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California public electric vehicle charging stations' accessibility to amenities: A GIS network analysis approach

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This Master's Project

California public electric vehicle charging stations' accessibility to amenities: A GIS network analysis approach

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List of Acronyms and Abbreviations

AC: Alternating Current

CA: California

Caltrans: California Department of Transportation

CARB: California Air Resources Board

CEC: California Energy Commission

CO_2: Carbon Dioxide

CSE: Center for Sustainable Energy

DC: Direct Current

DOE: Department of Energy

EV: Electric Vehicle

EVCS: Electric Vehicle Charging Station

GHG: Greenhouse Gas

GIS: Geographic Information System

$MMTCO_2e$: Million Metric Ton of Carbon-Equivalent

NAD: North America Datum

PEV: Plug-in Electric Vehicle

SOC: State-of-Charge

ZEV: Zero-emission Vehicle

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Abstract

In California, the number of electric vehicles (EVs) on the roads has been increasing over the past several years. As EVs continue to grow, additional electric vehicle charging stations (EVCSs) will be needed for EV drivers to utilize. However, before implementing EVCSs in the public, there are various criteria that need to be considered. One of these criteria is public EVCSs' accessibility to amenities. When people are charging their EVs that require a significant amount of waiting time, having amenities nearby will provide them with the option to spend their time efficiently on worthwhile activities. To understand the accessibility of California public EVCSs to amenities, existing charging stations were examined with two popular amenities. Closest facility analysis from ArcGIS 10.4.1 was used to analyze and compute the distance from each of the public charging station to the closest amenity. The accessibility was based on whether the distances between the EVCSs and the amenities are within a tolerable walking distance. From the data analysis, two results were produced for the amenities examined and presented different percentages of the accessibility. For more precise results, further examination of public EVCSs' accessibility to amenities is needed and can be accomplished by considering additional amenities in the data analysis. Additionally, this study provides an approach to evaluate the accessibility of charging stations to amenities, which can be useful for locating optimal EVCS sites.

1. Introduction

Greenhouse gas (GHG) and air pollutant emissions from the tailpipes of conventional vehicles are known to have direct and indirect harmful effects on both the environment and the human body. The environmental impacts that GHGs have contributed include ocean acidification, desertification, and global warming. The effects on human health that are caused by air pollutants include premature death and respiratory and cardiovascular diseases. In California, roughly 84% of the total population lives in a county with at least one pollutant that earned a failing grade based on the EPA Air Quality Index and American Lung Association grading system (American Lung Association, 2016). Emissions of GHGs have also intensified climate change, causing depletion of water resources and increased risks of wildfires in California (LARWQCB, n.d.; EPA, n.d.).

One of the most emitted GHGs in California is carbon dioxide (CO_2), which accounted for 84.3% of GHG emissions in 2014 (CARB, 2016c). According to the California Air Resources Board (CARB), in 2014, California's transportation sector was responsible for 42% and 36.9% of the total CO_2 and GHG emissions, respectively (CARB, 2016a; CARB, 2016b).

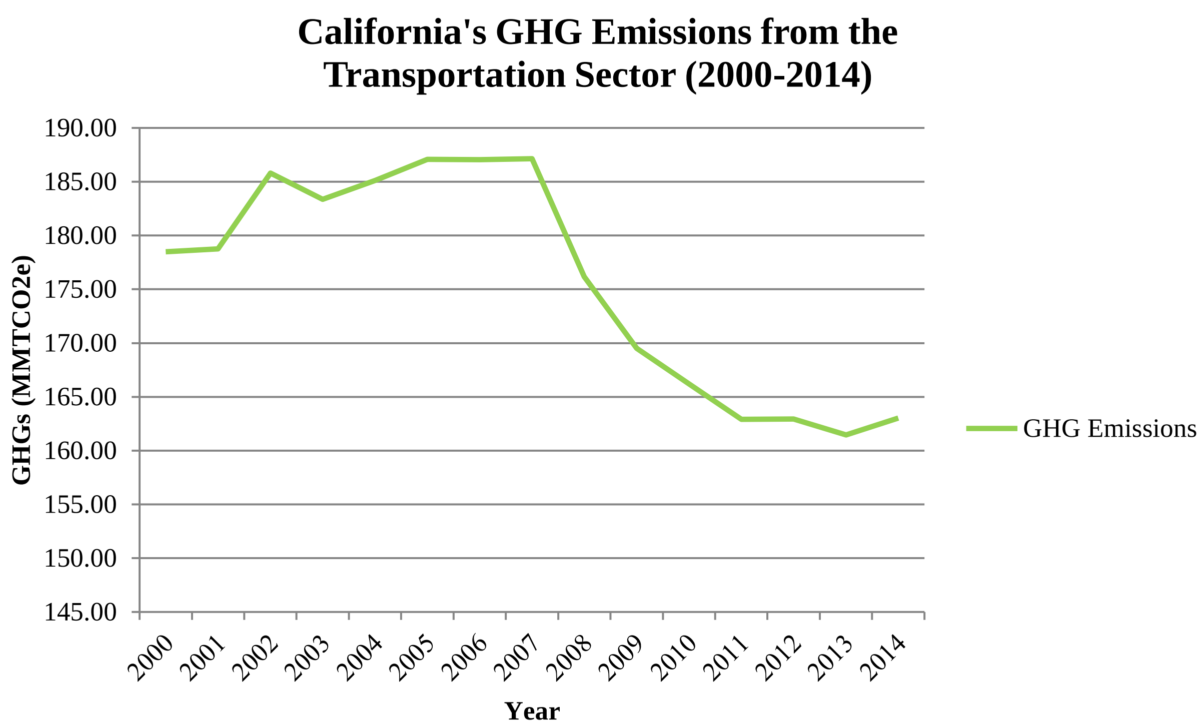


Figure 1. Information from the California Air Resources Board. This line graph shows California's transportation sector GHG emissions (MMTCO2e) from 2000-2014.

Additionally, around 70% of the total GHG emissions came from light-duty, commuter vehicles (CARB, 2016d). The number of light-duty, commuter vehicles alone released approximately 114 million metric tons of CO_2 equivalents ($MMTCO_2e$), which was about the same amount of $MMTCO_2e$ produced from the combined of industrial and commercial sectors (CARB 2016b; CARB 2016d). Looking back in 2013, the transportation sector was also accountable for the largest contribution of GHG emissions (36.3%) (CARB, 2016b). Even though the GHG emissions by sector slightly rose (0.6%) from 2013 to 2014, the transportation sector was still able to reduce its GHG emissions by 24.1 $MMTCO_2e$ or roughly 13% decrease (see Figure 1) from the peak level in 2007 (CARB, 2016b).

To mitigate GHG emissions from its transportation sector, California has been taking vigorous actions such as enforcing clean, renewable energy regulations and transitioning from conventional vehicles to alternative vehicles. The movement towards alternative vehicles, especially electric vehicles (EVs), has expressed a new approach to reduce GHGs and increase energy security (Alternative Fuels Data Center, n.d.b). From an examination of the full life cycle assessment, which comprises production, use, and end stages, EVs have demonstrated their potential of taking an important role in preventing global warming (Shi et al., 2016). Moreover, although EVs might not impact climate change immediately due to slow sales growth and lack of EV fleet replacement, the long-term effects of EV and cleaner energy usage were able to trim down GHG emissions and prevent climate change intensification (Lutsey, 2015; Shi et al., 2016). Thus, replacing conventional vehicles with EVs has the potential to alleviate GHG emissions as well as the adverse effects they have on the environment and human health.

As EVs begin to receive more attention from the public and the number of EVs start to rise, the demand for electric vehicle charging stations (EVCSs) will also increase. One of the main purposes of introducing more EVCSs in the public is to strengthen people's confidence in EVs (Nigro et al., 2015). In addition, public EVCSs are essential when it comes to long-range traveling and charging EVs in remote areas outside of the home. These EVCSs can also reduce and prevent range anxiety of EV drivers. Range anxiety is a feeling that EV drivers get when they fear that the battery of their EVs will run out before reaching their destinations (Dong, 2014). However, the waiting time for EVs to be charged can be lengthy and be consuming for EV users. To allow enough time to charge the EVs, the EVCSs need to be effectively located so that EV users can utilize their time efficiently on worthwhile activities while waiting for their vehicles to charge. Co-locating charging stations with service areas is beneficial for EV drivers (Vermont Energy Investment Corporation, 2014).

Before implementing EVCSs, there are various criteria that need to be considered such as the availability of electric power at the locations or sites that are prone to natural disaster (Vermont Energy Investment Corporation, 2014). This paper will examine the current public EVCSs' accessibility to amenities, which can be essential for future planning on locating optimal EVCS sites. In addition, the accessibility of EVCS locations seemed to be one of the criterions that non-EV users, who are not opposed to EVs, would consider in the decision-making of preferable sites (Philipsen et al., 2015). Increasing the availability of public EVCSs, in the sense of having the charging stations nearby familiar locations, can build up EV and non-EV users' dependence on EVs as well as potentially encourage non-EV users to adopt EVs (Bailey et al., 2015; Weissler, 2011). Familiar locations, such as the amenities that people often visit, are suitable places for EVCSs to be around because people can easily locate them and can spend their time at the amenities while waiting for their EVs to be charged. That being said, EVCSs are a driving force and reassurance for the growth of EVs, which has the capability to assist EVs on mitigating GHG emissions (CEC, 2016).

Statement of Purpose

For this paper, the goal will be to evaluate whether existing public EVCSs in California are accessible to two amenities within a proper walking distance (i.e., between 0 and 0.25 miles). The paper will begin by examining an overview of public EVCSs in California. This section includes the types of EV chargers, the barriers to EVCSs, and the locations of public EVCSs. Next, the paper will explore why EV drivers are important in the decision-making of public charging locations and what preferences are significant in evaluating the accessibility of EVCSs to amenities. For this section, travel patterns, frequency of charging, awareness of public EVCSs, and preferences of EV drivers related to EVCSs will be examined. Subsequently, two amenities will be investigated: McDonald's and Starbucks. These two public facilities are widely known and are located throughout California, making them suitable targets to be studied.

In the methodology section, an overview of the analysis apparatus, tool, and GIS data used in this study will be discussed. In addition, data analysis will be explored to provide the analytical process completed in this study. Next, using the closest facility analysis tool and data classification technique, the results of California public EVCSs' accessibility to amenities will be produced and presented. The conclusion section will summarize the results from data analysis and discuss the importance of this research. Subsequently, research limitations will also be given. Finally, recommendations of ArcGIS closest facility analysis tool will be provided to discuss how this apparatus can be utilized for future applications such as locating optimal public charging station sites.

