UC San Diego

UC San Diego Electronic Theses and Dissertations

Title

Overstay at Electric Vehicle Charging Stations at the University of California San Diego

Permalink

https://escholarship.org/uc/item/4tb3p59q

Author

Harish, Akanksha

Publication Date

2021

Peer reviewed|Thesis/dissertation

eScholarship.org Powered by the California Digital Library
University of California

UNIVERSITY OF CALIFORNIA SAN DIEGO

Overstay at Electric Vehicle Charging Stations at the University of California San Diego

A thesis submitted in partial satisfaction of the
requirements for the degree
Master of Science

in

Engineering Sciences (Mechanical Engineering)

by

Akanksha Harish

Committee in charge:

Professor Jan Kleissl, Chair
Professor Michael Davidson
Professor Thomas Murphy

2021

Copyright

Akanksha Harish, 2021

All rights reserved.

The thesis of Akanksha Harish is approved, and it is acceptable in quality and form for publication on microfilm and electronically.

University of California San Diego

2021

DEDICATION

I dedicate this thesis to my mother and father, Anuja Harish and Harish Dwarakanathan whose endless encouragement and support have emboldened me to tenaciously pursue and achieve my goals. Thank you for always giving me strength and being there for me.

I also dedicate this thesis to my maternal uncle, Amar Chegu whose advice and guidance have helped me broaden my perspective. Thank you for your constant encouragement and support.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Apt	:	Apartment
Aqm	:	Aquarium
C.	:	Campus
Ctr	:	Center
DCFC	:	Direct Current Fast Charger
DSA	:	Del Sol Apartments
EV	:	Electric Vehicle
°F	:	Degree Fahrenheit
GFH	:	Graduate and Family Housing
L2	:	Level 2
N	:	North
NOAA	:	National Oceanic and Atmospheric Administration
OMS	:	One Miramar Street
S	:	South
SIO	:	Scripps Institute of Oceanography
SOM	:	School of Medicine
UCSD	:	University of California San Diego
w.r.t.	:	With respect to

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENT

My sincere to thanks my faculty advisor, mentor and committee chair, Professor Jan Kleissl for his guidance, continuous support and patience throughout my academic research and the writing of this thesis. I am grateful for his advice and mentoring during my graduate career at the University of California San Diego. Without his guidance and encouragement, this thesis would not have been possible.

I would also like to thank the defense committee members, Professor Michael Davidson and Professor Thomas Murphy for their input and suggestions, and for agreeing to serve on my committee.

Many thanks to all my course instructors and colleagues at the University of California San Diego for their contribution to my personal and professional growth. I would also like to thank my graduate program coordinator and academic affairs advisor for all their assistance.

Last but not the least, I would like to acknowledge and thank the Department of Mechanical and Aerospace Engineering at the University of California San Diego for the opportunity to conduct research.

ABSTRACT OF THE THESIS

Overstay at Electric Vehicle Charging Stations
at the University of California San Diego

by

Akanksha Harish
Master of Science in Engineering Sciences (Mechanical Engineering)

University of California San Diego, 2021

Professor Jan Kleissl, Chair

Electric vehicles (EV) have been gaining more popularity in the consumer market in recent years due continuous improvements in purchase price and driving range, thus amplifying environmental benefits and lower operating costs. While more public charging stations have been installed to cater to increasing numbers of electric vehicle users, charging demand has outpaced supply, especially at early adopter locations such as university campuses. Station overstay – when

an EV remains plugged-in after completion of charging – adds to the shortage of charging opportunities as stations remain unusable while the parking space is occupied by a fully charged vehicle . Understanding user behavior is essential to develop a solution to solve station overstay.

In this analysis, the effect of meteorological factors and school/work schedule on EV user behavior and overstay patterns was examined using charging data collected from EV charging stations at the University of California San Diego (UCSD). The statistics for duration and hourly rate of overstay were determined for different campus areas. Overstay patterns during school and non-school days were also examined to determine the impact of school/work schedules. The effect of high daytime temperature and rainfall on overstay was analyzed through comparison of overstay occurrence during these weather events with that observed during other weather conditions.

The analysis showed that overstay at UCSD's EV charging stations was found to be primarily influenced by school/work schedules of EV users. Most areas of the campus saw an increase in station overstay during the busiest hours on campus (9AM to 5PM) and on school days. On the hottest days, depending on the campus area, overstay was higher by 5-51% when daytime temperatures were very high. Station overstay during hours with heavy rainfall was 7-40% lower than when there was no rainfall.

1. Introduction

The sales of electric vehicles (EVs) over the past decade has been on a rise in the United States with sales in the first two quarters of 2021 surpassing that of any quarter in the preceding years [1]. California accounted for 39% of national sales since 2011 with cumulative sales of 147,347 EVs in 2019, 145,099 EVs in 2020 and 121,006 EVs in the first half of 2021. San Diego saw an increase in new EV sales by approximately 10% from 2019 to 2020 [2] despite the COVID-19 pandemic which was expected to affect auto sales across the United States in 2020. In San Diego, 10,024 EVs have been sold from January to June of 2021 and this number is 82% of the county's cumulative EV sales in 2020. Given these statistics, there will likely be a rise in the number of active EVs in San Diego and across the United States in the coming years.

The University of California, San Diego (UCSD) has been a pioneer in energy system demonstration including the development of a smart EV charging network for the campus through collaboration with over 18 companies [3]. According to engineers and researchers who studied charging patterns for EVs at UCSD from 2017 to 2020, there was a rise in the use of EV charging stations from 2017 until the start of the COVID-19 pandemic in 2020 which caused a drop by 84% from the pre-pandemic levels [4]. Although the use of charging stations is increasing, pre-pandemic levels of usage may not be observed anytime soon [5] until all employees return to on-site work. With the return to in-person instruction for the 2021-2022 academic year, it is highly probable that there will be at least a slight increase in the use of charging stations from 2020 levels of use. In anticipation of a return to pre-pandemic functioning of the UCSD campus and a

corresponding increase in the use of charging stations in the coming years, understanding EV user behavior and charging patterns at UCSD can help in future planning and expansion of the university's current EV charging network.

