Strategies to Reduce Congestion and Increase Access to Electric Vehicle Charging Stations at Workplaces

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Abstract

This paper investigates strategies to increase charging station utilization, reduce congestion, and increase access to chargers at workplaces. Interviews with plug-in electric vehicle (PEV) drivers across California revealed three styles of workplace charging management: authoritative (rules introduced by the employer), collective (rules introduced by employees), and unmanaged (no rules in place). Authoritative charging included digital queuing, time limits with pricing, pricing, and valet charging. Collective management included day restrictions, time restrictions, messaging groups, and spreadsheets with driver information. Charging management strategies can increase accessibility and utilization of stations by reducing congestion, increasing vehicle throughput and discouraging those that do not need to charge from doing so. Workplaces with charging management may need less charging infrastructure to support more PEVs. Interviewees reported positive experiences with the charging management strategies at their workplaces. Charging management strategies appear to be a user-friendly approach to reducing charge point congestion, vehicles overstaying, and increase utilization of workplace charging.

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1 Introduction

In attempts to curb light-duty-passenger vehicle emissions, California has a goal of 250,000 electric vehicle charging stations by 2025 [1], and goals to achieve 100% electric new vehicle sales by 2035. Home, public, and workplace charging infrastructure will be needed to reach this goal. While most charging events occur at home, some PEV drivers depend on, or want to charge away from home [2–5]. Workplace charging is the second most used charging location after home, and having dependable access to charging at work is an important factor for people considering purchasing or leasing a plug-in electric vehicle (PEV) [2, 3, 6, 7], including battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs).

This paper aims to uncover if and how workplaces manage employee use of electric vehicle charging and to understand driver experience with managed charging. As more people adopt PEVs, workplace charging could see more use as more consumers who cannot charge at home purchase PEVs. By managing how people charge at work, more people can reliably access and use the charging infrastructure, herein known as EVSE (electric vehicle supply equipment (i.e. charging stations)) per day. This leads to fewer EVSE needed to support a larger number of PEVs, allowing more PEVs to charge per dollar spent on EVSE.

Managed charging is any set of formal or informal rules that PEV drivers follow when using EVSE. Without managed charging, vehicles using EVSE at workplaces may remain plugged in after they have completed charging, making the stations unavailable to others. Conversely, if there was higher turnover of vehicles, fewer EVSE would be needed to meet demand. Finding effective ways to encourage drivers to do this may be necessary in ensuring infrastructure is not underutilized. This research is relevant to policymakers, EVSE network providers, workplaces, and any stakeholders in charging infrastructure interested in implementing managed charging and increasing the utilization of existing and new charging infrastructure. Workplaces are installing EVSE for a variety of reasons: as a work perk, improving employee productivity and loyalty, improving the image of the company, helping to achieve company sustainability goals, and supporting employees sustainable transportation [8, 9].

1.1 Charging Location, Levels, and Management Strategies

Here we define charging congestion, vehicle overstay, and charging management strategies. We also define Level 1 (L1), Level 2 (L2), and Direct Current Fast Charging (DCFC) charging, as well as home, work, and public charging locations.

Charging congestion arises when PEVs are unable to charge because EVSE is currently occupied. PEV drivers must either wait to charge, travel to a different EVSE, or choose not to charge. Vehicle overstay, as discussed in [10–13], occurs when EVSE is occupied when charging has completed and the driver has not moved their PEV. This can exacerbate the issue of charging congestion and can lead to charging infrastructure being underutilized. Charging management strategies include any rules that can reduce vehicle overstay and congestion. These strategies can increase vehicle turnover and make the EVSE available for those who want or need it.

Table 1 shows different speeds of PEV charging. Level 1 charging is the slowest speed, here a PEV plugs directly into a standard wall outlet using a charging cable. Level 2 EVSE charges the vehicle at about twice the speed as Level 1 but requires additional charging equipment or the use of a 240V outlet (e.g. a clothes dryer plug). DCFC is the quickest and usually costliest way to charge a BEV, it is typically installed in public locations [7, 14–19].

Table 1: Types of PEV Charging in North America, charge power, typical location of the charger type, and typical charging speeds.

	Typical Power (kW)	Typical Location	Charge Speed (miles of range added per hour of charging)
Level 1 (L1)	1-3	Home	2-5
Level 2 (L2)	3-7	Home, Work, Public	10-20
DC Fast Charging (DCFC)	50-150	Public	60-80
Adapted from [7, 14]			

Home charging is defined as charging while the driver is at home. This does not necessarily mean in a dedicated parking space or garage but could be a public parking lot or any location drivers park their vehicle when they are at home. Workplace charging is defined as charging while the driver is at work; this could be in the workplace parking lot or another location where the driver parks for the day such as a public lot or a parking lot at a public transit station. Public charging is any charging event neither while at work nor at home. The definitions of home, work, and public charging are consistent with previous studies [2, 3, 7, 20]. We are using these definitions because they most closely represent how drivers perceive the charging locations. For example, home charging can mean a dedicated L2 charging station in a private garage or an EVSE in a public lot that a driver parks in while they are home. Some studies defined their charging locations differently [18, 19, 21, 22] or not at all [15, 17, 23–26].

2 Literature Review

Here we review literature on charging behavior, charging demand management (e.g. smart charging) as it is related to the strategies in this paper, and the small amount of literature that closely resembles the work in this paper.

2.1 Charging Behavior

Research shows home charging is the most frequently used (50-80% of charging events) charging location [2, 3, 5, 7, 18, 20–22, 27–30]. Many papers assume drivers will be able to charge their vehicles at home [17, 19, 23–25, 31, 32], though as the PEV market progresses more PEV drivers may not have access to home charging especially those living in multi-unit dwellings (MUDs) [30, 33].

Workplace charging is the most commonly used charging location outside of the home; with 15-20% of charging events occurring here [2, 3, 7, 21]. Charging at work can be important to complete a commute [28], and can enable PEV drivers to travel further per day [21, 34]. PEV drivers who live in multiunit dwellings (MUDs) charge at work with higher frequency than those who live in detached-single family houses [2, 3]. This is likely due to MUD residents being unable to charge at home. BEV drivers have been found to charge at work with higher frequency than PHEV drivers, and BEV drivers are more willing to pay for work charging, whereas PHEV drivers may not charge when there is a charging fee [2, 3, 6, 33]. While free charging at work can motivate PEV adoption Nicholas and Tal [6] found that free workplace charging can cause congestion as drivers substitute home charging for free workplace charging; those findings are corroborated by a later study by Chakraborty et al. [2]. Paid charging may be beneficial as it prevents those who do not need to charge from doing so, which gives those who need to charge more reliable access to charging [2, 6, 35, 36]. Philipsen et al. [37] found that non-BEV drivers thought workplace DCFC was important; however respondents indicated they were unwilling to move their vehicles when charge is complete, rendering this hypothetical DCFC unusable for more than one driver per workday. One study [6] assumed that one workplace charging station would serve two cars per day, and another assumed four cars per day could charge from one workplace EVSE [25]. These assumptions may depend on the presence of charging management.

