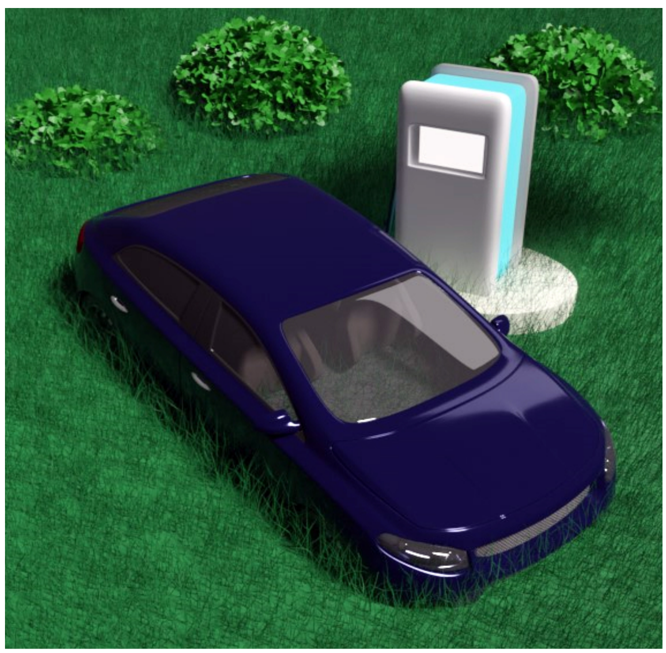
JOINT TRANSPORTATION RESEARCH PROGRAM

INDIANA DEPARTMENT OF TRANSPORTATION
AND PURDUE UNIVERSITY

A Strategic Assessment of Needs and Opportunities for the Wider Adoption of Electric Vehicles in Indiana



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16. Abstract

INDOT plans to invest nearly $100 million to build a statewide electric vehicle (EV) charging network as part of the National Electric Vehicle Infrastructure Formula Program. SPR-4509 Phase-I identified energy EV charging deserts in Indiana for long-distance trips. SPR-4509 Phase-II further examines the charging stations' impact on EV long-distance trips in Indiana. Using an agent-based simulation model, the number of charges, vehicle miles traveled, energy used during the trip, and energy used during charging were estimated for nine different cases. High EV daily charging demand areas in Indiana were shown in ArcGIS based on multiple scenarios of different charging station construction phases and EV market penetration rates. The study findings can inform the state's EV charging plan development.

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EXECUTIVE SUMMARY

Introduction

INDOT plans to invest nearly $100 million to build a statewide electric vehicle (EV) charging network as part of the National Electric Vehicle Infrastructure Formula Program. SPR-4509 Phase-I identified energy EV charging deserts in Indiana for long-distance trips and further examined the charging stations' impact on EV long-distance trips in Indiana.

Findings

Using an agent-based simulation model, the number of charges, vehicle miles traveled, energy used during the trip, and energy used during charging were estimated for nine different cases. High EV daily charging demand areas in Indiana were shown in ArcGIS based on multiple scenarios of different charging station construction phases and EV market penetration rates.

Implementation

The study findings can inform the state's EV charging plan development.

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1. INTRODUCTION

INDOT plans to invest nearly $100 million to build a statewide EV charging network over the next 5 years. The plan will bolster the availability of fast and reliable EV charging infrastructure to address EV owners' range anxiety. Range anxiety refers to the phenomenon where EV owners constantly worry about running out of battery charge before reaching their destinations or a suitable charging station. Careful planning of new EV charging infrastructure using simulation results from SPR-4509 could help expedite the process. The SPR-4509 Phase-I project (Konstantinou et al., 2022) simulated EV charging demand using Indiana's origin-destination (O–D) travel data for long-distance EV trips using the concept of stop-markers. The stop markers in the Phase-I simulation model represent the exact GIS coordinates where the simulated EV ran out of charge and stopped in the middle of the trip. The simulated EV would start a trip from the origin to the destination and attempt to complete the trip on its initial charge level. The proposed framework during the Phase-I project analyzed EV infrastructure deficit areas for long-distance EV travelers.

The proposed framework needs to show the energy demand required to charge the EVs and the usage of existing EV charging stations, as no existing or planned EV charging stations are incorporated in the model. As the model only gives a general idea about the charging deficit areas in Indiana where EVs tend to run out of energy, it does not help to identify the charging demand of significant highway corridors in Indiana. Hence, the objectives of this study (SPR-4509 Phase-II) are the following.

1. Identifying charging demand for tailored highway corridors in Indiana by using Indiana's origin-destination (O-D) travel data for long-distance EV trips.
2. Simulating EV charging demand by incorporating existing and potential charging stations as stops for the simulated EVs.
3. Visualizing the high EV daily charging demand areas in Indiana using ArcGIS based on multiple scenarios (different charging station construction phases and EV market penetration rates).

While the new model is still based on the framework of the original model from the Phase-I, significant changes had to be made to address the new objectives of this study. One of the most significant changes is that failed EV long-distance trips are no longer considered in the new model, as EV charging stations are embedded in the new simulation model. With the outcome of the model, a more advanced detailed analysis is possible to identify EV charging demand regions in greater detail. The analysis allows for a clear visualization of charging demands on a county, region, and even station level.

The project's work plan is reflected in the report's structure and as follows. Chapter 2 discusses (a) data used for the updated model, (b) the simulation model's structure, and (c) scenarios being used for analysis. Chapter 3 discusses the analysis results of the simulation model. Chapter 4 provides extra layers of research findings which are expected service patterns of existing and planned charging stations depending on different market penetration and INDOT districts. Chapter 5 is a summary of the key findings and implications, limitations, and recommendations for future work. Appendices provide additional visual aids for the report—Appendix A. EV Charging Demand Data Map Visualization, Appendix B. Average Charging Station Uses in Counties, Appendix C. Histogram of Charging Stations and Provided Charging Services, and Appendix D. Charging Demand Analysis of Traffic from Neighboring States.

2. SIMULATION MODEL OF EV ENERGY CHARGING DEMAND (PHASE-II)

The simulation model developed during Phase-I has no consideration for existing and planned charging stations. The research team enhanced the simulation model to enable the analysis of the current and expected capacity of EV charging infrastructures in Indiana. In the Phase-I simulation model, only three types of data were employed: EV trip data, EV conditioners, and driving behavior, and GIS map environment (shown in Figure 2.1). The Phase-II simulation model employed EV charging station data as additional data. As a result, the Phase-II simulation model received an updated feature: "EV Charging Station Agent." In the Phase-II simulation model, the EV Charging Station Agent exchanges messages and information with EV Trip Agent when EV Trip Agent detects the battery energy level to be low and sends a charging request to the nearest charging station. EV Charger Agent sends information during and after charging to EV Trip Agent. The Phase-II simulation model shows six numerical outcomes, which are (1) total vehicle trips, (2) total energy used, (3) number of charges, (4) energy used during charging, (5) average number of charges, and (6) vehicle miles traveled. Numerical outcomes are graphically shown on GIS maps. The conceptual logic flows of the Phase-I model and the Phase-II model are represented in Figure 2.1 and Figure 2.2, respectively.

2.1 Data Used for the Phase-II Simulation

The data used for the simulation model is the Indiana Statewide Travel Demand Model (ISTDM) 2015. ISTDM is INDOT's published projection model for planning statewide projects. It consists of traffic volumes and location of origin-destination (O-D) data. ISTDM classifies Indiana as seventeen regions that are called traffic analysis zones, and traffic analysis zones consist of multiple counties. The ISTDM region map is shown in Figure 2.3.

The Phase-II simulation model needed new data to accommodate the objectives of the Phase-II study. The study identified the locations of existing charging stations in Indiana and selected the charging stations for the simulation model based on the distance between the charging stations and the Alternate Fuel Corridors

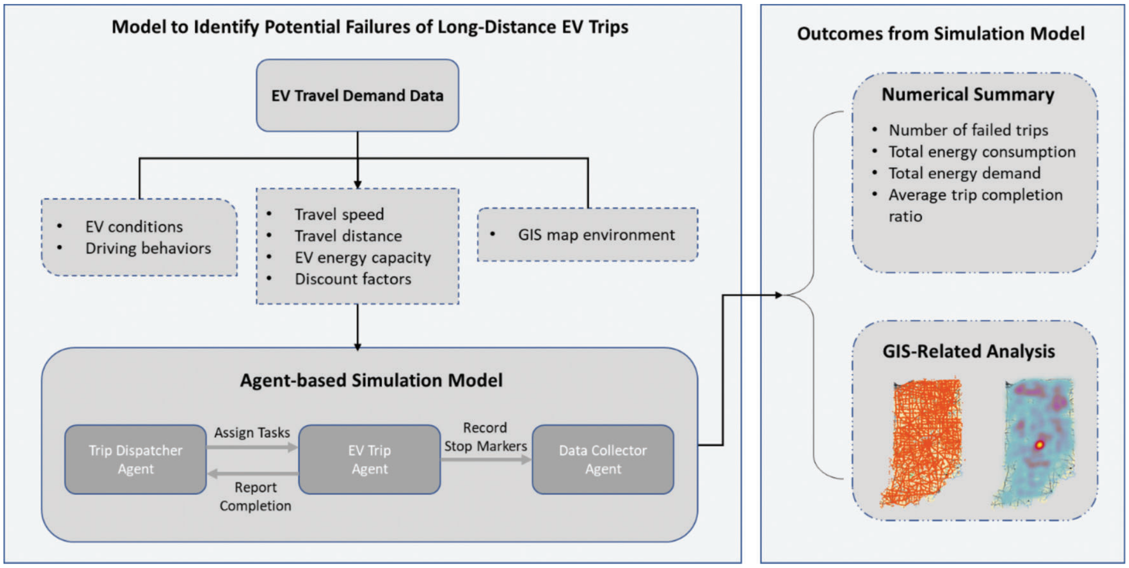

Figure 2.1 Logic flow of the simulation model developed in SPR-4509 Phase-I (Konstantinou et al., 2022).

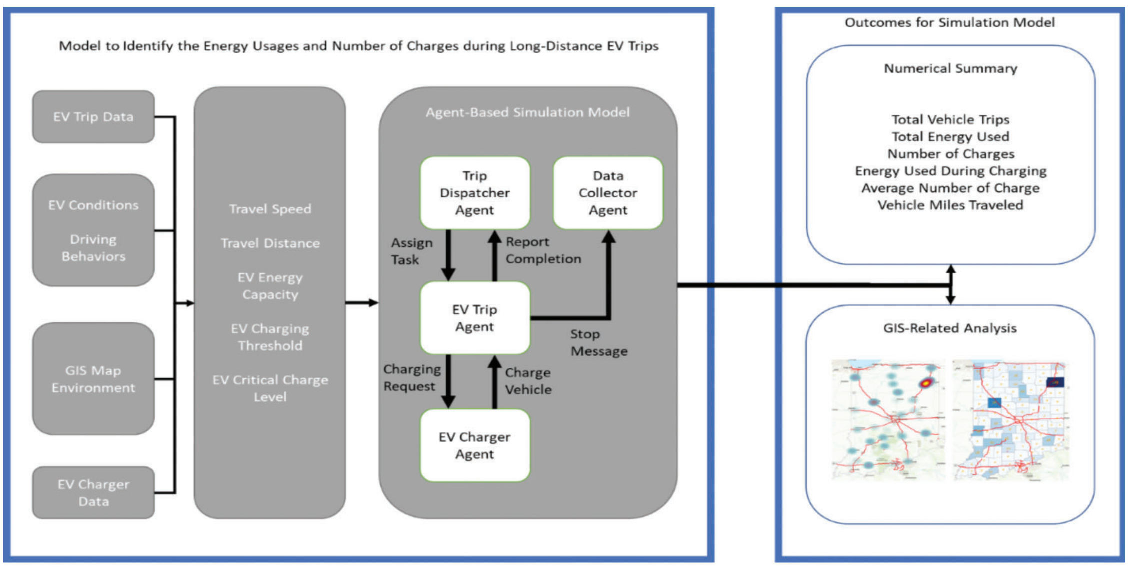

Figure 2.2 Flow chart of the Phase-II simulation model in SPR-4509 Phase-II.

(AFC). The selected charging stations were placed within 0.5 miles of AFC. Furthermore, this research included the charging stations that would be installed in the future. The charging stations were selected based on the identified locations from the Indiana Electric Vehicle Infrastructure Deployment Plan (INDOT, n.d.).

2.2 Three Simulation Scenarios by EV Charging Station Deployment

Three simulation model scenarios were developed: Scenario 1–currently existing charging stations (as of October 2022), Scenario 2–the existing charging stations and half of the planned charging stations to be constructed, and Scenario 3–existing charging stations and all planned charging stations. The location of charging stations is displayed on the map in Figure 2.4.

In Scenario 1, there are 57 charging stations (excluding Tesla Super Chargers) deployed in the simulation environment throughout the state. The selected charging stations provide the charge to the EV in the simulation model when the vehicle battery is in a low state, thus, enabling the vehicles to finish the journey. Scenario 2 assumed the addition of half of the planned charging stations and resulted in 86 charging stations in the model. This study simulates INDOT's charging station deployment plan in two separate phases (INDOT, n.d.). The integration was expected to bring changes in the resulting figures. Figure 2.4 (center) displays the charging stations used for the Scenario 2 simulation. Lastly, Scenario 3 uses all proposed charging

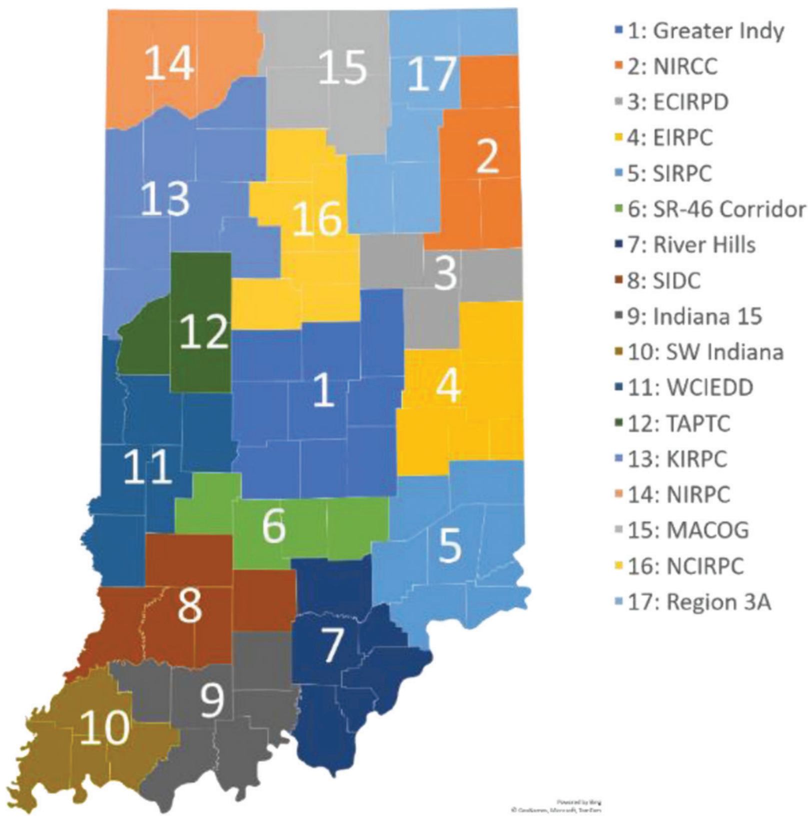

Figure 2.3 The 17 regions of the Indiana statewide travel demand model (ISTDM).

stations in the simulation model. Scenario 3 assumed the full integration of planned charging stations along with currently existing charging stations in Indiana. The number of charging stations in Scenario 3 is 116, which is almost double in Scenario 1. Table 2.1 shows the number of charging stations in each county. The table only shows the counties that have more than one charging station in the scenarios.

2.3 Updated Model Structure

The general structure of the simulation model is similar to the SPR-4509 Phase-I model. A key difference was adding an agent to the simulation model: EV Charger Agent, which is assigned to each charging station in the simulation model. The essential function of the EV Charger Agent is to send information on how much energy was charged to EV Trip Agent. EV Charger Agent receives a request for charging from EV Trip Agent, and relevant charging information is relayed back to EV Trip Agent. EV Trip Agent measures the total energy used for each charging station and stores the data in EV Charger Agent. The simulation model charges the battery to a maximum level, and a specific charge level is calculated. The agents used for the Phase-II simulation model are summarized in Figure 2.5.

2.4 Sub-Scenarios by EV Market Penetration Rates

As mentioned earlier, the simulation model has three scenarios. Each scenario is further divided into three sub-scenarios. The sub-scenarios were determined by the EV market penetration rate. The defined sub-scenarios were 5%, 10%, and 15% EV market penetration rates (MPR). These rates do not differentiate between commercial and passenger vehicles. Hence, this simulation model is analyzed based on 9 cases of charging demands: (Case-1) existing charging stations at 5% MPR, (Case-2) at 10% MRP, (Case-3) at 15% MPR, (Case-4) existing charging stations with half of the planned charging stations at 5% MPR, (Case-5) at 10% MPR, (Case-6) at 15% MPR, (Case-7) existing charging stations with full of planned charging stations at 5% MPR, (Case-8) at 10% MPR, and (Case-9) at 15% MPR.

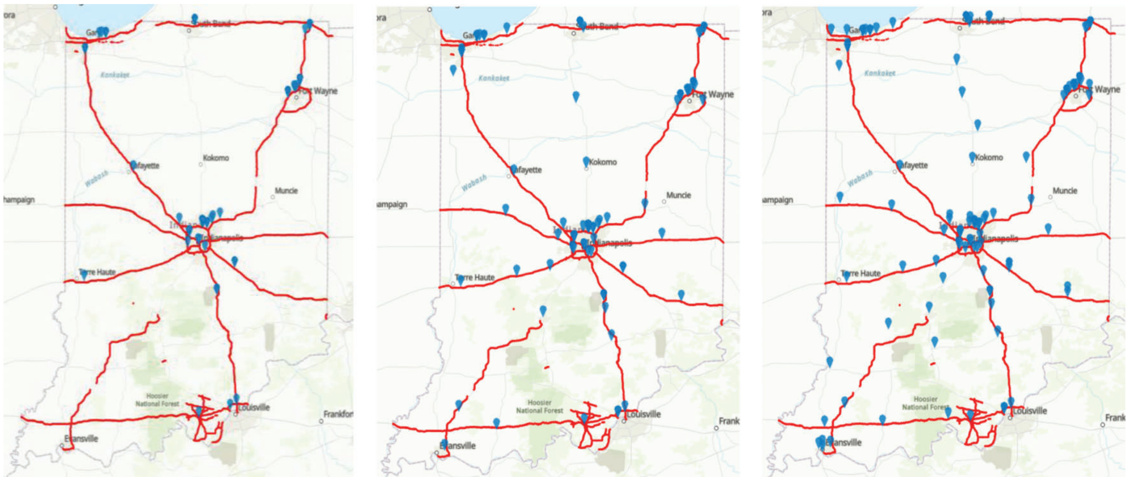

Figure 2.4 Deployed charging stations for Scenario 1–only existing charging stations (left). Scenario 2–existing charging stations and half of planned charging stations constructed (center). Scenario 3–existing charging stations and all planned charging stations.