Analysis of charging data reveals a potential concern that could affect effective, optimal use of the EV charging stations on the university's campus, the concern being an extended plug-in duration after the completion of charging of an electric vehicle which will be referred to as 'overstay'. The possible factors – meteorological, location-related, school or work scheduling – that could affect user behavior and correspondingly overstay have been analyzed and discussed in this thesis. Existing literature examines the effect of traffic, travel time and weather or season on the charging load at public EV charging stations [6]. Thus, it is highly probable that similar factors (such as weather) could affect the likelihood of overstay. Although there is literature proposing solutions for the overstay problem, which shall be briefly discussed in the conclusion, there is a gap in literature related to the possible factors affecting overstay in large institutions or campuses, such as UCSD, consisting of a population with diverse school or work schedules.

This thesis is structured as follows. Chapter 2 explores UCSD's EV charging network and provides a brief overview into some existing EV charging data and statistics. Chapter 3 defines 'overstay' and describes methods of data selection and analysis for different factors affecting user behavior. The results of the analysis have been discussed in Chapter 4. This chapter also includes plausible explanations for certain patterns observed and conformance or non-conformance of the observed results with speculated trends. The Appendix section includes tables and figures related to Chapters 3 and 4 and discusses some observations that possibly affected overall results.

2. Electric Vehicle Charging at UCSD

EV charging stations have been installed by several companies at UCSD, the majority of them by a company ChargePoint whose charging stations provided a total of 1.9 GWh of energy from March 2016 until July 2021 [7]. There are two types of chargers available on campus – Level 2 (L2) and Level 3 (or Direct Current Fast Chargers) with a larger percentage of the chargers belonging to the former type. A L2 charger has two charging ports and a DCFC has one charging port. EV charging stations are spread across the entire campus and are located in parking structures (multilevel) or parking lots which shall be referred to as 'plazas'. Most vehicle owners have to commute a short distance from a plaza to their place of study/work and the estimated commute time can be any duration up to 15 minutes on an average; a longer commute time is possible if parking spots are unavailable at the nearest plaza. There are designated park-and-charge spots in plazas specifically for EVs but can be used only if the EV is actively charging. Despite the time limits on active charging time and use of these park-and-charge spots [8], there are many EVs that 'overstay' (defined in Chapter 3) since the time limits are not enforced. Overstaying at a park-and-charge spot inconveniences other EV owners who may need to charge their vehicles and can also be misuse of a parking spot that is designated specifically for EVs. There is no fee charged by EV charging providers for station overstay at park-and-charge spots across UCSD. In order to enforce and promote EV charging etiquette, imposing a time-based financial burden for station overstay could change user behavior and reduce the occurrence of overstay across campus. With a continuously growing campus population and the rise in sales and use of EVs, as stated in the

introduction, it is highly likely that EV charging overstay may affect optimal, effective use of the EV charging network at UCSD.

Charging station overstay at UCSD could be affected by several factors, some of them being meteorological, location-related, school/work scheduling. Meteorological factors such as high daytime temperatures and rainfall could discourage EV owners from commuting to plazas due to unfavorable weather conditions thus increasing the likelihood of overstay. Distance of work or study location from the plaza could also affect overstay in combination with meteorological factors. The field of work or study could also affect overstay, for example, a healthcare worker may be unable to move their EV from a park-and-charge spot if they are occupied with important or urgent medical matters. The university's academic and administrative calendars could also affect the number of overstay events. Analyzing the effect of these factors on user behavior and consequently overstay could help in solving the problem of overstay at charging stations. Statistics of duration and hourly occurrence of overstay events have been discussed in Chapter 4, in addition to the effect of weather and academic calendar/schedule on the occurrence of overstay events at UCSD.

3. Selection & Method of Analysis of Data

The dataset used in the analysis consists of charging data from EV charging stations managed by the company ChargePoint at UCSD during 2019. The year 2019 was selected for analysis as it is the most recent year with ideal, pre-pandemic functioning of the UCSD Campus (in-person classes and work-on-site culture). Thus, 2019 charging and overstay patterns can represent EV overstay for any year. Unless otherwise mentioned, the data analyzed and results discussed are for the year 2019.

The charging dataset consists of 74,748 data points (referred to as events) collected from 117 charging stations spread across different plazas. Each event consists of data such as charging station name, charger type, plug-in duration, date and time for start and end of plug-in duration, active charging time, and other data that was not used in this analysis. Plug-in duration refers to the duration for which the EV remains connected to the charger and active charging time represents the duration for which the EV was being charged. All the events considered in the analysis have a registered EV user identification number implying that actual number of charging events could be much higher since some EV users may not be registered users. Also, the actual number of overstay events would be much higher if charging data from all EV charging providers was considered. To study overstay trends, the UCSD Campus was divided into four sub-campuses – Main Campus, Scripps Institute of Oceanography (SIO) Campus, Medical Campus, Graduate and Family Housing (GFH) Community – according to location. Additionally, each sub-campus is largely affected by factors such as composition of sub-campus population (students, faculty, administrative and

service employees, healthcare workers) and work/school patterns. The plazas housing the charging stations have been grouped according to sub-campus location. Table A1 in the Appendix shows the list of plazas used in the analysis along with corresponding sub-campus group, number of charging stations in 2019 and total number of overstay events recorded at each sub-campus.

3.1 Defining 'Overstay'

'Overstay' is defined as the duration for which an EV has been left plugged-in at the charging station after charging is complete. As stated in Chapter 2, most EV users, like other vehicle users, would likely park their vehicle nearest to their place of work/study. Most campus buildings have a plaza within a 15-minute walking distance (considering the average walking speed of most adults). Assuming 15 minutes is the longest time required to commute from an EV user's place of work or study to their vehicle after receiving a notification of charging completion from the ChargePoint app [9], an overstay of 15 minutes can be considered acceptable. Thus, only overstay events longer than 15 minutes have been considered for analysis in this thesis. The subsequent mentions of overstay events shall refer to those as described in this section.

'Overstay rate' refers to the fraction of charging events that are overstay events during a given time period. This term will be used in the discussions of hourly occurrence of overstay events and the effect of the academic calendar on overstay.

3.2 Selection of Data for Analysis

UCSD has two types of EV charging stations – Level 2 and Level 3 (or DC Fast Chargers). In the analysis, only Level 2 charger data (72,091 events) was considered as this data constitutes approximately 97% of all recorded charging events from the initial dataset and thus can represent general charging and overstay trends at UCSD (most charging stations are of Level 2 type [8]). Only 2019 data was analyzed and the events considered had both the start and end date for plug-in duration in 2019. Some data points were deleted due to missing data such as charging station name, charger type, user identification number, plug-in duration, date and time for start and end of plug-in duration, active charging time, thus downsizing the dataset to 71,779 events. This dataset of 71,779 events consisting of charging data from 112 stations will be referred to as charging dataset. To create the overstay dataset, the data was further downsized with respect to overstay duration. The overstay duration varied from no overstay to 551 hours. Events with overstay of up to 15 minutes (35% of the events) were deleted for reasons mentioned in Section 3.1. Additionally, events with overstay longer than 12 hours were omitted as these events are most likely related to charging of UCSD's electric vehicle fleet. After data sorting and deletion, the overstay dataset that was analyzed to study factors affecting overstay patterns and EV user behavior consisted of 45,283 events collected from 112 charging stations.

