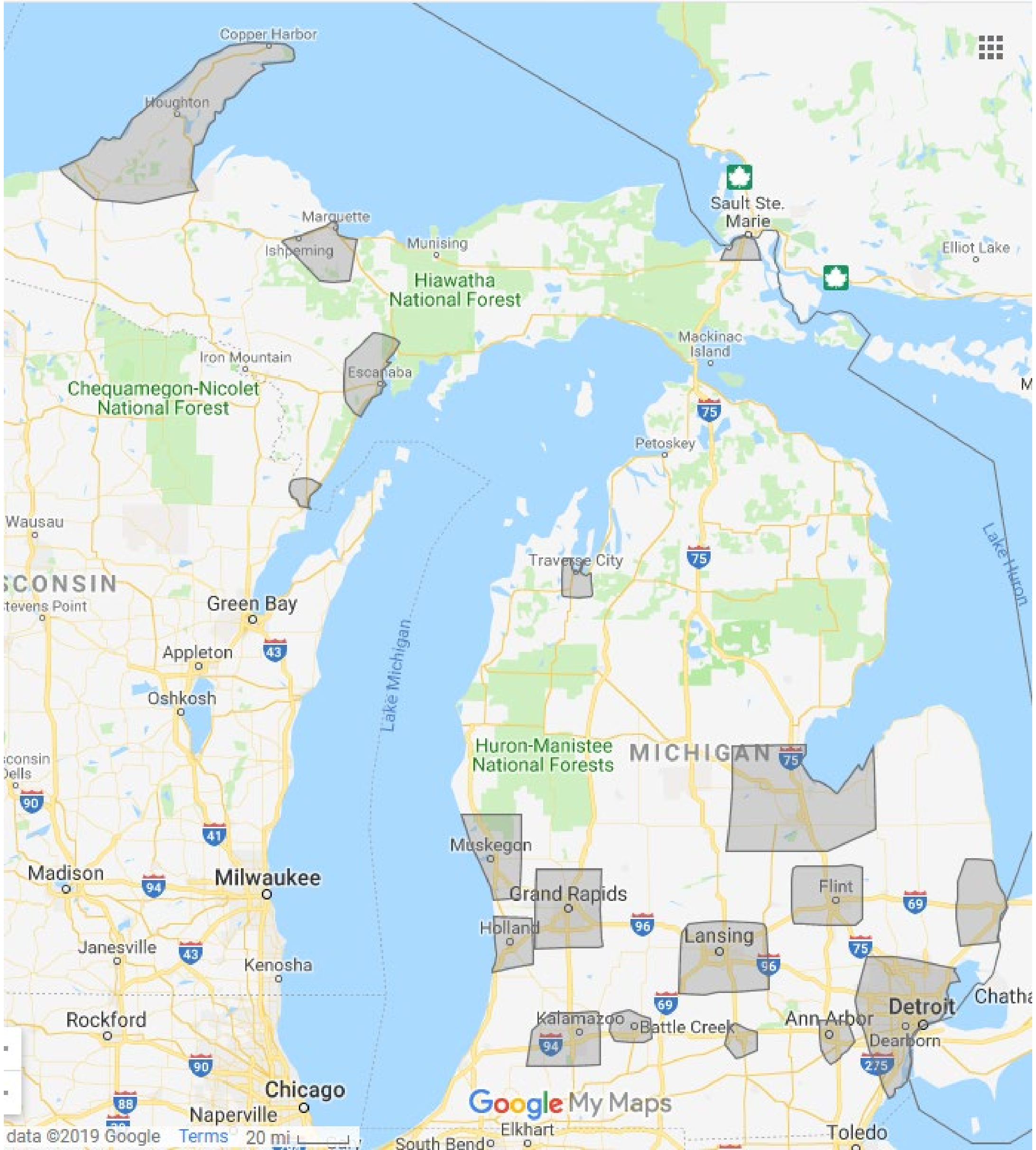
Selected Cities

- Muskegon
- Ann Arbor
- Kalamazoo
- Flint
- Saginaw
- Lansing
- Grand Rapids
- Detroit
- Marquette (UP)



Summary of Information

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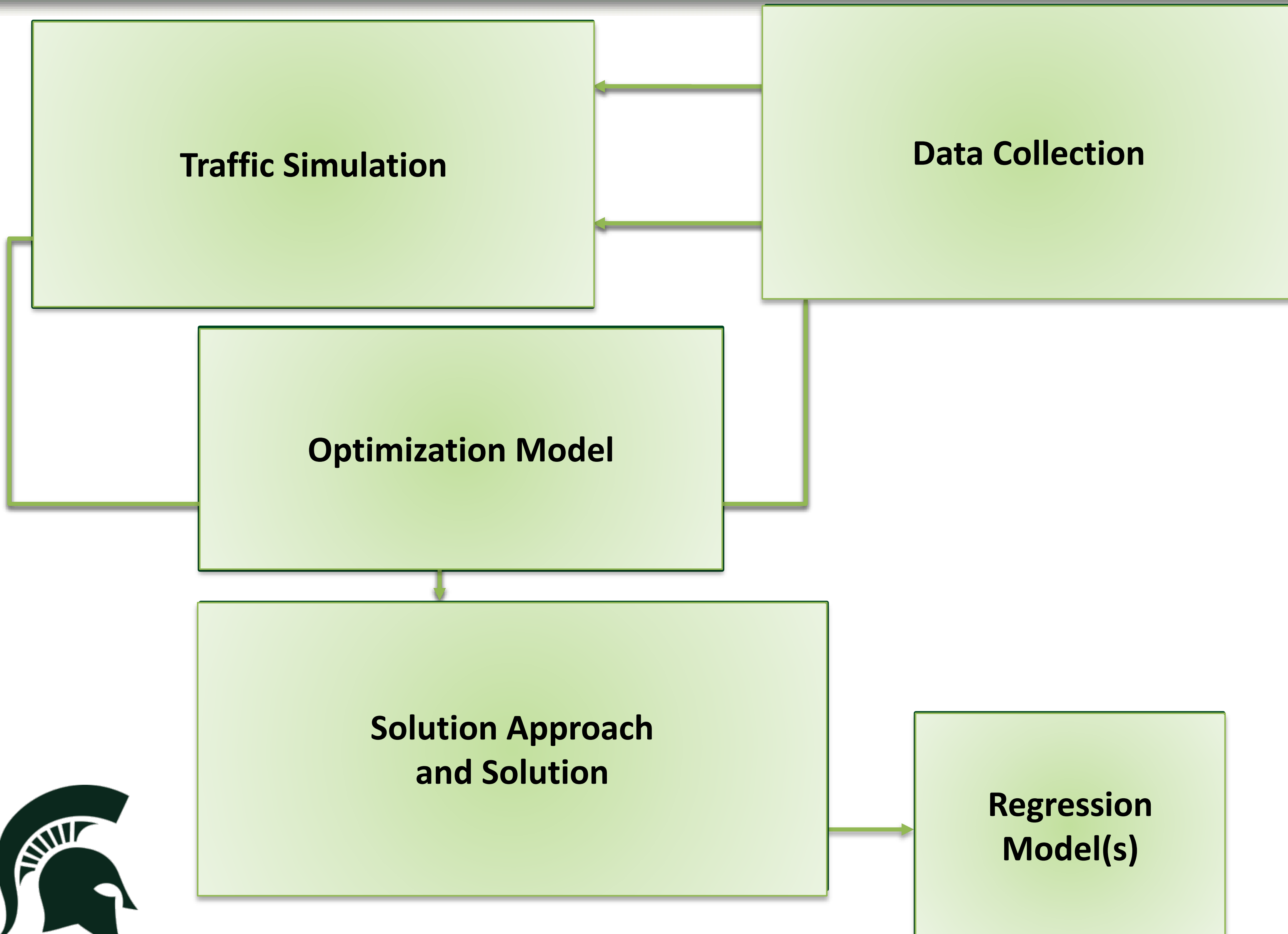
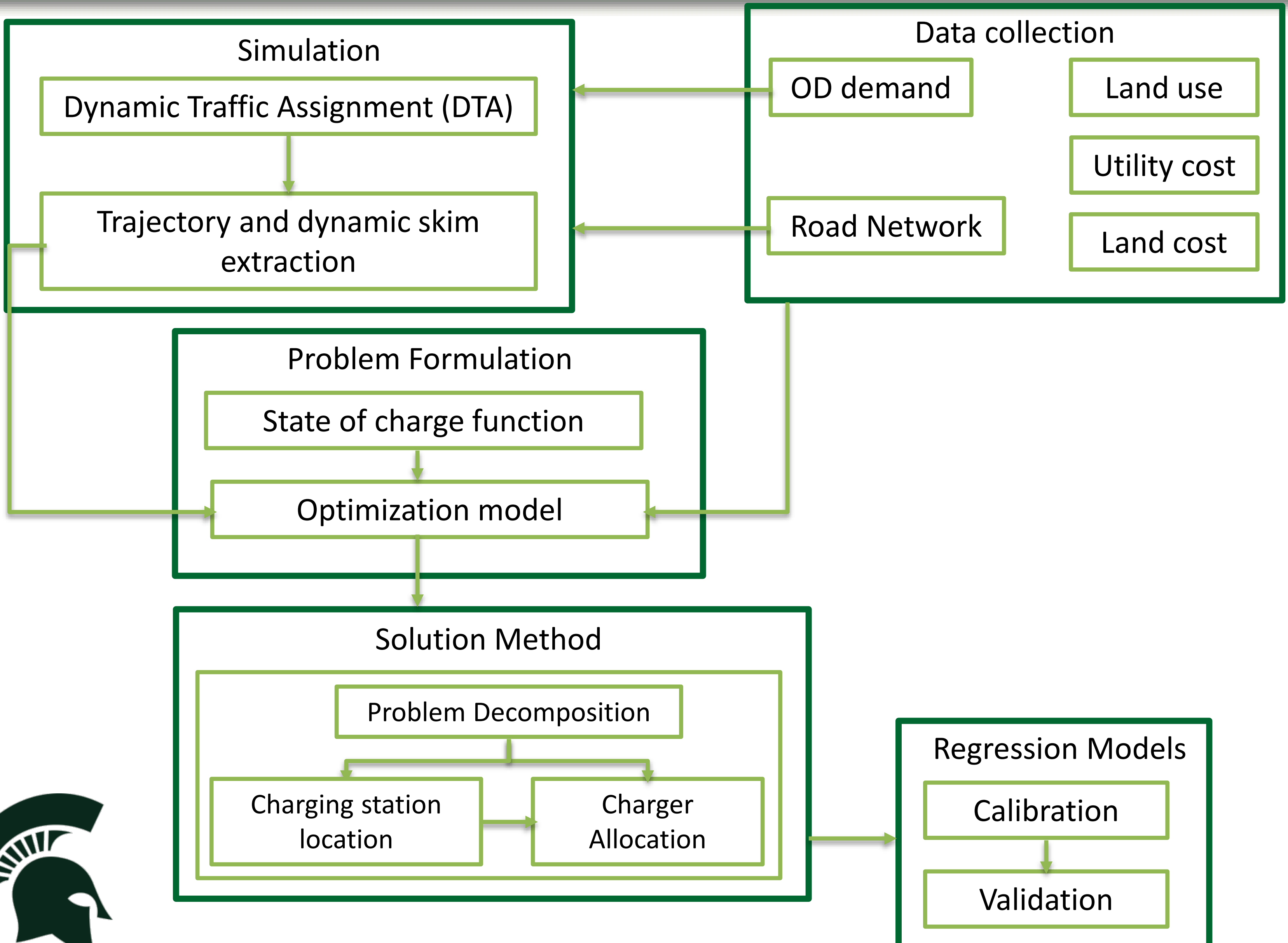
Cities/Parameter	No. of Nodes	No. of Zones	Generated Demand	Generated Demand (without Intra-Zone)	Lane Length (mi)	Miles Traveled
Marquette	62	21	178,741	142,042	336	931,957
Muskegon	387	52	535,443	410,954	916	3,161,057
Ann Arbor	413	36	624,618	503,611	789	3,894,950
Kalamazoo	369	55	712,796	534,587	1128	4,085,052
Flint	694	84	985,411	787,699	1557	6,760,436
Saginaw	783	116	1,054,842	808,925	2726	7,122,931
Lansing	896	91	1,086,242	890,079	2030	7,183,037
Grand Rapids	1031	82	1,726,732	1,353,026	2045	10,447,668
Detroit	5461	301	8,185,778	6,568,349	8776	52,293,864