Researchers have investigated the cost of public charging installation [17–19, 29], the user's cost to charge [13, 15, 19, 29, 38, 39], the appropriate charging speed [17, 39], and where to install these stations [17, 19, 20, 26, 29, 37, 40]. Adjusting the cost to charge was seen as a method to reduce congestion in the hopes more vehicles will be able to charge [15, 29, 39]. Philipsen et al. [37] used a stated preference method and found respondents would not move their vehicles when finished charging, nor were they willing to wait to charge their vehicle if the station was occupied. Research also indicates consumer do not want to move their vehicle from DCFC when charging is complete [15, 37]. Research on DCFC queuing [39] found that more DCFC at a location reduces queue times and setting a maximum state of charge (SOC) (e.g. 80% full) can lead to faster vehicle turnover and a shorter queue times. Biswas et al. [13] suggest a $4/hour overstay penalty could maximize EVSE utilization and revenue for the EVSE owners be encouraging PEV drivers to move their vehicles once charging has finished.

2.2 Demand Management

Valentine et al. [32] found that a high use of unmanaged L2 charging could results electricity demand peaks. Papers that investigated smart charging [11, 19, 25, 31, 32, 41, 42], grid management [27, 32, 35], system cost reduction [11, 32], peak shaving [12, 32, 34, 43], and dynamic pricing [39, 43], are plentiful, but generally do not focus on increasing EVSE use since their focus is on managing electricity demand, local grid impacts, or emissions. We review these papers briefly since they inform our investigation into how charging access could be managed and users perceptions of this management.

Through a 2016 survey, Will and Schuller [42] examined user acceptance of smart charging and found that renewable energy integration and grid stability were significant factors for smart charging acceptance among EV adopters in Germany. They found that drivers wanted to be able to set a range buffer, manually override the smart charging protocol, set an expected departure time, and set a planned range [42]. Ferguson et al. [44] investigated smart charging at workplace and assumed that only one vehicle could charge per day per EVSE, but used the large time window to charge that single PEV at the most optimal times.

Vagropoulos et al. [25] investigated how may PEVs a workplace charging system could serve while not charging during peak electricity hours. This meant EVSE was only operational for 5.5 hours of the workday. They assumed vehicles are not charged from completely empty. Using pricing as an as an incentive, Zhang et al. [43] investigated how pricing could shift driver charging behavior to off-peak times with the aim of smoothing electricity demand. Zhang et al. [11] and Lee et al. [45] suggested using drivers known departure times to optimize power flow to fully charge the vehicle by that time using off peak electricity. Zhang et al. [11] suggested reducing the power of EVSE during periods of high electricity tariffs as a cost saving measure. These studies did not consider user behavior in their analysis.

2.3 Increasing EVSE Utilization

Here we review papers identified as being most relevant to charging management strategies, most of the studies identified are modelling studies that do not focus on consumer behavior. Kong et al. [38] recommended varying the price of DCFC based on congestion and station location to mitigate charging congestion. Caperello et al. [46] found that some drivers would like to see a reservation system for charging station access. Kong et al. [38] implemented this concept into their model; other papers also discussed a charging reservation system [23, 38, 40, 41, 46, 47].

Biswas et al. [13] modeled the trade-off between a steep penalty for overstaying (an idle fee) with the drivers' decision to not charge due to the penalty and uncertain parking duration. They found that a $4/hour overstay fee maximized both the utilization of the EVSE and the revenue for EVSE owners. This paper assumed drivers would interrupt their appointments to move their vehicle when they find the overstay cost to be too high; this creates vehicle turnover and increases EVSE utilization.

Zeng et al. [10], Zhang et al. [11], and Chen et al. [12] modelled how changing EVSE design could improve utilization. Zeng et al. [10] broadly suggested that "interchange" technology could be used for EVSE port rotation to reduce vehicle overstay. This does not require drivers to change their behavior, rather adapt a system around them by creating a method to rotate the charge ports. The authors suggested robots or humans (not the driver) could rotate the charging ports. Zhang et al. [11] created coordinated charging simulation with multiple charging ports from the same EVSE that would allow multiple vehicles to be plugged in, but only one to charge at a time; Bonges et al. [40] called this octopus charging. Attaching more ports to a single EVSE significantly reduced the infrastructure cost and mitigates the need for grid improvement. The ability and timeline to charge would depend on how much energy the previous vehicle needed before charging the next. Finally, Chen et al. [12] suggested charging interchange through power sharing from multiple EVSE across multiple charging ports. This design allowed vehicles that finished charging to continue to stay parked and redistributed the power to other vehicles plugged in and waiting to charge.

Bonges et al. [40] discussed how to increase EVSE accessibility with user-interface design and the location of EVSE in parking lots. They recommended maximizing the number of parking spaces EVSE can reach. This allowed drivers to remove the charging cable from a PEV that had finished charging and plug it into their PEV. The paper highlighted possible legal consequences around unplugging another vehicle and interfering with another person's property, which was also observed elsewhere [36]. The paper also suggested that an overstay fee is important, but warned that some drivers may be willing to pay it, thus decreasing its effectiveness of reducing vehicle overstay; the authors further agreed with [11] about the usefulness of EVSE that has more ports than it can charge at once. Caperello et al. [46] found that PEV drivers felt more comfortable charging away from home if there were formalized charging etiquette and structure. Interviewees reported being unable to charge because of others who are plugged in but had finished charging. The authors found that PEV drivers limit their driving based on perceptions of charging congestion or technical issues with charging.

We were unable to identify any studies that investigated workplace charging management strategies, though some studies do suggest strategies that could be used. Our study builds upon previous work by factoring in human behavior and reports what charging management strategies are currently being used in California. By using interviews to examine workplace charging, we were able to detect workplace charging management strategies that were previously unknown.

3 Methods

The data for this research is from forty semi-structured qualitative interviews conducted with PEV drivers across California in summer 2018. All interviews were transcribed verbatim and coded using the qualitative analysis program NVIVO. Interviews were the ideal method to collect data as we did not know enough about charging management strategies to develop a survey.

3.1 Interviewee Recruitment

The 40 interviewees were recruited from an existing study [4, 5] in which PEV owning households had loggers installed in their vehicles. These households were initially recruited via an online questionnaire survey. This survey was sent to California drivers who purchased or leased a new or used PEV in 2016 or 2017. Survey respondents were those who applied for and received California's Clean Vehicle Rebate Program (CVRP) funds [48]. Recruitment was via email; email addresses were provided by the California Air Resources Board. This study also included used PEVs with records obtained from the California DMV. These drivers were mailed a letter with a survey link. At the end of the PEV surveys, respondents were asked if they would like to participate in future studies.

This paper focuses on a subset of 40 drivers from the survey and vehicle logger project who agreed to be interviewed. For the logger study, households were recruited from survey respondents and had data loggers installed in all household vehicles for one year [4, 5]. The households were selected based on the PEV model they drive, their charging behavior, home location, home type, and secondary vehicle characteristics. For PEV model, we sampled based on the best-selling (as a percentage of new PEV sales using CVRP data) PEV models in California in 2017. For charging behavior, we only recruited PHEV who charged their vehicles. For home location, we sampled households based on their utility district across the state. For home type we recruited those living in single family home, apartments, and condos. Finally, for secondary vehicle characteristics we sampled based on yearly mileage, vehicle year, and ability to install the data logger. The project has logged 400 households between 2015-2020. These households were compensated with $350 for their participation in the logger project.