3.3 Calculation and Plotting of Overstay Duration

From available time-specific data, overstay duration was calculated as the difference between the end time of plug-in duration and the end time of active charging duration. In other

words, the start of overstay is the end time of charging duration and the end of overstay is the end time of plug-in duration. Section 4.3 discusses the statistics for duration of overstay events for each sub-campus and the Appendix shows the intra sub-campus (according to plazas) statistics. Time intervals of 30 minutes were considered up to a maximum of 12 hours, resulting in 24 intervals of time. The overstay events were distributed amongst these intervals based on the corresponding time interval for the overstay duration. The number of overstay events plotted were normalized by the total number of events occurring at the corresponding site for the year 2019 (see Table 4.1) in order to understand the distribution of overstay events across different overstay durations.

3.4 Analyzing Hourly Occurrence of Overstay

The start time and end time of overstay were used in generating plots representing the cumulative number of overstay events occurring during every hour of the day. The plot was generated using an hour-ending time stamp and shows the cumulative number of overstay events occurring every hour for a 24-hour time span. Section 4.2 discusses the results of this analysis for the four sub-campuses using plot lines normalized by the total number of overstay events at the corresponding site throughout 2019. This analysis was also carried out for plazas of each sub-campus (see Appendix). Additionally, the charging events were also plotted in a similar manner to that of overstay events. The hourly overstay rate (see Section 3.1 for definition) was found and plotted in order to determine the hourly fraction of charging events that are overstay events for each sub-campus. The results of hourly occurrence of overstay using the overstay and charging datasets were analyzed to understand overstay trends at UCSD.

3.5 Analyzing the Effect of Academic Calendar on Overstay

To analyze the effect of the academic calendar on overstay, school and non-school days have been defined by referring to the UCSD academic calendar [10]. An academic year at UCSD consists of the Fall, Winter, Spring Quarters with an optional Summer Session. The three quarters are attended by the majority of the student population due to mandatory attendance resulting in maximum attendance of students and faculty. The number of students attending the Summer Sessions is significantly lower due to fewer classes being offered and optional enrollment. Considering the student and faculty population on campus during these terms, the days of instruction in the three quarters were considered school days in the analysis while the Summer Sessions have been considered as non-school days along with weekends, quarter breaks (Thanksgiving break, Winter and Spring breaks), national and state holidays. There were 164 school days (all weekdays) and 201 non-school days (104 of them being weekends) in 2019. The academic calendar was chosen over the administrative calendar because the majority of the campus population consists of students and faculty and this affects the number of vehicles on campus which directly corresponds to the likelihood of EV station overstay. Plots were generated representing the overstay rates and number of overstay events recorded on school and non-school days and have been discussed in Section 4.4.

3.6 Analyzing the Effect of High Daytime Temperature on Overstay

The following analysis was used to determine if high daytime temperatures are a contributing factor to likelihood of overstay at EV charging stations. A group of days (shown in

Table 3.1) when peak daytime temperatures exceeded 85 degrees Fahrenheit (°F), referred to as 'hot days', was selected after referring to recorded maximum daily temperatures from the National Oceanic and Atmospheric Administration (NOAA) [11]. The data from the weather station at the San Diego International Airport was used.

Recorded hourly temperatures from a commercial weather service, Weather Underground [12] were used to determine the time of occurrence of high daytime temperatures. It was observed that the maximum temperature was recorded around midday and that there was only a ±2°F temperature variation during that time making midday hours the warmest. Thus, a time period for peak daytime temperature on hot days was chosen to determine the effect of high temperatures on overstay. The time period was found to be 12PM – 4PM which is also when ultraviolet (UV) radiation is at its maximum during the hottest months in San Diego.

Table 3.1: 'Hot days' in 2019 when temperature >85°F

Date	***High Temperature (°F)***	***School/ Non-school Day***
2-Sep-19	86	Non-school
21-Oct-19	88	School
22-Oct-19	92	School
23-Oct-19	86	School
24-Oct-19	94	School
25-Oct-19	90	School
17-Nov-19	88	Non-school
18-Nov-19	91	School

Plots were generated using an hour-ending time stamp for the group of hot days showing normalized values of overstay events occurring on an hourly basis throughout a 24-hour duration. The normalization was done with respect to the total number of overstay events recorded at the

corresponding site on hot days in 2019. The occurrence of overstay on hot days in the chosen time period was compared to that outside of this period on hot days and also with overstay occurrence in the same time period throughout 2019, the results of which are described in Section 4.5. To analyze the latter, normalized values for every hour in the selected time period were averaged for each hot days and throughout 2019 for each sub-campus. Subsets of 'hot days' were selected through preservation of the fraction of school and non-school days in the main overstay dataset and the average percentage changes in overstay were calculated. These values were averaged for each sub-campus and are reported and discussed in Section 4.5. The change in overstay occurrence was used to determine the effect of high daytime temperatures on occurrence of overstay for each sub-campus and is discussed in Section 4.5.

3.7 Analyzing the Effect of Rainfall on Overstay

To analyze the effect of rainfall on occurrence of overstay, a group of 'rainy days' (see Table 3.2) with total rainfall greater than 0.5 inches were selected using data from NOAA [11]. Unlike daytime temperature where there is consistency in the hours of the day when the highest temperature is recorded, rainfall can occur at any time of the day since it depends on variable factors such as atmospheric pressure and wind speeds. For this reason, it was not possible to select a specific time period for all rainy days. The hours of rainfall were obtained through hourly weather data from Weather Underground [12] and overstay was analyzed during these hours on rainy days.

Plots were generated using an hour-ending time stamp for each rainy day showing normalized values of overstay events occurring on an hourly basis throughout a 24-hour duration. Values were normalized with respect to the total number of overstay events recorded at the

corresponding site on rainy days in 2019. The average change in overstay events was calculated for station overstay on rainy days during hours of rainfall using overstay occurrence throughout 2019 calculated for the same hours (results from analysis described in Section 3.4). Three non-school days – November 28 (Thanksgiving break), December 23 and December 26 (campus winter holiday closure) – were omitted as the parking and overstay events on these days are very low. Since these days make up 30% of the initial group of days, the effect on average percentage increases from these days would be large on such a small data subset. These days were not omitted from the 2019 hourly occurrence plots which are used for comparison since the effect of three days on such a large group is negligible.