2. Public Electric Vehicle Charging Stations in California

California is one of the leading states on the adoption of EVs and has the most public EVCSs available for EV consumers to utilize. The EVs, in the case of this study, refer to battery electric vehicle (BEV) and plug-in hybrid electric vehicle (PHEV), which both are considered as the plug-in electric vehicle (PEV). For about a six-year period between 2010 and 2016, the acquisition of PEVs in California has been increasing exponentially (PEV Collaborative, 2017). According to the California Energy Commission (CEC), approximately 223,000 PEVs and more were purchased during the time (CEC, 2016). With the rise of EVs on the roads, an adequate amount of public EVCSs will be necessary to accommodate EV consumers. Similar to the growth of EVs, the number of public EVCSs has also been growing since 2010. As an example, in 2015, the Pacific Gas and Electric Company received the permission to implement 7,500 EV charging ports in Northern California (The Pacific Gas and Electric Company, 2016). In California, there is roughly 3,650 public EVCSs with 12,200 charging outlets (Alternative Fuels Data Center, 2017). This number of public EVCSs does not account for charging stations in the residential area. Figure 2, created using data from Alternative Fuels Data Center, Caltrans, and National Geographic et al., shows that majority of the public EVCSs are clustered around major cities like Los Angeles, Sacramento, San Diego, and San Francisco. Other locations that public EVCSs can be frequently seen are nearby major highways and amenities such as grocery stores, restaurants, and recreational areas.

Figure 2. Locations of public electric vehicle charging stations in California. Electric vehicle charging station and major highways are symbolized as red point and black solid lines, respectively. Data for 3,514 locations were collected and displayed. Approximately 87% of these locations open 24 hour, 7 days a week. This map is created by using data from Alternative Fuels Data Center, Caltrans, and National Geographic et al.

One of the main drivers that keep California in the direction of expanding EVs and

EVCSs is the Executive Order B-16-2012. This order, which Governor Brown initiated in 2012, aims to achieve the long-term goals of having 1.5 million zero-emission vehicles (ZEVs) on the roads with accessible charging and fueling stations by 2025 (Office of Governor Edmund G. Brown Jr., 2012). The ZEVs consists of PEVs and fuel cell electric vehicles (FCEVs); however, the FCEVs will not be discussed in this paper since they utilize compressed hydrogen as a fuel for electrical power. To follow-up, the targets that were established under the Executive Order B-16-2012, one of the new goals listed under the 2016 ZEV Action Plan is to provide sufficient amount of EV charging and fuel cell stations for 1 million ZEVs by 2020 (Governor's Interagency Working Group on Zero-Emission Vehicles, 2016). Furthermore, agencies and energy companies such as California Public Utilities Commission (CPUC), NRG Energy, and California Energy Commission (CEC) have been working and cooperating to deploy more EVCSs in public and at major highway corridors (Governor's Interagency Working Group on Zero-Emission Vehicles, 2016).

Before addressing the core of this study, it is necessary to become familiar with the EVCS through examining some elements of its background. In this section, the types of EV chargers will be discussed to present the differences between each type of charger (amount of available charging outlets, charging time, the rate of charging, and costs of installation). Following the overview of EV chargers is a discussion of the barriers to EVCSs, which emphasize the challenges (costs and time) of implementing EVCSs. Lastly, common locations of public EVCSs will be discussed to provide a sense of where to find charging stations and why those EVCSs are often located near specific sites, particularly amenities.

2.1 Types of Electric Vehicle Chargers

In California, there are currently three types of EV chargers that are accessible to the public, which comprise of alternating current (AC) level 1, AC Level 2, and direct current (DC) fast chargers. At each of the EVCS location, different quantities and types of EV chargers are offered. For instance, some locations only offer one type of EV charger while others provide multiple types. The EVs are designed to have the capability of charging at residential home by connecting to a standard household outlet, or Level 1 charger, using the portable cords that are provided upon purchase (CSE, 2016). Correspondingly, every EV can also charge with an AC Level 2 charger. However, some EVs are not compatible with the DC fast chargers, which can limit the charging options for a number of EV customers (CSE, 2016).

AC Level 1 chargers are commonly located at residential homes and office buildings, but are also accessible in the public. In California, there are 306 public EVCSs with 624 charging outlets available for EV drivers that prefer to use AC Level 1 charger (Alternative Fuels Data Center, 2017). For AC Level 1 charger that has the power levels of 110 and 120 volts (V), it typically takes approximately 17 hours to fully charge the battery from 20 percent state-of-charge (SOC) (CEC, 2016). However, the time of charging also depends on the battery capacity and EV types. Additionally, the charging rate for AC Level 1 charger can allow EVs to travel roughly 3 to 6 miles per each hour of charging (CSE, 2016; Nigro et al., 2015). When comparing to AC Level 2 and DC fast chargers, AC Level 1 charger is much cheaper because it costs as low as $600 to install in public and it does not require installation fees for home charging (Smith and Castellano 2015; Nigro et al., 2015).

AC Level 2 chargers can be found at residential homes, office buildings, and public EVCSs. Since AC Level 2 charger is operable for all EVs and provides faster-charging rate than the AC Level 1 charger, this charger is the most common, accessible appliance for charging in the public. Within the state, there are 3,302 public EVCSs that provide 10,097 charging outlets for AC Level 2 charging (Alternative Fuels Data Center, 2017). This number of public EVCSs includes legacy chargers as well, which use a cordless inductive charging appliance to recharge the EVs. AC Level 2 chargers have the power levels of 208 and 240 V that can completely charge EVs in the same SOC condition as AC Level 1 charger in 7 hours to as short as 1.2 hours (CEC, 2016). In addition to battery capacity and types of EV, the charging speed or kilowatt (kW) available from the chargers can also affect charging time. The charging rate for AC Level 2 charger allows EVs to drive around 8 to 75 miles per each hour of charging (CSE, 2016; Nigro et al., 2015). Costlier than the AC Level 1, the AC Level 2 charger requires installation fees of around $1,500 for homes and $6,500 for public locations (DriveClean, n.d.; Nigro et al., 2015).

DC fast chargers are mostly available at commercial buildings and public EVCSs, especially near major highway corridors. California has 498 EVCSs with 1,426 charging outlets in the public for DC fast charging users (Alternative Fuels Data Center, 2017). This charger has the power levels of 200 to 480 V and takes only about 30 minutes or less to charge up from 0 to 80 percent SOC (CEC, 2016; CSE, 2016). Since DC fast charger takes a considerable amount of electrical energy from the grid and requires an on-site power grid, the charger is not feasible to be installed at home. The charging rate for DC fast charger is between 100 to 300 miles of travel per each hour of charging (Nigro et al., 2015). With various advantages from this charger also comes with drawbacks. DC fast charger cannot be used on every EV and the charger is the most expensive comparing to the other two types of chargers. The cost for installing DC fast chargers can be up to as much as $90,000 (Nigro et al., 2015). Moreover, the Tesla supercharger is one of the more advanced DC fast chargers available to the public. According to the Tesla Incorporation, this supercharger has the charging rate of approximately 170 miles of travel per each 30 minutes of charging (Tesla, n.d.). However, the charger is only compatible with Tesla EVs.

2.2 Barriers to Electric Vehicle Charging Stations

EVCSs are fundamental to the growth of EVs; however, there are barriers that can delay or prevent the implementation of EVCSs. For example, the expense of installing public EVCSs can be relatively high, especially for AC Level 2 and DC fast chargers mentioned in the previous subsection (Nigro et al., 2015). Public EVCSs are also experiencing lower usages comparing to home charging because EV drivers do not usually travel for long distance trips and often are not aware of the locations of charging stations (Frades, 2014). From a data collection of 4,000 Nissan Leafs and 1,800 Chevrolet Volts in the U.S., the study results showed that only 16% of Leaf and 13% of Volt drivers charge away from home (INL, 2015). Therefore, with the high cost of installation and low usage of public charging stations, it may seem like it is not cost-effective to implement them.

Another barrier that holds back the implementation of EVCSs is the permit that is required for the installation of EVCS. One of the issues with the permit is that there is no fixed fee, which means that the cost of the permit can vary over time (DOE, 2013). In addition, the fluctuation of the fee can lead to uncertainties on whether to implement the charging stations or not for investments. Other issues with the installation permit include the frequent delays on the requests of the permit and the inconsistent inspecting procedures (CSE, 2016; DOE, 2013).

The key barriers that challenge the implementation of EVCSs are the lack of communication and knowledge (Kettles, 2015; Frades, 2014). Effective communications with stakeholders and working partners are important because they are the proponents of EVCS progression. Insufficient interactions with potential adherents can lead to postponements of

EVCS installations (Frades, 2014). Moreover, there seemed to be a lack of knowledge associated with the implementation of EVCSs. For example, uncertainties regarding future demand for public EVCSs, decision-making on the ideal types of chargers to be implemented depending on the public EVCS locations, and the installation procedures of EVCSs are some of the areas that require substantial knowledge and adequate information about EVCSs (Frades, 2014; CSE, 2016). Thus, the barriers to EVCSs can restrain the progression of public EVCSs and potentially limit the convenience for EV drivers to access charging stations.

2.3 Locations of Electric Vehicle Charging Stations

The locations where public EVCSs are sited play a significant role in determining the accessibility and usage of the charging stations. In addition, the locations of EVCSs that provide multiple types of EV chargers can also influence the frequency of charging events and the decision-makings of EV users regarding the locations to charge their EVs. Before looking at the locations of public EVCSs, it is important to understand why only public EVCSs will be focused in this study. The EVCS has two applications, public and private usages. Apart from Tesla superchargers, the majority of the public EVCSs are accessible to the community and are located near places like coffee shops, grocery stores, restaurants, shopping malls, and highway corridors (City of Houston, 2010; Powers, 2014). Private EVCSs are mainly located at residential homes and office buildings. These EVCSs can only be used for private purposes, whether for the households or for the employees from the workplaces (General Services Department - County of Sonoma, 2011). Since private EVCSs are not available for public usage, they will be excluded in this paper.

Grocery stores and restaurants are locations where people stay for a considerable amount of time. These two amenities are common locations for public EVCSs. While waiting for their EVs to be charged, EV users can spend their time on grocery shopping at the stores. According to the U.S. Bureau of Labor Statistics (USBLS), consumers on average spent around 44 minutes in grocery stores (USBLS, 2016b; USBLS, 2016a). With this amount of time use on grocery shopping, it is adequate for charging EVs to travel miles of distance. Similar to grocery stores, restaurants are places that EV users can visit while charging their EVs. Eating at restaurants can take anywhere from minutes to hours depending on restaurant types (e.g., fast food, casual dining, and fine dining) and other external factors (e.g., time spent on break, conversation, and waiting). Other locations (see Table 1) including institutional, recreational, and shopping areas are also places that EV drivers can find public EVCSs. Most of these locations offer activities that people can spend their time while waiting for their EVs to be charged. However, some EVCS locations are predominantly meant for EV users who need to park for moderate to a long period of time while they are away doing errands or work.