TABLE 2.1
Number of Charging Stations in Each County (Reference)

	# of Charging Stations				# of Charging Stations		
County	**Scenario 1**	**Scenario 2**	**Scenario 3**	**County**	**Scenario 1**	**Scenario 2**	**Scenario 3**
ALLEN	14	17	19	KNOX	0	0	1
BARTHOLOMEW	2	3	3	LAKE	2	4	6
BOONE	1	1	2	LAPORTE	0	1	1
CLARK	1	1	1	LAWRENCE	0	0	1
CRAWFORD	0	0	1	MARION	16	20	24
DELAWARE	0	1	1	MARSHALL	0	0	1
ELKHART	0	0	2	MIAMI	0	0	1
FLOYD	1	2	2	MONROE	0	1	1
FOUNTAIN	0	0	1	MONTGOMERY	0	1	1
FRANKLIN	0	0	1	MORGAN	0	1	2
FULTON	0	1	1	PORTER	4	5	6
GIBSON	0	1	2	PUTNAM	0	1	1
GRANT	0	0	1	RIPLEY	0	1	1
GREENE	0	0	1	SHELBY	2	2	3
HAMILTON	5	5	6	SPENCER	0	1	1
HARRISON	1	1	1	ST JOSEPH	3	4	5
HENDRICKS	0	1	1	STEUBEN	3	4	4
HENRY	0	1	1	TIPPECANOE	1	1	1
HOWARD	0	1	1	VANDERBURGH	0	1	4
JACKSON	0	1	1	VIGO	1	1	1
JOHNSON	0	0	1	*Total Number*	*57*	*86*	*116*

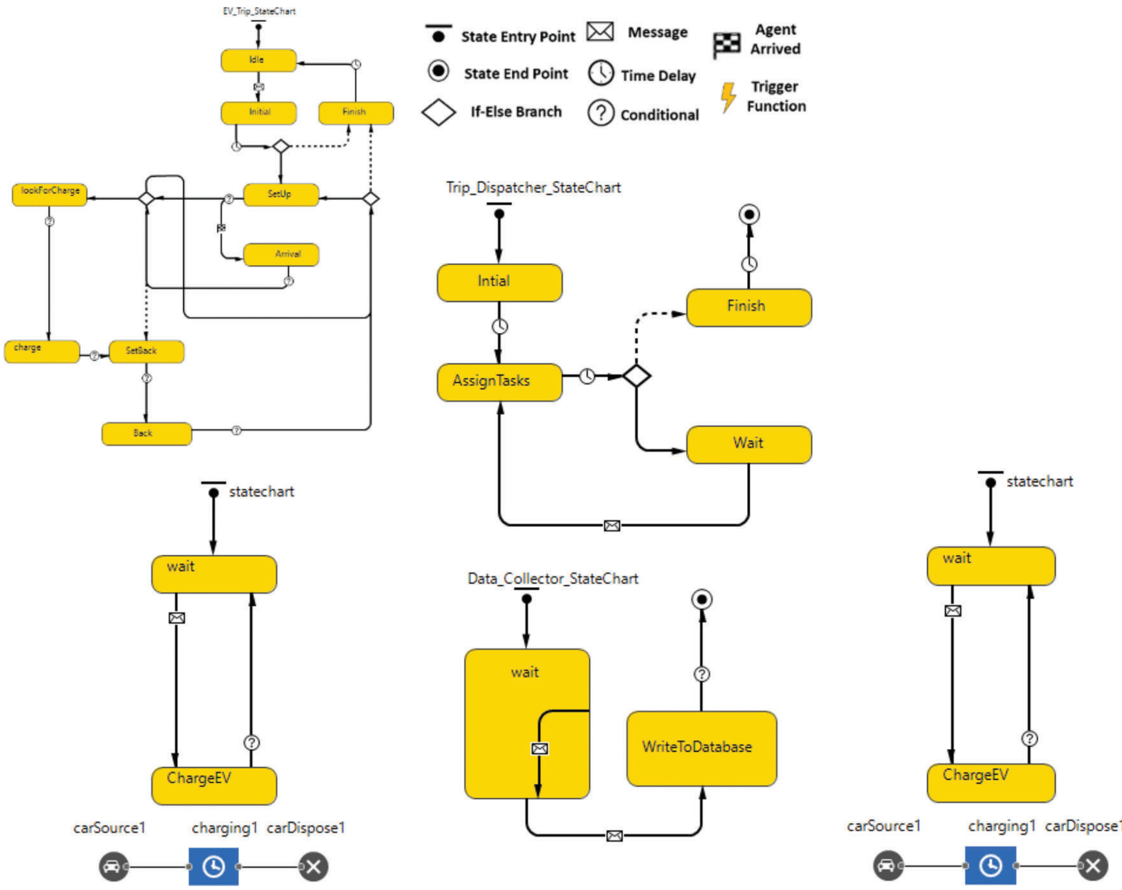

Figure 2.5 The agents used for simulation model from SPR-4509 Phase-II (left).

3. EV CHARGING DEMAND ANALYSIS

This chapter discusses the results and findings of the simulation model from nine cases. The simulation results represent the number of EVs charged, EV miles traveled, energy used during the trips and energy used during charging. The detailed results per scenario are discussed in the following subsections. The simulation model results from nine cases are summarized in Table 3.1.

3.1 Scenario 1—Currently Existing EV Charging Stations

Scenario 1 analyzed the current state and potential consequences of lacking a future charging station. Scenario 1 assumed the number of charging stations in the State of Indiana to neither decrease nor increase while the EV market penetration rises over time. The result of Scenario 1 with 15% MPR (Case 3) showed that 513 vehicles per day required charging services and consumed 26,177.07 kWh of charging energy in Indiana. The total vehicle miles traveled peaked at 4,247,055 miles, and the vehicle's total energy consumption reached 877,821.40 kWh. The simulation result showed that the area with the most demand for EV charging was Allen County, followed by Vigo and Tippecanoe County. Table 3.2 summarizes the Scenario 1 simulation result. The simulation data of Scenario 1 at 15% EV market penetration, combined with ArcGIS to generate visualized data image, produced the following results in Figure 3.1. The vast majority of charging demand that occurred in the Allen County area, reaching 186 instances of charging actions. The areas with the second most demands were Tippecanoe and Vigo County, with 64 charging demands; Bartholomew County, with 49 charging demands; and Harrison County, with 45 charging demands. The heat map generated from Figure 3.1 (right) shows the intensity of charging demands from potential EV drivers when conducting long-distance travel within the State of Indiana.

3.2 Scenario 2—Existing Stations and Partial Implementation

Scenario 2 analyzed the implementation phase of charging stations planned by INDOT. Scenario 2 assumed the charging stations would be installed in two phases, and half of the proposed charging stations were selected for implementation. Existing charging stations and partial implementation of charging stations are incorporated into the model. Scenario 2, at a 15% MPR, showed 76,291 vehicles engaged in long-

TABLE 3.1
Results Data of Simulation Model from SPR-4509 Phase-II

			Total Trips	Number of Charges	Mileage (miles)	Energy Used (kWh)	Charging Energy (kWh)
Scenario 1	5%	Case 1	24,023	186	1,336,337	277,649.66	9,848.76
	10%	Case 2	49,428	343	2,751,620	568,464.43	18,380.31
	15%	Case 3	76,291	513	4,247,055	877,821.40	26,177.07
Scenario 2	5%	Case 4	24,023	180	1,341,585	277,371.60	9,655.054
	10%	Case 5	49,428	342	2,755,693	568,054.90	18,402.89
	15%	Case 6	76,291	492	4,248,936	876,232.23	26,275.56
Scenario 3	5%	Case 7	24,023	191	1,343,503	275,726.74	10,274.36
	10%	Case 8	49,428	335	2,750,104	567,076.87	17,937.84
	15%	Case 9	76,291	513	4,235,335	876,327.79	27,375.26

TABLE 3.2
List of Counties by Number of Charging Services Provided–Scenario 1

	Scenario 1–Currently Existing EV Charging Stations		
Rank	**EV Market Penetration 5%**	**EV Market Penetration 10%**	**EV Market Penetration 15%**
1	Allen (64)	Allen (138)	Allen (186)
2	Vigo (29)	Vigo (52)	Tippecanoe, Vigo (64)
3	Tippecanoe (25)	Tippecanoe (31)	Bartholomew (49)
4	Harrison (12)	Harrison (22)	Harrison (34)
5	Bartholomew (11)	Bartholomew (21)	Hamilton (12)
6	Saint Joseph (10)	Saint Joseph (20)	Shelby (20)
7	Shelby (8)	Shelby (17)	Saint Joseph (19)
8	Hamilton, Steuben (5)	Hamilton (13)	Steuben (11)

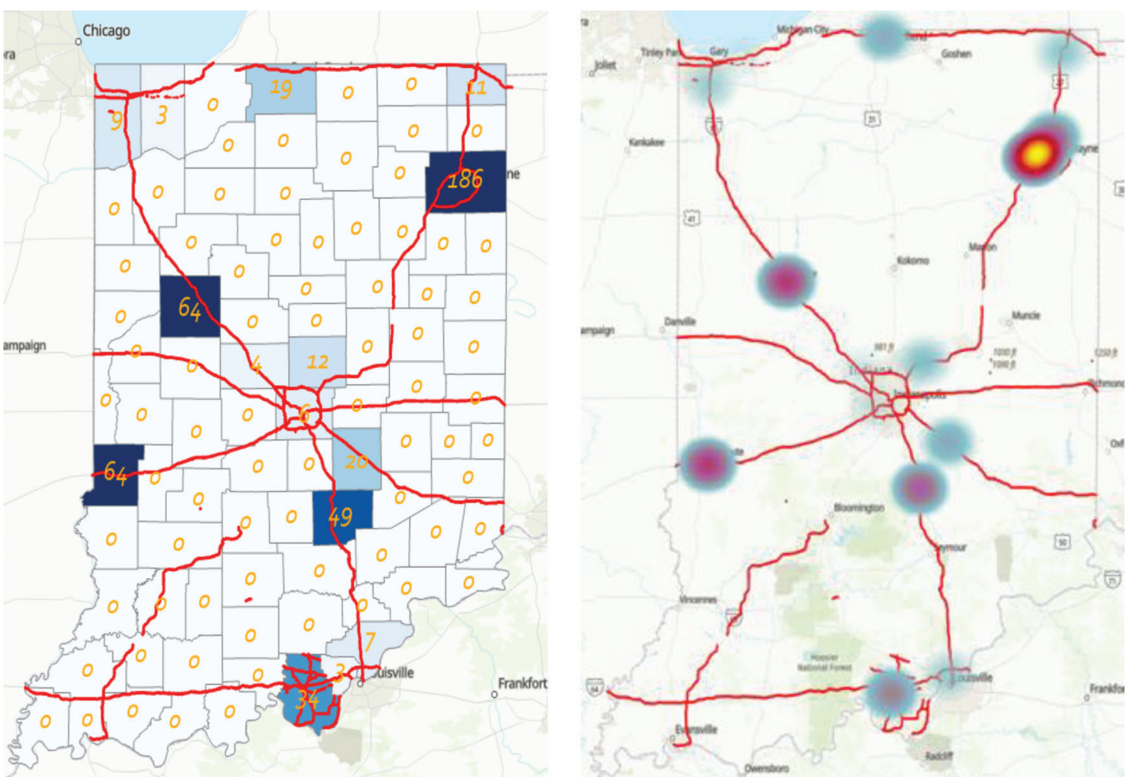

Figure 3.1 Number of charges by county (left) and heat map of charges that occurred (right) for Scenario 1 at 15% EV market penetration (Case-3).

TABLE 3.3
List of Counties by Number of Charges in Scenario 2

	Scenario 2–Existing Charging Stations With Half of the Planned Charging Stations		
Rank	**EV Market Penetration 5%**	**EV Market Penetration 10%**	**EV Market Penetration 15%**
1	Allen (55)	Allen (128)	Allen (183)
2	Fulton (16)	Tippecanoe (28)	Tippecanoe (40)
3	Tippecanoe (15)	Ripley (19)	Monroe (32)
4	Monroe, Vigo (12)	Monroe (18)	Vigo (31)
5	Gibson, Howard (9)	Gibson (16)	Howard (26)
6	Ripley (7)	Vigo, Fulton (15)	Fulton (25)
7	Marion (5)	Spencer, Saint Joseph (13)	Gibson (22)
8	Lake, Putnam, Steuben, etc. (4)	Howard (12)	Spencer (18)

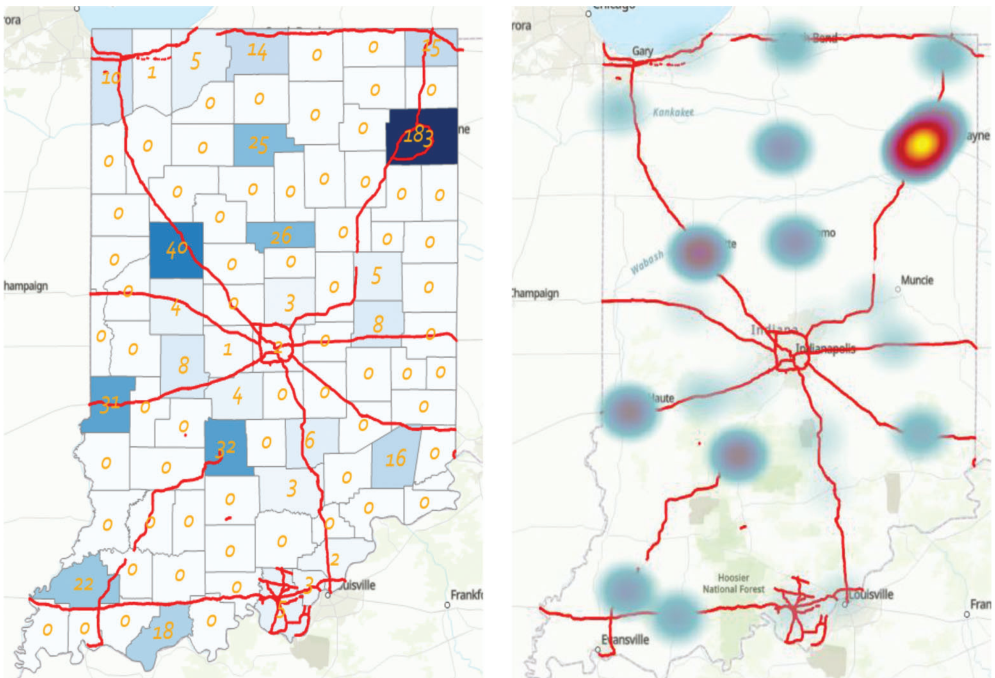

Figure 3.2 Number of charges by county (left) and heat map of charging that occurred (right) for Scenario 2 at 15% EV market penetration (Case-6).

distance trips traveled a total of 4,248,936 miles and consumed 876,232.2 kWh of energy. Out of 76,291 vehicles, 492 vehicles required charging and consumed 26,275.56 kWh of charging energy.

Scenario 2 simulation results demonstrated that Allen County was the area with the most charging demands in Indiana. It was followed by Fulton County at 5% EV MPR and Tippecanoe County at 10% and 15% EV MPR. The simulation result of Scenario 2 is summarized in Table 3.3. The simulation was further processed with ArcGIS to generate the visual data images shown in Figure 3.2. The distribution of charging demand can be observed as the implementation of charging stations absorb the charging demand. It is most prevalent in the regions where I-69 and US-31 are passing.

3.3 Scenario 3—Existing Stations and Full Implementation

Scenario 3 analyzed the scenario where all planned charging stations are implemented in the Indiana road system. It assumed all INDOT planned charging stations are present on the road system and functional. Existing charging stations are included as it was in the Scenario 2 simulation model. In Scenario 3 of 15% market penetration, 76,291 vehicles consumed 876,327.79 kWh of energy to travel 4,235, 335 miles on the road. Five hundred and thirteen instances of charging occurred and consumed 27,375.26 kWh.

Allen County remained the area with the most charging demands in Indiana, with 166 charging

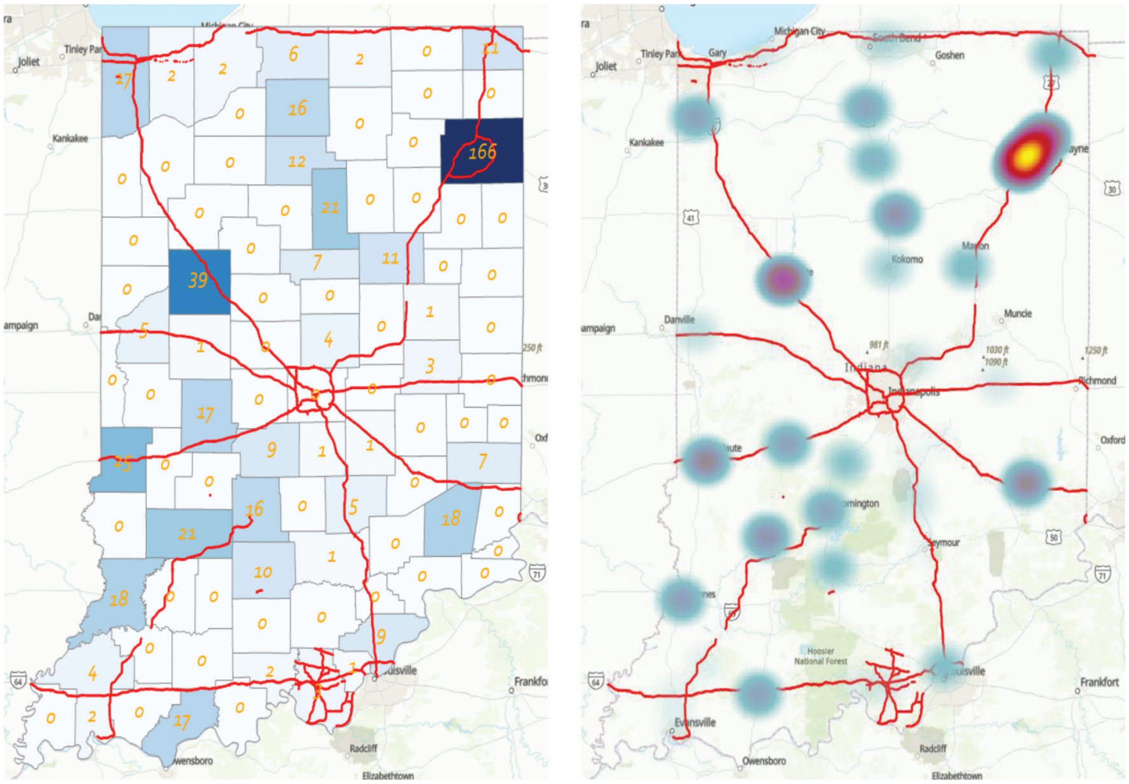

Figure 3.3 Number of charges by county (left) and heat map of charges that occurred (right) for Scenario 3 at 15% EV market penetration (Case-9).

TABLE 3.4
List of Counties by Number of Charges in Scenario 3

	Scenario 3—Existing Charging Stations With Fully Planned Charging Stations		
Rank	**EV Market Penetration 5%**	**EV Market Penetration 10%**	**EV Market Penetration 15%**
1	Allen (72)	Allen (111)	Allen (166)
2	Tippecanoe (12)	Tippecanoe (28)	Tippecanoe (39)
3	Lake (9)	Green (17)	Vigo (25)
4	Spencer (8)	Vigo (14)	Green (21)
5	Steuben, Miami (7)	Knox (13)	Knox, Ripley (18)
6	Ripley (6)	Miami (12)	Putnam, Spencer, etc. (17)
7	Monroe, Green, Knox, etc. (5)	Putnam, Monroe, etc. (10)	Marshall, Monroe (16)
8	Marshall, Fulton (4)	Marshall (9)	Fulton (12)

demands at 15% EV market penetration. Tippecanoe County was behind Allen County, with 39 charging demands at 15% EV market penetration in Scenario 3. The simulation result is summarized in Table 3.4. High charging demand distribution was observed near I-69 and US-31 (shown in Figure 3.3). This observed pattern is more significant than the pattern observed in Case 6 (shown in Figure 3.2).

3.4 Considering the Traffic Flow from Neighboring States

This section discusses the results and findings of the simulation model from 9 cases in which vehicles are traveling from neighboring states rather than within Indiana. The simulation results represent the number of EVs charged, EV miles traveled, energy used during the trips, and energy used during charging. The neighboring states considered are Illinois, Michigan, Ohio, and Kentucky. The regions used for the simulation are from ISTDM, and they are as follows: Eastern Michigan; Central Michigan, Michiana; Greater Chicago; Champaign, IL; Effingham, IL; SE Illinois; Western Kentucky; Central Kentucky; Eastern Kentucky; SW Ohio; Central Ohio; and NW Ohio. Figure 3.4 depicts the regions used on a map.