Subsets of 'rainy days' were selected through preservation of the fraction of school and non-school days in the main overstay dataset and the average percentage changes in overstay were calculated. These values were averaged for each sub-campus and are reported and discussed in Section 4.6. The change in overstay occurrence was used to determine the effect of rainfall on occurrence of overstay for each sub-campus and is discussed in Section 4.6.

Table 3.2: 'Rainy days' in 2019 when rainfall >0.5 inches

Date	***Rainfall (inches)***	***School/ Non-school Day***
6-Jan-19	0.75	Non-school
31-Jan-19	0.62	School
2-Feb-19	0.72	Non-school
4-Feb-19	0.98	School
14-Feb-19	0.59	School
20-Nov-19	0.51	School
28-Nov-19	1.37	Non-school
4-Dec-19	1.19	School
23-Dec-19	1.34	Non-school
26-Dec-19	1.28	Non-school

4. Results and Discussion

Trends in overstay at EV charging stations on the UCSD campus are affected by EV users whose behavior is influenced by some meteorological factors and the university's academic calendar. The results have been analyzed and presented according to sub-campus as described in Chapter 3. The discussion of the effect of factors on trends in overstay involves some expected trends and the conformance or deviation of the analysis results from these expected trends.

4.1 Distribution by Sub-campus

A significant majority of overstay events were recorded at the UCSD Main Campus (63% as shown in Figure 4.1) as expected since the Main Campus constitutes most of the administrative buildings, educational and research facilities, student centers, community spaces and undergraduate residence halls, and hence is visited by the majority of the campus population. The Main Campus is followed by the UCSD Medical Campus (23% as shown in Figure 4.1) which has the second largest campus population that includes doctors, nurses, administrators, medical students and patients. The SIO Campus and the Graduate and Family Housing Community collectively constitute 13% of the total number of overstay events analyzed as shown in Figure 4.1. These sub-campuses are smaller compared to the Main and Medical Campuses and this result was expected.

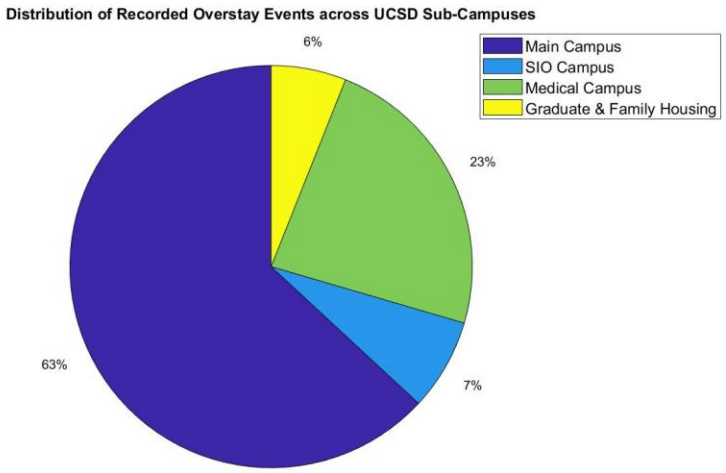

Figure 4.1: Distribution of overstay events at Level 2 EV chargers at UCSD in 2019

Table 4.1: Overstay statistics at each sub-campus in 2019. Percentages calculated from values in Table A1 in the Appendix.

Sub-campus	***Distribution of Stations as %***	***Distribution of Total Charging Events as %***	***Overstay Events as % of Sub-campus Charging Events***
Main	48	62	65
SIO	10	8	58
Medical	18	23	63
GFH	24	7	57
Total	***100***	***100***	***N/A***

Overstay events across all the sub-campuses cumulatively make up 63% of all charging events in 2019 (see dataset sizes in Section 3.2). The Main Campus has the highest number (48%) of ChargePoint Level 2 charging stations, followed by Graduate & Family Housing at 24%, Medical Campus at 18 % and SIO at 10%. From these results, we can say that demand for charging

is likely higher at the Main and Medical Campuses; the demand could vary within the sub-campus or among the plazas but that will not be discussed in this thesis. The demand for charging at GFH Campus is the least since despite having the second highest number of charging stations, the number of charging events recorded is the lowest among all sub-campuses. Thus, we can say that overstay at the Main, Medical and SIO campuses is more likely to affect charging demand and station availability. From Table 4.1, it is also observed that within a sub-campus, more than 50% of the charging events are overstay events implying that overstay could most likely impede the optimal use of the EV charging network, considering little to no expansion of network, if there is sharp increase in demand for EV charging in the coming years.

4.2 Hourly Occurrence of Overstay

The Main, SIO and Medical Campuses follow a similar trend as seen in Figure 4.2 and Figure 4.3 whereas Graduate and Family Housing shows a trend converse to that of the former group. These trends seem to correspond to the changing population on these sub-campuses throughout the day.

The Main and SIO Campuses, as seen in Figure 4.2, show a steady yet sharp increase in overstay events starting at 7AM which could be attributed to the presence of a small percentage of the academic community for early morning classes and some service/administrative employees starting work early in the day. Most classes are scheduled between 10 AM and 5 PM, these hours being a common work hours for both academic and non-academic employees thus contributing to the plateau-like peak of overstay events from 11AM to 4PM (as seen in Figure 4.2). After these

hours, the sharp decrease in overstay numbers until 8PM and gradual decrease post-8PM could be a result of decreasing campus population due to fewer classes and lesser employees.