Table 1.Common locations for public EVCS and examples in California.
Source: SJVAPCD (2014)

Locations	Examples in California
Airport	Ontario Airport, Sacramento Airport, San Francisco Airport, and San Jose Airport
Amusement park	Disneyland, Legoland - California, SeaWorld - San Diego, and Universal Studios Hollywood
Aquarium	Aquarium of the Pacific, Cabrillo Maine Aquarium, and UCSD - Birch Aquarium
Hospital	Cedars-Sinai Medical Center, UCLA Medical Center, UCSF Medical Center, and Stanford University Hospital
Library	Palm Springs Library, Ramona Public Library, and Saratoga Library
National park	Sequoia National Park, Yosemite National Park, and Zion National Park
Shopping mall	Fashion Valley Mall, Ontario Mills, and Stanford Shopping Center
University	San Francisco State University, University of California - Berkeley, and University of California - San Diego

Highway corridors are another familiar location for public EVCSs. The corridors are one of the major backbones for the expansion of EV routes, especially for trips that require long-distance traveling (Frades, 2014). To expand the growth of EVCSs and allow easier access for the EV drivers, California has been collaborating with states of Oregon and Washington on the West Coast Electric Highway project. This project aims to provide accessible EVCSs to EV consumers by placing DC fast chargers alongside the corridors of Interstate 5 at an incremental distance of 25 to 50 miles (Powers, 2014). In addition, other similar, planned EVCS projects are underway to extend the available DC fast chargers along the highway network such as the State Highway 99 and the U.S. Highway 101 (Governor's Interagency Working Group on Zero-Emission Vehicles, 2016). Highway corridors are great locations for public EVCSs but also common locations for setting up gas stations, restaurants, and shopping centers, which allow EV drivers to easily locate and access the charging stations. With public EVCSs at the corridors of highways that connect cities and popular travel destinations, EV drivers will be able to feel less anxious about their trips that require multiple charging sessions. This progression of EVCS reinforces people's confidence in the capability of EVs to travel for long distance (Nigro, 2015).

3. Electric Vehicle Drivers

The preferences of EV drivers need to be considered when deciding on the optimal charging sites. Although there are other criteria that have to be taking into account such as environmental, economic, and social matters, the decision-making of public EVCS locations remains fairly dependent on the EV users (Guo and Zhao, 2015). For example, in previous studies, drivers' daily activities were examined to determine the locations of EVCSs in Flanders, Belgium, and drivers stated preferences were used to analyze the charging and route choice behavior of BEV drivers, which can be useful to solve the charging location problem (González et al., 2014; Yang et al., 2015). Besides the two illustrations, EV drivers have been continually considered in studies to find their influences on the charging infrastructures. In this section, travel patterns and frequency of charging will be discussed to lie down the importance of considering EV drivers as a criterion. Moreover, awareness of public EVCSs will be explored to emphasize how aware EV drivers are regarding the charging stations. Lastly, EV drivers' preferences will be investigated to provide preferential types of chargers, locations of public EVCSs, and miles that they are willing to detour to recharge their EVs as well as tolerable walking distance.

3.1 Travel Patterns

When deciding where to implement public EVCS, travel patterns of EVs can be an important factor to be considered. Examining the travel patterns, which specify preferential travel routes of EV drivers, is useful to locate potential public EVCS sites (Haddadian et al., 2015). Travel patterns can also be used to identify routes that are less commonly travel by EV drivers. Knowing these routes can prevent unnecessary spending on the installation of charging stations. However, to present a real-world condition or at least one partially comparable to the existing situation, conventional vehicle travel patterns are commonly used as a replacement. While there may be discrepancy using conventional vehicle travel patterns to represent the EV travel patterns due to a probable difference in driving behavior, the substitution is relatively reasonable because there appears to be a lack of desire from people to change their normal driving routes and patterns (Philipsen et al., 2015).

Taking this into account, several of the studies that investigated locating optimal EVCS sites or related to charging infrastructures have been employing travel patterns of conventional vehicles as a part of their considerations. For instance, in their literature, Cai et al. (2014) analyzed the travel patterns of 11,880 taxis in Beijing and their implication on public EVCS development. By utilizing taxi stop events to assess charging opportunity, potential locations for implementing EVCS were defined (Cai et al., 2014). Like the study by Cai et al., Li et al. (2017) explored and employed travel patterns of 46,765 taxis in Beijing to construct future planning on public EVCS implementation. Nicholas et al. (2011) obtained travel patterns through the use of global positioning system (GPS) to track down the conventional vehicles from 48 households that live in Sacramento, California. The study examined the number of charging events required when considering DC fast charging as the only charging choice, for different EV ranges and highlighted the need of public EVCS at the locations where the charging facilities were not available for the drivers (Nicholas et al., 2011). Additionally, Andrenacci et al. (2016) evaluated travel patterns that consist of 57,890 trips from private vehicles to locate optimal EVCS sites in Rome. These examples demonstrated that drivers' travel patterns are important to be considered during the preparation of EVCS implementation and that drivers, or EV drivers, can influence the locations where charging stations will reside.

3.2 Frequency of Charging

Before installing more EVCSs in the public to assist progression of EVs, it is important to recognize the proper locations to implement EVCSs in the sense of usage. To make public EVCSs to become more cost-effective, adequate utilization of the EVCSs will be necessary. However, not every public EVCS in the U.S. has been sufficiently used. Based on the charging event data studied by the Idaho National Laboratory (INL), which covered 2,400 public AC

Level 2 charging locations in the U.S., the median occurrence of charging event for each location was approximately 1.4 charges per week. The data also displayed that well-liked public AC Level 2 charging locations had higher usages and the potential to increase the charging event to a maximum of 11 charges per day (INL, 2015). As for DC fast charging sites, the median frequency of charging event per site was comparatively greater than the AC Level 2 with 7.2 charges per week (INL, 2015). In addition, Morrissey et al. (2016) monitored and collected charging event data from 711 charging stations in Ireland (Northern and Republic of Ireland) to examine the frequencies of usage on fast and standard public EVCSs. The results indicated that standard public EVCSs had a median charging event frequency of 0.06 charges per day while fast public EVCSs had a median frequency of 0.46 charges per day (Morrissey et al., 2016). From both cases, the non-DC fast charging stations in the public seem to experience relatively low usages and the DC fast EVCSs appear to have higher occurrences of usage. But, these usage frequencies are still falling short from the cost-effective EVCS suggestion of 3 to 4 charges per day for each charging stations (Madina et al., 2015).

According to the U.S. Department of Energy (DOE) (2013), charging event data is a useful indicator to find locations of EVCSs that are most beneficial for EV drivers. Similarly, Haddadian et al. (2015) stated that searching suitable locations for EVCSs require data on the tendencies of EV charging. Instead of spending money on installing EVCSs that have low usages and visibility, it is better to locate sites that are commonly used by EV consumers. The frequency of charging per location illustrates that the amount of usages from EV drivers can act as a critical role in determining the public EVCS locations.

3.3 Awareness of Public Electric Vehicle Charging Stations

While it is significant to consider using EV drivers' travel patterns and frequency of charging as components to locate public EVCS sites, examination of EV drivers' awareness regarding the EVCSs is equally noteworthy for future implementation of public EVCSs. With over 80% of 4,000 Leaf and 1,800 Volt drivers charging mostly at home during nighttime, it is questionable whether EV drivers are aware of public charging stations (INL, 2015). Based on the data results collected from a survey of 2,032 adult respondents that possess valid driver's licenses, about 12% of those responders had noticed EVCSs in the public (Carley et al., 2013). Utilizing similar data collecting approach, Bailey et al. (2015) gathered valid survey data of

1,739 Canadian respondents and found that 18% of the responders had seen a minimum of one public charger while only 5% or less had detected public chargers at different locations. These two studies indicated that drivers, in general, have a lack of awareness of public EVCSs.

To help increase EV drivers' awareness of public EVCSs, various reinforcing actions have been established. For instance, the U.S. Department of Transportation Federal Highway Administration has laid down guidelines for EVCS general service signs under the Manual of Uniform Traffic Control Devices (Kettles, 2015). Correspondingly, in 2013, the California Department of Transportation has also announced to put forth orders on standardizing signs for public EVCSs throughout the state (Governor's Interagency Working Group on Zero-Emission Vehicles, 2016). Implementing signage for EVCSs, especially at public highways and roads, is beneficial for bringing awareness while guiding EV drivers to the charging stations. In addition, the state of Oregon has been collaborating with a travel agency, Travel Oregon, on the Oregon Electric Byways program that aims to support EV travels through raising awareness of available, public EVCSs along the scenic byways as well as tourist attractions (Powers, 2014). These actions not only provide EV drivers' awareness of public EVCSs but also draw people's attentions to the progress that has been accomplished for the EVs.

Even though it is significant to have supportive actions that promote the awareness of charging stations, people's familiarities regarding the public EVCS locations is as essential. Having public EVCSs located near familiar sites, such as chain restaurants and stores, that people can recognize even before adopting EVs are another substantial way to bring awareness of the charging stations. Additionally, to raise awareness of EVCSs and minimize perplexity for EV drivers to locate the charging infrastructures, it is most advantageous for the public charging stations to have a common visible distinctiveness, particularly the surroundings (WXY Architecture + Urban Design, 2012). With the EVCSs nearby familiar locations, visibility of the charging stations will also be increased. As mentioned in Section 1, accessibility of public EVCS locations is critical to people; therefore, charging stations need to be sited at places that can be easily located as well as accessible (Philipsen et al., 2015). Similarly, the U.S. DOE stated that it is fundamental for optimal EVCS location to be both convenient and greatly perceptible to a large proportion of EV drivers and possible EV adopters (Clean Cities, 2012).

3.4 Preferences

As stated earlier, the preferences of EV drivers need to be taking into account. Much of the EV and charging infrastructure progressions rely on the growth of EV drivers; thus, providing easier access to the EVCSs and considering their preferences relate to the charging stations are reasonable. In the same way, EV consumers' preferences play an important role in the markets of EV and EVCS (Al-Alawi and Bradley 2013; Gordon et al., 2012). However, that does not mean to consider all preferences that EV drivers have in mind, but rather to a certain degree such as the common ground they share.