There is potential for sample bias in the sample as interviewees had previously agreed to and completed two other data collection forms (the survey and logger study). The sample is not intended to be representative of all PEV owning households or of the general population. These drivers may be more enthusiastic about PEVs since they had completed two other data collection forms. The PHEV households in this sample may charge more than the average because sampling criteria required them to charge their vehicle. However, the fact that we reached topical saturation with a diverse sample (geographically, by PEV type, by house type, etc. (see Appendix 2)) leads us to believe the interviews detected common charging management strategies currently employed in California.

3.2 Interview Protocol

Interviews were semi-structured with non-leading neutral questions to allow the interviewees freedom to express what was important to them about the topic being discussed. The semi-structured nature of the interviews meant there was a loose outline of predetermined topics, and other questions were asked as necessary for clarification, to explore topics in more detail, or as needed from the dialogue. All interviews were conducted by the primary author for consistency and to ensure interviewees all had a similar experience.

The interviews explored driver commute information, charging behavior, and experiences with charging etiquette (see Appendix 1 – Interview Topics). Interviews lasted on average 45 minutes, were audio recorded, and were conducted at the interviewees' homes.

The interviews roughly followed the stages of rapport outlined in [49]; these are apprehension, exploration, co-operation, and participation. The author had formerly established a rapport with the interviewees from their participation in the previous logger study [4, 5], so the apprehension phase of the interview was greatly lessened. This allowed the interviews to quickly delve into the exploration and co-operation stages for more comfortable and in-depth responses to questions asked. All interviewee identities were kept confidential.

3.3 Data Analysis

Interview audio recordings were transcribed verbatim, transcripts were reviewed for accuracy and completeness. After, the interviews were coded and categorized by topic using the NVIVO 12 software.

The coding process used for this research was a thematic analysis of the transcripts [50, 51]. We used an inductive approach since there are no preexisting theories, so the theories (or findings) are based on the data that is being analyzed [51–53]. First, we used open coding to go through the transcriptions line by line to classify similar topics [53]. Coding in qualitative data refers to classifying and categorizing specific words and phrases. After open coding, we developed initial themes from the data by grouping similar topics together [51]. Next, it was possible to develop and interpret themes based on repeated patterns (e.g. phrases or concepts) across the interviews [50]. By analyzing with an open mind, the theories evolved as more data was evaluated. Once trends had emerged, we went back though the interviews to update and add additional coding to the transcriptions as needed [50, 52]. This type of coding is known as constant comparative analysis and is a nonlinear process that was repeated as more data was analyzed and new ideas emerged [52, 54].

We used an inductive method derived from grounded theory to analyze the data. Inductive coding, or the "bottom up" approach, allowed the themes to emerge from the data without prior guidelines [50, 53]. However, a definition for each code was created to serve as a framework for coding for consistency within the data [53], though the definitions and codes come from the data itself . This method allowed the data to fit into a categories of codes that were generated from the interviews, not previous studies [51, 53].

4 Results

The PEVs driven by study participants and discussed in the interviews are as followed: 15 Tesla Model S BEVs, 14 Chevrolet Volts PHEV, six Ford C-Max PHEVs, four Nissan Leaf BEVs, two Ford Fusion PHEVs, and one Chevrolet Bolt BEV. The results cover 20 BEVs and 22 PHEVs. There were 11 (28%) households who live in a MUD and 29 in a single-family home. This sample included seven households who had two PEVs, but only two interviews were conducted with both PEV drivers were present. Because of the uncertainty of one driver knowing the habits of the other, we only explored the use of the second PEV for the two households where both PEV drivers were present. Appendix 2 details respondents age, gender, house type, region they live, number of vehicles in the household, and the 42 PEVs that were discussed.

4.1 Charging Behavior

First, we explore interviewee charging behavior as it is relevant to workplace charging management. Thirty interviewees charge their vehicles at home, ten are unable to, and two can charge at home but chose not to (Figure 1). The interviewees who charged at home cited convenience and low refueling costs as their main reasons behind this choice. Of the 11 interviewees that lived in MUDs, eight are unable to charge at home. These interviewees noted not having a garage or access to electricity at their parking spot. Of those who chose to not charge at home one charges exclusively at work for free, and the other relies solely on public charging which they received free from Nissan as part of their vehicle lease.

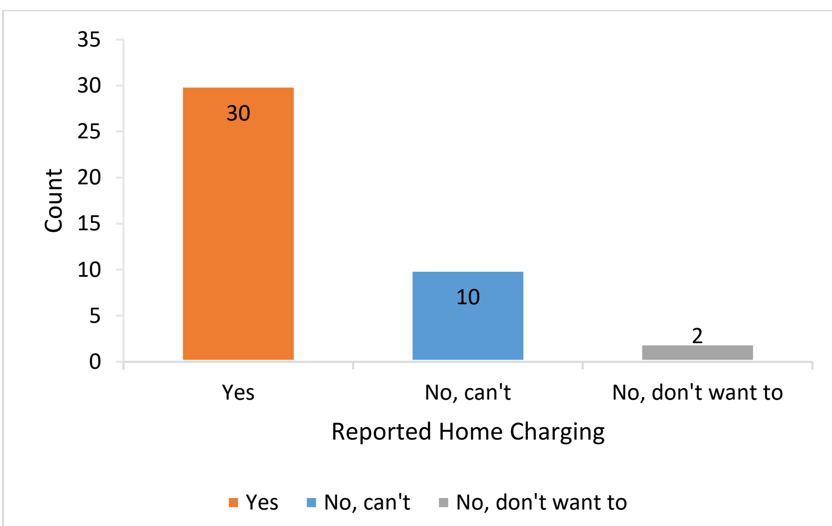

Figure 1. Interviewees reported home based charging (N=42)

Public charging frequency is presented as always, frequently, occasionally, rarely, and never (Figure 2). This classification scheme was created from the data and is based on how interviewees reported their public charging frequency. Supercharging (the proprietary network for Tesla drivers) is included in this definition of public charging since it is charging away from home and work.

Eight drivers reported 'always' charging their vehicles in public. Of those four are unable to charge at home, and one chooses not to charge at home. These drivers cited choosing to charge in public for a convenient parking spot, to keep their battery's state of charge (SOC) high, a desire to drive more electric miles (for PHEVs), and/or supporting EVSE companies.

Six interviewees reported 'frequently' charging in public. They may check EVSE in places they regularly drive and may adjust their parking patterns to charge their vehicles but did not actively search for locations to charge. Seventeen interviewees charged in public 'occasionally'; this was the most common behavior observed. These drivers only charged at stations they knew of or conveniently come across when parking in public locations. If it was opportune, they will charge their vehicle, but they will not seek out chargers. Ten interviewees 'rarely' charged in public. Drivers noted that they may only be charging because they needed a parking space, and the available one happened to allow charging. One interviewee (a PHEV driver) never charges in public. They cited the hassle of charging compared to home charging, the efficiency of the gasoline engine, and time to charge as preventing them from seriously considering using it.

Irrespective of public charging frequency, seven drivers only charged in public when it was free. This was an additional grouping and was not a category of charging frequency. Drivers reported they didn't feel it was necessary to pay for charging when they could charge elsewhere for cheaper.