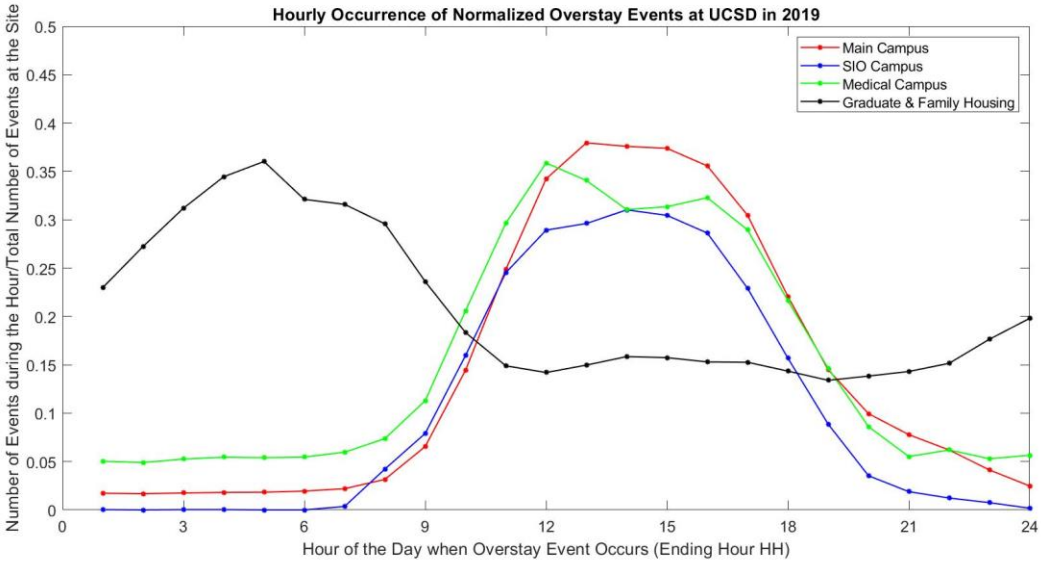

Figure 4.2: Hourly occurrence of normalized overstay events on each sub-campus. Normalization was performed using values calculated from Table A1 in the Appendix. The results have been plotted using an hour-ending time stamp. An example of how to read the plotted points: Starting from the left of the x-axis, the first plotted point for SIO Campus shows that 0% of the total number of overstay events at SIO Campus in 2019 occurred during the first hour of the day i.e.; from midnight to 1AM (00:00:00 to 00:59:59).

The Medical Campus shows trends similar to the former sub-campus group due to similar population patterns in medical academic (trends similar to non-medical academic community) and non-academic community. Medical centers generally operate between 9AM and 5PM which are general business or work hours resulting in a plateau-like peak observed around 11AM to 5PM. The normalized overstay occurrence from midnight until the start of peak hours is consistently 1.5x to 2x higher than that on the Main Campus which can be owed to the nature of healthcare workers' work shifts.

Graduate and Family Housing as expected has a higher overstay occurrence during non-school/business hours as most EV users probably charge their vehicles after returning from school/work. But overstay during school/business hours is surprisingly higher than anticipated. This could be attributed to the possibility of medical students and healthcare workers using the charging stations in the housing community parking structures due to the proximity of the housing community to the Medical Campus. Refer Figures A1-A4 in the Appendix for hourly overstay occurences for plazas grouped by sub-campus.

Figure 4.3 shows the hourly occurrence of charging events for each sub-campus in 2019. The Main, Medical and SIO Campuses show a charging event trend similar to that of the overstay trend but the increase in charging events starts at around 6AM and then starts decreasing from 3PM. The peak in charging events occurs from 11AM to 3PM. Graduate and Family Housing is the only sub-campus that follows a different charging trend. The reasons for these charging trends are similar to that stated for overstay trends earlier in this Section 4.2.

When considering hourly occurrence of overstay events as the percentage of charging events (overstay rate) occurring at the respective sub-campus as shown in Figure 4.4, it is observed that the overstay rate increases steadily from 9AM for the Main, Medical and SIO Campuses and slightly dips after 6PM. Relating the results from Figures 4.2, 4.3 and 4.4, the overstay rate increases steadily from 9AM (see Figure 4.4) owing to the increase in both charging and overstay events. Despite the decrease in charging events after 3PM until 6PM as seen in Figure 4.3, the overstay rate increases implying that the overstay events are all charging events that most likely began before 3PM. This also implies that there are a considerable number of overstay events that last for a few hours between 9AM and 5PM which are business/school hours. For the aforementioned campuses, it can be said that most events between 9AM and 12PM are charging

events as seen in Figure 4.4. Between 6PM and 6AM, it is likely that the overstay rate is higher at the Main, Medical, SIO Campuses since there are very few non-overstay events during those hours. GFH Campus shows higher overstay rate during night hours until 9AM owing to overnight charging of EVs.

Thus, it can be concluded that the sub-campus population at a given time and EV user behavior affects the rate of overstay events.

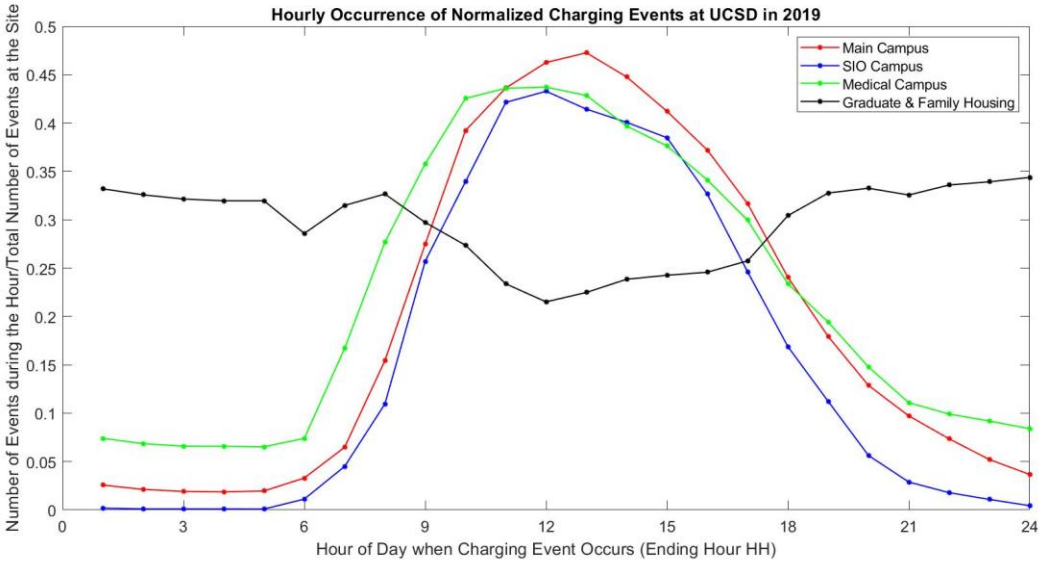

Figure 4.3: Hourly occurrence of normalized charging events on each sub-campus. Normalization was performed using values calculated from Table A1 in the Appendix. The results have been plotted using an hour-ending time stamp. An example of how to read the plotted points: Starting from the left of the x-axis, the first plotted point for SIO Campus shows that 0% of the total number of charging events at SIO Campus in 2019 occurred during the first hour of the day i.e.; from midnight to 1AM (00:00:00 to 00:59:59).