The research team ran the simulation model and yielded the following figures regarding EV charging

TABLE 3.5
Results Data of Simulation Model from SPR-4509 Phase-II Regarding Traffic from Neighboring States

			Total Trips	Number of Charges	Mileage (Miles)	Energy Used (kWh)	Charging Energy (kWh)
Scenario 1	5%	Case 1	24,915	116	1,540,516	274,195.36	6,131.76
	10%	Case 2	49,726	212	3,065,470	547,199.39	11,478.95
	15%	Case 3	74,540	297	4,583,543	817,243.87	15,929.06
Scenario 2	5%	Case 4	24,915	137	1,533,446	273,483.45	73,25.63
	10%	Case 5	49,726	257	3,064,556	546,659.78	13,753.37
	15%	Case 6	74,540	345	4,583,999	821,316.57	18,413.25
Scenario 3	5%	Case 7	24,915	137	1,541,587	274,022.54	7,331.447
	10%	Case 8	49,726	193	3,066,912	548,309.96	10,316.23
	15%	Case 9	74,540	303	4,588,949	818,940.70	16,283.73

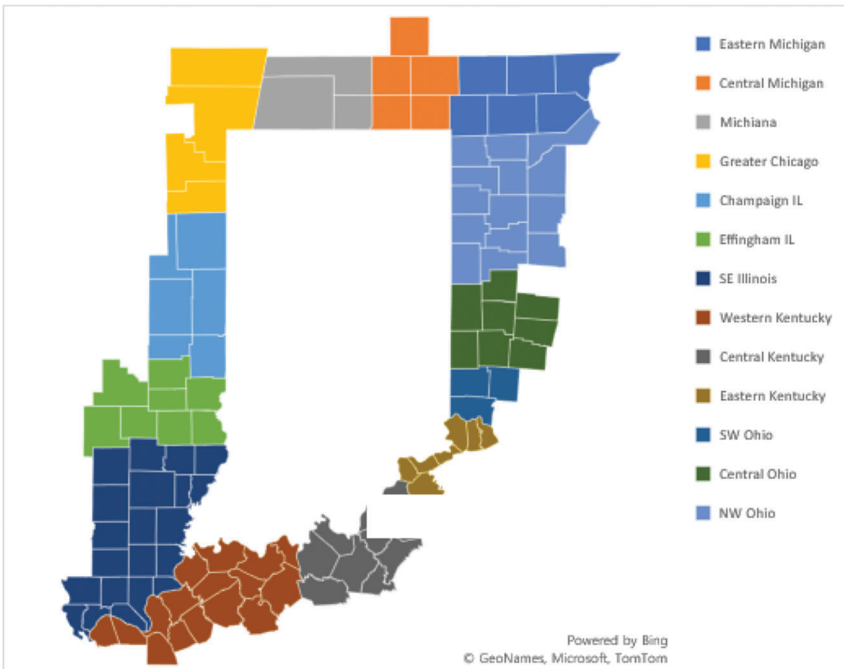

Figure 3.4 Neighboring state regions in Indiana statewide travel demand model (ISTDM).

demands from other states. At 15% MPR with only the existing chargers in Indiana, the charging energy demand was 15,929.06 kWh of energy, which served 297 vehicles out of 74,540 total trips. Total energy consumption for travel was 817,243.87 kWh, and the vehicles traveled 4,583,543 miles. Meanwhile, simulation assuming 15% MPR with fully implemented planned chargers in Indiana yielded the following result. The energy used for charging was 16,283.73 kWh, which serviced 303 vehicles out of 74,540 total trips. The vehicles traveled 4,588,949 miles and consumed 818,940.70 kWh of energy. Table 3.5 shows the detailed simulation model results for charging demand analysis of vehicles from neighboring states.

The charging demand analysis result also showed that the location where charging occurred differed distinctively. The result of 5% MPR with only the existing chargers demonstrated that the charging occurred in the following regions: Allen County, Vigo County, and others. The number of charging occurred for the simulation for 15% MPR with fully implemented charging stations demonstrated that charging occurred in the following regions: Allen County, Ripley County, and others. Comparing the results generated from Figure 3.3, charging demand data of traffic from neighboring states demonstrate that most of the charging is concentrated near the state border and dispersed throughout the state border compared to intrastate travel, which demonstrates the charging demand concentration near Fort Wayne and Allen County. Figure 3.5 shows the number of charging that occurred and a heat map of the simulation results. Further information regarding the simulation results is provided in Appendix D of this report.

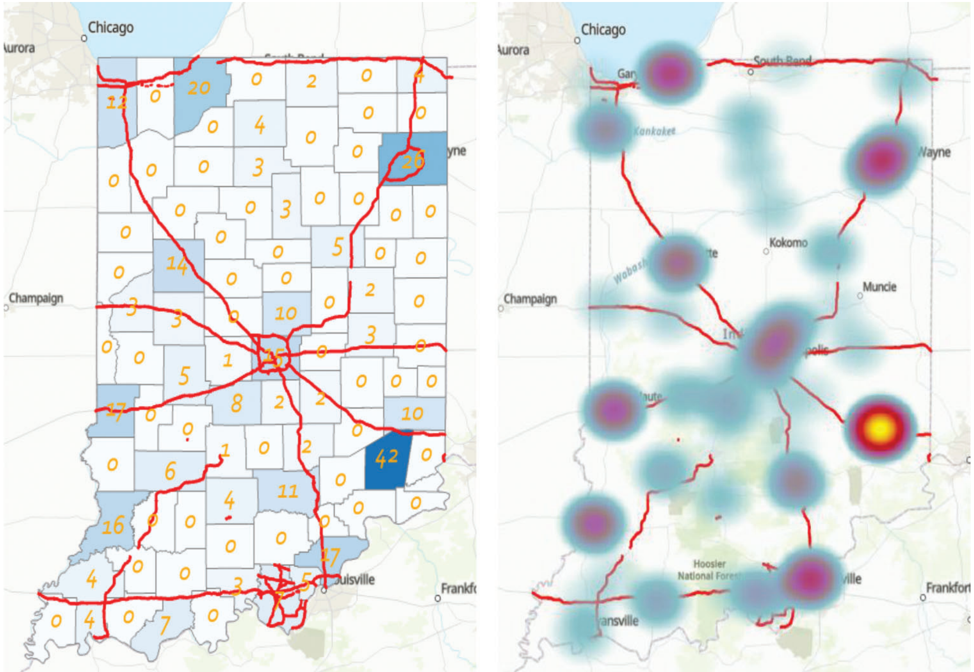

Figure 3.5 Number of charges by county (left) and heat map of charges that occurred (right) for Case 9 of traffic from neighboring states at 15% EV market penetration.

4. EV CHARGING PATTERN ANALYSIS

4.1 Per ISTDM Region

This section presents the EV charging service pattern observed per ISTDM region at 5%, 10%, and 15% EV MPR. The charging service pattern is observed based on the provided charging services per day in the ISTDM regions (shown in Figure 2.3).

Near Allen County (Region #2 of ISTDM data) is the area with the highest charging demands at the 5% EV market penetration rate. Near Vigo County (Region #11) and near Tippecanoe County (Region #12) are the areas that also have high charging service demand for long-distance EV trips in simulation Scenario 1. Interestingly, these high charging demands in Regions 11 and 12 get distributed to other ISTDM regions when the planned charging stations are partially or fully implemented in simulation Scenarios 2 or 3 (see Figure 4.1 top). For instance, the charging stations near Vigo County are expected to provide 29 EV charging services per day for long-distance travelers when the INDOT has not constructed any further charging stations. The charging demands from Vigo County decrease to 16 services and only five services per day if the INDOT constructs half and full of the planned charging stations, respectively, with 5% market penetration. Similar to the area near Vigo County, the charging demand per day in Tippecanoe County will constantly decrease (25 services to 18 services to 14 services per day) as the INDOT constructs charging stations throughout the state.

The overall behaviors and patterns of simulation results at the 10% and 15% EV MPR rates were similar to the simulation results at 5% EV MPR. The area near Allen County still showed the highest daily charging demands in Indiana, followed by the areas near Vigo and Tippecanoe Counties. Interesting behavior was observed from Vigo County as charging demand for Vigo dropped significantly with the introduction of additional charging stations. Furthermore, in Vigo County, daily charging demands per scenario slightly increased with EV MPR while the number of charging stations increased (see Figure 4.1 middle and bottom). For instance, the expected EV daily charging services in the area near Vigo County at a 10% penetration rate is 52 services. This number decreases to 22 daily charging services if the INDOT constructs half of the planned charging stations in the state (Scenario #2). However, the number has been slightly increased to 24 daily charging services in the area if the INDOT fully constructs the planned charging stations (Scenario #3).

4.2 Per INDOT District

This section discusses daily charging services per INDOT district depending on different scenarios and EV penetration rates. The Fort Wayne District is the highest daily EV charging service provider district for long-distance EV travelers, regardless of the scenarios and the EV MPR (shown in Figure 4.2). Overall numbers of charging services provided in the Fort Wayne District are not changed much as scenarios changed.

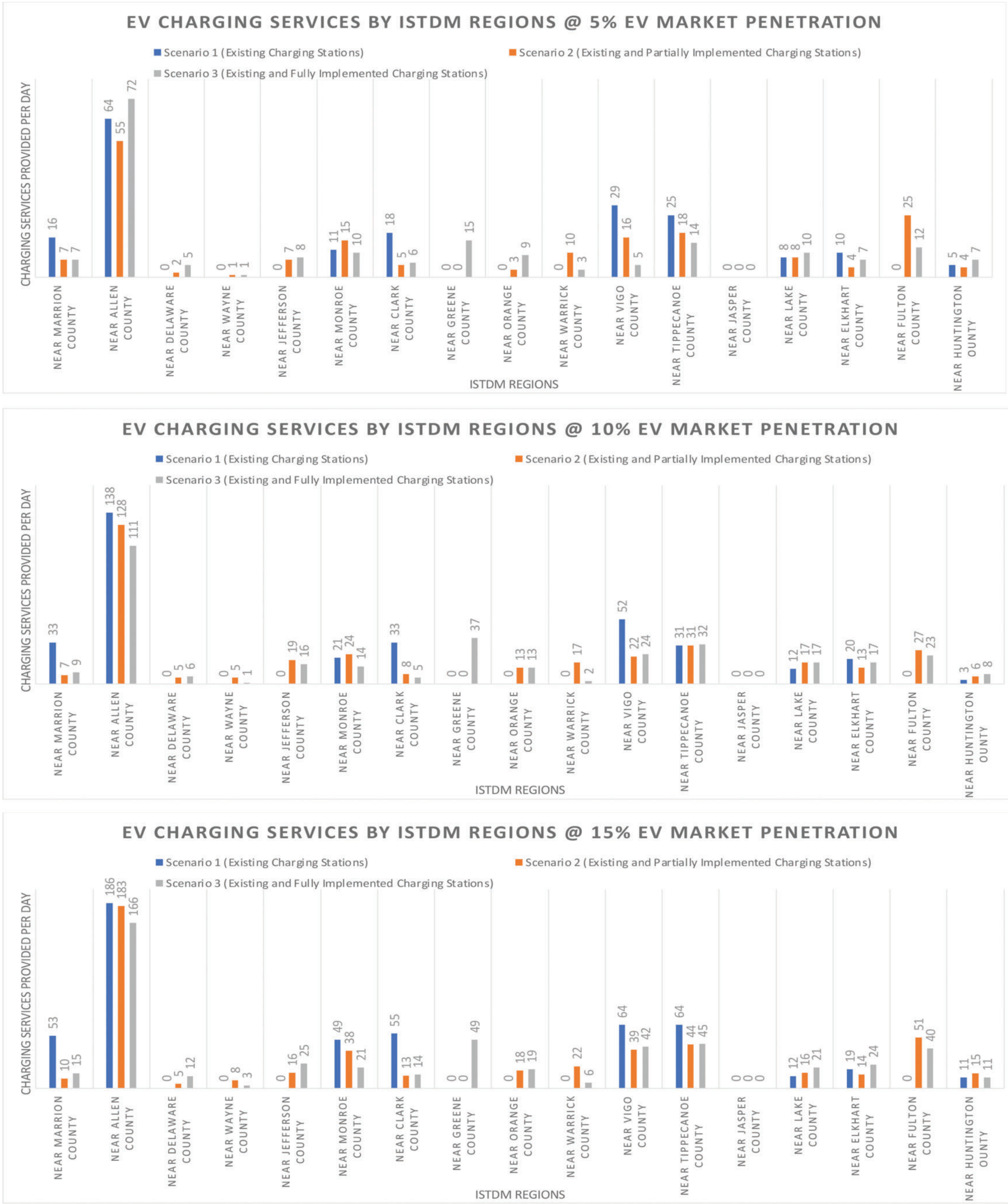

Figure 4.1 Compared scenario results of expected EV daily charging demands between ISTDM regions at different EV market penetration rates.

For instance, approximately 140 charging services will be provided in the Fort Wayne District at an EV penetration rate of 10%, and this number is not changed among three different scenarios. This means that the new charging station constructions in the Fort Wayne District would not impact the daily demands of existing charging stations in this district. However, the number of daily charging services will get increased as the EV market penetration rate gets increases. For example, the charging stations in the Fort Wayne District are expected to provide 90 daily charging services (in Scenario 3) for long-distance EV trips, and this number is increased to approximately 210 (in Scenario 3) if the EV market penetration rate is increased to 15% from 5%. The Fort Wayne District contains Allen County, and the presence of Allen County significantly contributed to Fort Wayne's demand, but also it can be seen that charging station installation near US-31 contributed to the increase in charging demand.

Another district with high demand is the Crawfordville District, as the district includes both Tippecanoe and Vigo County, where a large number of charging

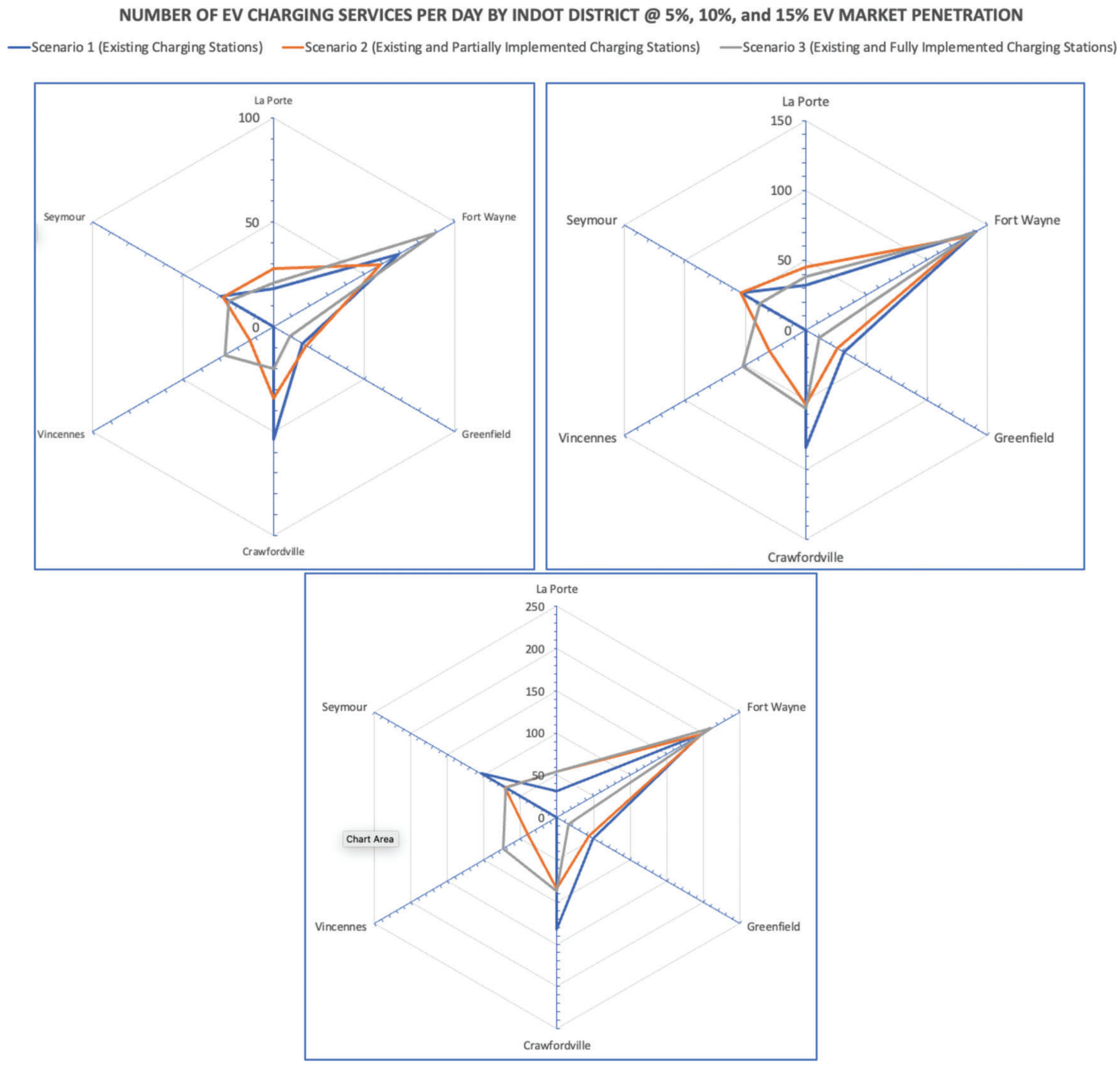

Figure 4.2 Compared scenario results of expected EV daily charging demands between INDOT districts at different penetration rates (5%-left, 10%-right, and 15%-bottom).

demands occurred during the simulation for Scenario 1. As the simulation model experiences from Scenario 1 to Scenario 3, charging demands that occurred in Crawfordsville reduced while Vincennes gained demands from 0 in Scenario 1 to approximately 30 in the Scenario 3 simulation result. It may be an indication that the priority for charging station installation is to be assigned to Vincennes District. Seymour District showed no sign of distribution of charging demand. A relatively small decrease in charging demand was observed in Greenfield District and La Porte District as the simulation models developed from Scenario 1 to Scenario 3. Figure 4.2 summarizes the findings of the simulation result at 5% EV MPR grouped by INDOT districts.

As the EV MPR increased from 10% to 15%, the number of charging services provided in districts changed. The concentration of charging demands is notable in Scenario 1 as it forms a triangular-star shape pointing to Fort Wayne, Crawfordville, and Seymour Districts. As the simulation progressed from Scenario 1 to Scenario 3, the demands in Greenfield District were absorbed by other districts. It is thought that absorption of demand occurred mostly in Vincennes and La Porte District with their increased demand in Scenario 3 compared to Scenario 1 results. Crawfordville District lost charging demands to other districts as well. Vincennes District showed that there are potential demands for charging once the charging stations are implemented. To relieve the burden on charging stations located in other districts, prioritizing charging stations for Vincennes District can be considered. Given that charging demands in Crawfordville, Seymour, and Greenfield Districts halved in Scenario 3, less prioritization could be considered contrary to Vincennes District. The number of charging stations and their locations is the key factors in determining EV charging behaviors.