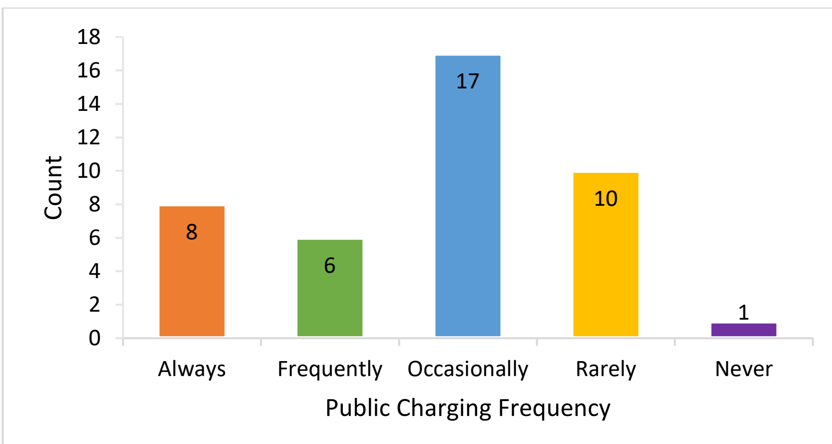

Figure 2. How often interviewees reported charging their vehicles in public (N = 42)

Twenty-seven of the 33 interviewees who regularly commute, were able to charge at work. Seventeen interviewees reported 'always' charging their vehicle at work, six charged 'sometimes', five had the option to charge at work and chose not to, and seven had no access to charging at work. Nine interviewees are either retired, did not commute, or had a driving schedule with no regular commute location (Figure 3). A few drivers reported workplace EVSE being blocked by conventional vehicles, but this was a less common occurrence than with public infrastructure.

The main motivators to charge at work were cost-savings, convenience, and avoiding using gasoline (for PHEV owners). Free or cheap workplace charging meant some interviewees prioritized charging at work over charging at home. Ten of the eleven drivers who live in a MUD always charged at work since they did not have access at home. Some interviewees reported wanting to charge every day but were unable to because of charging station congestion. Six interviewees in the sample charged at work 'sometimes'. These drivers used workplace charging as secondary to home charging. They would charge at work because they needed additional charging due to forgetting to charge at home or driving additional miles beyond their normal routine. Some interviewees reported charging at work because the parking space was in a better location. One interviewee only charges when the weather is cool because it is too long of a walk when it is hot. Five interviewees who have charging at their workplace did not charge at work. Some drivers found workplace charging inconvenient because the EVSE was too far from their office, some did not charge due to cost, or because the charging management strategies did not align with their schedule. One PHEV driver chose not to charge at work to keep the spaces open for BEVs owners.

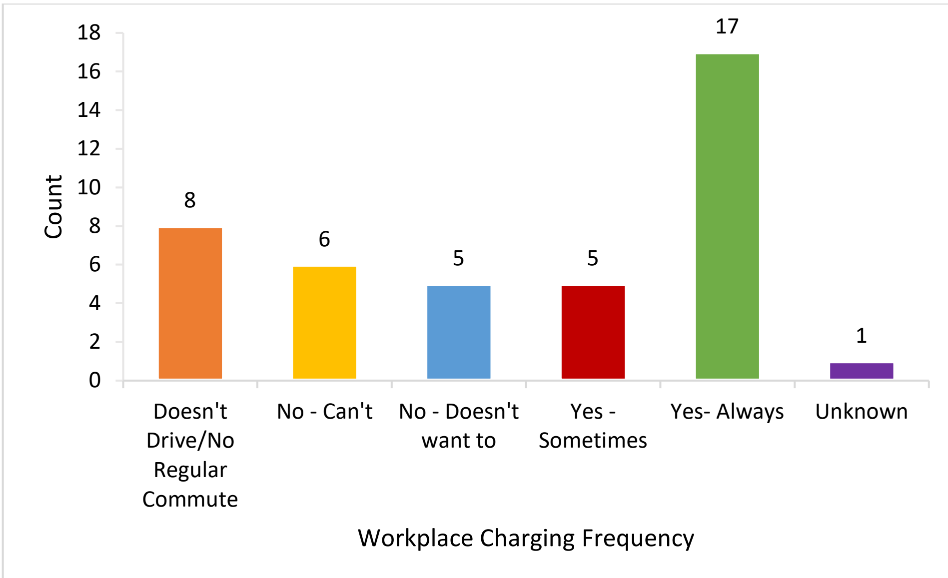

Figure 3. Break down of interviewee's work charging patterns and availability. Eight interviewees did not have a regular commute or were retired. (N=42)

4.2 Workplace Charging Management Strategies

Three categories of workplace charging management strategies were detected in this study. We refer to these as 'authoritative charging management strategies', 'collective charging management strategies', and 'unmanaged charging'. 'Authoritative charging management strategies' are rules that have been applied to a workplace or parking lot by administrators (e.g., the employer or manager of the parking lot), not by the charging station users. 'Collective charging management strategies' are created and administered by the employees who charge their PEVs at work. These interviewees' workplaces did not have any formal rules in place and were motivated to develop a system that allowed fair use of the infrastructure. 'Unmanaged charging' is where no rules for charging at work exist.

4.2.1 Authoritative Charging Management Strategies

Twelve of the 27 interviewees who charge at work reported having a set of rules enforced by and created by their workplace or organization managing the parking lot. Authoritative management strategies reported by interviewees include digital queuing, pricing, a time limit with pricing, and valet charging. These are not independent strategies: one workplace could employ multiple strategies.

Digital queuing occurs when one vehicle is charging, and a second parks next to it waiting to charge. The driver of the second vehicle taps a card against a reader to get in a virtual queue to use the charging station. When the first vehicle has finished charging, the second driver is notified via email that they can unplug the first vehicle and plug in their vehicle. This requires having more than one parking spot accessible to the EVSE. Interviewees appreciated not having to move their vehicle when it completed charging and knowing when they could unplug the previous vehicle.

"Is it awkward [to unplug another vehicle]? Not really because there's, the [queuing] system, and there's like a social code and everybody follows that social code" (Interview 01, Chevrolet Volt)

"I'll go upstairs [in the parking garage] to move, the charger over to my car, but I'm not gonna move my car and like help other people, even if they might be my coworkers, I just don't have the time for it" (Interview 10, Chevrolet Volt)

Pricing is where the workplace sets a cost to charge. The fee can be a per charging session, a per kWh, or a per hour fee. Depending on the fee, some drivers will not charge at work, which makes the charging more available for those that need to charge. Some interviewees had negative perceptions of this and decided to not charge at work. Though this does mean the systems has the effect of making charging more available.

"I try to avoid [charging at work] just because it gets um, I mean it's not too expensive 19 cents [per kWh], but it's more than what it costs at home off-peak usually. Especially since I have solar." (Interview 07, Tesla Model S)

A time limit with pricing is when charging is free or very low cost, and after a set number of hours, the price ramps up substantially. For example, charging may be free for the first 2 hours and then will cost $3/hour after that. Generally, drivers report complying with the time limit; they report moving their car after charging has finished, making the charging infrastructure available for others.

Interviewees reported occasionally running into the penalty. Most interviewees were not concerned about hitting the penalty occasionally, since it was infrequent enough that it balanced out the free charging they received. Their attitudes indicated that they felt more in control of their charging than those with other authoritative charging management strategies. They knew exactly when they would get charged a fee and can move their vehicle accordingly. They also knew hourly costs which they perceived as more comprehensible than a cost per kWh.