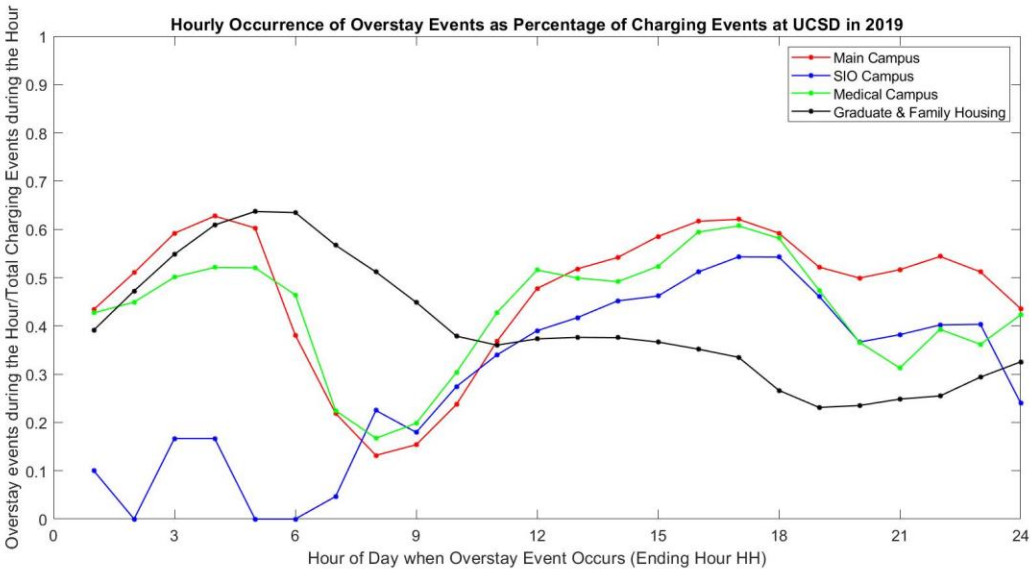

Figure 4.4: Overstay rates for every hour on each sub-campus. The results have been plotted using an hour-ending time stamp. An example of how to read the plotted points: Starting from the left of the x-axis, the first plotted point for SIO Campus shows that 10% of the number of charging events at SIO Campus which occurred during the first hour of the day i.e.; from midnight to 1AM (00:00:00 to 00:59:59) are overstay events.

4.3 Duration of Overstay

All sub-campuses show a general decrease in the number of overstay events with an increase in duration of overstay. The number of events with the shortest overstay duration, lasting 15-30 minutes (refer Chapter 3.1 for event selection criteria), represent the largest percentage of recorded overstay on each sub-campus and are the first plot points for every sub-campus in Figure 4.5. Approximately 50% of the total events analyzed at each sub-campus have an overstay duration of at most 1 hour at SIO, 1.5 hours on the Main Campus, 2 hours on the Medical Campus and 2.5 hours at Graduate and Family Housing.

Graduate and Family Housing is the only sub-campus that slightly deviates from the general trend observed and shows an increasing trend after its lowest point at the 4th hour mark in

Figure 4.5. This increase could be attributed to resident students leaving their EV plugged in at stations overnight for charging resulting in overstay events with longer durations.

From the above discussion, more than 50% of overstay events at each sub-campus are likely to have an overstay duration not longer than three hours. Plaza-wise statistics for overstay duration are shown in Figures A5-A8 in the Appendix.

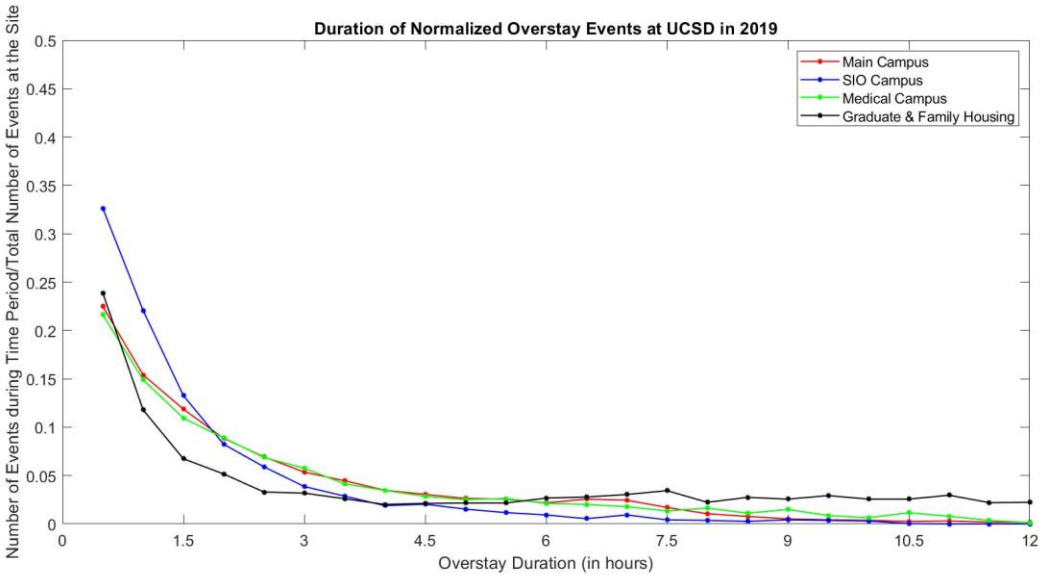

Figure 4.5: Duration of normalized overstay events on each sub-campus. Normalization performed using values in Table 4.1. The results have been plotted using an hour-ending time stamp. The x-axis represents duration periods of 30 minutes. An example of how to read the plotted points: Starting from the left of the x-axis, the second plotted point for SIO Campus shows that approximately 22.5% of the total number of overstay events at SIO Campus in 2019 lasted for a duration between 0.5 hours to 1 hour.

4.4 Effect of Academic Calendar on Overstay

The Main and SIO Campuses are expected to show a considerably larger number of recorded events of overstay than the other sub-campuses on school days as the number of daily visitors to these sub-campuses is likely higher owing to the presence of classroom and research

buildings. As expected, the overstay events on school days on the Main and SIO Campus is 1.19x and 0.67x that on non-school days as seen in Figure 4.6.

I hypothesized that the Medical Campus show a number of school day overstay events similar to non-school days since the medical institutes and facilities operate throughout the year; the medical community consists of healthcare workers besides students and faculty. There are more non-school days than school days in 2019, as stated in Chapter 3.5, which supports this hypothesis. The results for the Medical Campus show a considerable difference between the values with overstay count on school days being greater by 61% which could possibly be attributed to the higher medical academic (student and faculty) population on school days.