When looking at the types of EV chargers, specifically for the public EVCSs, EV drivers prefer to use DC fast charger because of its shorter charging time (Morrissey et al., 2016; DOE, 2014). In addition, revisiting the subsection of the frequency of charging, the examples demonstrated that fast chargers have greater usages, which further indicate EV drivers' preference of DC fast chargers. However, due to the expense of DC fast chargers and the current early stage of EV development, it is not feasible to solely install fast chargers in the near future. In their study, Dong et al. (2014) stated that if there is a limited fund for charging infrastructures, implementing more AC Level 1 and 2 chargers are preferable than fewer DC fast chargers. Even so, they also concurred that having DC fast chargers nearby highway corridors is important (Dong et al., 2014). Meanwhile, a combination of various types of EV chargers is ideal for EV drivers that have diverse preferences (Wang and Lin, 2013).

There are multiple public EVCS locations that EV drivers prefer to charge their EVs. Survey respondents from the study of Philipsen et al. (2015) preferred EVCS locations to be both packed and perceptible for the reason of safety. The charging locations are also favored when there are amenities like fast-food restaurants and shopping stores within a tolerable walking distance (Clint et al., 2015). Some reports and studies have indicated that shopping areas (malls, grocery and retail stores, and outlets) are great for EV chargers, especially AC Level 2 chargers, because people tend to stay for considerable amount of time (City of Houston, 2010; Vermont Energy Investment Corporation, 2014; Huang et al., 2016). In addition, coffee shops and fast-food restaurants are suggested for the locations of DC fast chargers (Clean Cities, 2012; Vermont Energy Investment Corporation, 2014).

Lastly, other preferences of EV drivers are the miles of a detour to the charging stations and the distances they are willing to walk to the amenities. According to the study of Sun et al.

(2016), EV drivers usually prefer taking a shorter detour distance to EVCSs. The willingness of EV drivers to detour during their on and off-duty days were roughly 1750 meters (m) and 750 m, respectively, which are equivalent to approximately 1 mile (mi) and 0.5 mi (Sun et al., 2016). Moreover, since there are hardly any studies specifically examined on EV drivers' preferential walking distance to the amenities from the charging stations, the daily walking distance of 308,901 individuals will be used instead (Yang and Diez-Roux, 2012). In their study, Yang and Diez-Roux (2012) were able to collect 98,192 walking trips and concluded that the median walking distance was 0.5 mi while approximately 65% and 18% of the walks are greater than 0.25 mi and 1 mi, respectively. The study also mentioned that 0.25 mi is a common tolerable walking distance that researches have used in the U.S.

4. Amenities

When EV drivers are charging their EVs, it is essential to have amenities near the locations of EVCSs. For this study, the two public facilities that will be used to examine the accessibility of public EVCSs to amenities are McDonald's and Starbucks. Among all the fast-food restaurants and coffee shops in the U.S., McDonald's and Starbucks are one of the most popular places that people visit during short and long distance travels. Additionally, people are usually familiar with these two amenities and can easily spot them while driving on the roads. To correspond, based on a 2016 restaurant chains familiarity survey of 716 adults, 92% and 84% of the respondents were familiar with McDonald’s and Starbucks, respectively (Statistia, 2016). In this section, the consumerism of McDonald's and Starbucks will be explored, especially what make them so popular and how that popularity makes these two amenities suitable targets for this study.

4.1 McDonald's

McDonald's, a well-known fast-food restaurant, has been growing not only in the U.S. but also overseas. This fast-food chain is popular for various reasons such as accessibility, affordability, consistency, and marketing strategy. McDonald's ideology in consumerism is one of the main sources that keep this fast-food restaurant fresh even as time goes on. According to the McDonald's Corporation (2016), the company stated that it will continue providing McDonald's at optimal sites such as malls, markets, and transit facilities for consumers. Fast-food restaurants are also commonly located close to intersections, off-ramps, and rest areas for the convenient of people (Schlosser and Jung, 2002; Ritzer, 2002). Moreover, Figure 3, created using data from Caltrans, Esri, and National Geographic et al. illustrates that most of the McDonald's locations, like public EVCSs, are sited near major cities and highways. From these multiple sources, it can be seen that the locations of McDonald's are quite accessible and are available across California.

Comparing to other restaurants that serve breakfast, lunch, and dinner, McDonald's is a much more affordable alternative for consumers. The list of prices on the McDonald's menu ranges from a little more than a dollar for a cheeseburger to a meal that costs less than 10 dollars, which is considerably inexpensive. Besides its affordability, McDonald's also provides consistency of its food and services (Nozaki 2011; Ritzer, 2002). To retain customers' familiarities of McDonald's, uniformity is essential for the business to succeed (Schlosser and Jung, 2002). In addition, the simplicity of McDonald's food choices allows customers to easily familiarize with its menu that is offered at various locations (Lichtenberg, 2012).

Marketing strategy is another key factor to McDonald's popularity and success. One of McDonald's approaches is to introduce new products that fit the cultures and taste buds of people based on the locations (Han, 2008). For example, McDonald's found that people in China enjoy chicken products the most; thus, the chain restaurant decided to add new additional chicken meals into its menu. Similarly, McDonald's in France introduced espresso and brioche (Han, 2008). In addition, in the U.S., this fast-food restaurant offers limited time products such as the McLobster that is only available on the East Coast. McDonald's has not only been targeting the cultures and taste buds of people but also children and women (Nozaki, 2011; Light and Kiddon, 2015). As an illustration, McDonald's utilizes toys from the Happy Meal to draw children's attentions while presenting healthy side dishes and drinks like fruits, yogurt, milk, and juices. With a similar approach, this fast-food restaurant targets women by providing healthier and lighter food choices (e.g., salad, grilled chicken wrap, and yogurt) (Han, 2008). Another marketing strategy of McDonald's is the use of advertisements. Some common ways that McDonald's advertises its products are by using the billboards and signage to allure travelers (Lichtenberg, 2012). Movie and television advertisements, as well as sponsorships for public events, are other methods that McDonald's uses to promote its food (Ritzer, 2002; Lichtenberg, 2012). From looking at McDonald's accessibility and popularity, this fast-food restaurant is a suitable amenity to be employed in this study.

Figure 3. Locations of McDonald's in California. McDonald's and major highways are symbolized as yellow point and black solid lines, respectively. Data for 1,348 locations were collected and displayed. This map is created by using data from ArcGIS, Caltrans, and National Geographic et al.

4.2 Starbucks

Although there are numerous coffee shops in the U.S., Starbucks remains as one of the most popular coffee chains. This coffeehouse is available across the U.S. as well as various countries and is well-recognized by people (Geereddy, 2013). America is a heavy coffee drinking country. 54% of American adult drinks coffee every day with an average of 3 cups per day among those coffee drinkers (National Coffee Association, 2010). For that reason, besides drinking coffee at home or work, coffee shops have become common places for people to have coffee while taking breaks to rejuvenate their energy from traveling or work.

Starbucks is popular for a number of reasons. One of the noticeable differences between this well-known coffee chain and the other coffee stores is its convenience. For instance, U.S. Starbucks, particularly in the urban communities, provides consumers the option of a drive-through, which allows people that are in rush to order and receive their purchases in a faster manner (Luong, 2011). Locations of Starbucks also contribute to the popularity of this coffee chain. According to the Starbucks Corporation, Starbucks stores are usually sited at locations where there are high traffic and visibility. Moreover, to help daily coffee drinkers to have easier access to the coffee shops, the company tries to implement Starbucks near places such as business area, shopping centers, and universities (Starbucks Corporation, 2015). Figure 4, produced using data from Caltrans, Esri, and National Geographic et al., demonstrated that Starbucks in California is commonly located along the major highways and nearby urban areas.

Besides the convenience and accessibility of this coffee chain, Starbucks is well-liked for its coffee, environment, and customer service. The company's philosophy in consumerism is to provide high-quality coffee and products to customers while leaving them with great experiences (Geereddy, 2013). By satisfying its consumers, Starbucks will be able to gain more loyal customers that prefer better quality and experience. Additionally, this coffee chain not only sells coffees but also teas and non-caffeinated beverages to present more options for the customers. Like McDonald's, Starbucks has multiple targeting consumers, which consist of students and adults (Luong, 2011). With artistic interior design, soothing background music, and free Wi-Fi access, Starbucks have become one of the typical places for gathering, meeting, and studying (Geereddy, 2013). The overall environment of the coffee shop creates a comfortable atmosphere for customers to enjoy their food and drinks. Starbucks's customer service is also a contributor to its popularity. One of the main strengths of this coffee chain regard to customer service is its capability to allow customers to modify their beverages, whether is the type of milk or the ratio of beverage ingredients (Perepu, 2013). As a result, through the examination of Starbucks's accessibility and popularity, this coffeehouse is an appropriate amenity to be used in this research.

Figure 4. Locations of Starbucks in California. Starbucks and major highways are symbolized as neon green point and black solid lines, respectively. Data for 2,399 locations were collected and displayed. This map is created by using data from ArcGIS, Caltrans, and National Geographic et al.

5. Methodology

To examine whether existing California public EVCSs are accessible to amenities, geographic information system (GIS), or specifically ArcGIS 10.4.1, was used in this study as the analytical apparatus. ArcGIS is a GIS computer program that consists of several components such as the ArcMap, ArcCatalog, ArcGlobe, and ArcScene. These components are used for different applications that deal with geospatial data, comprised of raster, tabular, and vector data that are associated with geographic locations (Esri, n.d.). For this study, ArcMap 10.4.1 and ArcCatalog 10.4.1 were utilized for the data analysis. ArcMap, the core of ArcGIS, has the ability to execute numerous functions like holding and manipulating the geospatial data, but the key roles of this component are to perform data analysis and exhibit the data as digital representations (Esri, n.d.). For ArcCatalog, the major function of this component is to organize the geodatabase, whether to create, delete, or transfer the data.

The common applications of GIS are to examine patterns, trends, and relationships between different features (Esri, n.d.). The examined results of the features can then be portrayed as a form of figures or digital maps for people to have better and easier understanding. To provide some examples, GIS can be used to analyze migratory patterns of species, predict the paths of tornadoes, and find the correlation between crime rate and socioeconomic status. Moreover, GIS has been commonly used in studies as an apparatus for decision-making and problem-solving (University of Wisconsin - Madison, n.d.). For instance, Buruso (2017) used GIS and remote sensing to find proper habitat locations for hippopotamuses to live in Ethiopia due to the loss of their prior habitat. In another study, Weng and Yang (2006) utilized GIS to analyze the correlation involving the patterns of air pollution and city's land use and thermal landscape in Guangzhou City, China. From these illustrations, GIS has been employed widely in studies for different applications; therefore, this apparatus is relatively dependable to be used in this research.