"If you keep your car charged for longer than 3 hours, then they uh start charging you like 5 bucks an hour. So that's ah, it's a real- it's a strong incentive to move your car and let other people use it." (Interview 19, Chevrolet Volt)

"[The timed free charging] induces a natural cycling so that if you couldn't charge in the morning, you'll come down at lunchtime and see if [you can charge]. There are a couple times when I've worked too much or had too many meetings that I've paid because I didn't move my car in time which feels fair" (Interview 38, Ford C-Max)

Valet charging was observed in workplaces that had valet parking for their employees. Valets are responsible for charging the vehicles and rotating them as necessary. Interviewees with valet charging were unaware of how their vehicle's charging was managed because they were not physically involved in the process. These interviewees were indifferent about how their vehicle was charged so long as it was ready for them upon leaving work. Interviewees appeared to be satisfied with this system since their vehicles were usually charged by the end of their workday. For both interviewees there was a fee to charge.

"Valets are good about rotating the cars around, so everybody gets a charge and like, I'm usually charged up full by the time I go home" (Interview 18, Ford C-Max)

Nineteen workplaces required PEV drivers to join a charging network company before being able to charge. Requiring employees to have an EVSE membership (e.g. ChargePoint) does not automatically qualify as authoritative management because not all these workplaces had implemented mechanisms to increase charger utilization (e.g. pricing, digital queuing, time limits).

4.2.2 Collective Charging Management Strategies

Four interviewees reported they and their co-workers created rules for charging at work. These collective charging management strategies observed include day restrictions (e.g. only being able to charge on Mondays and Wednesdays), time of day restrictions (e.g. a 4-hour limit on charging), messaging an email group when your vehicle is done charging, and a spreadsheet of vehicle owner contact information which could be used to request someone to move their vehicle.

"I'm part of that google doc, so you know you have to coordinate with another person, go down and meet them, swap cars, um you know and then you have to check the doc cuz someone may say I want it when you're done." (Interview 20, Nissan Leaf)

Collective charging may only be functional if there is a strong sense of community to get everyone's vehicle charged with a shared resource. One interviewee reported that their collective leader left the company, and it was proving difficult to continue with the collective approach they had created. Another noted that the system was created by a group of work friends before expanding to others. One driver reported discovering his office's collective charging management strategy (messaging and moving vehicle when done charging) after working there for a few years. He ultimately decided he wasn't going to charge at work because he found it too complicated and not worth his time.

4.2.3 Unmanaged Charging

Ten drivers reported no rules for charging at work; we classified this as 'unmanaged charging.' Five had charging at work with dedicated EVSE installed, and another five interviewees reported that they charge by bringing their charging cord to plug into an 110V or 240V outlet. Interviewees reported there is competition to charge and sometimes they cannot charge if they arrive at work too late. Interviewees reported difficulties in charging since PEV drivers did not move their vehicles once charging had finished. Even interviewees who were willing to move their vehicle reported not doing so due to being too busy. This issue appeared to become more prevalent as more people at their workplace purchased a PEV.

"It's just like, you grab it, and it's yours all day. If you're going to be really nice you could move the car out and like, move to a different spot, but I usually don't have time during the day to do that." (Interview 10, Chevrolet Volt)

"Over the course of the past few years, as more electric vehicles have come to [work], it's become a little bit more challenging to make sure you get charge" (Interview 40, Tesla Model S)

Two interviewees had recently changed jobs and went from an authoritative management strategy to unmanaged workplace charging. Both reported frustrations with the lack of charging management. One asked their employer to instate managed charging and was waiting for a response at the time of the interview. Both interviewees worked at large companies with a large number of EVSE and PEVs which made it difficult to create a collective charging management strategy.

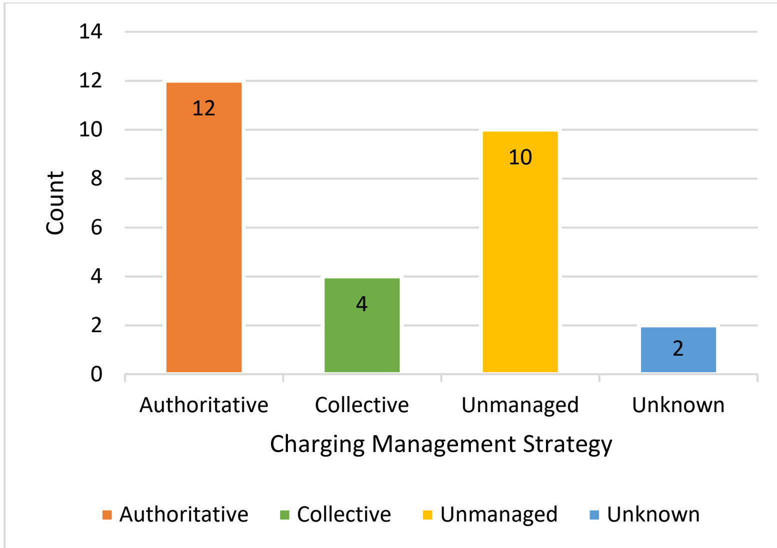

Figure 4. Charging management strategies of interviewees' workplaces (n=28, Twenty-seven interviewees reported charging at work, but 28 strategies are reported because one interviewee has two regular commute locations).

4.3 Charging Management Strategy Effectiveness

Four BEV owners chose to not charge at work. One has a collective charge management, one has authoritative charge management, and two did not give enough detail to classify (their lack of knowledge of the system indicative of the fact they never charge at work). A few drivers stated that if the management strategies aligned better with their work habits, they would charge at work instead of at home. This indicates the strategies were effective in encouraging some drivers to not charge at work making the workplace charging infrastructure available to those who need it. These interviewees who choose not to charge because of the management strategies still complete their travel without using workplace EVSE which leaves the stations available for others to use. The rules for charging access have the intended effect of increasing the availability of EVSE and decreasing congestion. Charging management strategies can mitigate congestion, making EVSE available for more PEV drivers.

One interviewee (quoted below) who had paid workplace charging stated if workplace charging was free, they would exclusively charge at work, even though they have L2 charging at home. This highlights the effectiveness of this charging management strategy in making charging accessible to those that need it.

"I would charge every day at work if it was free. [laughs] I would never charge anywhere else actually because that's like 9 hours of charging daily" (Interview 07, Tesla Model S)

Most interviewees had positive perceptions of their workplace's authoritative charging management strategies because they were able to charge easily within the guidelines specified. Interviewees who were part of collective charging management systems also reported positive experiences. They liked designing their own rules to fit the needs to themselves and their colleagues. Both authoritative and collective strategies increased the number of vehicles that could be serviced by the limited amount of infrastructure.

Collective strategies were only found at workplaces with a small number of stations and PEV drivers; this could be because in a smaller offices' drivers interact more regularly. Collective strategies however may not be intuitive to newcomers and could be impeded by unaware drivers. One driver had been working at his office for years before becoming aware of the collective charging management strategy.

Without any charging management strategies in place, drivers may not always be able to charge when they want or need. These workplaces have underutilized charging stations, not necessarily due to high charging demand, but vehicle overstay as the drivers have no incentive to move their vehicle when charging is complete.

5 Discussion and Conclusion

Moving a vehicle during the workday represents a behavior change as it is not something typically done with drivers of conventional vehicles. To ensure workplace charging infrastructure is not underutilized, it is important to find effective ways to encourage drivers to move their vehicle when charging is complete.