The Graduate and Family Housing Community as expected shows much lower values compared to other sub-campuses and similar values for school and non-school days owing to the fact that there are fewer events at this sub-campus and that students spend more time on campus during school days whereas on non-school days, most of them are away on vacation.

The overstay rate (fraction of charging events that are overstay events) for school and non-school days is at least 50% on non-school days and at least 60% on school days as seen in Figure 4.7. Higher overstay rates on school days is likely due to the school/work schedules during school/business hours as discussed in Section 4.2. SIO Campus shows the lowest overstay rate compared to other sub-campsues on non-school days. The overstay rate on school days for the Main, SIO, Medical Campuses and on non-school days for the Main, Medical, GFH Campuses is more or less the same. Thus, it can be said that the overstay rate for the type of day is similar across these campuses. From Figure 4.7, it can be said that the likelihood of overstay is higher on school than on non-school days.

The above results and discussion lead to the conclusion that the academic calendar has a significant effect on the overstay rate and the number of overstay events at UCSD. The distribution of overstay events between school and non-school days for plazas is shown in Figures A9-A12.

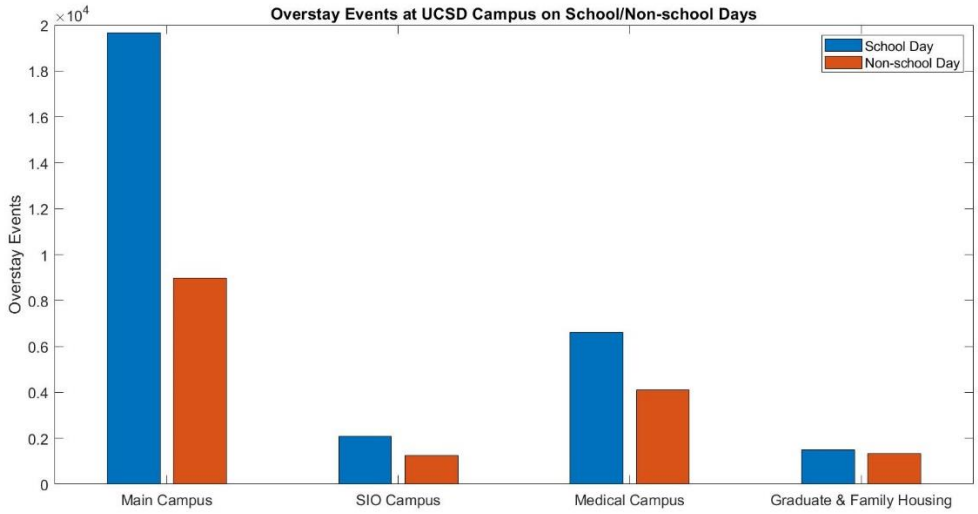

Figure 4.6: Overstay events on each sub-campus on school and non-school days as defined by the University's academic calendar.

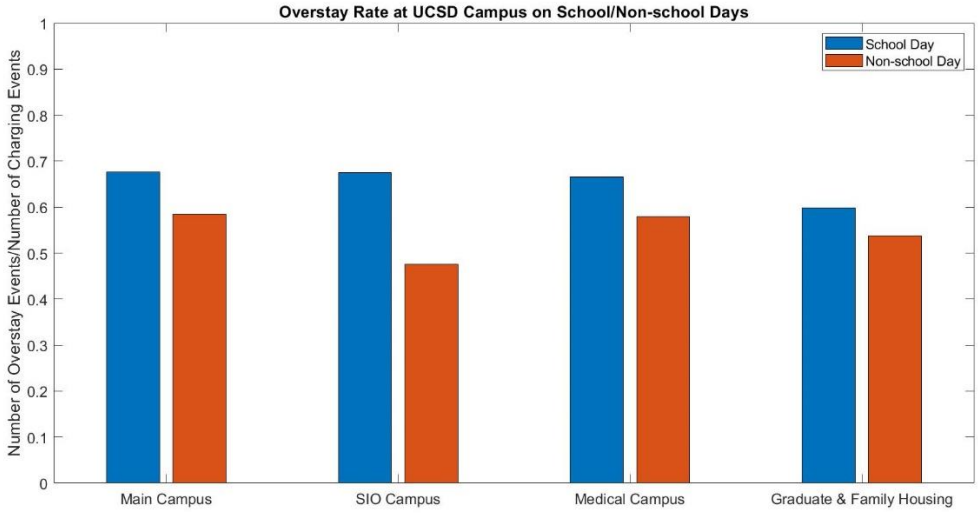

Figure 4.7: Overstay rates at each sub-campus on school and non-school days. Sub-campus total overstay and charging events calculated from Table A1 in Appendix.

4.5 Effect of High Daytime Temperature on Overstay

An increase in percentage of overstay events is expected on days that recorded high daytime temperatures (will be referred to as 'hot days') when compared to other days in the year as it is assumed that EV users would avoid walking to parking garages/lots during peak sunshine hours due to searing heat and very high ultra-violet radiation.

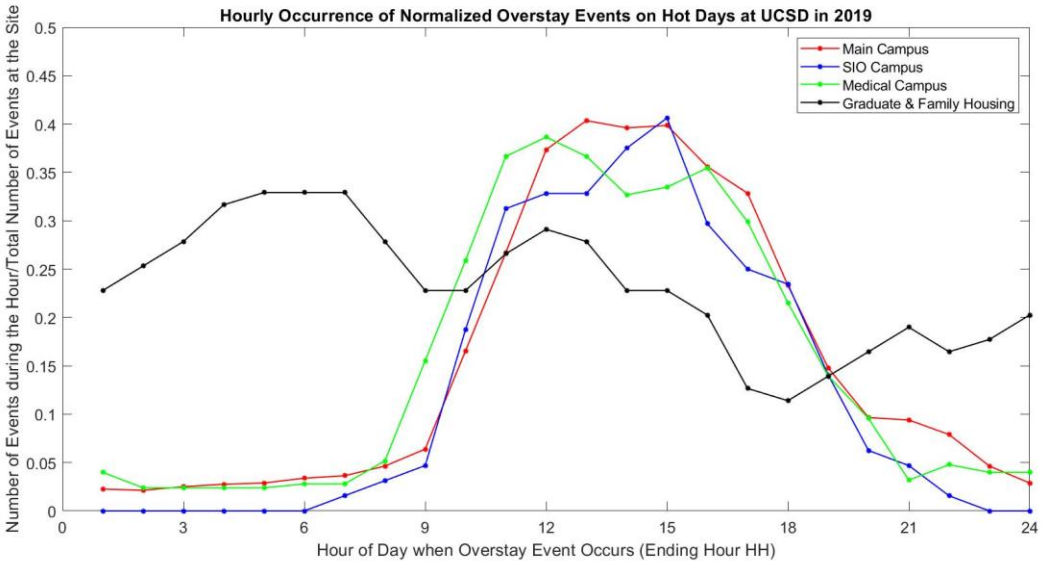

Figure 4.8: Hourly occurrence of normalized overstay events on each sub-campus on days with high daytime temperatures. Normalization done using values in Table A2 in the Appendix.