In this section, an overview of ArcGIS Network Analyst and closest facility analysis will be discussed to give a general knowledge of the data analytical tool utilized in this study. Next, data acquisition and information will be laid out to provide the locations where the geospatial data were obtained as well as information regarding those data. Finally, the data analysis section will present the processes of the closest facility analysis and data classification to demonstrate how the results were formulated.

5.1 Overview of ArcGIS Network Analyst: Closest Facility Analysis

The ArcGIS Network Analyst is an extension that primarily operates in the ArcMap and it is frequently used for solving network problems (ArcGIS Desktop, n.d.b). The extension contains several network analysis tools, which include route, service area, closest facility, origin-destination (OD) cost matrix, vehicle routing problem, and location-allocation. These analysis tools have distinct functions that are utilized for different purposes. To illustrate, route analysis can be used to find the optimal route between two locations whereas service areas analysis can create a polygon around a point of interest that covers all the reachable locations and streets within a specific mile or driving time (ArcGIS Desktop, n.d.b). For this research, closest facility analysis was employed to examine the accessibility of California public EVCSs to amenities.

Closest facility analysis is a network analysis tool that allows the user to locate the nearest facility from an incident based on the distance, expense, or traveling time (ArcGIS for Desktop, n.d.a). A line is drawn between the two locations to represent the shortest, less expensive or less time-consuming route. This tool is useful in several ways, for instance, it can be used to locate the closest grocery store from a residential area through computing and finding the path with the shortest distance. As an example, Figure 5 illustrates the closest restaurant from the three public EVCSs. Moreover, closest facility analysis can also examine multiple identical nearest facilities within a limited mile range or drive time from an incident. Thus, the closest facility network analysis is applicable for this study to investigate the distances from the charging stations to the amenities.

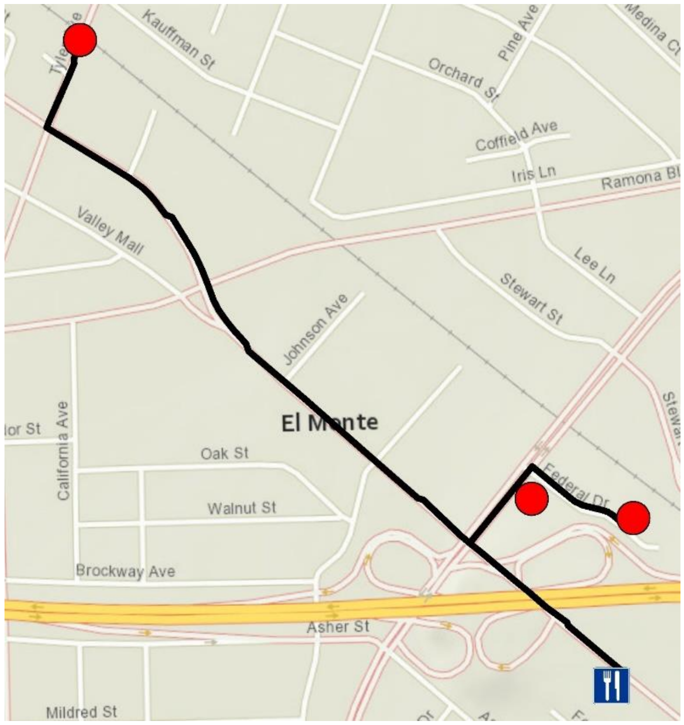


Figure 5. Example of closest facility analysis that examined the nearest restaurant from the public EVCSs.

5.2 Data Acquisition and Information

To perform the data analysis and produce the analysis results as figures, several geospatial data were utilized. The data employed in this study were collected from official corporate and governmental websites that provide open GIS data. As an example, National Geographic basemap data, sources of National Geographic et al. and acquired from the ArcGIS Online, was used for the digital maps to present the background setting of the study area. The following is a list of the geospatial data with information regarding the locations where the data were acquired and descriptions of those data.

North America Detailed Streets

The North America Detailed Streets is vector (line) data acquired from ArcGIS. This dataset was created in 2012 utilizing the source from 2007 TomTom Dynamap/Transportation v. 9.3 and it was last modified in 2014. The dataset displays a large variety and quantity of roads such as the connecting roads, local streets, access ramps, highways, and interstates within the boundary of the U.S. and Canada at a scale of 1:100,000 (Esri Data and Maps, 2012). Additionally, this dataset also contains attributes of the roads including the names, speed limits, and travel directions. To be precise, this geospatial dataset is a network that is comprised of polylines, or a series of joined line segments, and does not have much discontinuity, which can yield better and accurate results in the ArcGIS network analysis. The purpose of this dataset is using it as the base to create a new network dataset with ArcCatalog 10.4.1 required for operating the closest facility analysis.

Before using this dataset for the data analysis, there were two modifications done. First, the Intersect geoprocessing tool was used to minimize the covered network area from North America to only the state of California. The North America Detailed Streets (intersect feature) was overlapped onto the CA Counties (input) to form a new dataset that shows the detailed streets network of California (output) (see Figure 6). All the attributes from the intersect feature that are within the input boundary were computed and transferred to the output (ArcGIS Desktop, n.d.a). Next, the Project geoprocessing tool was utilized on the new dataset to set the projection as North America Datum (NAD) 1983 California (Teale) Albers (U.S. Feet), which is common, recommended projected coordinate system for examining statewide datasets (Geospatial Innovation Facility, n.d.; Patterson, 2015).

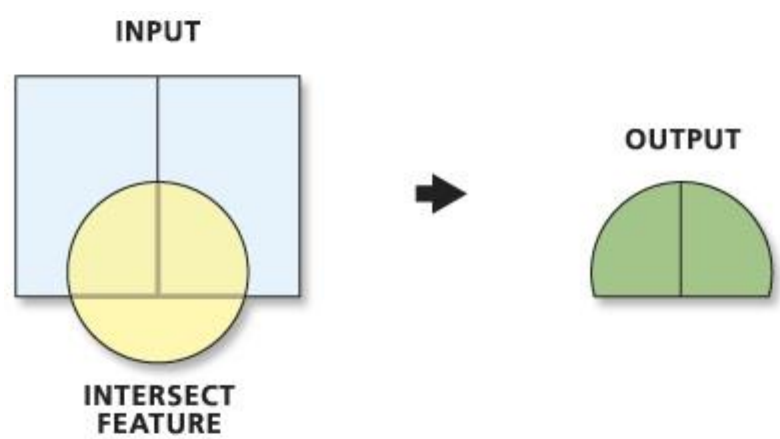


Figure 6. Example of Intersect geoprocessing tool.
Source: ArcGIS Desktop (http://pro.argis.com)

CA Counties

The CA Counties is vector (polygon) data obtained from the ArcGIS. This dataset was created in 2012 in the format of TIGER/Line (Topologically Integrated Geographic Encoding and Referencing) using sources from the U.S. Census Bureau (Kelso, 2012). In addition, the dataset had been previously modified with the use of Clip geoprocessing tool to omit any county's territorial lands beyond the border of California. The CA Counties dataset exhibits several polygons that made up the state of California and each of the polygons represents a county. This dataset also provides attributes such as the name, land area, and water area of the counties. To keep the projected coordinate system consistent, the Project geoprocessing tool was employed on this dataset to place the projection as NAD 1983 California (Teale) Albers (U.S. Feet). Moreover, CA Counties was renamed as County Boundaries in the figures of this paper. The function of this dataset is to outline the boundaries around the state and counties of the study area for better presentation on the digital representations.

State Highway (Segments)

The State Highway (Segments) is vector (line) data acquired from the California Department of Transportation (Caltrans) GIS Data Library. This dataset was created in 2015 utilizing Census TIGER roads data from 2009. It was also based on the Caltrans State Highway Network and Transportation System Networks (California Department of Transportation, 2015). The State Highway (Segments) dataset displays state highways of California in the form of polylines similar to the North America Detailed Streets dataset; however, this dataset does have several discontinuities within its highway network. In this dataset, some of the attributes that it contains include the California district number, route number, and route type (e.g., U.S., Interstate, and State). Additionally, data extraction was performed on this dataset to create a new dataset that presents only the major highways in California (U-101 and 395; S-1 and 99; I-5, 8, 10, 15, 40, and 80). This new dataset was then projected as NAD 1983 California (Teale) Albers (U.S. Feet) utilizing the Project geoprocessing tool and was renamed as Major Highways in the figures of this study. With less complexity of its network but adequate data for visualization, the dataset is suitable to illustrate the relationship between the major highways and the locations of California public EVCSs as well as the amenities.

Electric Vehicle Charging Station

The Electric Vehicle Charging Station is raw data obtained from the Alternative Fuels Data Center of U.S. DOE. This data was acquired on January 30th of 2017 and downloaded in the format of comma-separated values (CSV) on Microsoft Excel. According to the Alternative Fuel Data Center, the National Renewable Energy Laboratory (NREL) collects and validates the raw data from Clean Cities facilitators, submissions of new station document, and trade publications (Alternative Fuels Data Center, n.d.a). In addition, the data center updates its database relatively often, thus, the number of charging stations retrieved can be different as time progresses. This raw data consists of all the available U.S. public EVCSs based on the date when the data is accessed. A total of 15,388 public EVCSs consisting of AC Level 1, Level 2, and DC fast chargers were collected. Additional information related to the charging stations is included such as the station name, complete address (e.g., street address, city, state and ZIP code), opening hours, and longitude and latitude. The use of this dataset is to investigate how accessible are the California public charging stations to amenities using the closest facility analysis.

Multiple processes were accomplished on this raw data to form the geospatial dataset used in the data analysis. To begin, the raw data was imported into ArcMap 10.4.1 as an Excel table. With the longitude (x-coordinate) and latitude (y-coordinate) information available from the raw data, vector (point) data was created with the points based on the coordinates. Subsequently, since only California public charging stations are needed for this study, data extraction was performed to collect EVCSs that have the state attribute as CA. The gathered data comprises of 3,514 public EVCSs, which was employed in the analysis. Lastly, the Project geoprocessing tool was utilized to set the projection of the dataset as NAD 83 California (Teale) Albers (U.S. Feet).

McDonald's

The McDonald's is vector (point) data acquired from the ArcGIS. This dataset was created in 2014 and contains attributes such as the city, state, street address, and longitude and latitude of McDonald's restaurant (ArcGIS, 2014). The dataset exhibits the locations of U.S. McDonald's in the form of points that are based on the x and y coordinates. A total of 14,315 McDonald's restaurants were collected in this data. Similar to the processes completed on the Electric Vehicle Charging Station dataset, data extraction was done on this dataset to gather only the McDonald's restaurant in California that has the state attribute as CA. The extracted data was generated as a new dataset, which comprises of 1,348 McDonald's restaurants and was utilized in the closest facility analysis. Additionally, the Project geoprocessing tool was used to place the projection of this dataset as NAD 83 California (Teale) Albers (U.S. Feet). The function of this dataset is to act as one of the amenities for this research to examine the accessibility of California public charging stations regarding amenities.