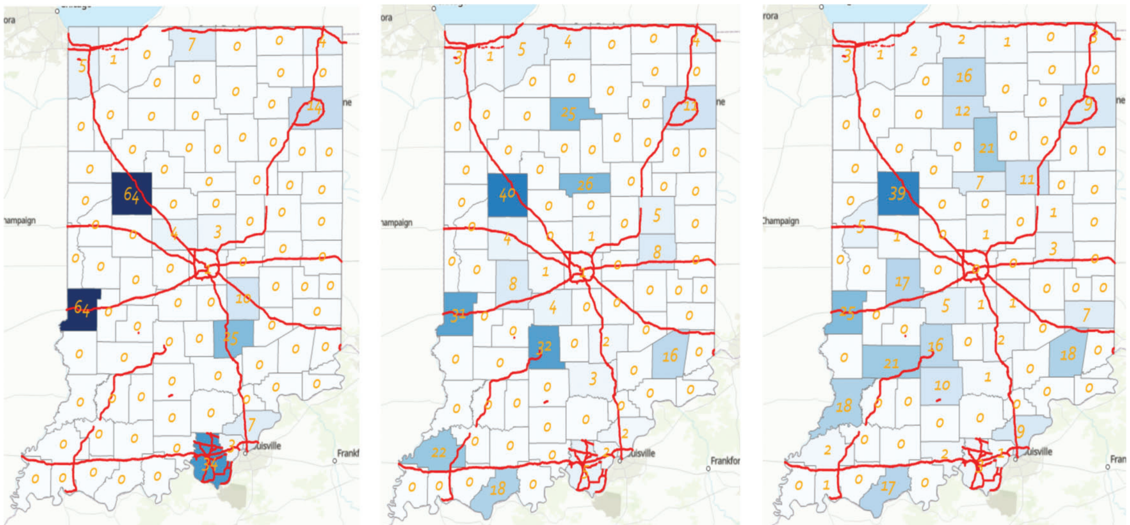

Figure 4.3 Average number of charges at the county level: Scenario 1—15% EV MPR (left), Scenario 2—15% EV MPR (center), Scenario 3—15% EV MPR (right).

4.3 Per County

Further analysis of simulation results was conducted by calculating the average charging demand per station in counties. Histogram results showed that the majority of charging stations are used less than five times per day, and it did not seem to be an appropriate result. Furthermore, the histogram showed the statewide data. As all information from the simulation scenario is combined into a single figure, the details at the county level disappear. The need for data regarding county-level demand rose. The average charging station usage per county is derived by dividing the total number of charges in the county by the number of charging stations in the county.

The average number of charging that occurred at the county level varied significantly, as expected, due to the absence of a planned charging station in Scenario 1. It was first assumed that Allen County would be the county with the highest average use per charging station based on the information provided by the simulation results. The actual value of average charging station usage was 14 in Allen County. However, Tippecanoe and Vigo Counties were found to have the highest average number of charging stations used at 64 instances per charging station. It is a clear indication that the charging stations in Tippecanoe and Vigo Counties are overused and overburdened with the demands. Based on the result, charging station installation priority could be given to relieve the demand concentration. The charging stations in Harrison County and Bartholomew County experienced similar but less severe demand concentrations. Figure 4.3 (left) summarizes and visualizes data regarding the average number of charging station uses from Scenario 1 at 15% EV MPR simulation result.

The increased number of deployed charging stations deployed decreased the number of charging demands per charging station in the county. The reduction would be most likely to improve the charging experience of the drivers. As for Scenario 2, the average charging station used in Tippecanoe County and Vigo County visibly decreased from 64 to 40 and 31. Meanwhile, the charging demands that did not exist in certain counties rose to existence. Such counties are Spencer County and Gibson County, and more. The counties with increased average charging demand are located near I-69 and US-31. The charging demands in Harrison County disappeared, and it may be a result of newly installed charging stations along I-69. The average number of charge demands is likely to decrease as a greater number of charging stations are deployed in the State of Indiana. Figure 4.3 (center) summarizes the findings from simulation results in Scenario 2 at 15% EV MPR.

The fully implemented charging stations planned by INDOT decreased the average number of charges in the simulation result of Scenario 3 at 15% EV MPR. The average charging demand in Allen County was found to be nine instances per charging station. The average charging demand in Tippecanoe County remained similar to the result from Scenario 2 at 15% EV MPR. It is thought that additional charging stations near US-31 did not affect the charging stations in Tippecanoe County. The average charging station uses per county are expected to provide more realistic figures to determine the severity of demand concentration and method to relieve by prioritizing the installation of charging stations. For example, the implementation of charging stations can be planned to lessen the burden on the overused charging stations in Tippecanoe County. Figure 4.3 (right) summarizes the findings of the average number of charges provided per charging station at each county from simulation results of Scenario 3 at a 15% EV MPR.

5. CONCLUSION

The objective of SPR-4509 Phase-II was to identify and observe the impacts of EV charging stations on the EV ecosystem by incorporating the charging stations into the simulation model. A simulation model was exposed to different scenarios regarding the number of charging stations from existing only to fully implemented charging stations planned by INDOT and varied EV market penetration.

The results found that the EV charging demands grew proportionally as the market penetration grew from 5% to 10% and then to 15%. The total energy demand and energy used for charging remained consistent throughout the simulations in Scenario 1, Scenario 2, and Scenario 3. One of the most significant findings is the sign of distributed charging demands as the number of charging stations increased. The charging demands were seen from the regions where charging stations were introduced and where charging stations were not available during the Scenario 1 simulation. The areas where I-69 and US-31 (near Fort Wayne and Kokomo) are passing are notable examples. Meanwhile, some counties have seen the demands plummet with the implementation of proposed charging stations, such as Harrison County in southern Indiana. The research team observed the charging station and charging demand patterns in various charging station implementation scenarios. The average number of charges provided per station varied by county. In Allen County, a relatively low average number of charges occurred from multiple charging stations available. Meanwhile, the charger in Tippecanoe County used 64 instances per station.

The research team sees several potential implementations from the project results. Although the current studies can estimate the charging demand from the EV by observing the number of vehicles and average drivers' behaviors, the specific demand could not be calculated as the previous data were more concerned with macro sets of data. The simulation provides the specific number of charging stations used depending on the scenario. Furthermore, the results of the project found that the charging demand was most concentrated in the Allen County area, but when concerned with the average number of charging stations used, the charging stations in Allen County were able to provide charges at reasonable waiting times when only considers the average charge number per charging station. The discovery can encourage private sectors to seek areas where enough charging stations are not present and needed. Further implementation of research findings could be for the grid operators as the available capacity in the electricity grid can be predicted. While the total charging demand in both the number of charges provided and energy did not change, the sign of distributed charging demand throughout the state allows the grid operators to prioritize the area where the grid needs to be upgraded.

Due to limitations, the simulation model for SPR-4509 can improve its capability and performance in the future. The model can randomly select the battery charge level, which the vehicle would start to look for a charging station. It would greatly enhance the variability in refueling demand points and reflect EV drivers' tendency to refuel at various points in their journey. The parameter can be a random value, for example, between 20% to 40%. Furthering from random selection, the simulation model can deploy the charging stations by randomly selecting the charging station deployment location. It could bring stakeholders the opportunity to study the effect of charging stations on the road. Finally, the simulation model can implement the time to further study the charging stations usage. The addition of the time variable would give results for the average time the drivers wait to use the charging station. However, the model would need to be restructured to accommodate the feature of the simulation.

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Konstantinou, T., Chen, D., Flaris, K., Kang, K., Koo, D. D., Sinton, J., Gkritza, K., & Labi, S. (2022). *A strategic assessment of needs and opportunities for the wider adoption of electric vehicles in Indiana* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2022/12). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317376

APPENDICES

Appendix A. EV Charging Demand Data Map Visualization

Appendix B. Average Charging Station Uses in County

Appendix C. Histogram of Charging Stations and Provided Charging Services

Appendix D. Charging Demand Analysis of Traffic from Neighboring States

APPENDIX A. EV CHARGING DEMAND DATA MAP VISUALIZATION

The figures below represent the results of the simulation model from SPR-4509 Phase II. The left images show the number of charging actions occurred in the county. Meanwhile, the images on the right side will show the heat map of the charging demand intensity within said County. Throughout the simulation from Scenario 1 (5% market penetration) to Scenario 3 (15% market penetration), the area with the most demand for charging was Allen County.

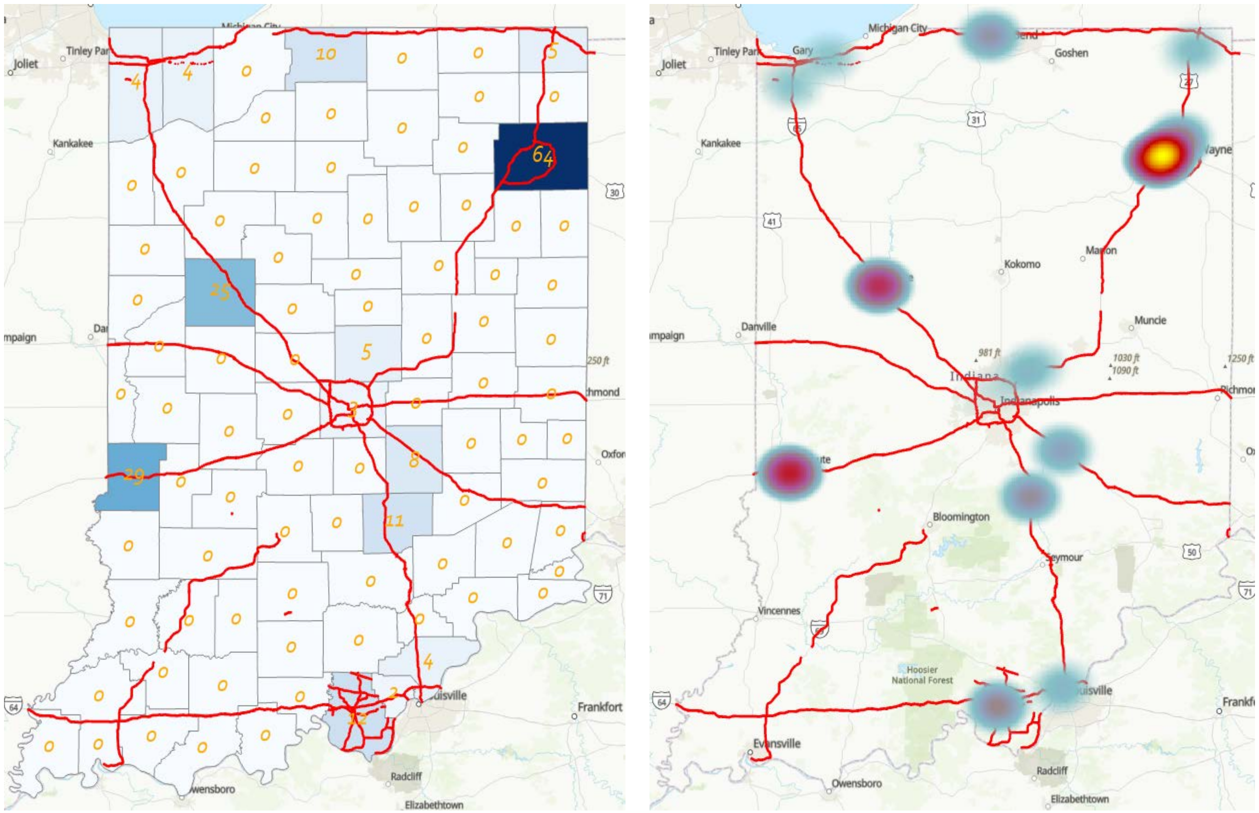

Figure A.1 Number of charging by county (left) and heat map of charging occurred (right) for Case 1 at 5% EV market penetration rates.

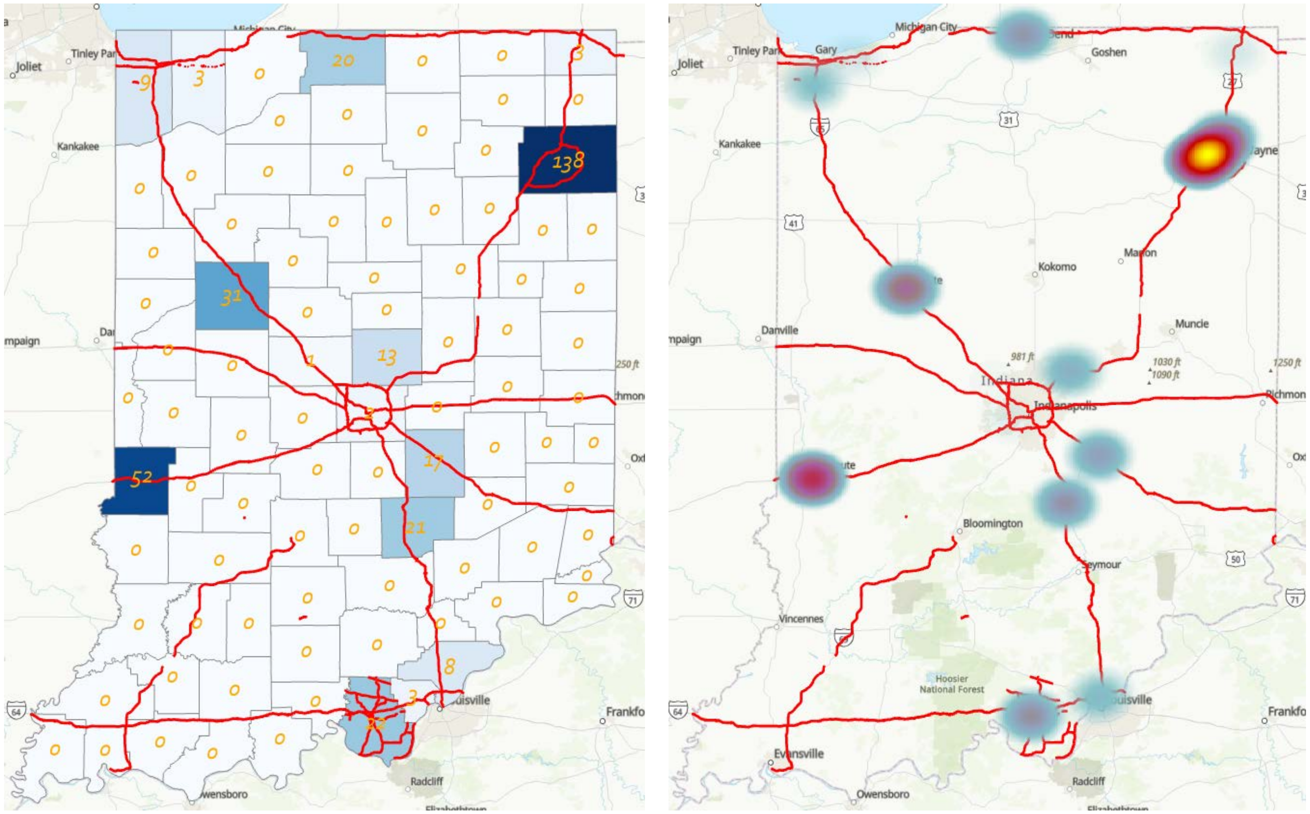

Figure A.2 Number of charging by county (left) and heat map of charging occurred (right) for Case 1 at 10% EV market penetration rates.

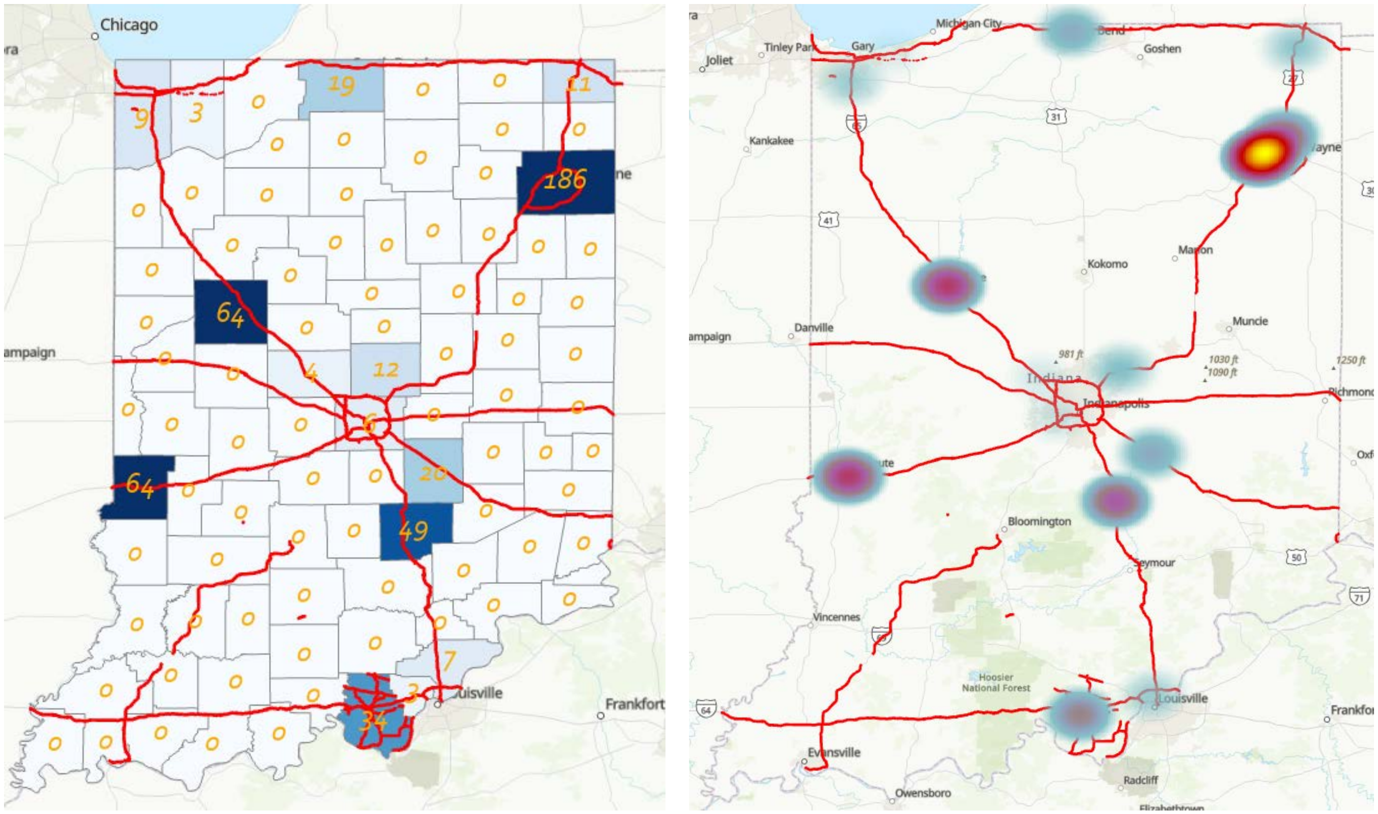

Figure A.3 Number of charging by county (left) and heat map of charging occurred (right) for Case 1 at 15% EV market penetration rates.