All charging management strategies observed here appear to be effective in increasing vehicle turnover at workplace EVSE. With higher turnover, more drivers can use the stations, allowing more PEVs to charge and reducing the number of EVSE a workplace may need to install. Results from this study show that a cost for charging at work helps alleviate congestion, agreeing with several existing studies [13, 15, 29, 33, 40]. Prior studies on charging assumed that drivers would not interrupt their tasks (e.g. working) to move their vehicle [11, 37, 47]. However, interviewees in this study were willing to move their vehicles to avoid paying a penalty or fee, and to allow others to charge.

Digital queuing was effective since drivers are not actively waiting to charge; they are working while waiting for EVSE to be available. It was also effective since drivers know when they should unplug one PEV and plug in their vehicle, and only requires one PEV driver to be active (the one who is next in the queue). PEV drivers only find it acceptable to unplug another when they can determine the vehicle is done charging, which interviewees had difficulties with. Even when interviewees can determine the charge is complete, some cars lock the cord into the vehicle or set off the car alarm if it's unexpectedly unplugged, a concern reported in prior studies [36, 40]. Without a standard way to determine if the vehicle has finished charging, there will continue to be questions. An advanced version of digital queuing is the idea of 'octopus charging' [11, 12, 40, 41] where many vehicles are plugged in and only a few of them are charged at a time. A few interviewees mentioned octopus charging unprompted as something they wished to see, but none reported experiencing it. It was seen as less effort on their end to get their vehicle charged.

Collective charging management has not been explored in the existing literature. Though the strategy is relatively simple, it appears to be effective in facilitating more PEVs to use EVSE. Drivers value the user control and customization based on individual work schedules with collective management strategies. Despite several studies on EVSE reservation systems where the charging infrastructure is reserved prior to arriving [23, 38, 40, 41, 46, 47], no interviewees brought up wanting, needing, or experiencing this.

5.1 Recommendations

Policymakers, EVSE network providers, workplaces, and any stakeholders in charging infrastructure can use this research when considering how to increase the utilization of existing and new charging infrastructure. Workplaces with infrastructure installed, or those planning installations should incorporate charging management strategies to decrease vehicle overstay and congestion while increasing EVSE utilization and dependability for drivers. This is especially important for drivers than depend on EVSE at work, due to no access at home or driving a short-range BEV. Based on reports by interviewees, our assumptions outlined in Appendix 3, information from EVSE providers, and previous studies [11, 12, 15, 36], we developed a ranking of the strategies reported by interviewees (Table 2). To maximize their charging effectiveness, workplaces will have to tailor their approach to charging management strategies to their own circumstances. We outline in Appendix 3 why we rank each charging strategy this way and the assumptions behind the rankings.

Some authoritative charging management strategies may be costly to implement due to needing additional software, hardware, or requiring an employee to maintain. For example, systems with digital queueing or pricing on a per kWh or per minute basis generally require specific hardware and software to manage (e.g. ChargePoint) which can be costly. One way to add pricing without additional software is with a flat rate parking pass fee (e.g. $20/month) to access the EVSE and a time limit restricting the number of hours the EVSE can be used per day. These systems can be visible, effective, and enforced, if properly signposted, or controlled through apps or email alerts; however, it could encourage drivers to use the EVSE as much as possible (within the time limits) to receive maximum value from their flat payment. Though with the correct pricing, those who would charge at work when it is free could be dissuaded from charging. Valet charging can be very costly to implement and maintain because of the cost to employ Valets.

Collective charging management strategies are cheaper to implement and maintain because drivers administer system, though this does use employee time. The systems are less visible because the communication around rotation the cars is a pre-set schedule or digital messaging. With low visibility, potential PEV buyers may think they would be unable to charge their vehicles due to the EVSE being in frequent use despite the system in place; this could be solved with communication about the system. Collective charging management strategies can be difficult to implement because it requires coordination with all or most PEV drivers in a workplace. The systems are also less enforceable and generally rely on the goodwill of participants. While we did not observe this in our sample, it is possible that workplaces themselves could introduce one of the collective strategies. This could be a low-cost way for them to manage EVSE utilization without the need to purchase additional equipment or software, this also is suggested in [36].

Table 2. Framework ranking of workplace charging management strategies reported in this study.

		Cost to implement	Ease of implementation	Cost to maintain	Simplicity (to users)	Visibility	Enforceability	Effectiveness
Authoritative	Digital Queuing	$$	X	$$	-	X	-	✓✓
	Time Limit w/Pricing	$$	X	$$	-	✓	✓	✓✓
	Pricing	$ to $$$	-	$$	-	✓	✓	✓✓
	Valet Charging	$$$	X	$$$	✓	-	✓	✓✓✓
Collective	Day Restrictions	$	✓	$	✓	X	X	✓✓
	Time Restrictions	$	✓	$	✓	X	X	✓✓
	Email/messaging Groups	$	✓	$*	-	X	X	✓
	Spreadsheet of vehicle/driver information	$	✓	$*	-	X	X	✓

* While this is cheap to implement and maintain it does require employee time and effort.
Note: Implementation cost and ease of implementation assume introducing the system with no existing systems in place

$ indicates good (lowest) cost to implement or maintain
$$ indicates medium (middle) cost to implement or maintain
$$$ indicates poor (highest) cost to implement or maintain
✓ indicates good ease of implementation, simplicity, visibility, and enforceability.
- indicates medium ease of implementation, simplicity, visibility, and enforceability.
X indicates poor ease of implementation, simplicity, visibility, and enforceability.

Having more parking spaces around the EVSE and charge cords that can reach multiple parking spaces (e.g. 1 EVSE in the center of 4 parking spaces) should be kept in mind when designing the infrastructure layout; this is also recommended in [40]. Coupled with a digital queue, this layout means drivers do not have to move the PEV when it's done charging, and others can plug their vehicle in when one is finished. This would allow a single EVSE to charge up to 4 vehicles in one day. Drivers cite good parking as one reason for charging, placing EVSE in less convenient locations may be a natural deterrent to charging when not necessary [40]. If EVSE is located farther from the front of the parking lot, it can also reduce the risk of gasoline vehicles blocking the charger. Keeping the stations visible, however, may help create awareness of the available charging infrastructure [46, 55]. Workplaces without charging management strategies and without a desire to introduce them could consider installing slower L1 infrastructure [36].

For workplaces with existing unmanaged charging, we recommend adding a time limit, pricing, digital queuing and/or a time limit with pricing to the EVSE to spur vehicle turnover. A reasonable charging cost, such as a few cents over the cost of electricity at home, could in theory not dissuade those who rely on workplace charging, since the electricity price would be cost comparable to what they would pay if they had access at home. The aim should be to increase the utilization of costly infrastructure to allow as many PEVs to be charged per dollar spent on infrastructure.

5.2 Limitations and future research

This study did not detect differences in PEV driver perceptions of charging management strategies based on vehicle type or location across California perhaps due to the small sample size compared to a questionnaire survey. There could be differences between higher and lower end PEVs. High-end PEV drivers (e.g. Tesla Model S) could be less price sensitive due to their high-household incomes than drivers of more modestly priced PEVs. Drivers of short range PEVs could also be less price sensitive or more willing to accept different charge management strategies due to their increased need to charge. Future studies could examine relationships between vehicle types and effective charging management strategies.

Above all any charging management strategy should aim to rotate vehicles through EVSE, prevent overstay, and ease congestion while being simple, dependable, and easy for the drivers to use. The result of effective charging management should be increased EVSE use and the potential for EVSE to support more PEVs per charging station.