StarbucksLayer

The StarbucksLayer is vector (point) data obtained from the ArcGIS. This dataset was created in 2014 and consists of the city, state, and longitude and latitude attributes of Starbucks store (Esri Retail Industry, 2014). The geospatial dataset presents U.S. Starbucks locations as points according to the longitude and latitude. There were 10,882 Starbucks stores gathered in this dataset. Since the study area only focuses within the California boundary, data extraction was applied to collect only the Starbucks store that has the state attribute as California. A new dataset containing 2,399 Starbucks stores was formed and employed in the data analysis. This dataset was also projected as NAD 83 California (Teale) Albers (U.S. Feet) utilizing the Project geoprocessing tool and renamed as Starbucks in the figures. Like the McDonald's dataset, StarbucksLayer dataset plays the role of amenity to examine if California public EVCSs are accessible to this coffee shop.

5.3 Data Analysis

To investigate California public EVCSs' accessibility to amenities, two major steps were performed in the data analysis. The first step comprises utilizing the geospatial datasets and performing closest facility analysis. In the second step, data classification of distance ranges was executed to identify the number of California public charging stations that are accessible to the amenities with the consideration of tolerable walking distance. Figure 7 displays a concise, step-by-step data analysis process of this research to clarify the overall steps.

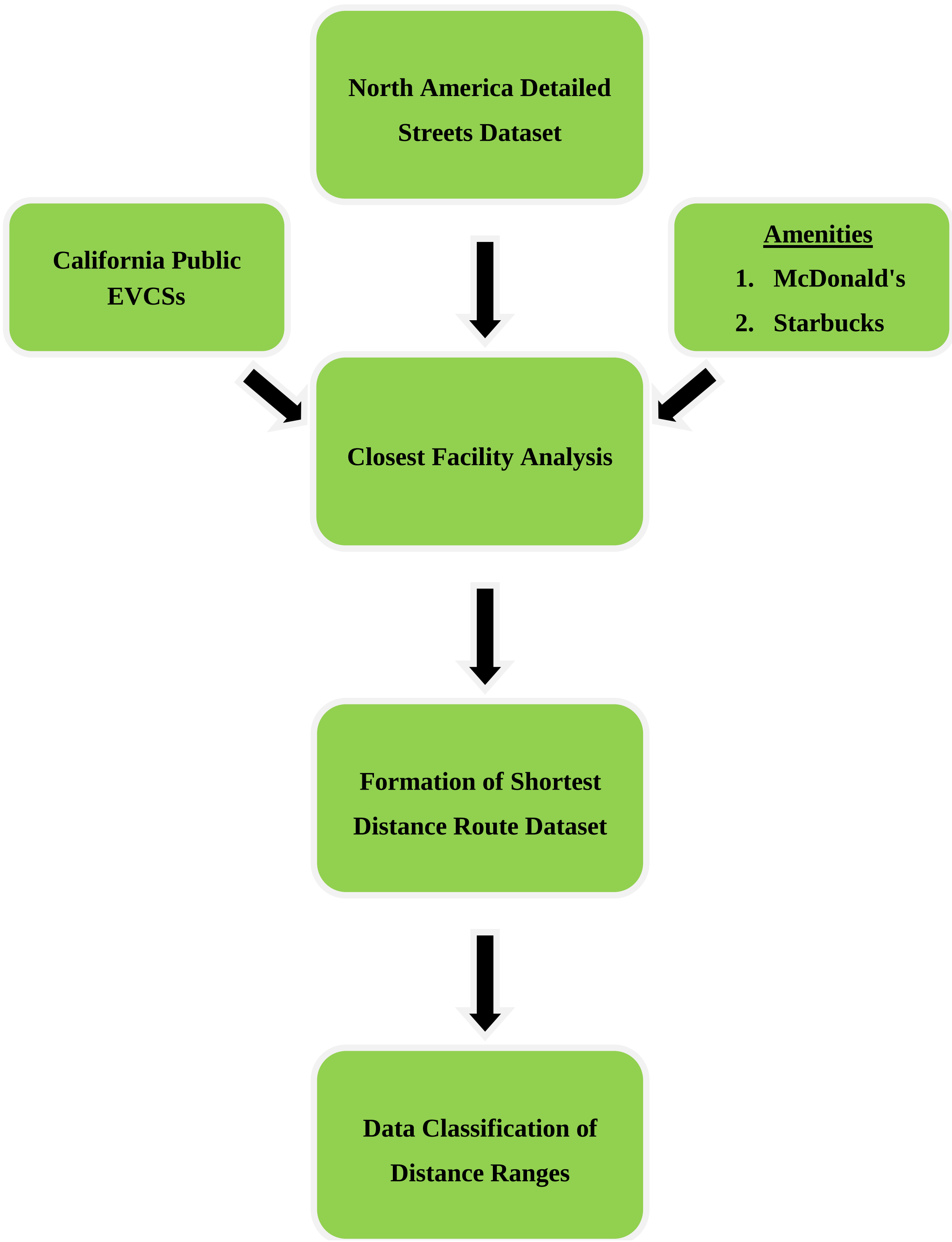


Figure 7. Flowchart of the data analysis process. The process begins with using geospatial datasets to operate the closest facility analysis and produce a new dataset consisting of calculated distances between California public EVCSs and the nearest amenities. Subsequently, data classification organizes the distances into specified ranges. The amenities of McDonald's and Starbucks were separately examined for the analysis using the same process.

Closest Facility Analysis

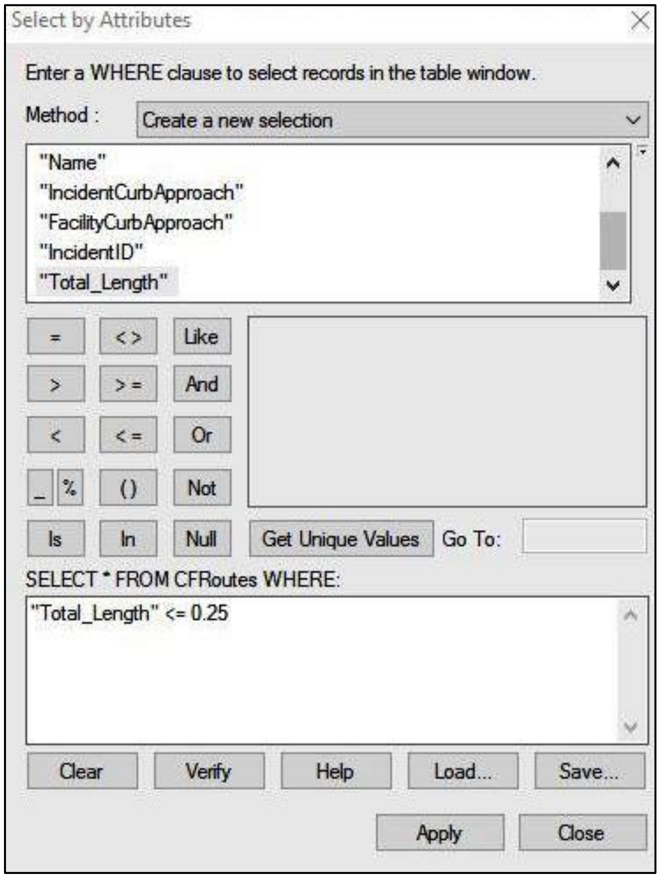
For the closest facility analysis to operate, new network dataset needs to be created. In this data analysis, North America Detailed Streets dataset was utilized as the foundation to build the new network dataset, which was accomplished in the ArcCatalog 10.4.1. This step is crucial because the connection of the edges (lines) and junctions (points of intersections) need to be established and recognized by the closest facility analysis tool to compute the distances between the points of location. Following the creation of the new network dataset, closest facility analysis was performed in the ArcMap 10.4.1 with the datasets of Electric Vehicle Charging Station, McDonlad's, and StarbucksLayer.

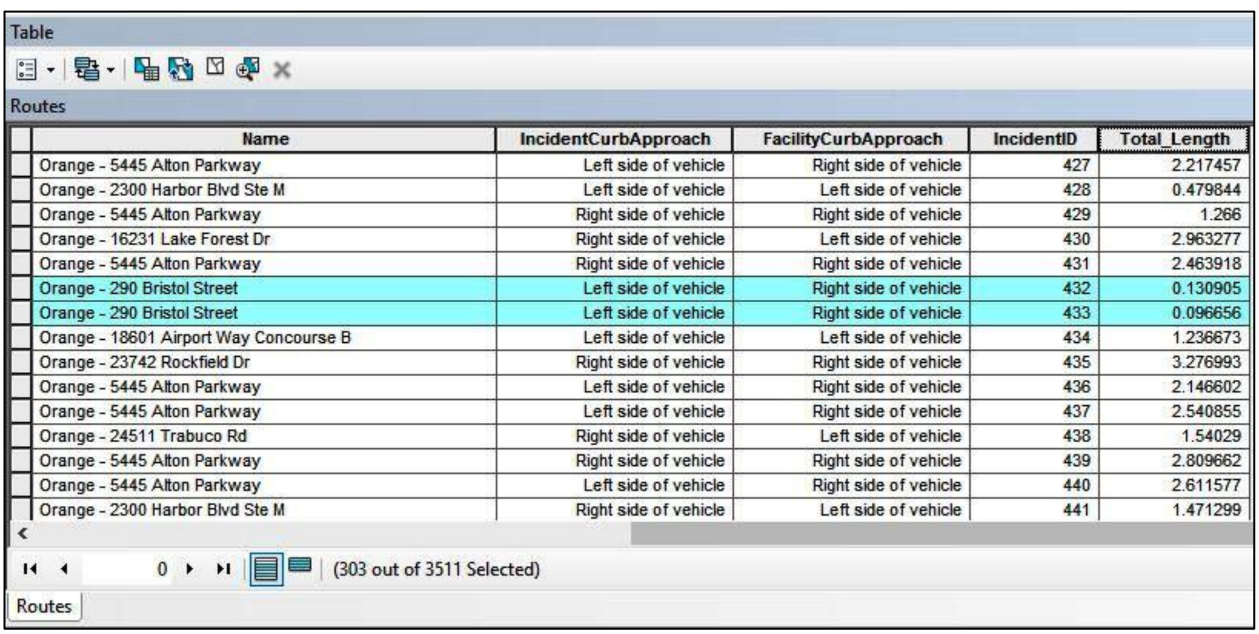
To run the closest facility analysis, the incidents (start-points) and facilities (end-points) must be defined. Normally, incidents and facilities are the terms used for closest facility analysis, but for this analysis, public EVCSs and amenities will be used instead, respectively. In this analysis, California public EVCSs were assigned as the public EVCSs while the McDonald's restaurants and Starbucks stores were set as the amenities. These two amenities were separately examined with the public charging stations. Next, the analysis settings were put to travel from public EVCSs to amenities and to locate one nearest amenity from each public EVCS. In addition, the distances from the public EVCSs to amenities were set to calculate in the unit of miles. The U-Turns at Junctions setting was also set to allow in this analysis. Since this research examines the walking distance of people, allowing U-turn at each intersection to be regarded in the distance computation is justifiable for the reason that people can walk across the pedestrian crosswalk at most of the intersection. After defining the public EVCSs and amenities as well as altering the analysis settings, the closest facility analysis was performed.