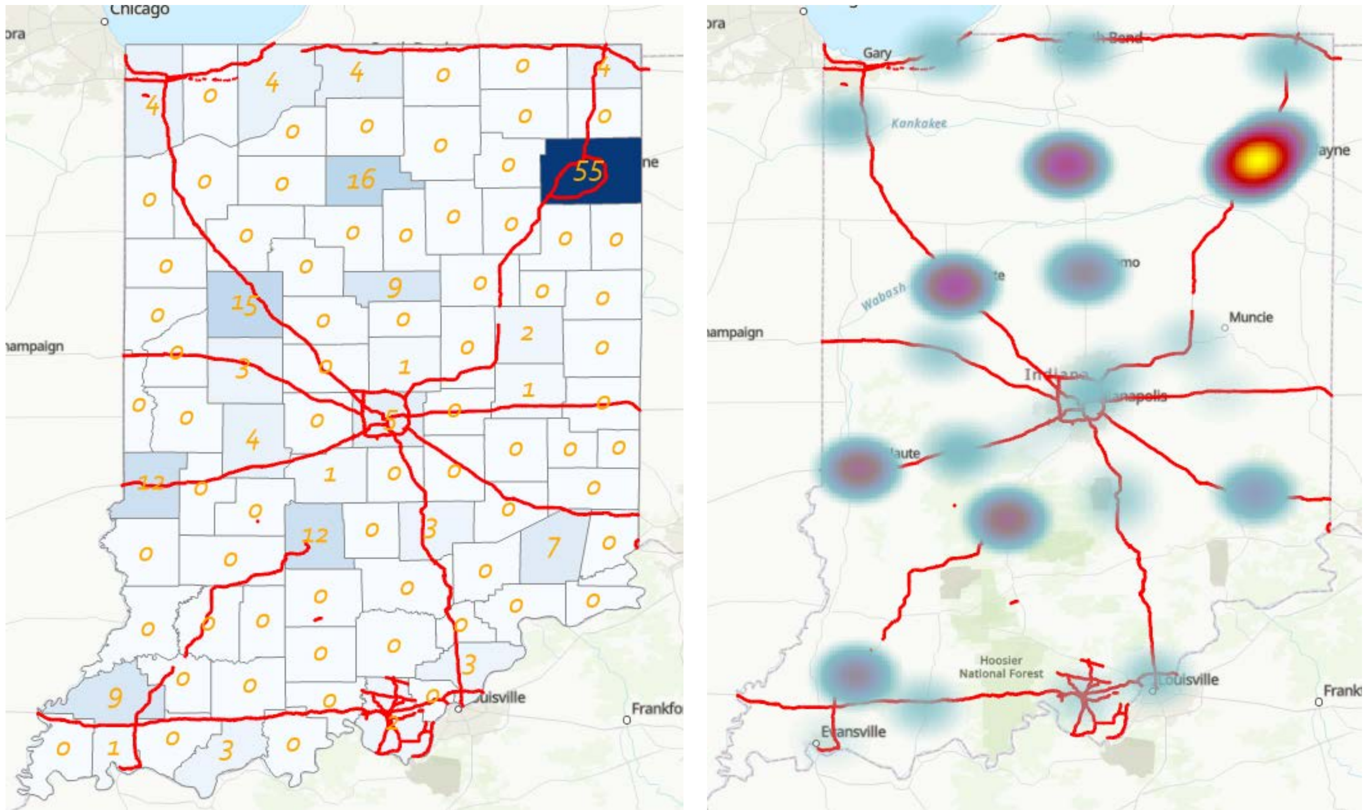

Figure A.4 Number of charging by county (left) and heat map of charging occurred (right) for Case 2 at 5% EV market penetration rates.

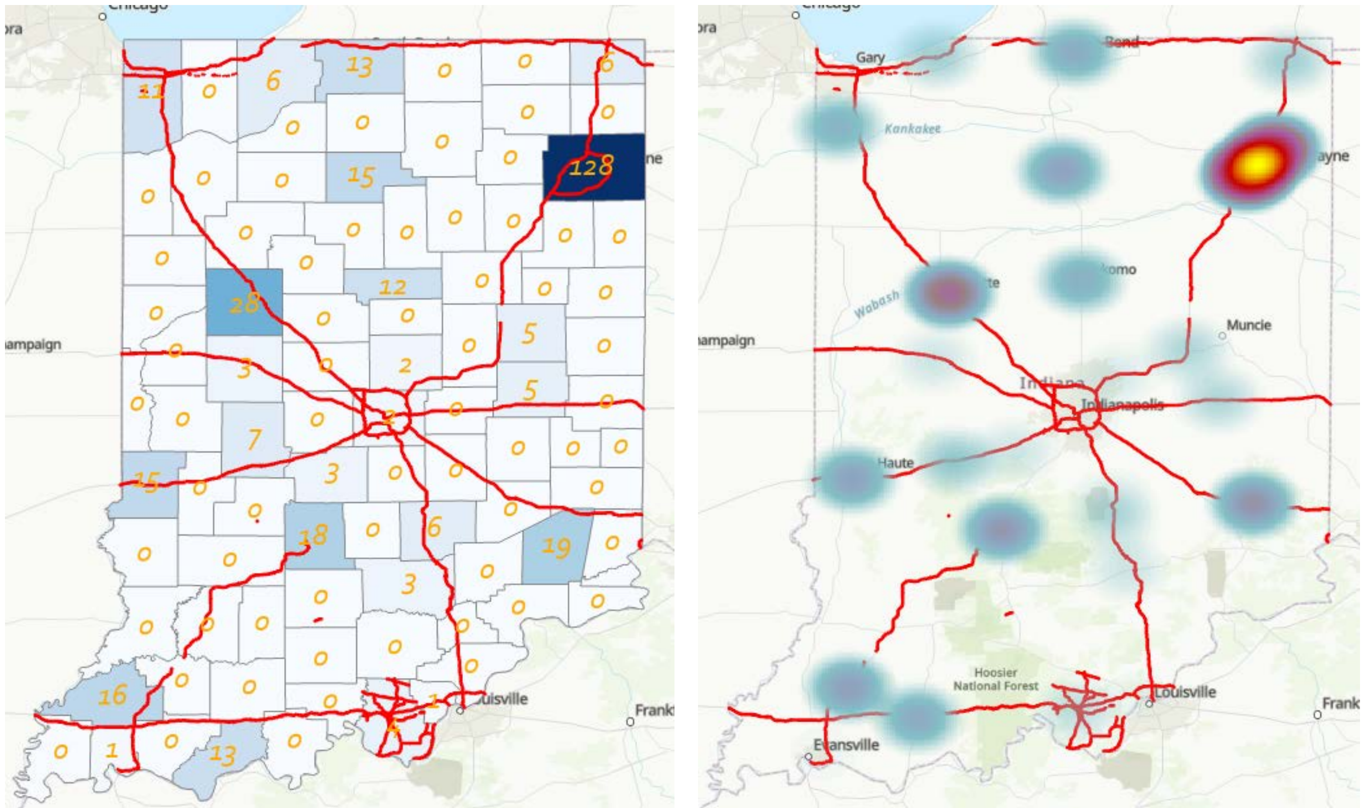

Figure A.5 Number of charging by county (left) and heat map of charging occurred (right) for Case 2 at 10% EV market penetration rates.

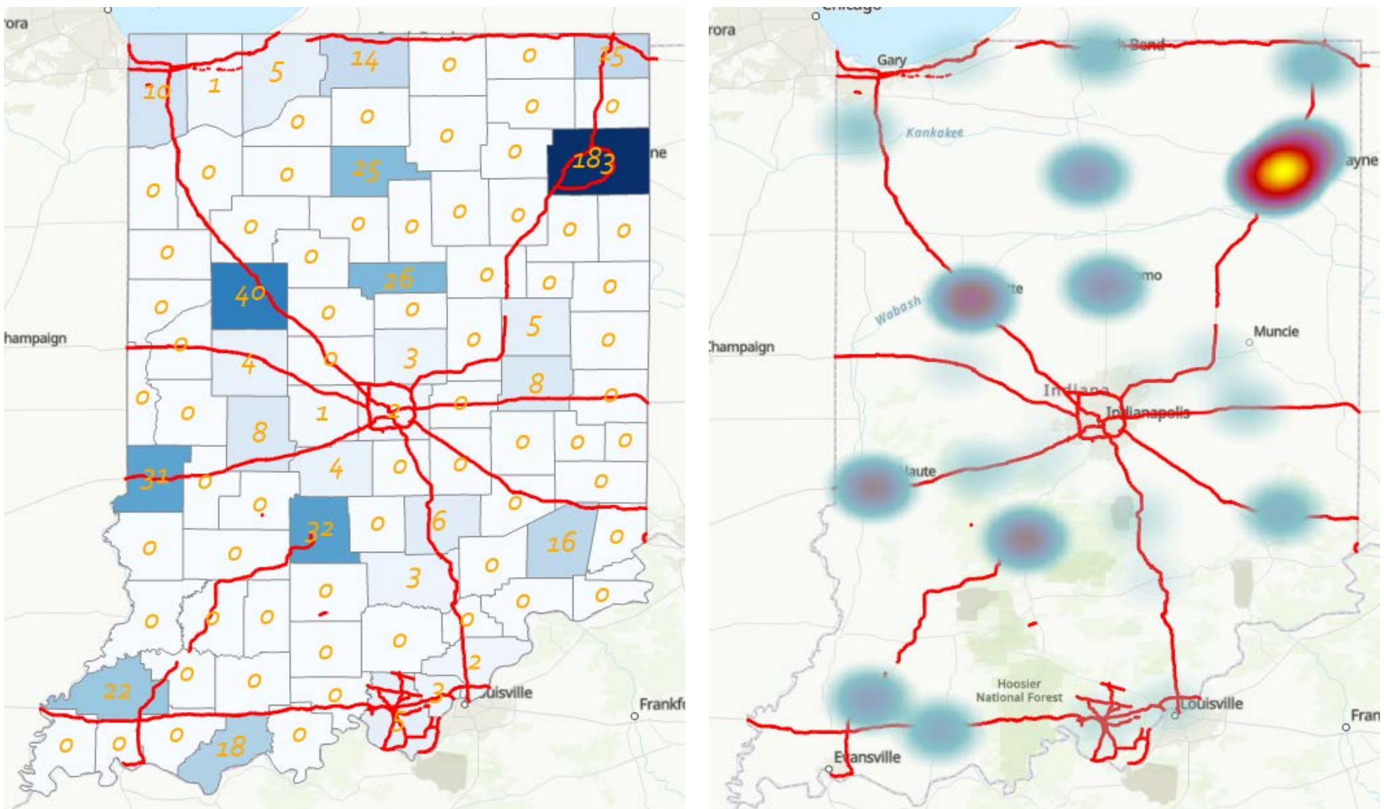

Figure A.6 Number of charging by county (left) and heat map of charging occurred (right) for Case 2 at 15% EV market penetration rates.

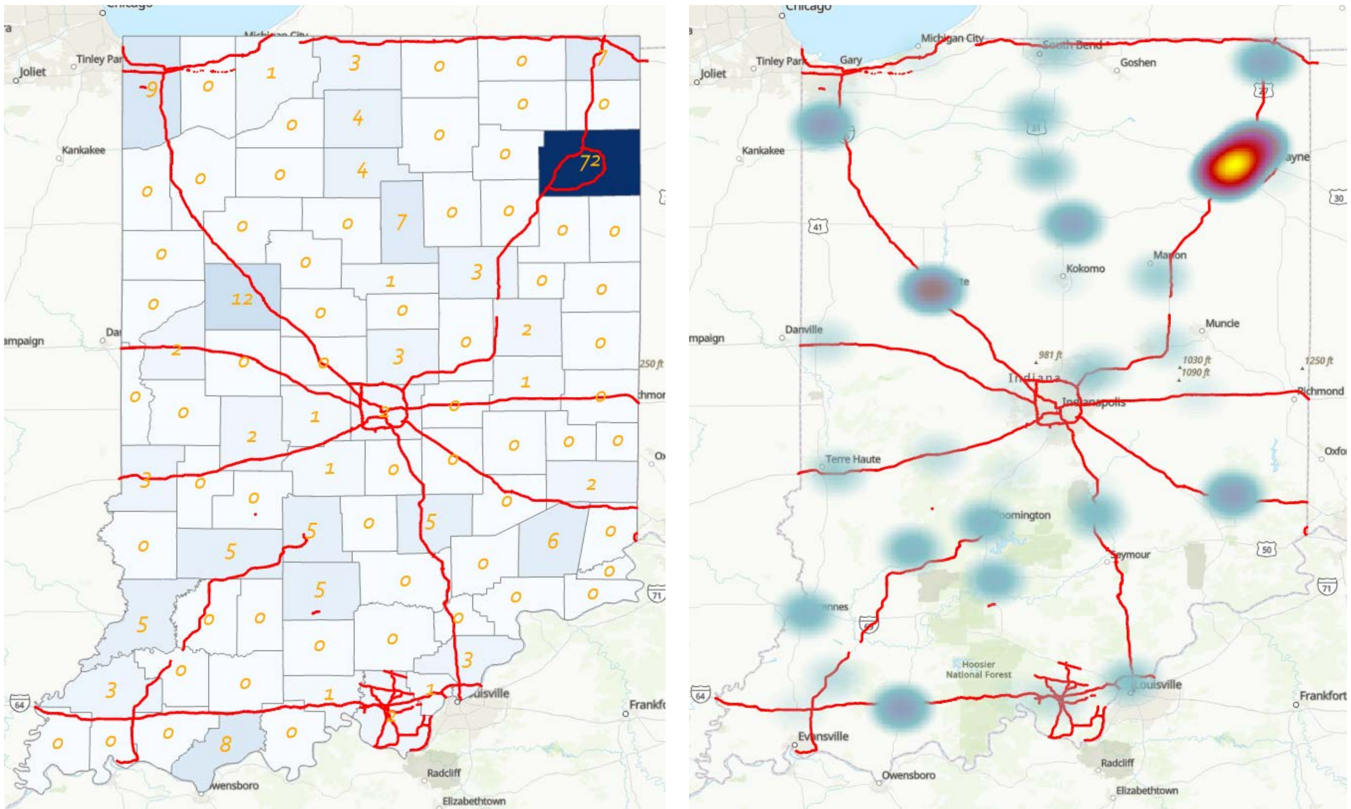

Figure A.7 Number of charging by county (left) and heat map of charging occurred (right) for Case 3 at 5% EV market penetration rates.

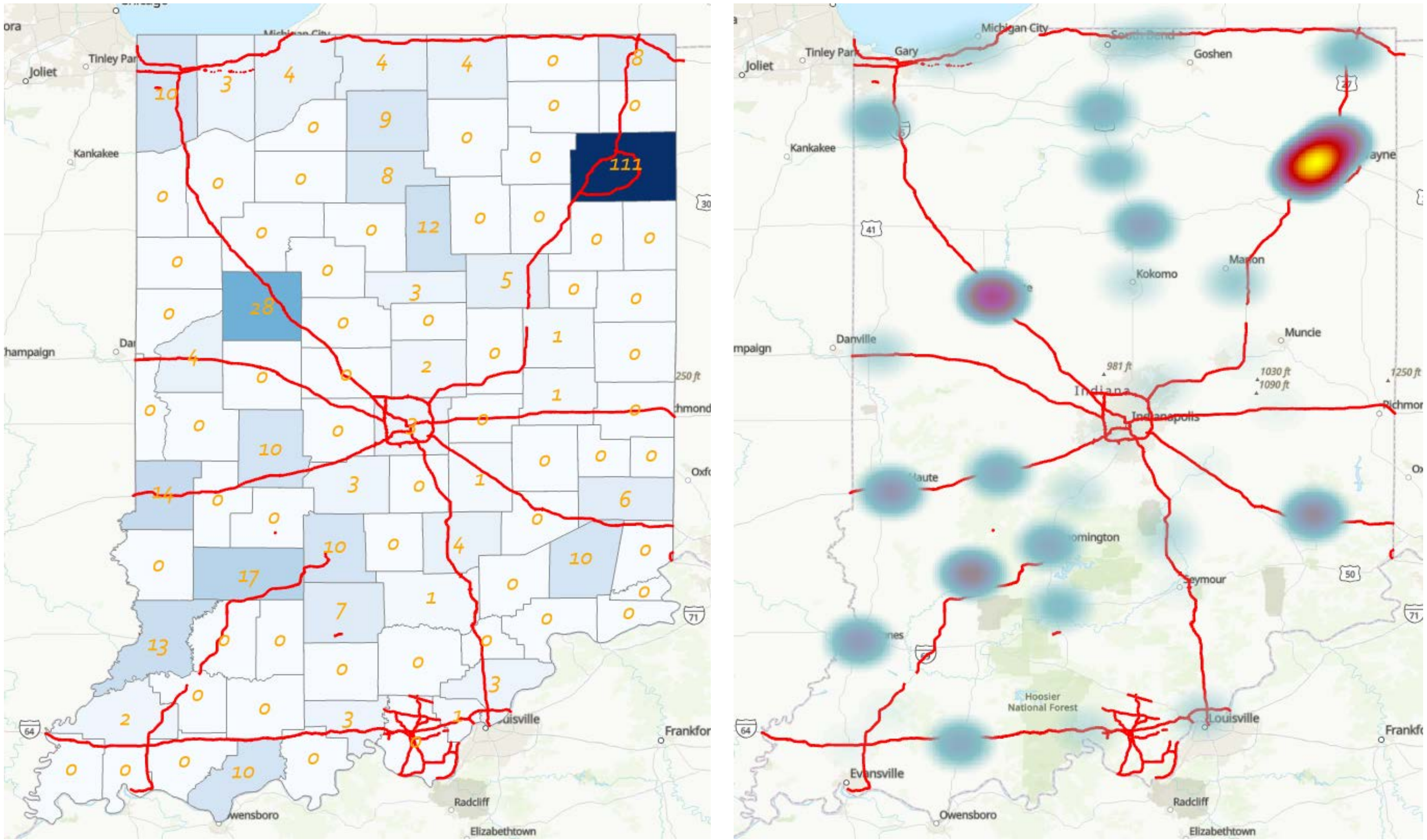

Figure A.8 Number of charging by county (left) and heat map of charging occurred (right) for Case 3 at 10% EV market penetration rates.

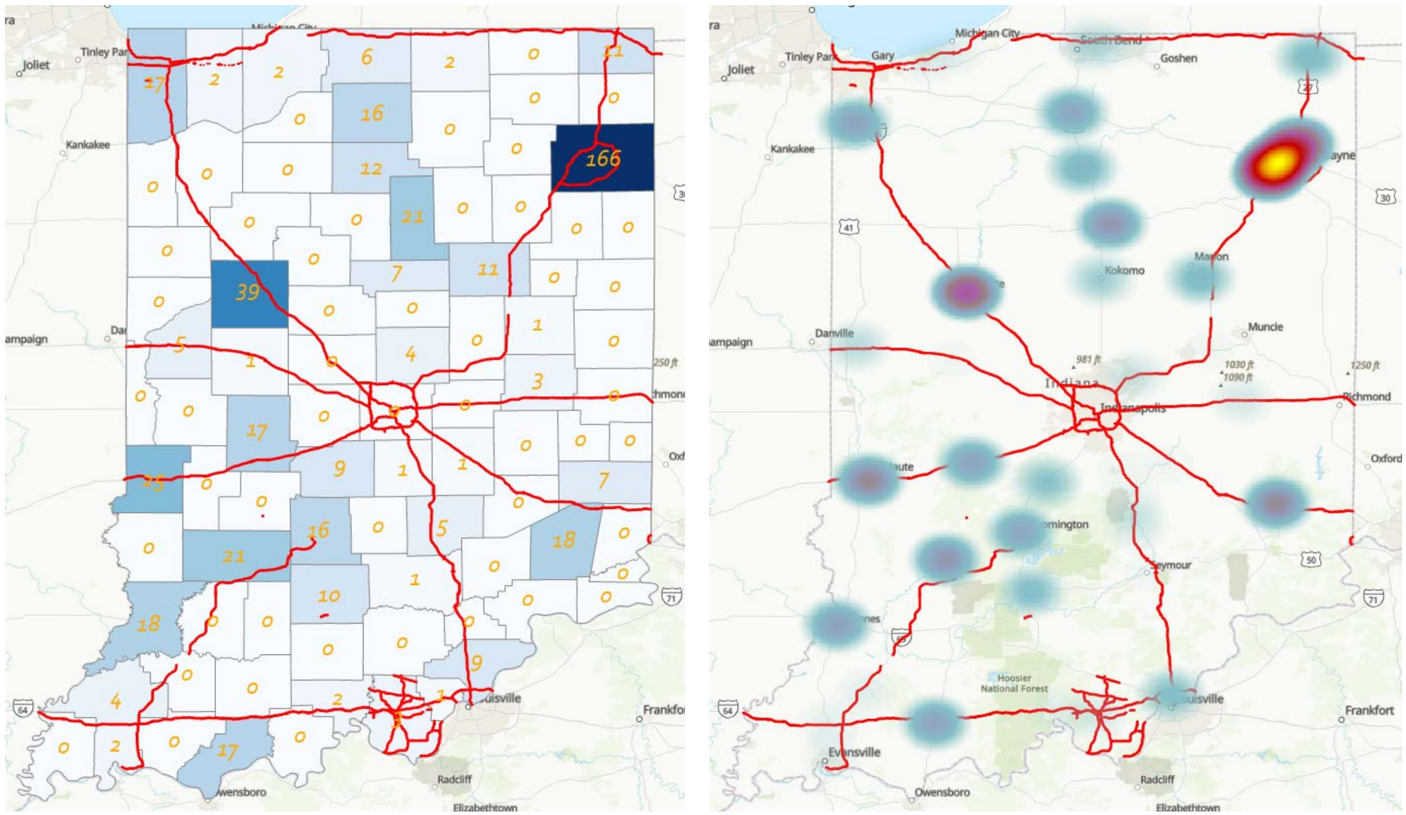

Figure A.9 Number of charging by county (left) and heat map of charging occurred (right) for Case 3 at 15% EV market penetration rates.