Modeling Framework-Urban Study




Simulation
Dynamic Traffic Assignment (DTA)
Trajectory and dynamic skim extraction
Data collection
OD demand
Land use
Utility cost
Road Network
Land cost
Problem Formulation
State of charge function
Optimization model
Solution Method
Problem Decomposition
Charging station location
Charger Allocation
Regression Models
Calibration
Validation

Data Collection

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Stakeholder Meetings

The required inputs to the model include:

- Road network (Michigan Department of Transportation)
- Traffic Analysis zones (Michigan Department of Transportation)
- Travel demand matrix (Michigan Department of Transportation)
- Electricity Provision Costs (Utilities)
- Land Use (Michigan Department of Transportation and MPOs)
- Average Land Cost (MPOs)
- Car Companies
- Charging station and charger costs (Charging Station Companies)

Modeling Framework

The modeling framework considers:

- Origin-Destination travel demand (input)
- Simulated trip trajectories

- Minimizing charging station investment cost
  - Cost of charger
  - Land cost
  - Electricity provision cost
- Minimizing travelers' detour

The required inputs to the model include:

- Road network
- Traffic Analysis zones
- Travel demand matrix
- Electricity Provision Costs
- Land Use
- Average Land Cost

This phase focuses on investing in DC fast chargers for urban trips of EV users

Land use and trip purpose

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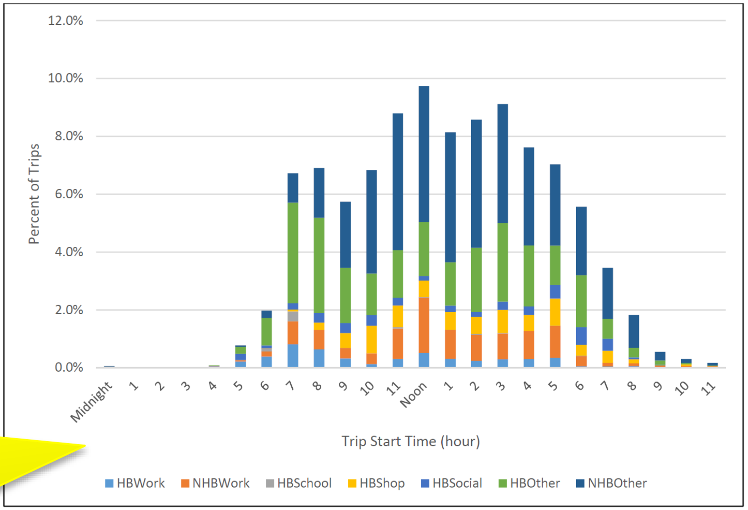
Trips start point are classified as:

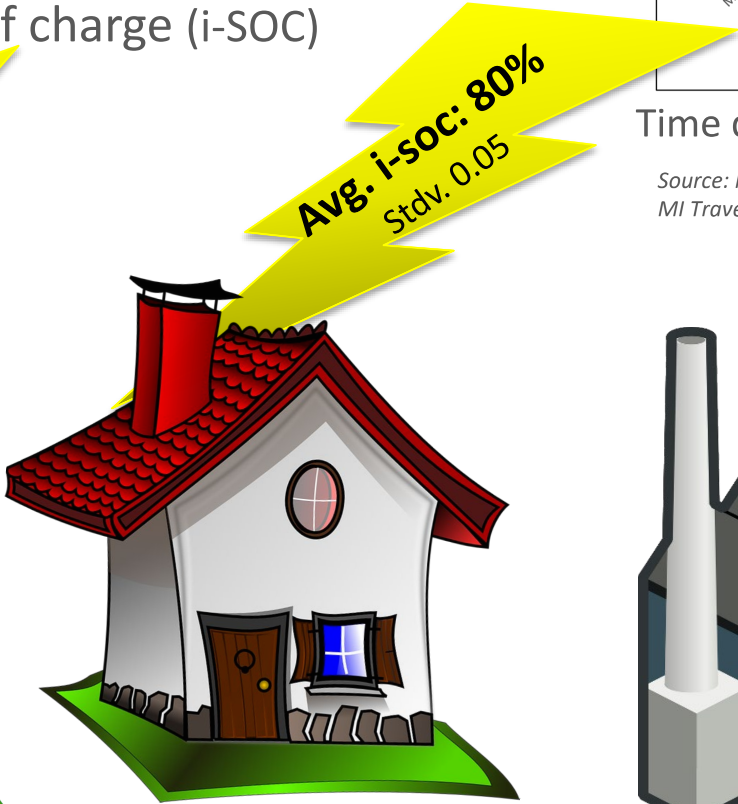
- Single family homes
- Multi-family residential
- Work places
- Other (i.e. commercial)

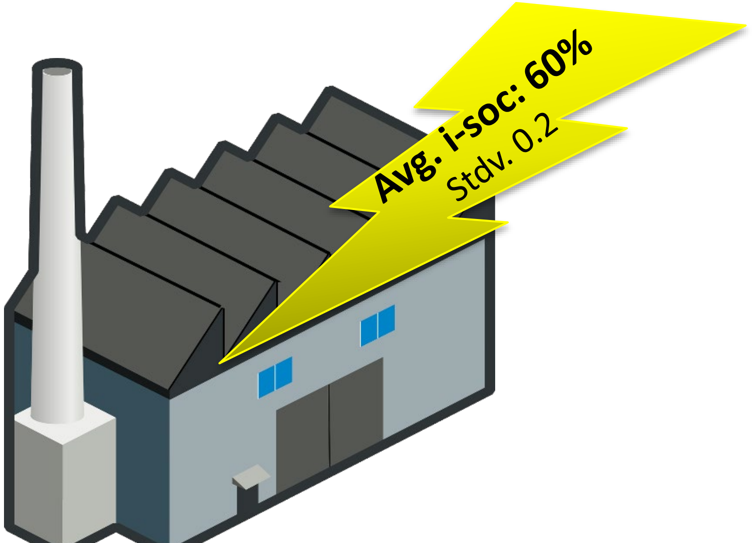
Affects initial state of charge (i-SOC)