Using the closest facility analysis tool, a route dataset was generated, which contains the calculated shortest distances from the public EVCSs to amenities. With a total of 3,514 public EVCSs assessed in this analysis, 3,511 routes were created for the amenity of McDonald's. Similarly, when the studied amenity was Starbucks, the exact number of routes were produced. These routes can be represented as the number of public EVCSs that were able to locate the closest McDonald's or Starbucks. In both cases, three of the routes were unable to be created in the San Diego region due to network discontinuities.

Data Classification of Distance Ranges

To classify the shortest distances from California public EVCSs to McDonald's restaurants or Starbucks stores into distance ranges, Select by Attributes tool of the dataset table in ArcMap 10.4.1 was utilized. As shown in Figure 8, the Select by Attributes tool allows the user to input query expression that specifies the selection criteria and apply it to select the data with the attribute that meets the criteria from the table (ArcGIS for Desktop, n.d.b). For this data classification, the input queries were "Total_Length" ≤ 0.25, > 0.25 AND ≤ 0.50, > 0.50 AND ≤ 0.75, > 0.75 AND ≤ 1.0, and > 1.0. The attribute of Total_Length is the shortest distance in miles from the public EVCS to amenity. Additionally, these queries represented the distance ranges that this study examined, which are 0 to 0.25 mi, 0.25 to 0.50 mi, 0.50 to 0.75 mi, 0.75 to 1.0 mi, and greater than 1.0 mi, respectively. As mentioned in Section 3, 0.25 mi is a commonly used tolerable walking distance for U.S. research; therefore, the main distance range that needs to be focused in this research is the 0 to 0.25 mi range. After the queries were applied, the data with the Total_Length attribute that matches the selection criteria were selected and the number of selected data was shown on the table. The number of selected data represents the number of public EVCSs that are accessible to the amenities within the specified distance range. This number for each of the distance range was then entered in the Microsoft Excel table to generate the results.



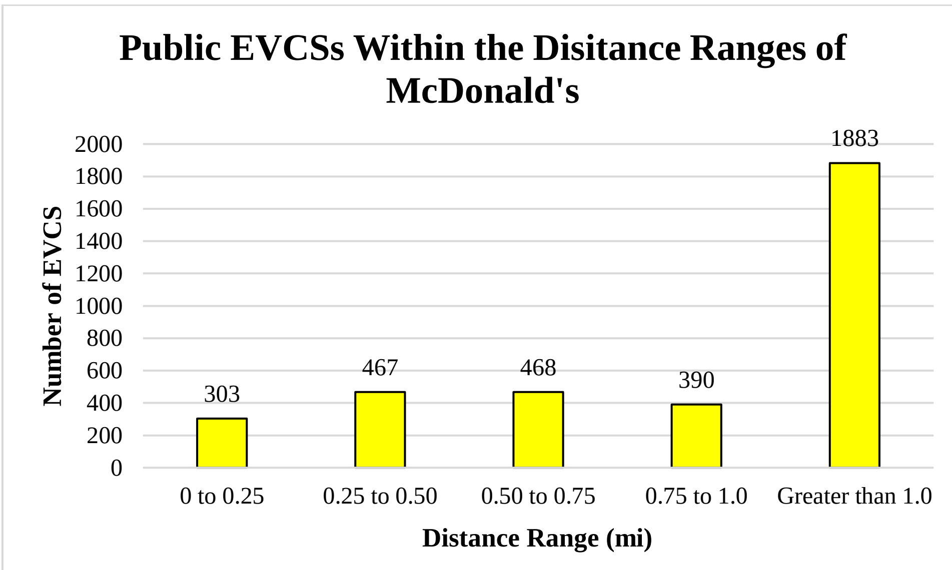


Name	IncidentCurbApproach	FacilityCurbApproach	IncidentID	Total_Length
Orange - 5445 Alton Parkway	Left side of vehicle	Right side of vehicle	427	2.217457
Orange - 2300 Harbor Blvd Ste M	Left side of vehicle	Left side of vehicle	428	0.479844
Orange - 5445 Alton Parkway	Right side of vehicle	Right side of vehicle	429	1.266
Orange - 16231 Lake Forest Dr	Right side of vehicle	Left side of vehicle	430	2.963277
Orange - 5445 Alton Parkway	Right side of vehicle	Right side of vehicle	431	2.463918
Orange - 290 Bristol Street	Left side of vehicle	Right side of vehicle	432	0.130905
Orange - 290 Bristol Street	Left side of vehicle	Right side of vehicle	433	0.096656
Orange - 18601 Airport Way Concourse B	Left side of vehicle	Left side of vehicle	434	1.236673
Orange - 23742 Rockfield Dr	Right side of vehicle	Right side of vehicle	435	3.276993
Orange - 5445 Alton Parkway	Left side of vehicle	Right side of vehicle	436	2.146602
Orange - 5445 Alton Parkway	Left side of vehicle	Right side of vehicle	437	2.540855
Orange - 24511 Trabuco Rd	Right side of vehicle	Left side of vehicle	438	1.54029
Orange - 5445 Alton Parkway	Right side of vehicle	Right side of vehicle	439	2.809662
Orange - 5445 Alton Parkway	Left side of vehicle	Right side of vehicle	440	2.611577
Orange - 2300 Harbor Blvd Ste M	Right side of vehicle	Left side of vehicle	441	1.471299

Figure 8. Select by Attributes tool utilized in this study (top). The query expression is input in the blank space and apply to select the attribute that satisfies the selection criteria. Additionally, the attribute along with its corresponding data from the table (bottom) is highlighted in neon blue to show that it is selected.

6. Results

The results from the data analysis illustrate the number of California public EVCSs within each distance range of McDonald's and Starbucks as shown in Figure 9. For the case that examined McDonald's as the amenity, the result shows that out of 3,511 public EVCSs, there are 303 or roughly 8.6% of charging stations within 0.25 mi of walking distance to McDonald's. This percentage indicates that there are not a large number of existing public EVCSs accessible to McDonald's in California. Additionally, when the studied amenity is Starbucks, the result



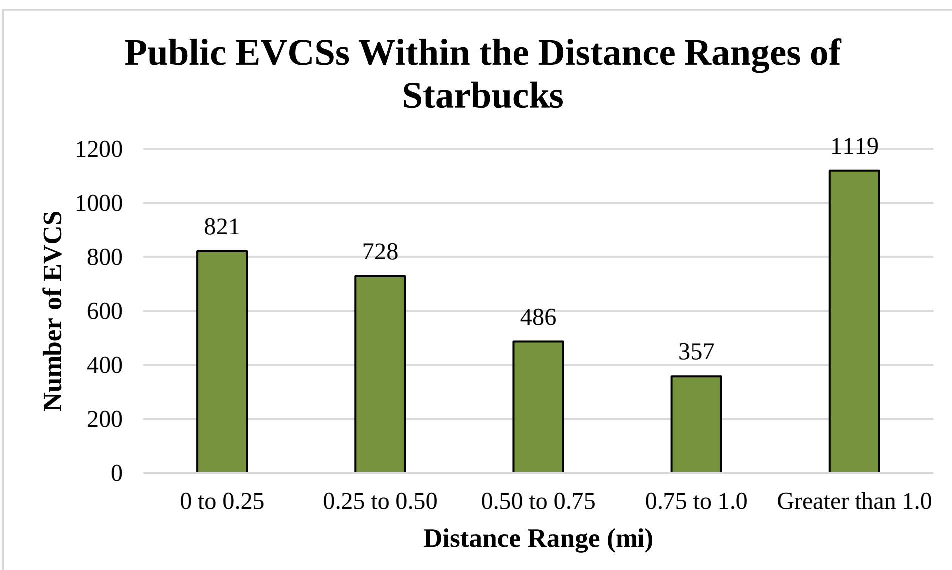


Figure 9. Number of California public EVCSs within each distance range of McDonald's (top) and Starbucks (bottom). A total of 3,511 California public EVCSs were able to be analyzed and contributed to the result of each case.

shows that 821 out of 3,511 or approximately 23.4% of public EVCSs are accessible to Starbucks. This outcome of California public EVCSs' accessibility to Starbucks signifies that there are quite a few existing public charging stations accessible to Starbucks.

Figure 10, 11, and 12 are zoomed in images showing public EVCSs that are and are not within 0.25 mi of McDonald's, Starbucks, or both. These figures look at the accessibility of charging stations to amenities at different locations, which include the San Francisco downtown area, Sacramento region, and a segment of I-80 to Lake Tahoe. In addition, the map images were produced utilizing data from ArcGIS, Caltrans, and National Geographical et al. Both the San Francisco downtown area and Sacramento region maps provide a perspective of the public EVCSs' accessibility to amenities in an urban area setting. Additionally, the I-80 to Lake Tahoe map offers a viewpoint of the public charging stations' accessibility to amenities for long-distance traveling on a major highway.

Figure 10. Public EVCSs' accessibility to McDonald's and Starbucks in the San Francisco downtown area. This map is created by using data from ArcGIS, Caltrans, and National Geographic et al.