APPENDIX B. AVERAGE CHARGING STATION USES IN COUNTY

Appendix B will show the results of simulation model of SPR-4509 Phase II. A processing of information has been conducted to display the average charger uses at the county level in the images. As the number of chargers increase from Case 1 to Case 3, the distribution of charging demand occurs in other locations while the average number of charger use decreases in a place where chargers already existed in Case 1.

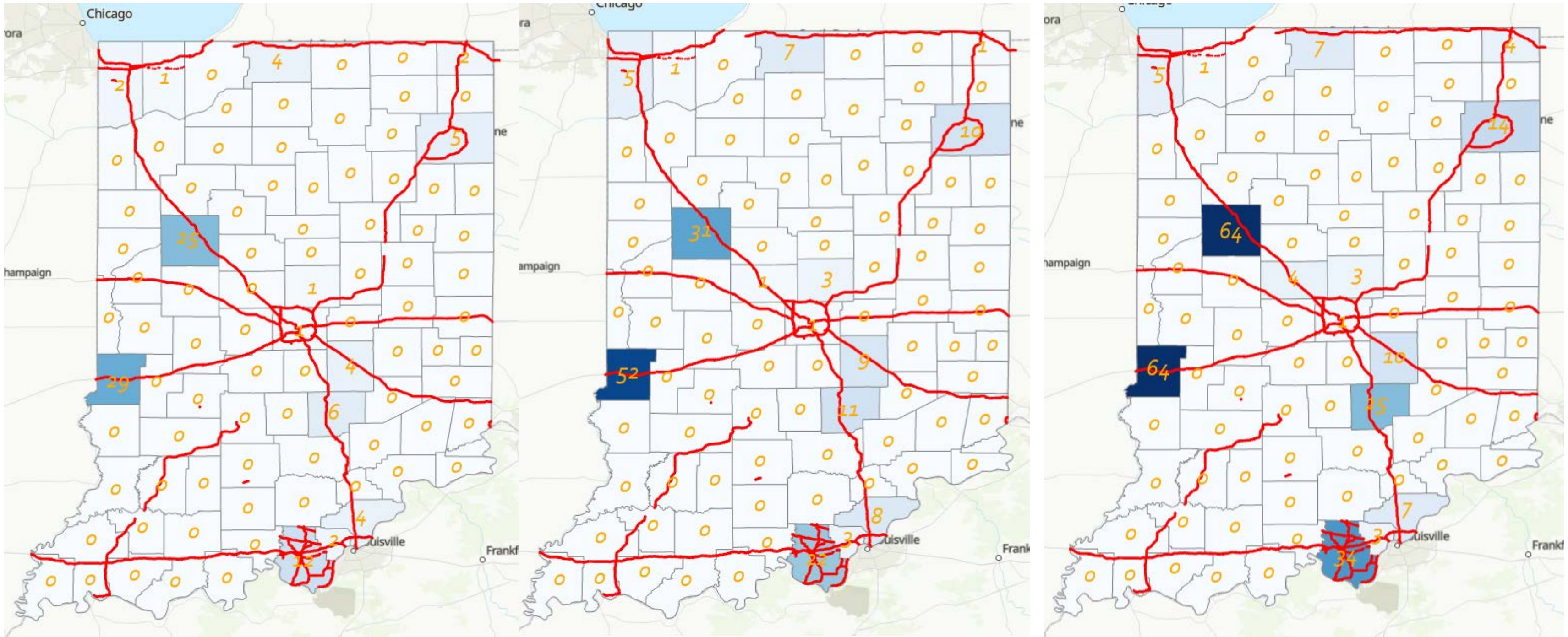

Figure B.1 Average number of charger use Case 1 at 5% EV market penetration rates (left), 10% EV market penetration rates (center), and 15% EV market penetration rates (right).

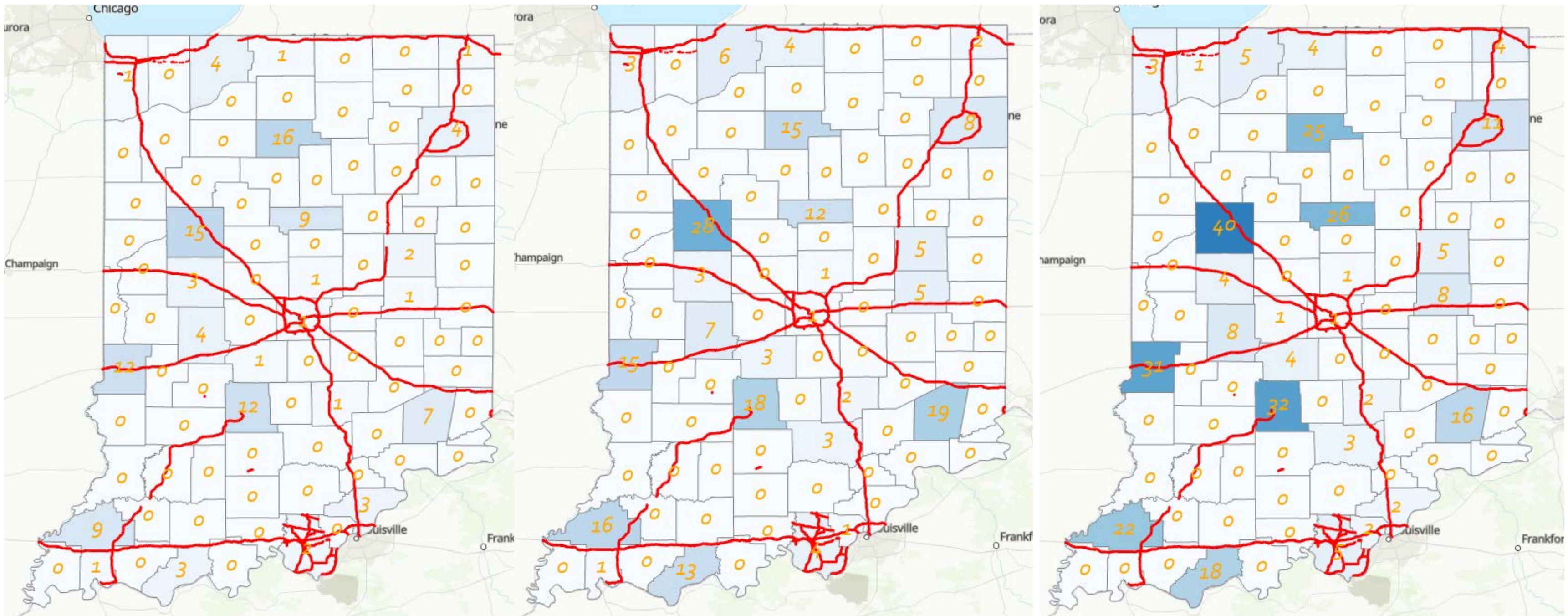

Figure B.2 Average number of charger use Case 2 at 5% EV market penetration rates (left), 10% EV market penetration rates (center), and 15% EV market penetration rates (right).

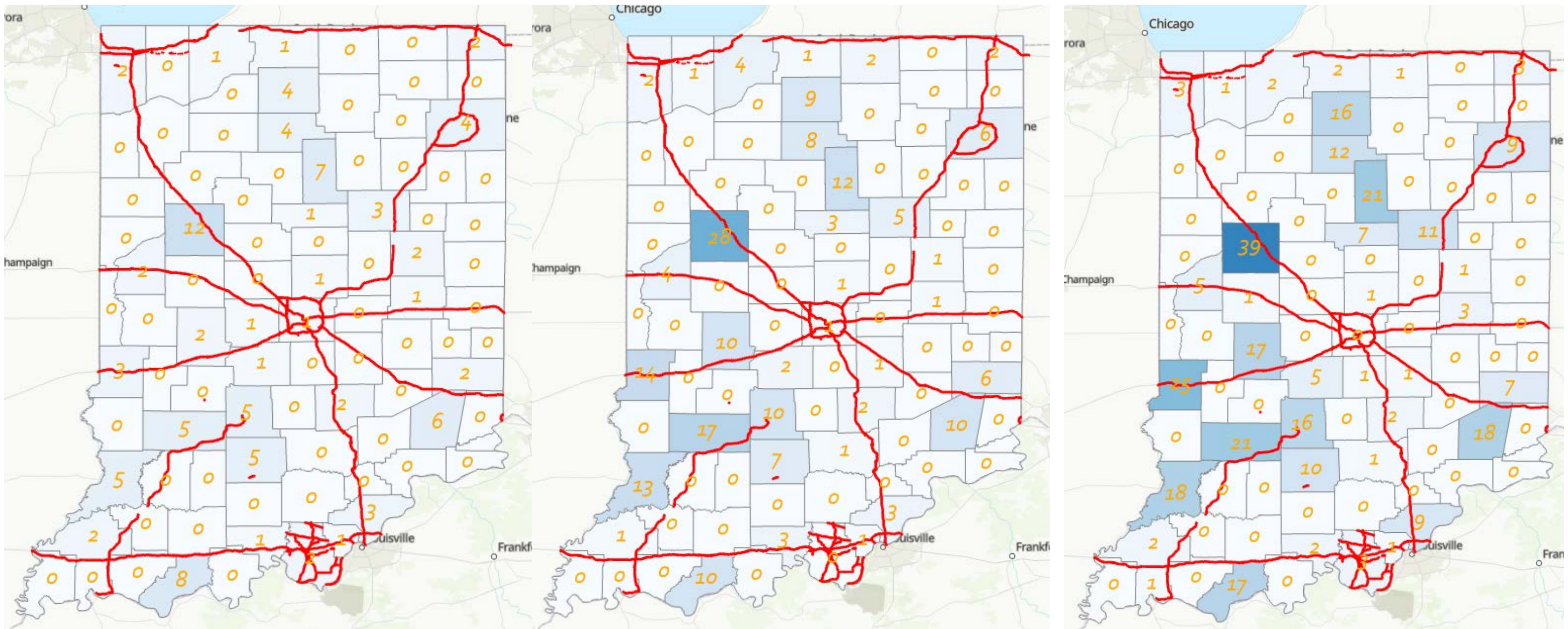

Figure B.3 Average number of charger use Case 3 at 5% EV market penetration rates (left), 10% EV market penetration rates (center), and 15% EV market penetration rates (right).

APPENDIX C. HISTOGRAM OF CHARGING STATIONS AND PROVIDED CHARGING SERVICES

Appendix C shows the result of charger uses throughout the State of Indiana in simulation environment. On the right side of images, the maximum number of uses can be observed, while the number of chargers which has been used that number of amounts is shown in bar. The average number of charging is shown on the graph as blue line which slices through the result bar vertically.

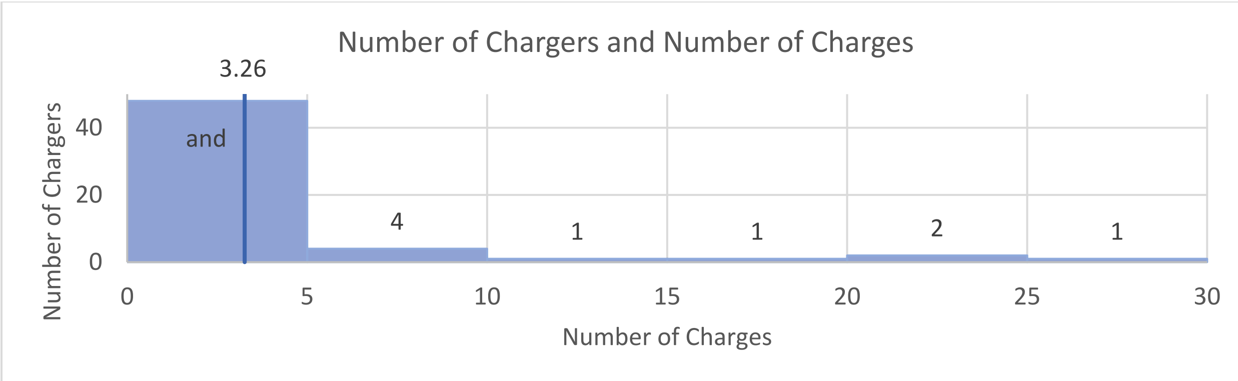

Figure C.1 Number of charges and number of chargers Case 1: 5% EV market penetration rates scenario.

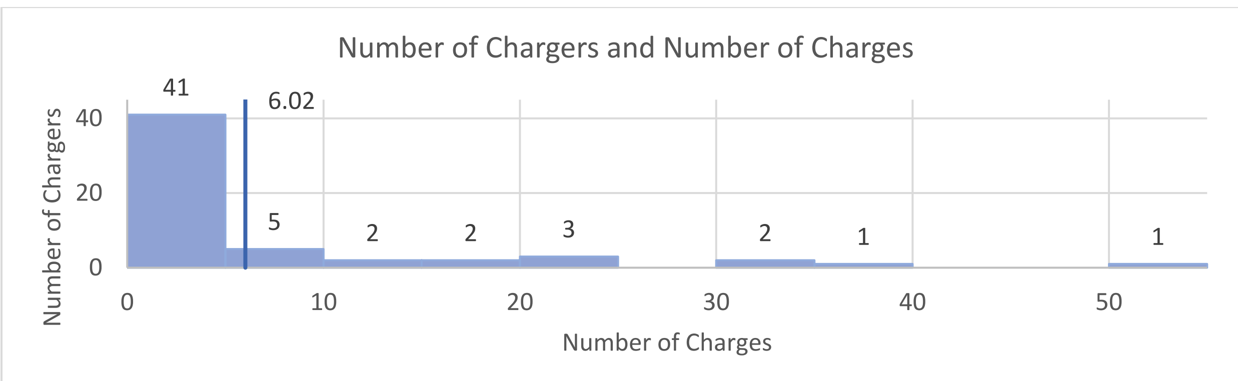

Figure C.2 Number of chargers and number of chargers Case 1: 10% EV market penetration rates scenario.

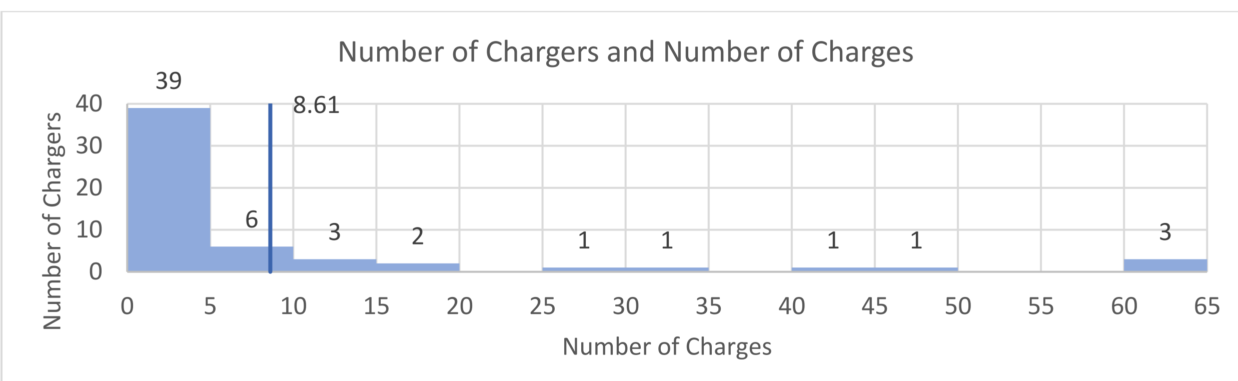

Figure C.3 Number of charges and number of chargers Case 1: 15% EV market penetration rates scenario.

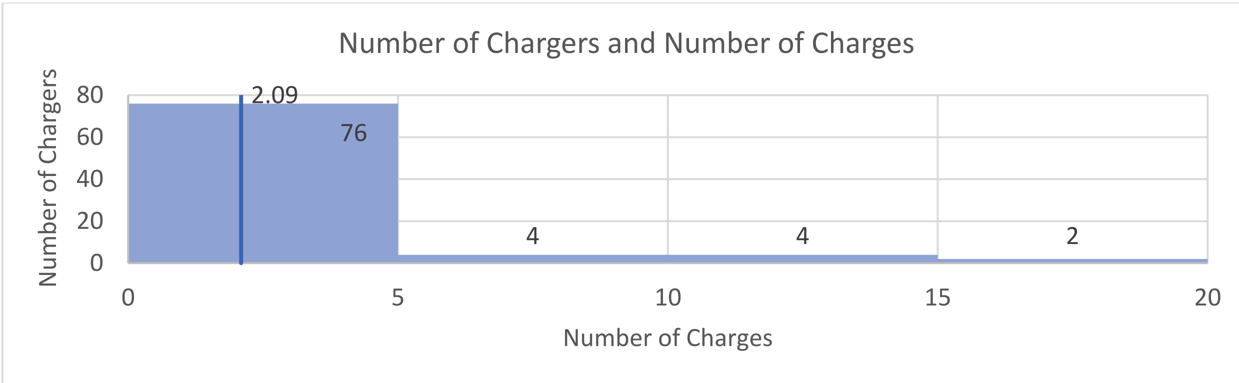

Figure C.4 Number of charges and number of chargers Case 2: 5% EV market penetration rates scenario.

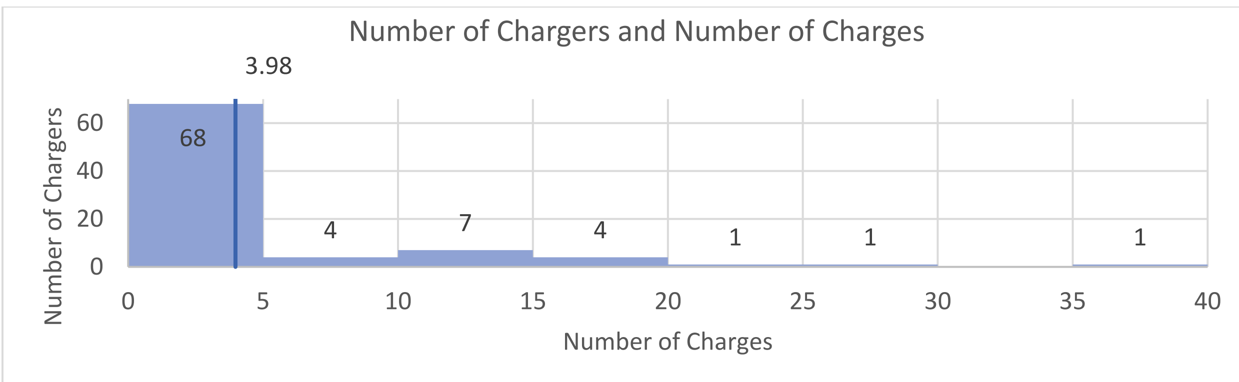

Figure C.5 Number of charges and number of chargers Case 2: 10% EV market penetration rates scenario.