Time dependent trip purpose in Michigan

Source: Nancy McGuckin, Jesse Casas, Martha Wilaby, (September 2016), MI Travel Counts III Travel Characteristics Technical Report





Candidate Points

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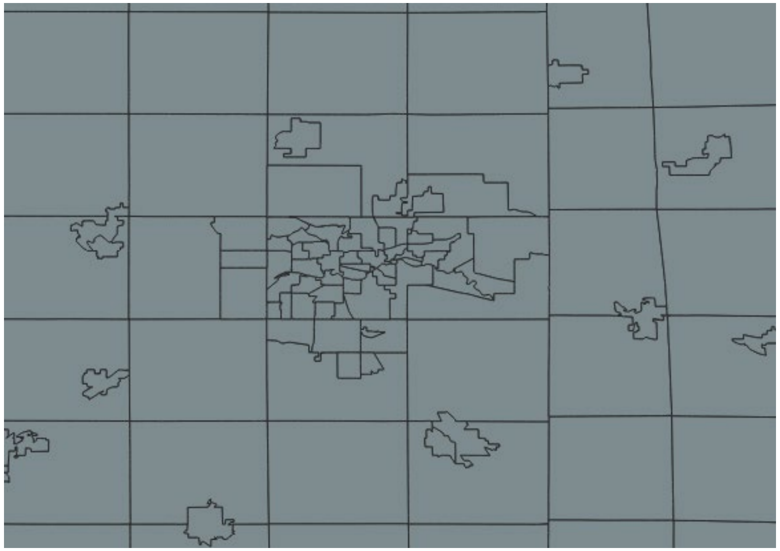
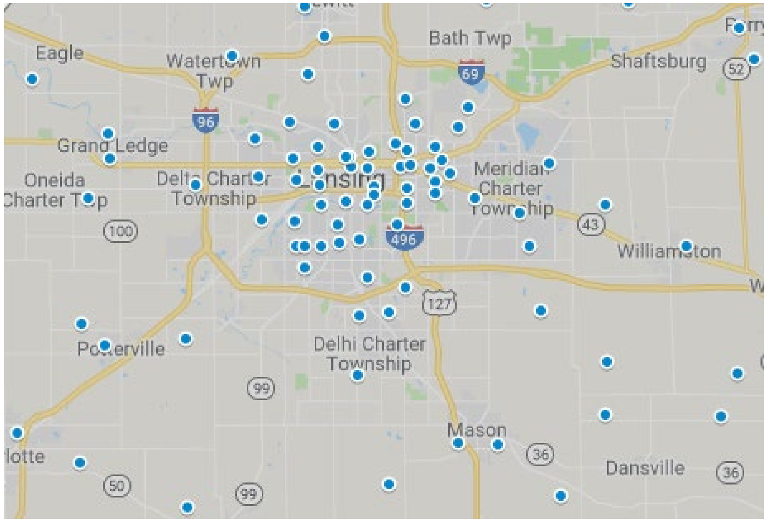
Traffic Analysis Zones (TAZ)

Unit area defined to be used in transportation planning.



Important factors:

- Size of area
- Density
- Land use
- Geographic features



Candidate Points

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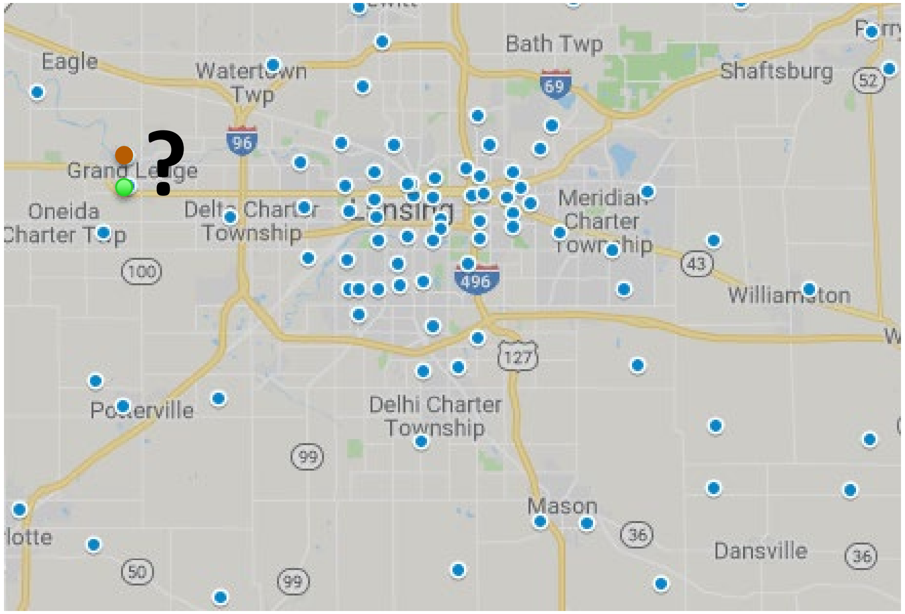
Select candidate points

- Electricity Provision Costs
- Average Land Cost



Candidate Points

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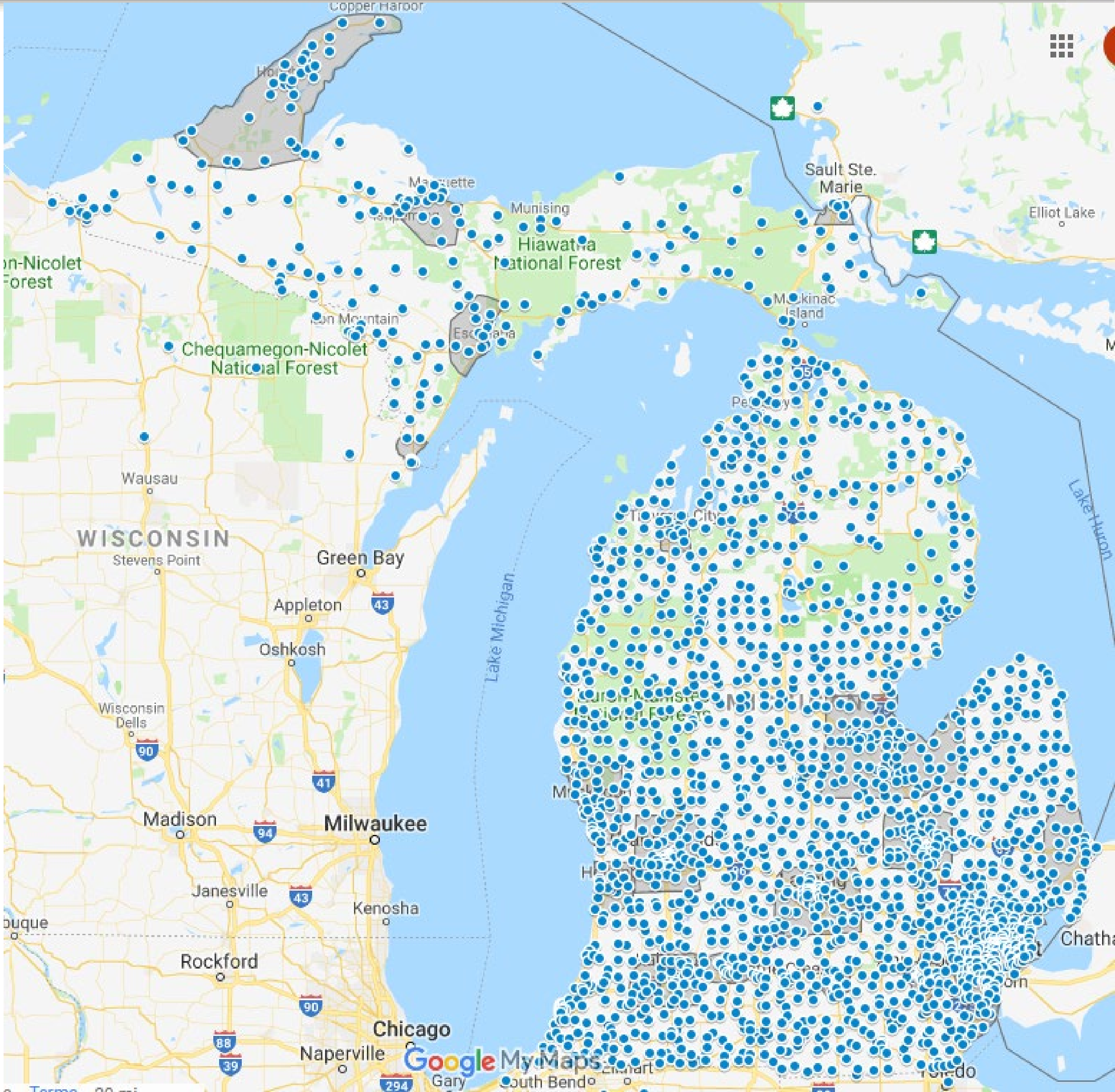