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Appendix 1 – Interview Topics

- Who uses the car? How do you use it?
- Where do you charge? When and why?
- What is your experience with public charging? Do you charge in public even when you have sufficient range to get home?
- Do you know how to read the blink pattern of other vehicles to know what their approx. SOC is? Do you move your car or unplug it when it is done charging?
- How would you feel if you someone unplugged your vehicle? Would you be upset if a PHEV unplugged you? A BEV? Would/have you ever unplugged a stranger? Someone at work? Ever leave a note or seen someone leave a note? Ever come back to your car and find a note?
- What does charging etiquette mean to you?
- Do you think you have good charging etiquette? How could you be incentivized to improve?
- PHEV: How often does your engine turn on for increased power?
- PHEV: How much is your engine on? Do you know of anything to do to prevent the engine from starting?

Appendix 2 – Interviewee Summary Table

Inter-view	Total # cars	# of PEVs	PEV	Vehicle Style	Gender	Age	Region
1*	1	1	Chevrolet Volt	PHEV	M	19-29	Bay Area
2	2	1	Ford Cmax	PHEV	M	30-39	Bay Area
3	2	1	Nissan Leaf	BEV	M	40-49	Bay Area
4	1	1	Tesla Model S	BEV	M	40-49	Bay Area
5	3	1	Tesla Model S	BEV	M	50-59	Bay Area
6*	1	1	Chevrolet Volt	PHEV	M	19-29	Bay Area
7	3	1	Tesla Model S	BEV	M	60-69	Bay Area
8	1	1	Chevrolet Volt	PHEV	M	30-39	N California
9	2	1	Nissan Leaf	BEV	M	30-39	Bay Area
10*	2	1	Chevrolet Volt	PHEV	M	30-39	Bay Area
11	2	2	Tesla Model S / Chevrolet Volt**	BEV / PHEV	M & F	30-39; 30-39	Bay Area
12	2	1	Ford Fusion	PHEV	M	40-49	Sacramento
13	1	1	Chevrolet Volt / Fiat 500e*	PHEV / BEV	M	50-59	Bay Area
14*	1	1	Chevrolet Volt	PHEV	M	30-39	Bay Area
15*	1	1	Chevrolet Volt	PHEV	M	30-39	LA Area
16	3	1	Tesla Model S	BEV	M	40-49	LA Area
17	2	1	Tesla Model S	BEV	M	50-59	LA Area
18	2	2	Ford Cmax / Chevrolet Volt**	PHEV / PHEV	M	30-39	LA Area
19*	2	1	Chevrolet Volt	PHEV	M	30-39	LA Area
20	2	2	Chevrolet Volt / Nissan Leaf	PHEV / BEV	M & M	40-49; 50-59	LA Area
21	1	1	Tesla Model S / Toyota RAV4EV**	BEV / BEV	M & F	40-49	San Diego
22	2	1	Chevrolet Volt	PHEV	M	50-59	Bay Area
23	2	1	Tesla Model S	BEV	F	50-59	Bay Area
24*	1	1	Chevrolet Volt	PHEV	M	40-49	LA Area
25	3	1	Tesla Model S	BEV	M	50-59	San Diego
26*	1	1	Chevrolet Volt	PHEV	F	40-49	LA Area
27	2	1	Tesla Model S	BEV	M	40-49	LA Area
28	2	1	Ford Fusion	PHEV	M	30-39	San Diego
29*	2	2	Nissan Leaf / Chevrolet Bolt	BEV / BEV	M & F	50-59; 40-49	San Diego
30	2	2	Chevrolet Volt / Ford Fusion**	PHEV / PHEV	M	50-59	San Diego
31	2	1	Tesla Model S	BEV	M	40-49	LA Area
32	1	1	Tesla Model S	BEV	M	70-79	Sacramento
33	2	1	Tesla Model S	BEV	F	60-69	N California
34*	1	1	Tesla Model S	BEV	M	30-39	Bay Area
35	4	1	Chevrolet Volt	PHEV	F	19-29	Sacramento
36	1	1	Ford Cmax	PHEV	M	19-29	Sacramento
37	2	1	Ford Cmax	PHEV	M	50-59	Bay Area
38*	1	1	Ford Cmax	PHEV	M	30-39	Bay Area
39	2	1	Ford Cmax	PHEV	M	40-49	Bay Area
40	4	1	Tesla Model S	BEV	M	50-59	Bay Area

*** Denotes MUD household**
**** Denotes vehicle was part of the household, but was not discussed because the primary driver of that vehicle was not interviewed.**

Appendix 3 – Description of framework rankings of workplace charging management strategies

Here we describe the ranking of the charging management strategies detected in this study shown in table 2. The rankings are based on information from EVSE providers and our assumptions which we outline. The ranking for collective strategies are based on reports from interviewees (since data on these strategies do not yet exist) and our assumptions which we outline. Our description of the ranking includes a description of our rankings for Cost to implement, Ease of implementation, Cost to maintain, Simplicity (to users), Visibility, Enforceability, and Effectiveness. All rankings are on a three-point scale from poor to good and for cost from lowest to highest cost. Our rankings assume no charging management strategy is currently in place.

Authoritative workplace charging management

Digital queuing

Digital queuing allows drivers to join a queue by tapping a card on a charging station. This strategy necessitates a networked charging station with a card reader. These charging stations are available from multiple providers including ChargePoint[1], Tellus power[2], Blink[3], SemaConnect[4] and several other EVSE providers. These chargers have additional hardware costs compared to non-networked stations, and associated network fees (monthly or annual). Networked charging stations with a payment/card reader cost in the region of $1000-3000 more than stations without this hardware[5]. Network fees are an additional expense on top of the electricity charges and hardware cost. Network fees cost in the region of $320 per year[6]. For these reasons we rank the cost to implement and cost to maintain as medium cost. Ease of implementation is ranked as poor due to the need to install specialized charging equipment. Simplicity to users is ranked as medium due to the need to get an access card from the EVSE company, and digital queuing as a concept can be difficult to explain to a new user or new PEV driver. However, drivers reported positive experiences once accustomed to using the system, so we do not rank the system as poor. Visibility is ranked poor because of the lack of outward visibility of the charging management strategy. No signage was present in the instances reported by interviewees. Enforceability is ranked as medium since there is typically no penalty for overstaying, however the EVSE provider does send notifications when one vehicle has finished charging and another can charge. In some instances, charging cables can reach multiple PEV parking spaces which can allow those waiting to queue to unplug the PEV that has finished charging and plug in their PEV. This can increase the potential of this strategy to increase PEV throughput at charging stations [11, 12]. Some PEVs lock the charge cable in the vehicle or may trigger the car alarm when unplugged and locked which can make digital queuing difficult to use in these cases.