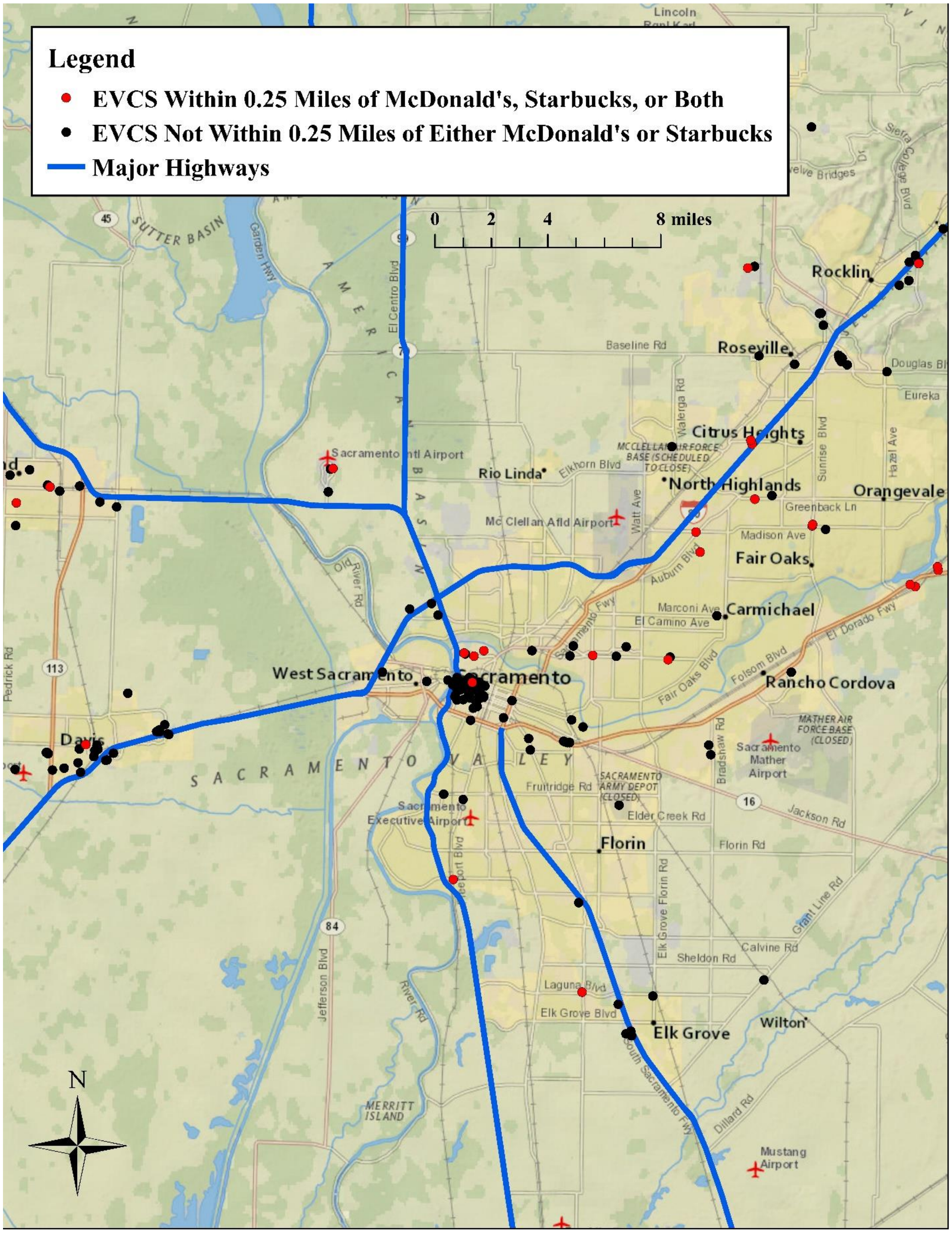


Figure 11. Public EVCSs' accessibility to McDonald's and Starbucks in the Sacramento region. This map is created by using data from ArcGIS, Caltrans, and National Geographic et al.

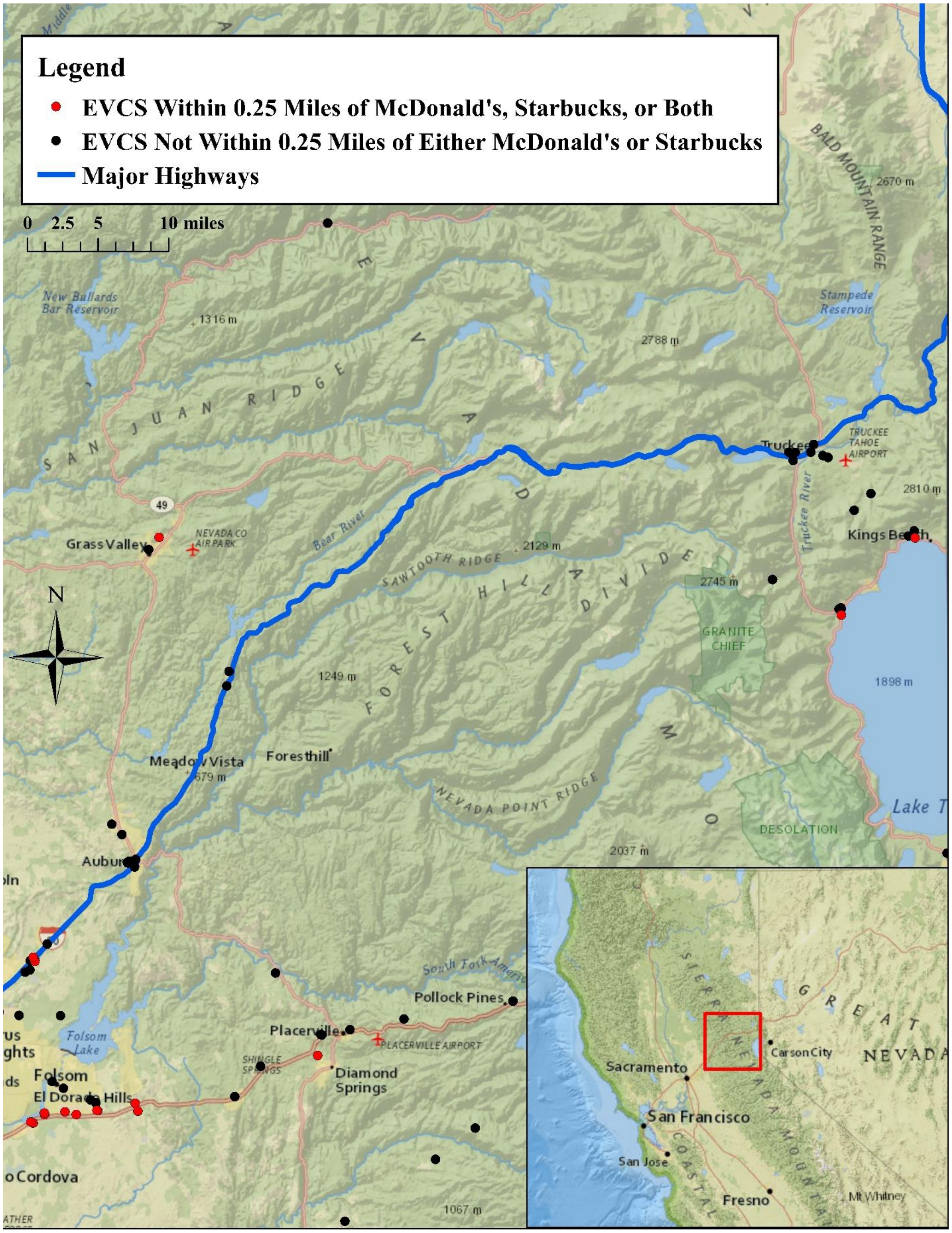


Figure 12. Public EVCSs' accessibility to McDonald's and Starbucks around a segment of Interstate 80 to Lake Tahoe. This map is created by using data from ArcGIS, Caltrans, and National Geographic et al.

7. Conclusion

From the results of data analysis, the accessibility of public charging stations to common, popular amenities can be perceived. Even though fast-food restaurants are recommended for the locations of EVCSs and people prefer charging station sites to be near these places, the existing charging stations do not seem to be substantially accessible to the amenity of McDonald's. The low percentage (8.6%) indicates that the locations of the charging stations were not well-thought-out such as considering people's preferences or McDonald's as targeting amenity. On the other hand, current EVCSs do appear to be relatively accessible to Starbucks. Although 23.4% of California public charging stations that are within tolerable walking distance to Starbucks might not seem like much, the percentage is considerably significant compared to the 8.6% of charging stations accessible to McDonald's. This means that more public EVCSs are accessible to Starbucks than to McDonald's. However, the comparison of the percentages does not mean that many public EVCSs are accessible to Starbucks. Additionally, it is worth noticing that the number of Starbucks available in California is greater than the number of McDonald's; therefore, potentially resulting in having more charging stations accessible to Starbucks.

Examining current public EVCSs' accessibility to amenities is important and has various purposes. One of the reasons for this study is that it allows people to understand whether existing charging stations are well located and accessible to the amenities. Since amenities can provide EV drivers the option to use their time efficiently on worthwhile activities rather than waiting for their EVs to be charged, it is crucial to implement EVCSs within a tolerable walking distance to amenities. Another purpose of this study is to provide useful technique on examining the accessibility of charging stations to amenities, which can be beneficial for finding optimal EVCS locations.

Limitations

In this study, the amenities of McDonald's and Starbucks that were analyzed for the data analysis do not represent every amenity accessible from the California public EVCSs. This limitation was due to insufficient GIS data available online for other potential amenities and time constraint to do the data analysis. Another limitation was the lack of precise or up-to-date GIS data available to be used. For instance, the discontinuities of the network from the North America Detailed Streets dataset impeded the closest facility analysis tool to compute a few distances. Moreover, the McDonald's and Starbucks datasets were created in 2014, which mean that the datasets do not completely represent the current available McDonald's and Starbucks in public.

8. Recommendations

As mentioned previously, the available GIS data for amenities are limited. However, if more amenity data are accessible in the future, I would recommend further exploration on the accessibility of public EVCSs to amenities and see if additional amenities will change the results. Another recommendation is to frequently update the GIS data, especially the EVCS and amenity datasets, for the closest facility analysis since some of these places might be closed while new ones might be available as time progresses. In addition, having precise GIS data would be helpful to produce better accessibility results.

From this study, ArcGIS closest facility analysis along with the data classification was shown to be a potential method to examine the EVCSs' accessibility to amenities. For studies that examine the optimal locations of EVCSs, this approach can be utilized to investigate the criterion of EVCSs' accessibility to amenities. Additionally, with up-to-date GIS data, this method can be employed to check if new additional charging stations are well located regarding the access to amenities.

Besides looking at the accessibility of California EVCSs to amenities, other states or even countries' EVCSs' accessibility to amenities can also be examined using the same technique. Moreover, since this study did not consider the types of chargers available at each public charging stations, I would recommend analyzing the types of chargers near the amenities to examine if the chargers are suitable based on the surrounding amenities. For instance, DC fast chargers would be ideal and proper than AC Level 1 chargers for amenities like fast-food restaurants.

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