Source: https://www.google.com/maps/d/viewer?mid=1tOVyNgq6TWeYNq1hyFLWaPq3bMXDDU_3&ll=44.614258938290696%2C-86.93730349321822&z=7

Candidate Points

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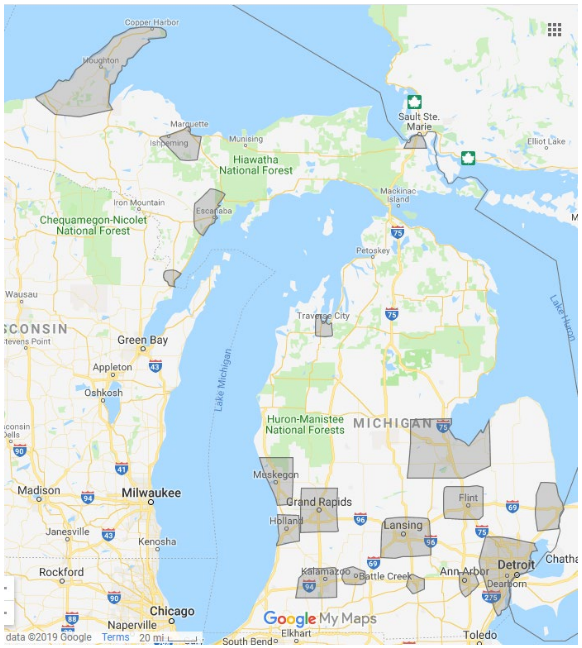

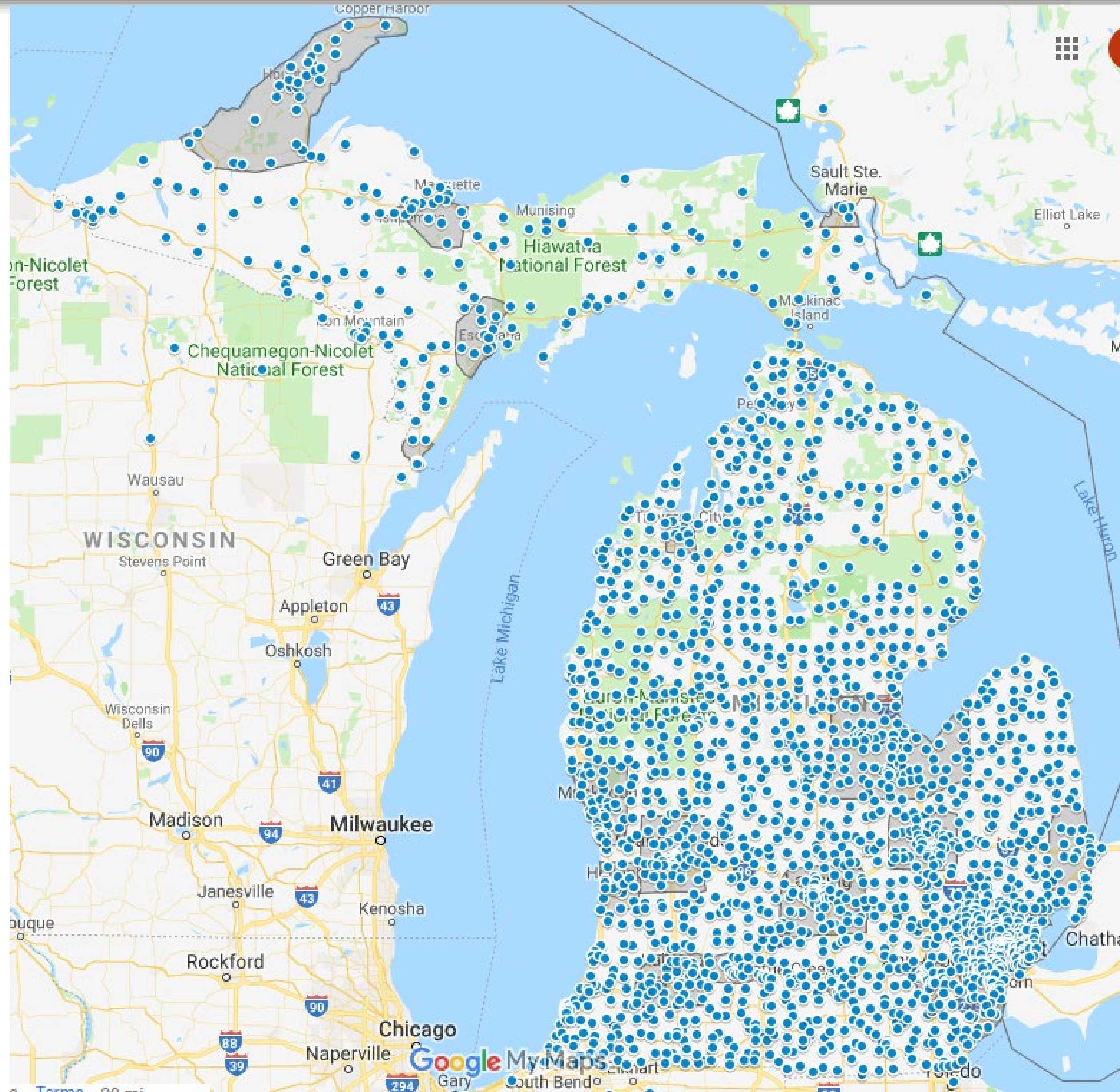

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Lansing

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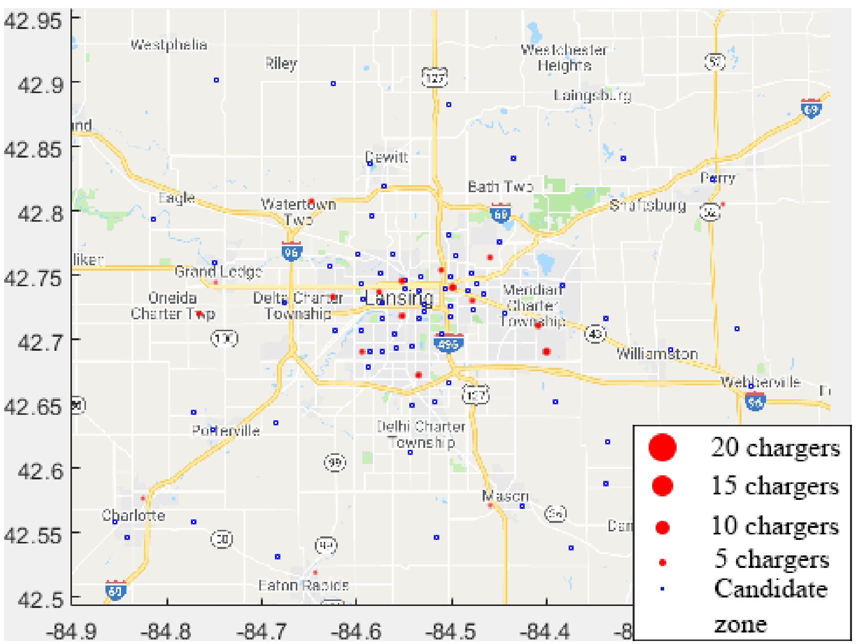
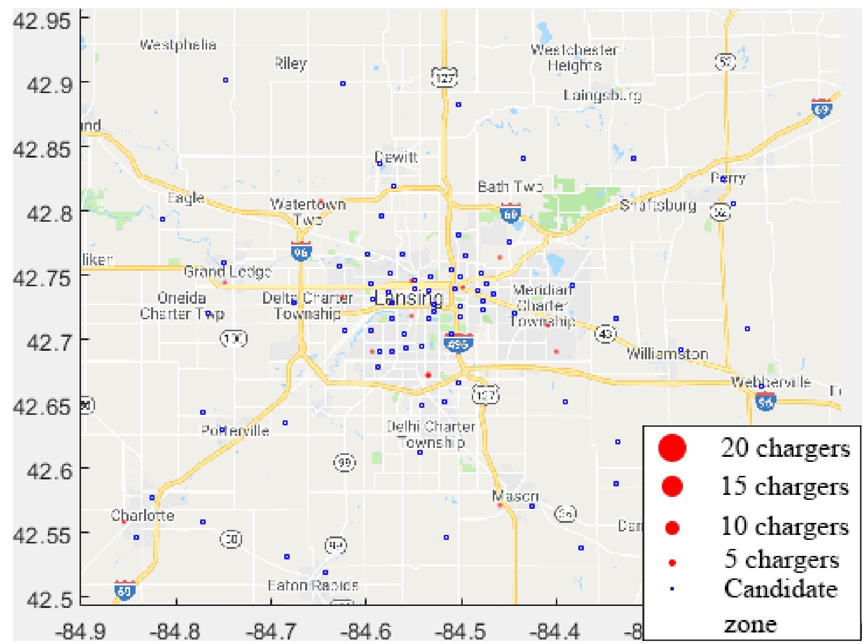
Scenario	Small battery and low tech charger	Large battery and low tech charger	small battery and high tech charger	large battery and high tech charger	Small battery and low tech charger-External demand
Battery size (kWh) =	70	100	70	100	**70**
Charging station (kW)	50	50	150	150	**50**
Number of zones =	92	92	92	92	**92**
Electric trajectories =	28574	28574	28574	28574	**32183**
Number of stations =	19	16	16	13	**24**
Number of spots=	60	65	32	27	**105**
Average charging and queuing delay (min)	10.27	14.11	3.48	4.78	**12.71**
Total station cost (m$) =	2.98	2.54	3.04	2.45	**3.80**
Total spot cost (m$) =	2.42	2.55	2.63	2.24	**4.14**
Total infrastructure cost (m$) =	5.40	5.09	5.67	4.69	**7.94**