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[1]ChargePoint CT4000: https://www.chargepoint.com/products/commercial/ct4000/,

[2]Tellus Pedestal AC Chargers: http://telluspowergreen.com/ac-chargers/

[3]Networked vs. Non-Networked Chargers for Hosts: https://blinkcharging.com/understanding-networked-vs-non-networked-chargers-for-host-locations/?locale=en

[4] Networked or Non-Networked Stations, That is the Question: https://semaconnect.com/blog/networked-non-networked/

[5]Based on the cost of an EVSE LLC payment Module which costs $1100-2597 per charging station https://evsellc.com/solutions/payment-solutions/

[6] Based on the network fees for Tellus power EVSE which cost $200.00 per year per port plus a monthly data charges starting at $10/month http://telluspowergreen.com/usa/ac-chargers/

Time limit with pricing

A time limit with pricing strategy allows for pricing based on the amount of time a vehicle is plugged in and sets a limit on the maximum charging duration, after which a penalty (or higher fee) is charged for using the charger for longer than permitted. As with digital queuing, this strategy requires a networked charging station with a payment module. For these reasons the strategy is ranked as poor for cost to implement and cost to maintain. These fees are the same as those for digital queuing, since the same equipment and network fees are required. Ease of implementation is ranked as poor because of the need to install specialized charging equipment. Simplicity to users is ranked as medium because it still requires an access card for charger access and payment and time limit and pricing scheme can vary among station owners. Visibility is higher than that of digital queuing because the systems reported by interviewees generally include signage or information on the pricing. Enforceability is ranked as good since a penalty is automatically imposed once a driver stays over the allocated time, which in the case of interviewees was effective in encouraging them to move their PEV (for example see quote from Interviewee 19 in "4.2.1. Authoritative Charging Management Strategies"). Research also shows that this system can lead to shorter charging sessions as consumers respond to the fees [15].

Pricing

Pricing strategies reported in this study included those that use networked or non-networked charging stations. Non-networked strategies charge PEV drivers an additional parking fee to use the available chargers. Access is typically enforced by the parking enforcement organization. This strategy can be cheaper to implement due to not needing any specific charging equipment but may only be possible if parking enforcement is in place. Networked chargers require specialized electric vehicle chargers including those with a payment module and those requiring an annual fee. This pricing strategy has a higher cost to implement and maintain due to these costs. Because of these differences in cost, we rank the system as being between good and poor for cost to implement and maintain. We rank simplicity to users as moderate; the systems are generally understandable as reported by interviewees but depending on the price structure (per minute/hour or per kWh) can be more complicated than other strategies especially for new PEV drivers. We rank visibility as good because pricing is usually signposted, or the charger provides information on the pricing. Pricing has good enforceability since the fees are automatically changed to drivers in the case of networked chargers, and in the case of non-networked chargers enforced by the parking enforcement organization. We rate pricing as medium for effectiveness since the system does not guarantee drivers move their vehicles. Some drivers may be unresponsive to the fees and willing to pay them and not move their PEV. However, most interviewees reported moving their EVs. Some interviewees also reported not charging, which makes chargers available for other PEV owners, a finding shared by Dong et al. [17]. The system is also beneficial since it can prevent those from not needing to charge, perhaps due to access to charging at home from doing so (for example see quote from Interviewee 7 in "4.2.1. Authoritative Charging Management Strategies").

Valet charging

Valet charging may be the most expensive charging management strategy to implement and maintain. While no physical signage or digital infrastructure are required a full-time valet is required to rotate the vehicles around charging stations. In California, the region of this study, salaries for Valets are in the region of $30,000 per year[7]. This makes the system expensive to establish and to maintain. Valet managed charging is more difficult to implement since an organization would have to hire a valet. Valet charging does have benefits, since no involvement from PEV drivers is needed, it is simple for users and does not require any action from them. Valet charging is also enforceable since a full-time employee is present rotating vehicles around the chargers. We rank visibility as medium; drivers do not necessarily need to be aware of the system

[7] https://www.glassdoor.com/Salaries/los-angeles-valet-salary-SRCH_IL.0,11_IM508_KO12,17.htm

since they are not actively involved with moving their PEV. The overall effectiveness of Valet charging is ranked 3/3, since there is a full time attendant rotating vehicles around the chargers allowing more reliable turnover compared to when employees are involved. The trade-off for this benefit is the high cost of this charging management strategy.

Collective workplace charging management

Day & time restrictions

Day & time restrictions manage charger access by allocating set days or times when PEV drivers can use workplace chargers. Interviewee 24 described a system that was originally a day restriction (every other day), which evolved into a system where drivers are given an allocated day and an allocated time in which they can charge. The cost to implement and ease of implementation is favorable for day and time restrictions since there is no physical or digital infrastructure needed (other than EVSE). The system is based on an honor system where drivers allocate days or times, they can use the chargers to one another. Since there is no physical infrastructure needed to maintain this system the cost to maintain is favorable; however, since drivers may spend time during working hours administering the system, there is an indirect cost of time spent introducing and maintaining the system, though once the system is in place time spent administering the system may be low provided drivers comply with the collective rules. Interviewee 24 reported meeting with colleagues to agree on the system, and as more coworkers adopted PEVs, they met again to update the time and day allocations. Day and time restrictions were easy for interviewees to understand since they allocate days or times in which users are and are not able to charge their vehicles.

Day and time restrictions are not visible since there is no physical signage indicating the system is in place, PEV drivers need to become aware of the system through word of mouth from other colleagues using the system. They are also not enforceable since the system relies on drivers' goodwill in using the chargers on their allocated days. For these reasons they may not be scalable to larger parking lots and larger workplaces. We rank day and time restrictions at 2 out of 3 for effectiveness due to it being a low cost, easy to implement strategy that is cheap to maintain, but lacking enforceability and visibility especially for newcomers to a parking location or infrequent users.

Email/messaging groups

Email or messaging groups were reported by interviewee 3 and interviewee 14. The cost to implement a messaging group is low since no physical or digital infrastructure is needed, however it does require employee time in collecting email addresses of PEV owners and establishing the email or messaging group. We rank email/messaging groups as medium for ease of implementation due to the potential difficulties in identifying all PEV drivers parking and charging in a location and obtaining their contact information. The cost to maintain can be low, though since continual communication is required over email this system may use more employee time than a time or day restriction. Email/messaging groups are simple for users to understand as participants send a group message when they would like to charge and respond to requests to move their vehicle if asked to do so.

Similar to day and time restrictions email/messaging groups are not visible to those not participating in the system. PEV drivers need to become aware of the message groups through word of mouth or through colleagues adding them to the email/message thread. Since there are no rules for EVSE use or requiring participants to move their PEV or respond to requests to do so, the system is not enforceable. For these reasons, they may not be scalable to larger parking lots and larger workplaces. We rank this system all ⅓ for overall effectiveness because of the challenges in maintaining the messaging group, and it being active whereas day and time restrictions are passive not requiring continual input to create vehicle turnover at workplace EVSE. However, it does benefit by being a system PEV drivers can implement on their own.

Spreadsheet with driver information

Interviewee 20 reported their workplace has a google sheet that is used by employees to manage access to charging. Similar to other collective charging management strategies, spreadsheets with driver info have a low cost to implement and maintain but will use employee time. The strategy is rated a medium for the ease of implementation due to the need to identify PEV drivers and which vehicles belong to employees to populate the spreadsheet that contains their information. The system is also rated as medium for simplicity due to drivers wanting to charge having to identify the PEV currently charging, identify who this belongs to and contact that individual to request they move their PEV to be able to use EVSE (as is shown in the quote from Interviewee 20 in "Collective Charging Management Strategies"). The system is also not visible, and drivers need to discover the system through word of mouth. The system lacks enforceability in the same way as other collective strategies do. Overall, we rank the system at 1/3 for effectiveness since the system does not rotate cars through chargers without substantial effort from PEV drivers and because of the lack of simplicity, visibility, and enforceability, and difficulty in creating a spreadsheet with all driver information and their vehicle.