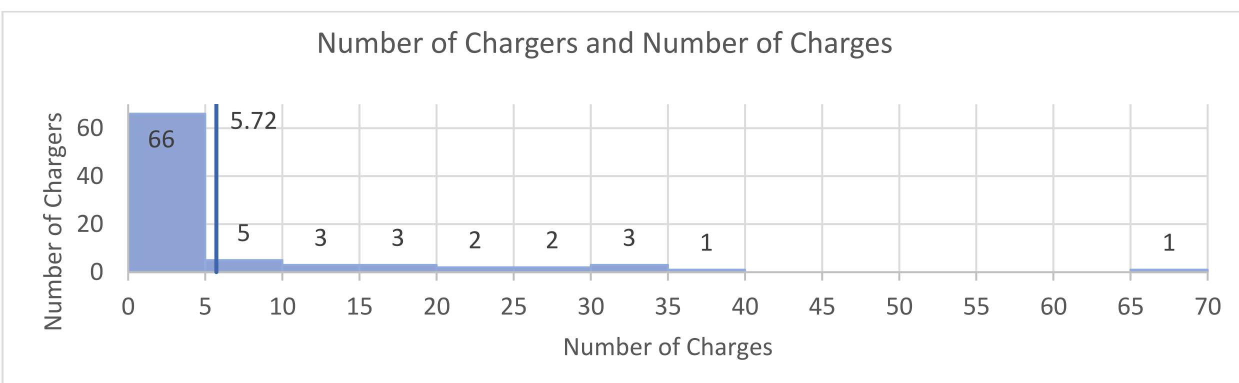

Figure C.6 Number of charges and number of chargers Case 2: 15% EV market penetration rates scenario.

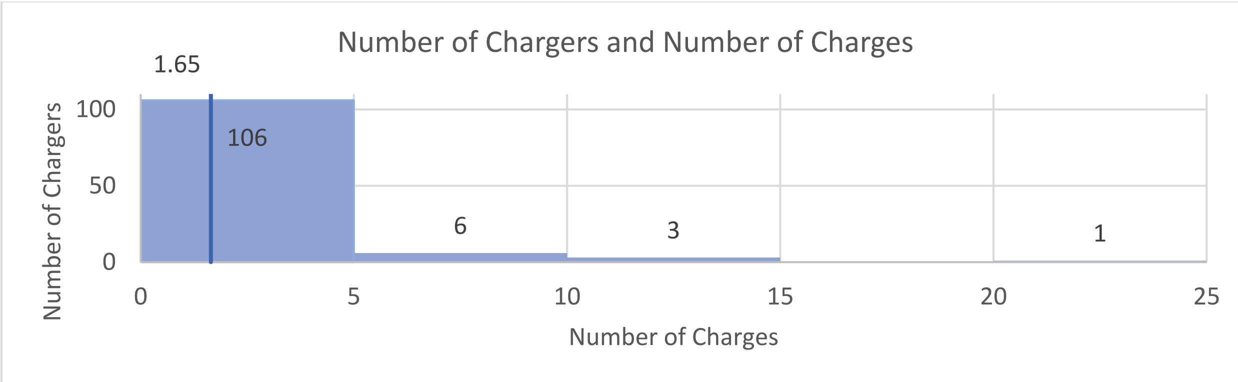

Figure C.7 Number of charges and number of chargers case 3: 5% EV market penetration rates scenario.

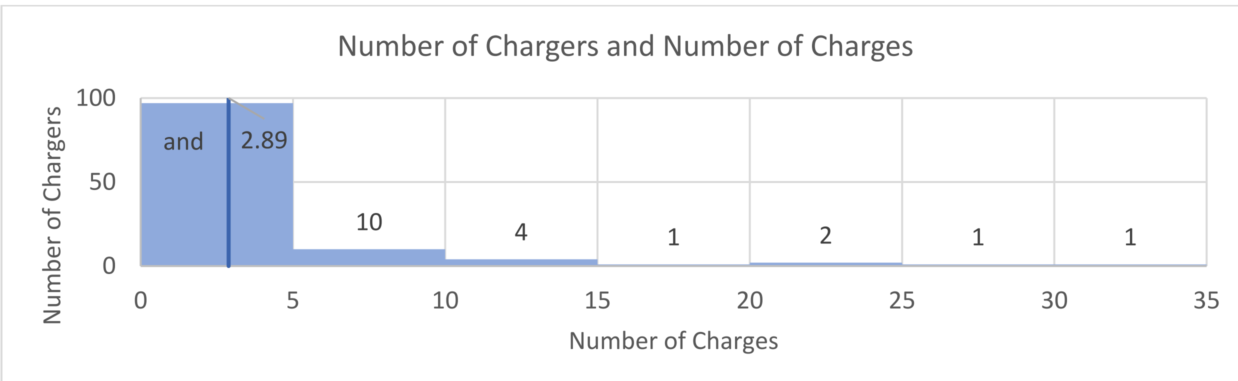

Figure C.8 Number of charges and number of chargers Case 3: 10% EV market penetration rates scenario.

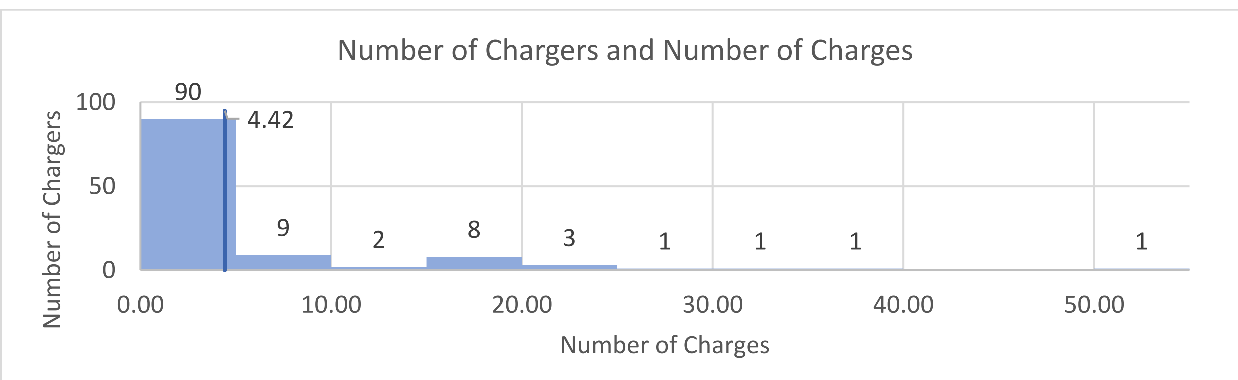

Figure C.9 Number of charges and number of chargers Case 3: 15% EV market penetration rates scenario.

APPENDIX D. CHARGING DEMAND ANALYSIS OF TRAFFIC FROM NEIGHBORING STATES

Appendix D shows the figures generated depicting the results generated for the traffic arriving from neighboring states to Indiana. On the left side of the figure, figures show the map of Indiana with number of charging occurred in the county. On the right side of the figures, it shows the heat map of the location where the charging occurred in Indiana.

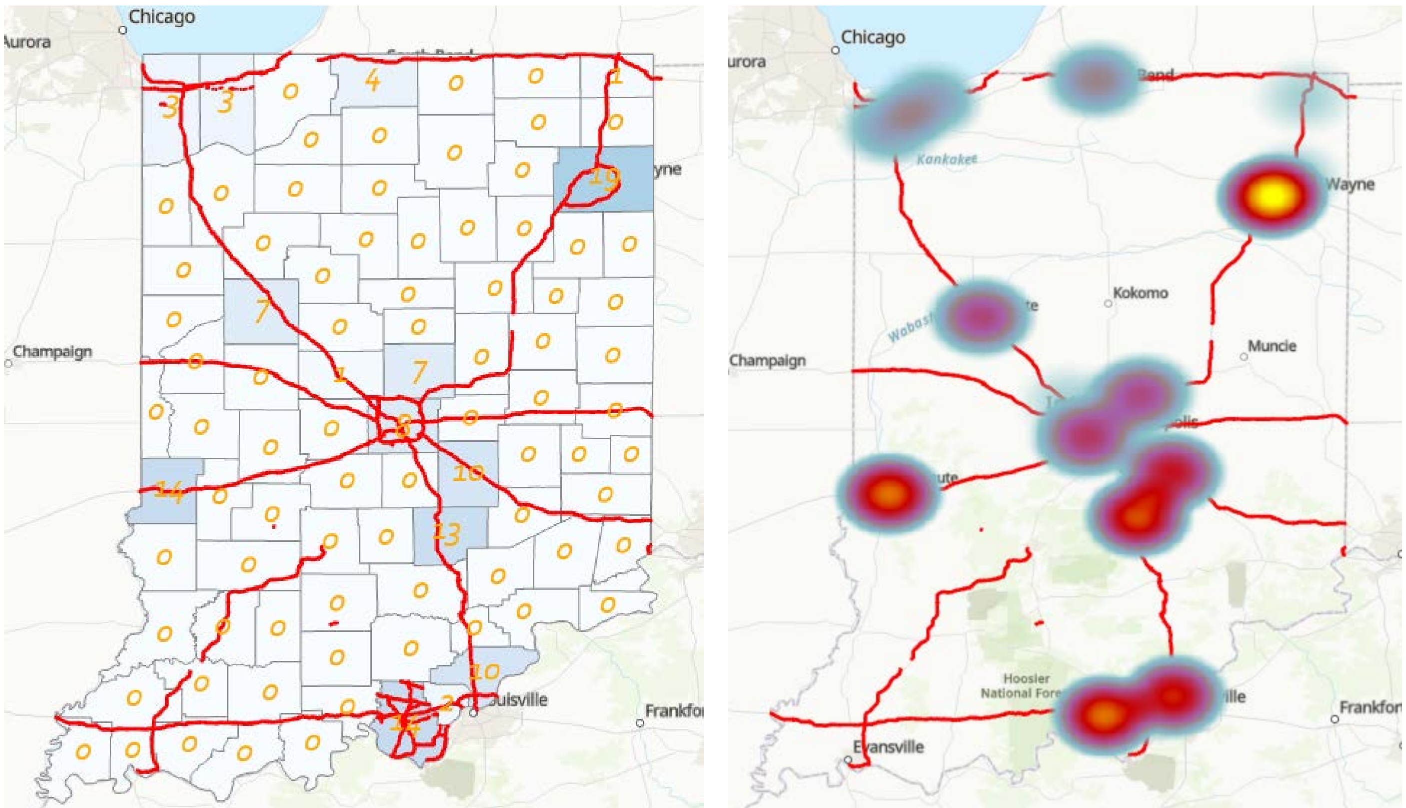

Figure D.1 Number of charging by county (left) and heat map of charges occurred (right) for case 1 of traffic from neighboring states at 5% EV market penetration.

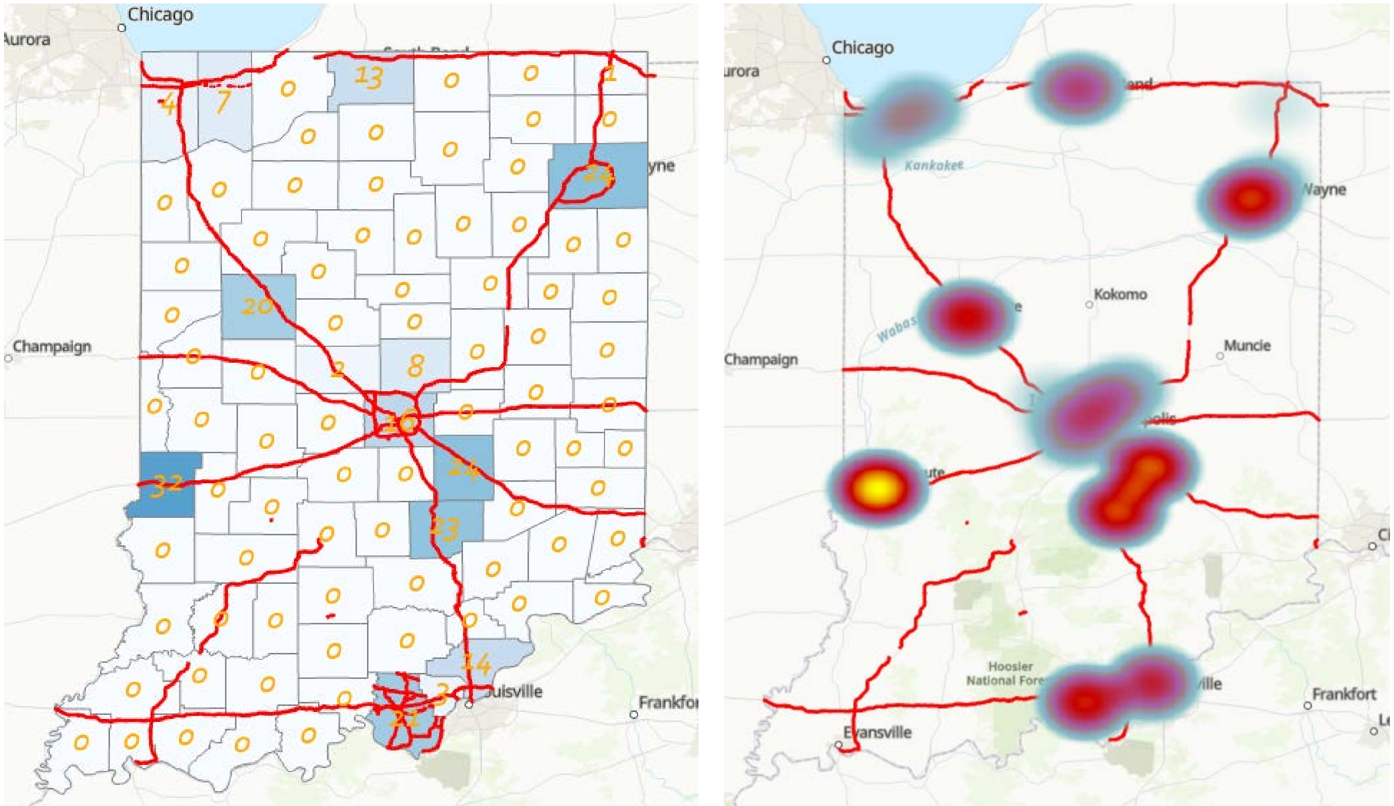

Figure D.2 Number of charging by county (left) and heat map of charges occurred (right) for Case 2 of traffic from neighboring states at 10% EV market penetration.

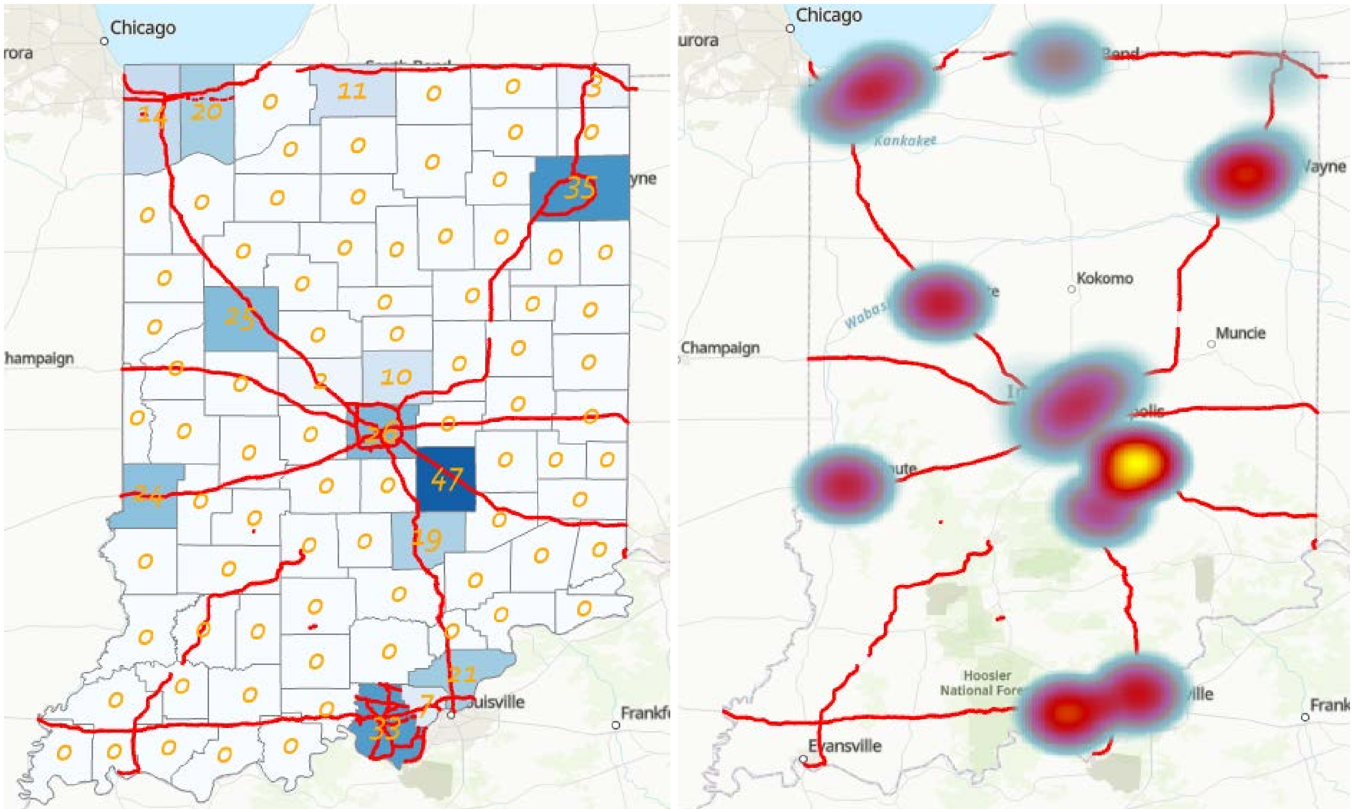

Figure D.3 Number of charging by county (left) and heat map of charges occurred (right) for Case 3 of traffic from neighboring states at 15% EV market penetration.

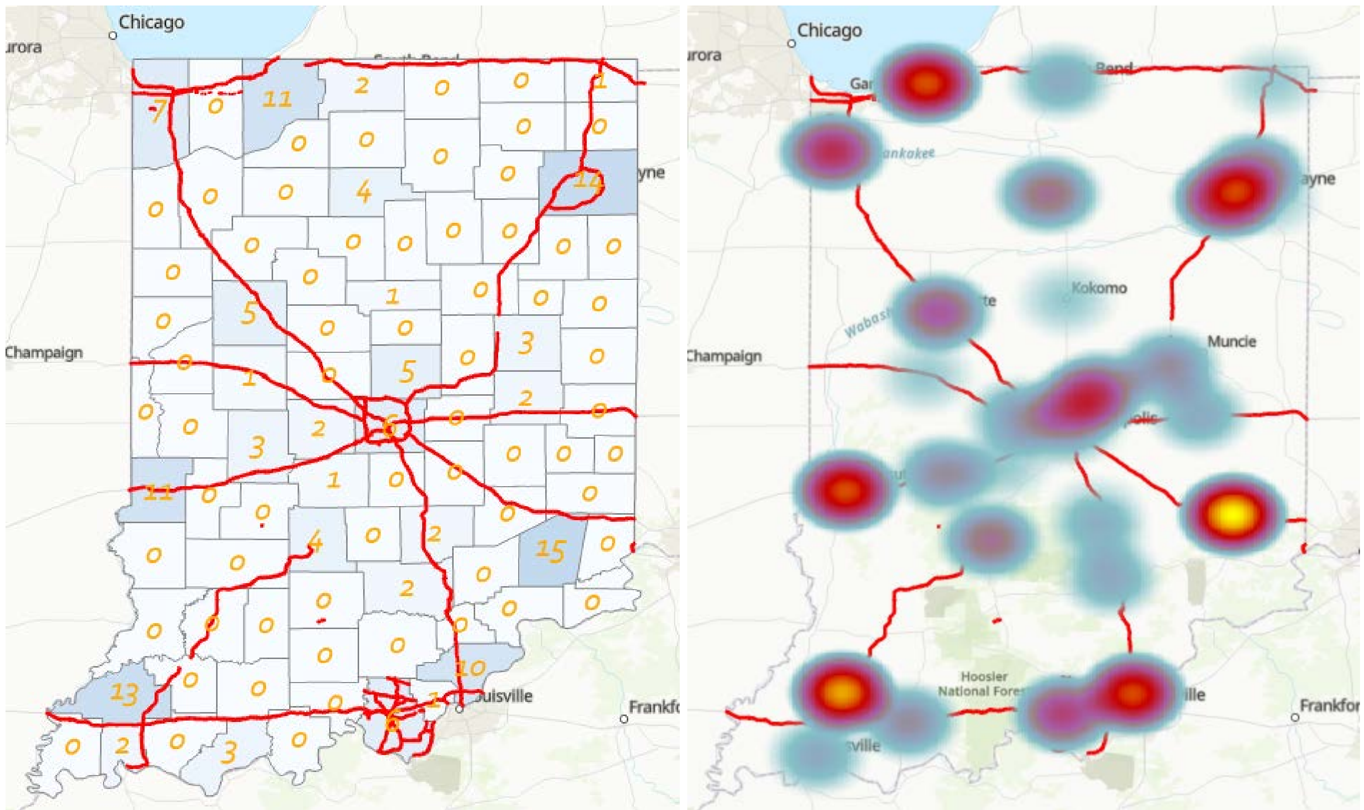

Figure D.4 Number of charging by county (left) and heat map of charges occurred (right) for Case 4 of traffic from neighboring states at 5% EV market penetration.