Lansing



Small battery (70 kWh) and low tech charger (50 kW)



Large battery (100 kWh) and high tech charger (150 kW)

Thank You

Backup Slides

Service Territories

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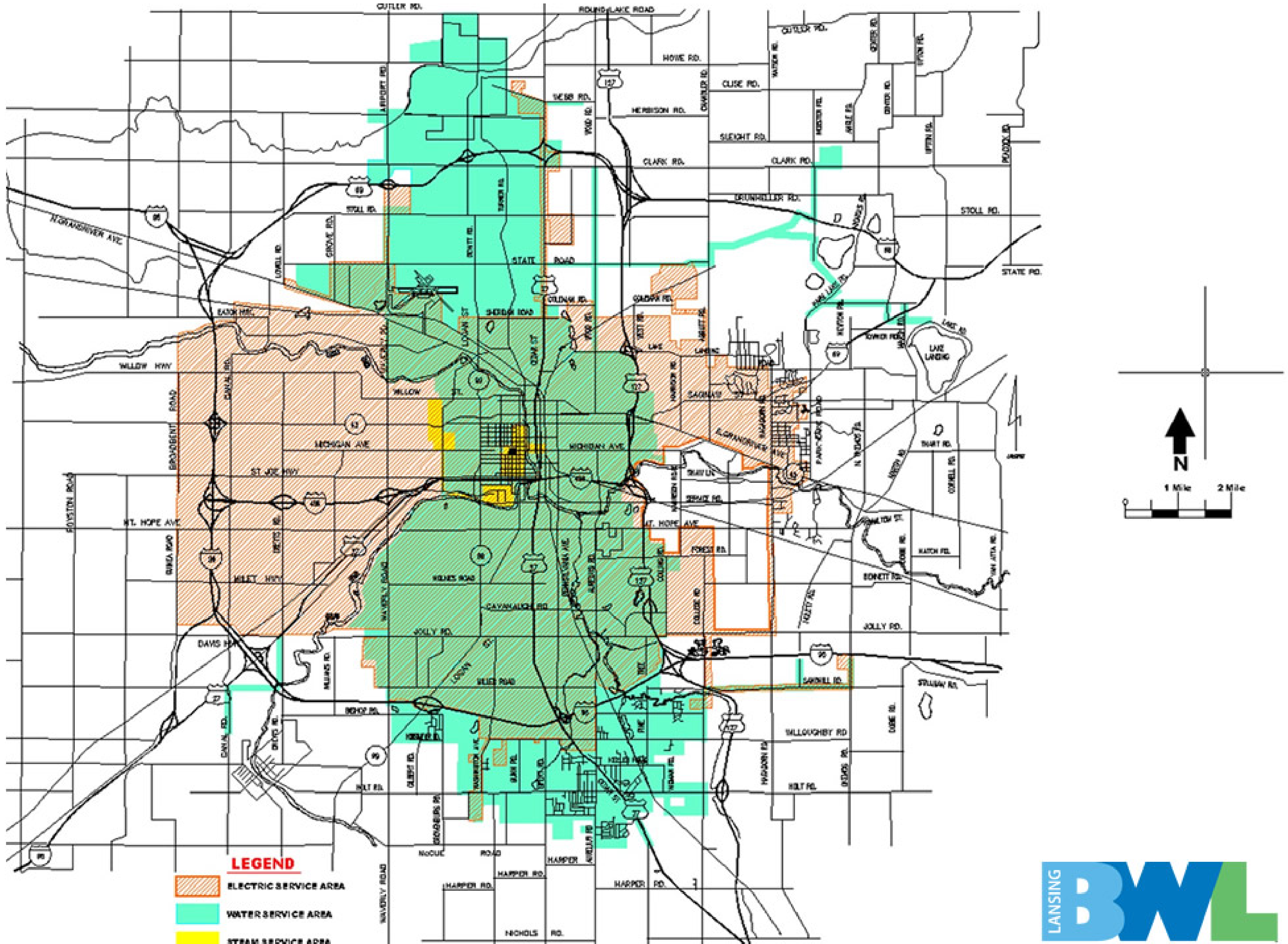


LANSING BWL
Hometown People. Hometown Power.

Source: https://www.google.com/url?sa=i&source=images&cd=&ved=2ahUKEwiqzcStw-zmAhUJHs0KHdDpBIMQjRx6BAgBEAQ&url=https%3A%2F%2Fwww.lansing.org%2Flistings%2Fboard-of-water-%2526-light%2F784%2F&psig=AOvVaw3r55oVSJBoq7XSiejQqCOp&ust=1578315978695070

Optimization Model (1/3)

Infrastructure Cost | Delay Cost | Detour Cost

$$\min \sum_{i \in I} (C_i^s x_i + C^p z_i) + \gamma \left(\sum_{\tau \in T} \sum_{i \in I} \pi_i^\tau + \sum_{j \in J} TTd_j \right) \tag{1}$$

subject to:

$$x_i \in \{0,1\}, \qquad \forall\, i \in I \tag{2}$$

$$z_i \leq x_i M, \qquad \forall\, i \in I \tag{3}$$

Required energy at each station to complete a trajectory

$$E_{ij}^\theta = \lambda_j F - S_j F + \frac{D_{(o(j),i)}^{t_j} + \psi_j D_{(i,d(j))}^\theta}{\beta}, \qquad \forall\, j \in J, i \in I \tag{4}$$

Charge up to battery capacity

$$\sum_{\tau \in T} \sum_{\theta \in T} Q_{ij}^{\tau\theta} E_{ij}^\theta \leq S_{max} F - S_j F + \frac{D_{(o(j),i)}^{t_j}}{\beta}, \qquad \forall\, j \in J, i \in I \tag{5}$$

Charge at accessible stations

$$\sum_{i \in I} \sum_{\tau \in T} \sum_{\theta \in T} Q_{ij}^{\tau\theta} D_{(o(j),i)}^{t_j} \leq \beta (S_j - S_{min}) F, \qquad \forall\, j \in J \tag{6}$$

Charge only at locations selected to build a station

$$\sum_{\tau \in T} \sum_{\theta \in T} \sum_{j \in J} Q_{ij}^{\tau\theta} \leq x_i M, \qquad \forall\, i \in I \tag{7}$$

Charge vehicles that need charging only once

$$\sum_{\tau \in T} \sum_{\theta \in T} \sum_{i \in I} Q_{ij}^{\tau\theta} = 1, \qquad \forall j \in J \tag{8}$$

Chargers' visiting flow

$$y_i^\tau = \sum_{j \in J} \sum_{\theta \in T} Q_{ij}^{\tau\theta}, \qquad \forall\, \tau \in T, i \in I \tag{9}$$

Chargers' energy demand

$$v_i^\tau = \sum_{j \in J} \sum_{\theta \in T} Q_{ij}^{\tau\theta} E_{ij}^\theta, \qquad \forall\, \tau \in T, i \in I \tag{10}$$

Optimization Model (2/3)

Detour time

$$TTd_j = \sum_{\tau \in T}\sum_{\theta \in T}\sum_{i \in I} Q_{ij}^{\tau\theta}\left(T^{t_j'}_{(o(j),i)} + T^{\theta}_{(i,d(j))} - T^{t_j'}_{(o(j),d(j))}\right), \qquad \forall\, j \in J \tag{11}$$

Arrival time window at candidate stations

$$t_j' + T^{t_j}_{(o(j),i)} - \mathrm{H}\tau \le \left(1 - Q_{ij}^{\tau\theta}\right)M, \qquad \forall\, \tau \in T, \theta \in T, i \in I, j \in J \tag{12}$$

$$t_j' + T^{t_j}_{(o(j),i)} - \mathrm{H}(\tau - 1) \ge \left(Q_{ij}^{\tau\theta} - 1\right)M, \qquad \forall\, \tau \in T, \theta \in T, i \in I, j \in J \tag{13}$$

Service rate

$$\mu_i^\tau = \alpha \frac{v_i^\tau}{P y_i^\tau}, \qquad \forall\, \tau \in T, i \in I \tag{14}$$

Arrival rate

$$\omega_i^\tau = \frac{y_i^\tau}{\mathrm{H} z_i}, \qquad \forall\, \tau \in T, i \in I \tag{15}$$

Queuing dynamics at each station

$$q_i^\tau \ge \left(\omega_i^\tau - \frac{1}{\mu_i^\tau}\right)\mathrm{H}\mu_i^\tau + q_i^{\tau-1} \tag{16}$$

$$q_i^\tau \ge 0, \qquad \forall\, i \in I \tag{17}$$

$$q_i^0 = 0, \qquad \forall\, i \in I \tag{18}$$

$$\left(\omega_i^\tau - \frac{1}{\mu_i^\tau}\right)\mathrm{H}\mu_i^\tau + q_i^{\tau-1} \le \chi_i^\tau M, \qquad \forall\, \tau \in T, i \in I \tag{19}$$

$$\left(\omega_i^\tau - \frac{1}{\mu_i^\tau}\right)\mathrm{H}\mu_i^\tau + q_i^{\tau-1} \ge \left(\chi_i^\tau - 1\right)M, \qquad \forall\, \tau \in T, i \in I \tag{20}$$

Optimization Model (3/3)

$$\delta_i^\tau = \mathrm{H}\chi_i^\tau + \frac{q_i^{\tau-1}}{1-\omega_i^\tau \mu_i^\tau + \varepsilon}(1-\chi_i^\tau), \qquad \forall\, \tau \in T, i \in I \tag{21}$$

Waiting time

$$\bar{W}_i^\tau = \frac{\delta_i^\tau}{\mathrm{H}}\left(\frac{q_i^\tau + q_i^{\tau-1}}{2}\right), \qquad \forall\, \tau \in T, i \in I \tag{22}$$

Refueling time

$$R_{ij}^\theta = \alpha \frac{E_{ij}^\theta}{P}, \qquad \forall\, i \in I, j \in J \tag{23}$$

Total delay

$$\pi_i^\tau = y_i^\tau \bar{W}_i^\tau + \sum_{\theta \in T} \sum_{j \in J} Q_{ij}^{\tau\theta} R_{ij}^\theta, \qquad \forall\, \tau \in T, i \in I \tag{24}$$

Departure time window at candidate stations based on delay

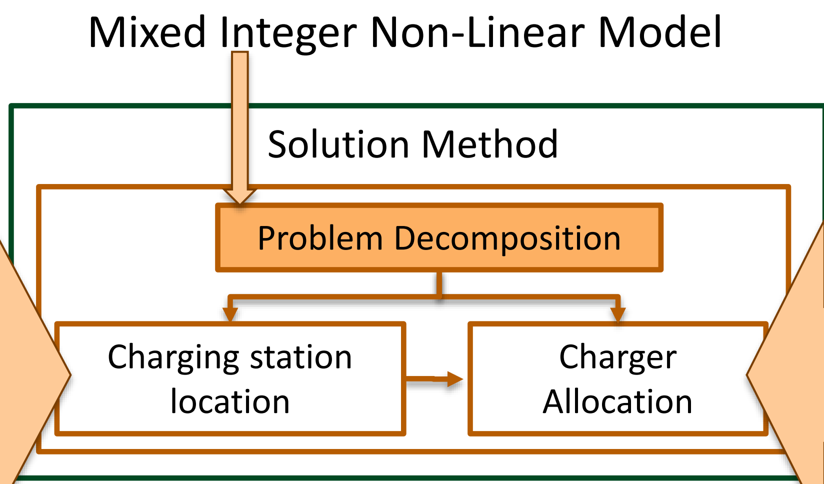
$$t_j^{'} + T_{(o(j),i)}^{t_j} + R_{ij}^\theta + \bar{W}_i^\tau - \mathrm{H}\theta \le \left(1 - Q_{ij}^{\tau\theta}\right)M, \qquad \forall\, \tau \in T, \theta \in T, i \in I, j \in J \tag{25}$$

$$t_j^{'} + T_{(o(j),i)}^{t_j} + R_{ij}^\theta + \bar{W}_i^\tau - \mathrm{H}(\theta - 1) \ge \left(Q_{ij}^{\tau\theta} - 1\right)M, \qquad \forall\, \tau \in T, \theta \in T, i \in I, j \in J \tag{26}$$

- Linear programming
- Minimizes the cost of refueling and detours' experienced
- Minimizes the cost of building charging stations
- Solved using commercial solver
- Solved using a metaheuristic algorithm for larger cities

Location of charging stations

Time-dependent EV demand at each station



- Queuing delay is minimized
- Solved using an analytical method

(Golden-Section Method)

Chargers at each charging station

Grand Rapids

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Scenario	Small battery and low tech charger	Large battery and low tech charger	Small battery and high tech charger	Large battery and high tech charger	Small battery and low tech charger- External demand
Battery size (kWh) =	70	100	70	100	**70**
Charging station (kW)	50	50	150	150	**50**
Number of zones =	82	82	82	82	**82**
Electric trajectories =	42383	42383	42383	42383	**48803**
Number of stations =	22	18	16	14	**32**
Number of spots=	90	90	34	34	**139**
Average charging and queuing delay (min)	10.09	14.22	3.51	4.87	**11.55**
Total station cost (m$) =	3.61	2.96	3.13	2.74	**5.26**
Total spot cost (m$) =	3.20	3.19	2.65	2.65	**4.93**
Total infrastructure cost (m$) =	6.81	6.15	5.79	5.40	**10.19**

Grand Rapids

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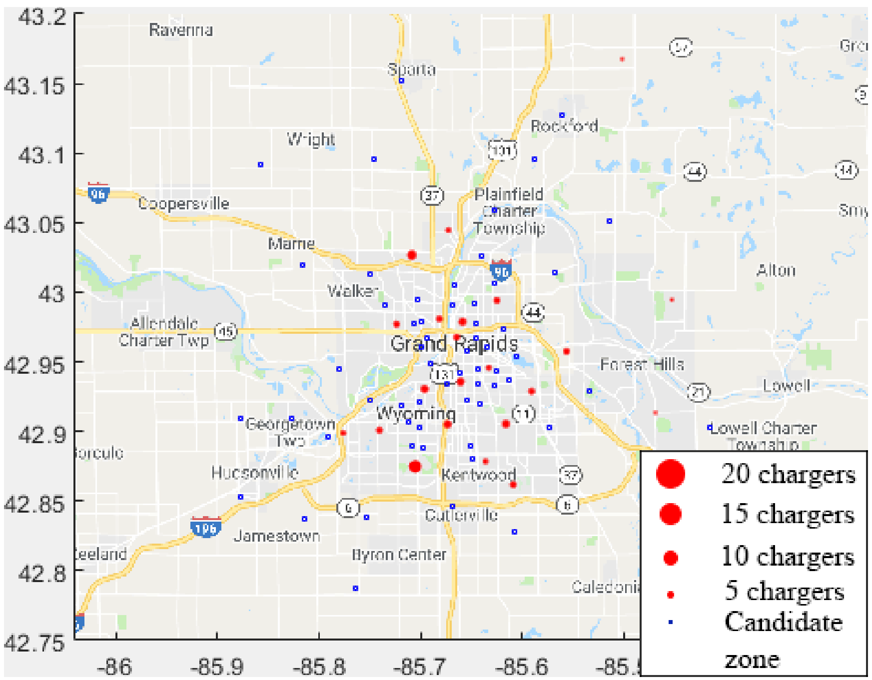
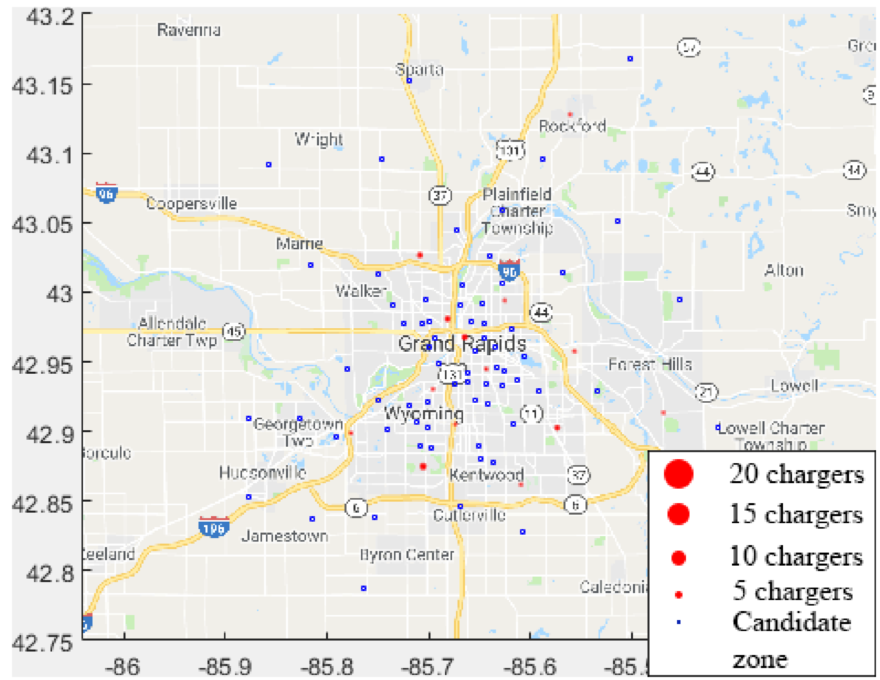