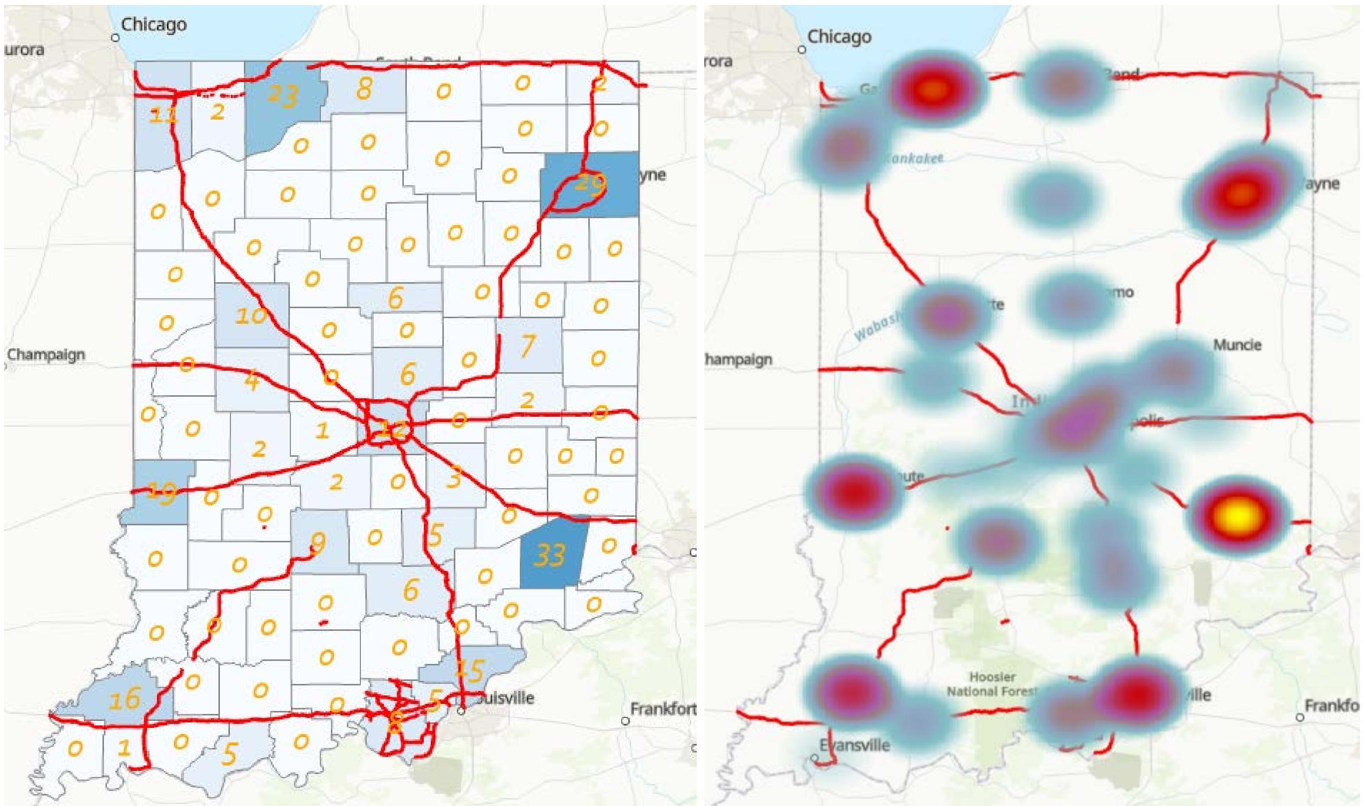

Figure D.5 Number of charging by county (left) and heat map of charges occurred (right) for Case 5 of traffic from neighboring states at 10% EV market penetration.

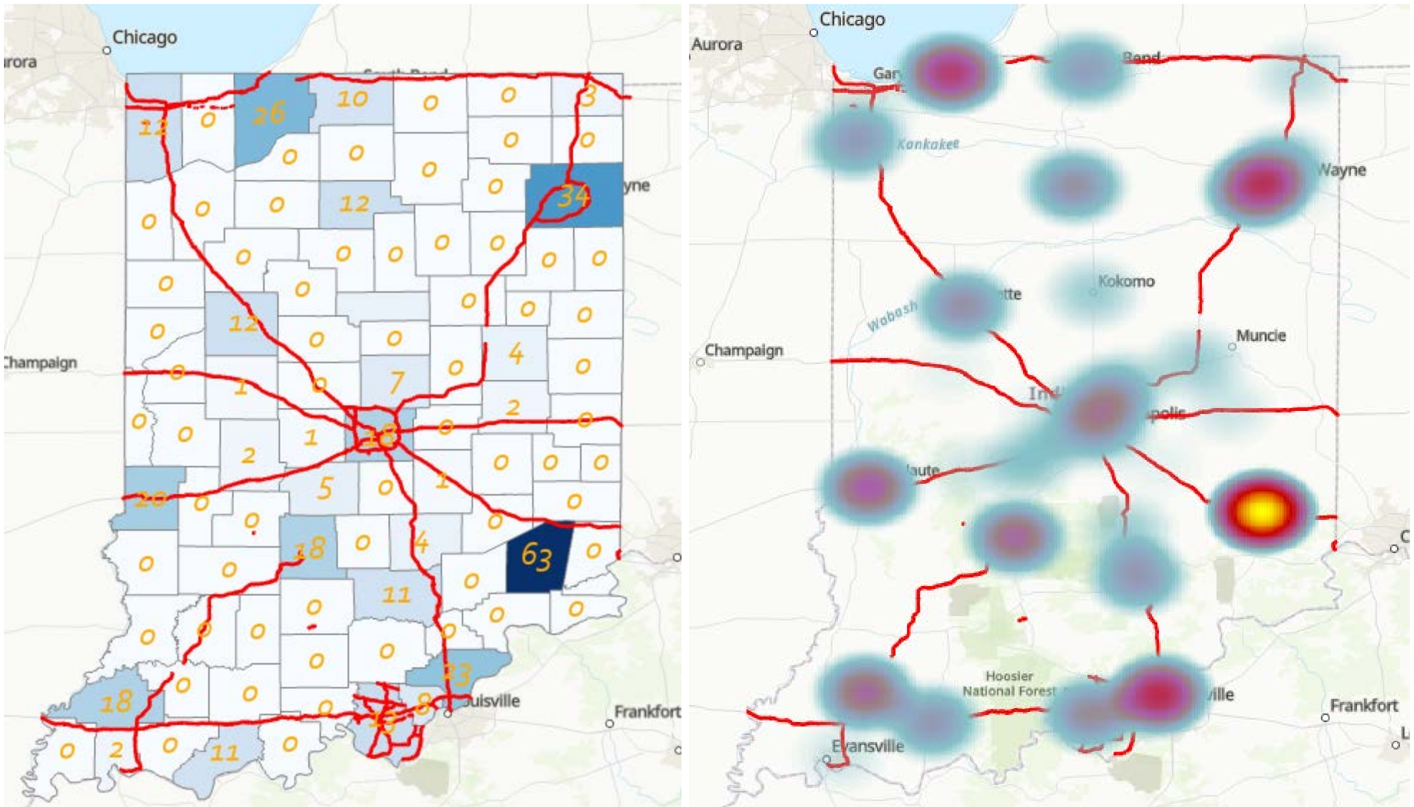

Figure D.6 Number of charging by county (left) and heat map of charges occurred (right) for Case 6 of traffic from neighboring states at 15% EV market penetration.

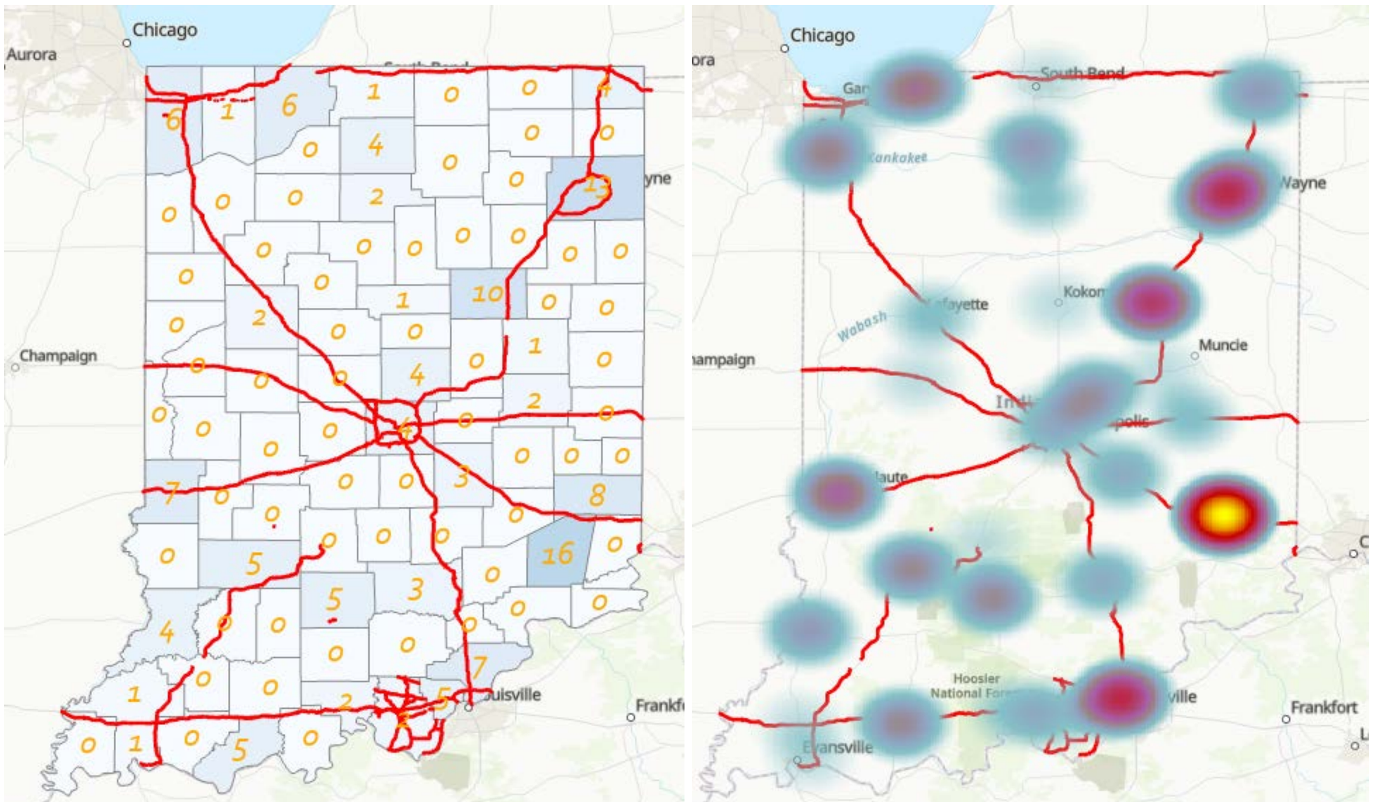

Figure D.7 Number of charging by county (left) and heat map of charges occurred (right) for Case 7 of traffic from neighboring states at 5% EV market penetration.

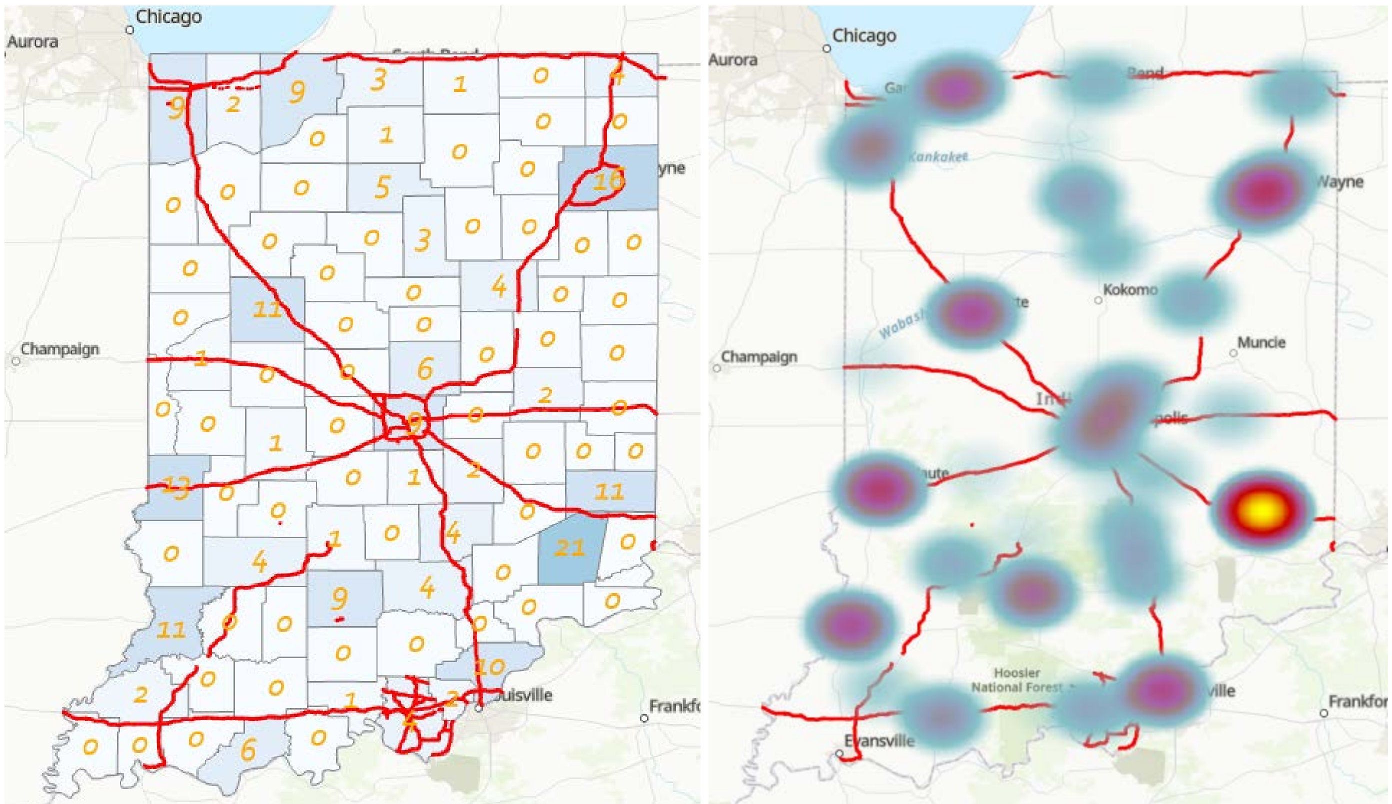

Figure D.8 Number of charging by county (left) and heat map of charges occurred (right) for Case 8 of traffic from neighboring states at 10% EV market penetration.

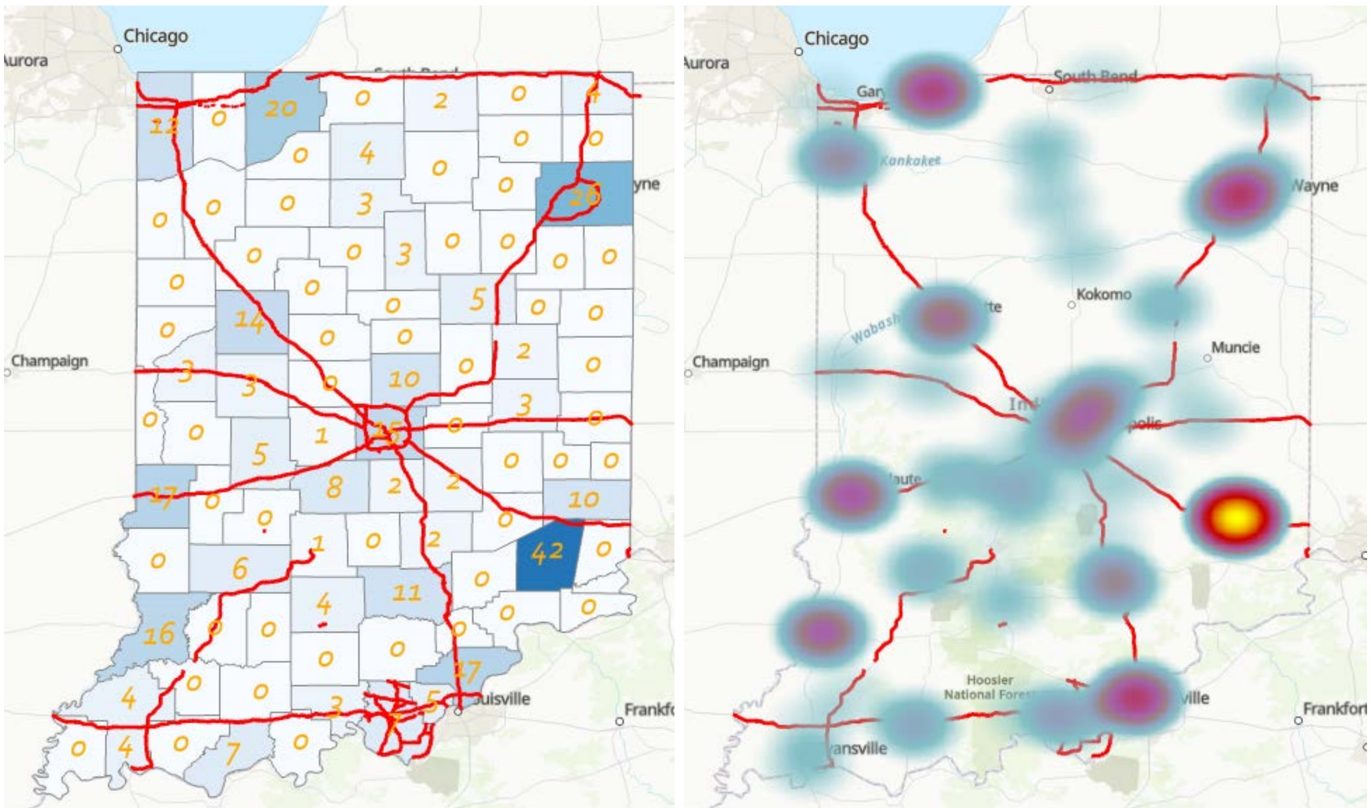

Figure D.9 Number of charging by county (left) and heat map of charges occurred (right) for Case 9 of traffic from neighboring states at 15% EV market penetration.

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

Further information about JTRP and its current research program is available at http://www.purdue.edu/jtrp.

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