Small battery (70 kWh) and low tech charger (50 kW)



Large battery (100 kWh) and high tech charger (150 kW)

Grand Rapids

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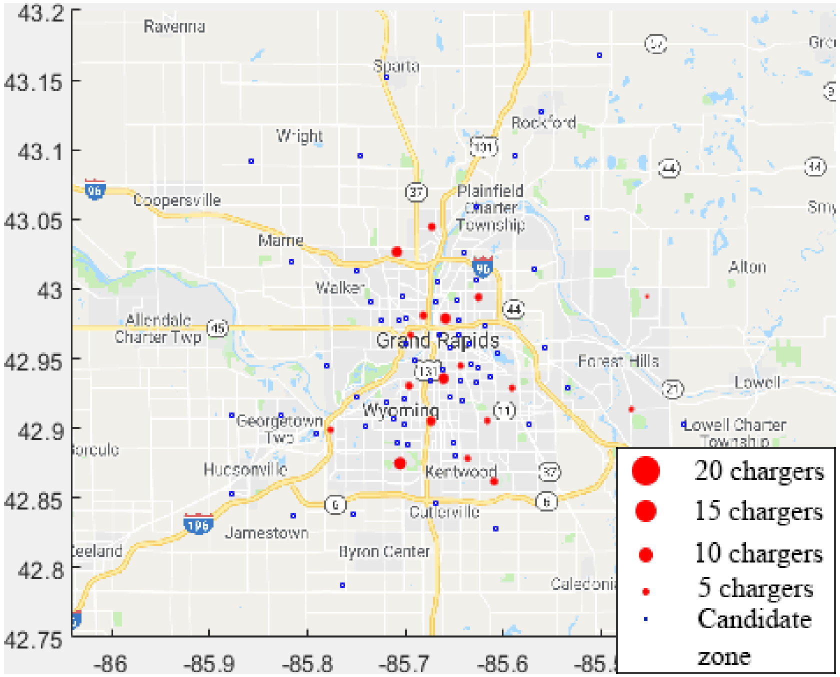
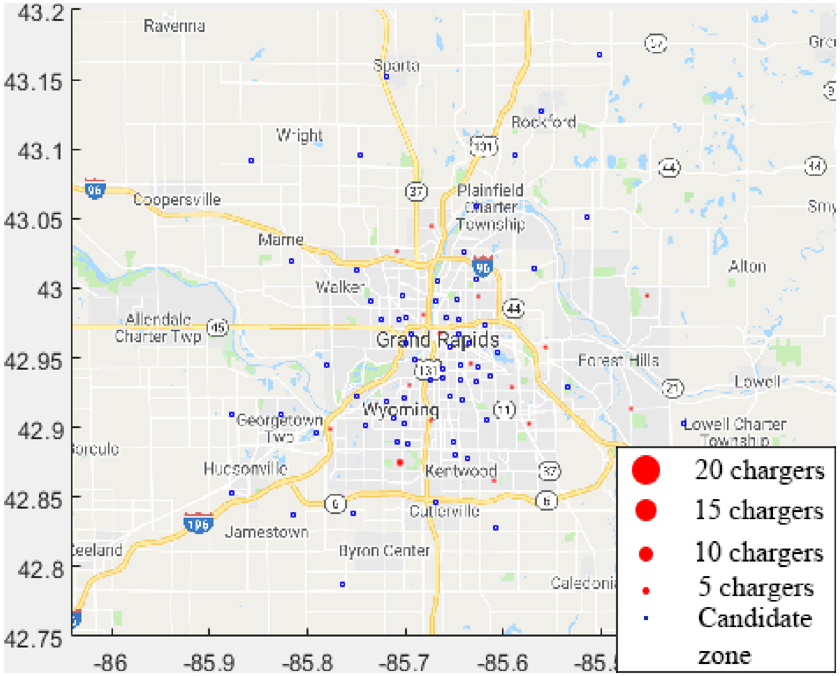


Large battery (100 kWh) and low tech charger (50 kW)



Small battery (70 kWh) and high tech charger (150 kW)

Grand Rapids

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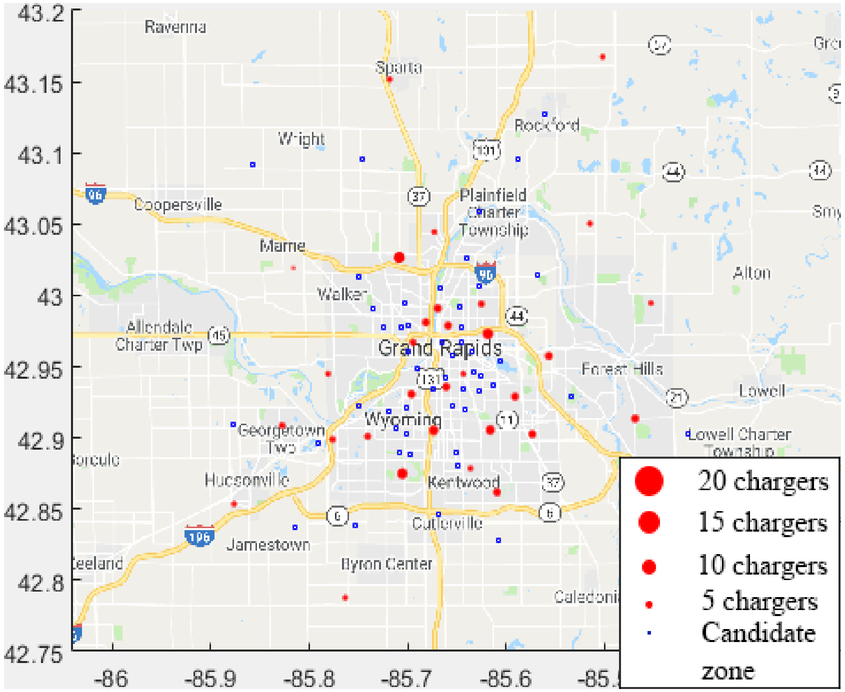

Small battery (70 kWh) and low tech charger (50 kW)- External demand

Lansing

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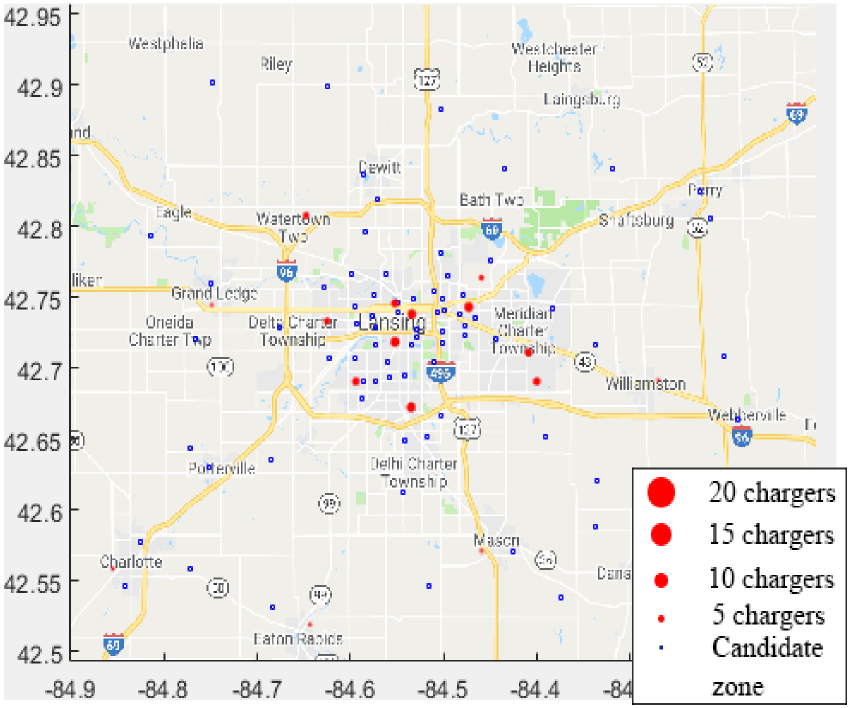
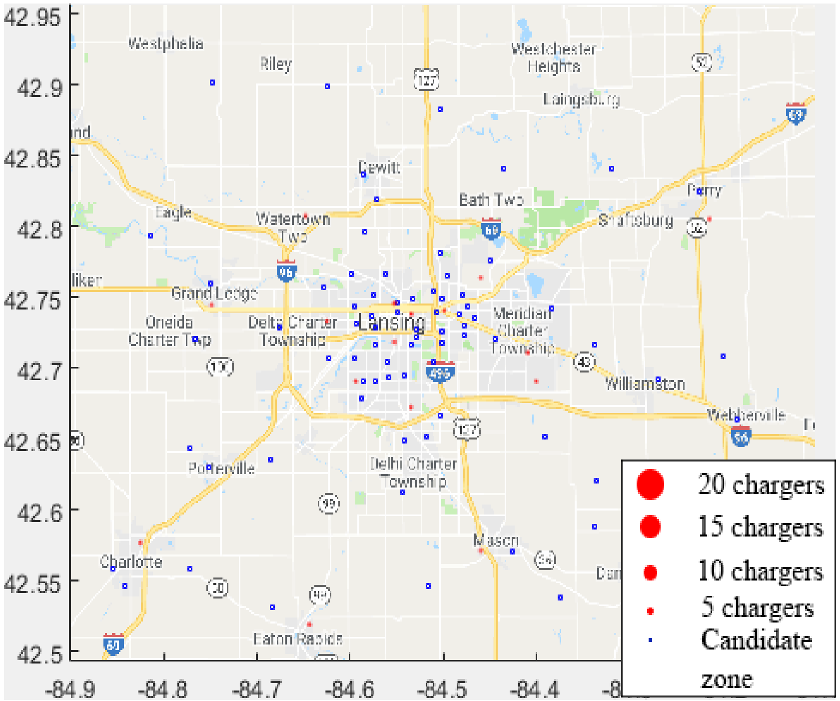


Large battery (100 kWh) and low tech charger (50 kW)



Small battery (70 kWh) and high tech charger (150 kW)

Lansing

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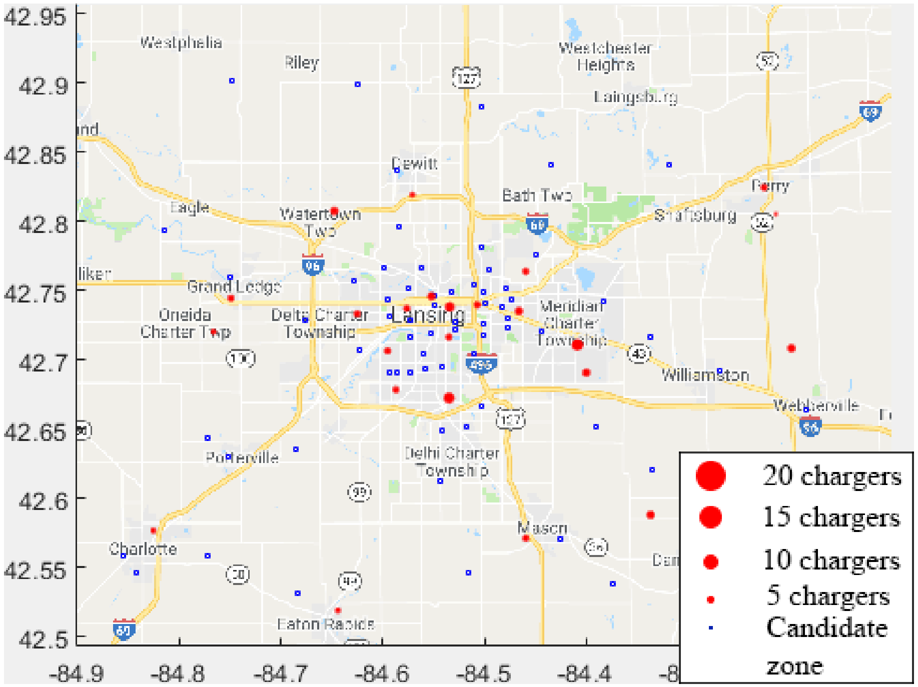

Small battery (70 kWh) and low tech charger (50 kW)- External demand

Saginaw

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Scenario	Small battery and low tech charger	Large battery and low tech charger	small battery and high tech charger	large battery and high tech charger	Small battery and low tech charger- External demand
Battery size (kWh) =	70	100	70	100	**70**
Charging station (kW)	50	50	50	50	**50**
Number of zones =	116	116	116	116	**116**
Electric trajectories =	26076	26076	26076	26076	**29191**
Number of stations =	35	25	26	19	**45**
Number of spots=	84	75	52	40	**126**
Average charging and queuing delay (min)	10.58	14.40	3.64	4.86	**13.39**
Total station cost (m$) =	3.37	2.40	3.32	2.43	**4.33**
Total spot cost (m$) =	3.00	2.68	4.07	3.13	**4.51**
Total infrastructure cost (m$) =	6.37	5.09	7.39	5.56	**8.83**

Flint

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Scenario	Small battery and low tech charger	Large battery and low tech charger	small battery and high tech charger	large battery and high tech charger	Small battery and low tech charger- External demand
Battery size (kWh) =	70	100	70	100	**70**
Charging station (kW)	50	50	150	150	**50**
Number of zones =	84	84	84	84	**84**
Electric trajectories =	22133	22133	22133	22133	**27590**
Number of stations =	16	13	13	11	**22**
Number of spots=	48	45	27	23	**88**
Average charging and queuing delay (min)	10.25	14.18	3.47	4.76	**12.71**
Total station cost (m$) =	2.35	1.91	2.32	1.97	**3.23**
Total spot cost (m$) =	1.73	1.62	2.12	1.81	**3.17**
Total infrastructure cost (m$) =	4.08	3.53	4.44	3.77	**6.40**

Kalamazoo

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Scenario	Small battery and low tech charger	Large battery and low tech charger	small battery and high tech charger	large battery and high tech charger	Small battery and low tech charger-External demand
Battery size (kWh) =	70	100	70	100	**70**
Charging station (kW)	50	50	150	150	**50**
Number of zones =	55	55	55	55	**55**
Electric trajectories =	16460	16460	16460	16460	**19276**
Number of stations =	16	11	10	9	**21**
Number of spots=	42	37	20	18	**69**
Average charging and queuing delay (min)	9.96	14.10	3.41	4.75	**12.58**
Total station cost (m$) =	1.74	1.20	1.41	1.27	**2.29**
Total spot cost (m$) =	1.50	1.32	1.56	1.41	**2.46**
Total infrastructure cost (m$) =	3.24	2.52	2.97	2.67	**4.75**

Ann Arbor

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Scenario	Small battery and low tech charger	Large battery and low tech charger	small battery and high tech charger	large battery and high tech charger	Small battery and low tech charger-External demand
Battery size (kWh) =	70	100	70	100	**70**
Charging station (kW)	50	50	150	150	**50**
Number of zones =	36	36	36	36	**36**
Electric trajectories =	11530	11530	11530	11530	**18162**
Number of stations =	5	5	4	4	**9**
Number of spots=	20	23	9	9	**54**
Average charging and queuing delay (min)	10.03	14.44	3.41	5.02	**11.87**
Total station cost (m$) =	1.35	1.35	1.20	1.22	**2.43**
Total spot cost (m$) =	0.80	0.92	0.74	0.72	**2.16**
Total infrastructure cost (m$) =	2.15	2.28	1.94	1.94	**4.58**

Muskegon

MICHIGAN STATE UNIVERSITY

Scenario	Small battery and low tech charger	Large battery and low tech charger	small battery and high tech charger	large battery and high tech charger	Small battery and low tech charger- External demand
Battery size (kWh) =	70	100	70	100	**70**
Charging station (kW)	50	50	150	150	**50**
Number of zones =	52	52	52	52	**52**
Electric trajectories =	12729	12729	12729	12729	**14852**
Number of stations =	11	9	9	7	**15**
Number of spots=	29	30	18	14	**44**
Average charging and queuing delay (min)	10.32	14.45	3.48	4.84	**12.14**
Total station cost (m$) =	1.22	1.00	1.29	1.00	**1.67**
Total spot cost (m$) =	1.04	1.07	1.41	1.10	**1.57**
Total infrastructure cost (m$) =	2.26	2.07	2.69	2.10	**3.24**

Marquette

MICHIGAN STATE UNIVERSITY

Scenario	Small battery and low tech charger	Large battery and low tech charger	small battery and high tech charger	large battery and high tech charger	Small battery and low tech charger- External demand
Battery size (kWh) =	70	100	70	100	**70**
Charging station (kW)	50	50	150	150	**50**
Number of zones =	21	21	21	21	**21**
Electric trajectories =	4753	4753	4753	4753	**5116**
Number of stations =	5	5	5	4	**6**
Number of spots=	12	12	10	8	**16**
Average charging and queuing delay (min)	10.70	13.98	3.57	4.69	**12.28**
Total station cost (m$) =	0.70	0.70	0.86	0.68	**0.84**
Total spot cost (m$) =	0.43	0.43	0.78	0.63	**0.57**
Total infrastructure cost (m$) =	1.12	1.12	1.64	1.31	**1.41**