From Figure 4.8 it can be observed that on hot days the number of overstay events recorded between 12PM – 4PM is significantly higher than other school/working hours (8AM-12PM, 4PM-6PM) on those days. This trend is similar to that observed in hourly occurrence of overstay throughout 2019 (see Figure 4.2). The overstay trends for plazas in each sub-campus have been discussed in Figures A13 to A16 of the Appendix section. When comparing the napping events between 12PM – 4PM on hot days with those occurring in the same time interval throughout 2019, the trends in the number of overstay events varies by sub-campus. An increase in the percentage

of overstay events is expected on hot days when compared to other days in the year as it is assumed that EV users would avoid peak sunshine hours. However, Table 4.2 shows that the above may not always be true.

As observed from Table 4.3, all sub-campuses besides the SIO Campus follow the expected trend and show an increase in overstay events between 12PM and 4PM on hot days when compared to other days in 2019. The SIO Campus shows a decrease in overstay occurrence when daytime temperatures are high. The large increase observed at Graduate & Family Housing is unlikely to be solely due to temperature effects. It could be a result of increased parking for an event that randomly occurred on one of the hot days or by Medical Campus employees which is commonly known to occur (due to proximity of the Medical Campus to graduate housing communities). A more significant increase was expected on the Main Campus compared to other campuses but the Medical campus shows a larger increase (6%) in overstay events compared to the Main Campus (2%).

From the results, it can be concluded that there is a generally positive correlation between high midday temperatures and the number of overstay events at UCSD except at the SIO Campus. Figure 4.9 serves as an example of how plots were compared in order to arrive at values used to calculate the average percentage change in overstay events shown in Table 4.3. Refer Appendix Figures A17-A23 for plots of overstay events at sub-campuses on other hot days.

Table 4.2: Cumulative average change in percentage of recorded overstay events on 'hot days' when compared to year-round overstay events. Hot days ordered from highest to least peak daytime temperature.

Hot Day in 2019	***Cumulative Average % Change in Overstay on 'Hot Days' between 12PM and 4PM***			
	Main Campus	*SIO Campus*	*Medical Campus*	*Graduate & Family Housing*
10/24/2019	-7	-8	14	-1
10/22/2019	-3	13	19	84
11/18/2019	0	14	12	100
10/25/2019	0	32	11	75
11/17/2019	-9	6	0	51
10/21/2019	-6	14	3	46
9/2/2019	-7	2	9	25
10/23/2019	-3	-2	6	22

Table 4.3: Average change in overstay occurrence at sub-campuses on 'hot days' (refer Section 3.6 for method of calculation)

Sub-Campus	Main Campus	SIO Campus	Medical Campus	Graduate & Family Housing
Average % Change in Overstay Events on 'Hot Days'	2	-6	5	17

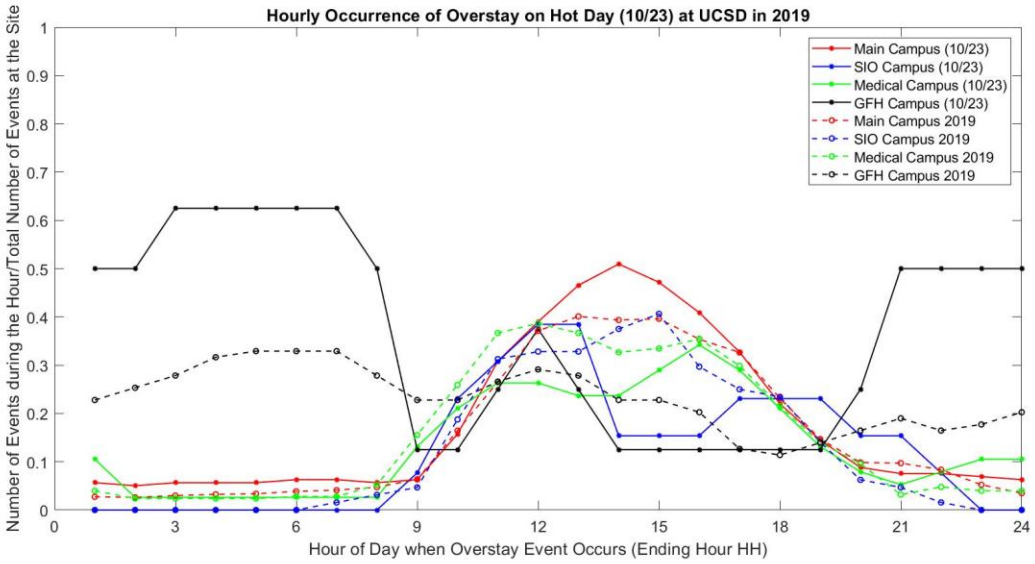

Figure 4.9: Hourly occurrence of normalized overstay events on each sub-campus on 'hot days' and throughout 2019. Normalization for 'hot days' done using values in Table A2 in the Appendix. The above plot for 10/23/2019 was one of many plots used to arrive at the percentage change of overstay events between 12PM and 4PM on hot days when daytime temperatures are very high. Refer caption of Figure 4.2 for example on how to interpret the plots.

4.6 Effect of Rainfall on Overstay

Overstay at EV charging stations was expected to show an increased occurrence during hours that experienced rainfall as most EV owners would likely avoid walking to the plazas in the rain. Table 4.4 shows that the above may not always be true. While comparing percentage changes across different rainy days for each sub-campus, there is largely a decrease in occurrence of overstay on the SIO and Medical Campuses with SIO and GFH showing the maximum 'no overstay' events (-100% in Table 4.3) which is likely due to very few or no events on these days. The cancellation of classes and closure of some campus services, if any, in event of a sudden downpour or high speed wind could have contributed to this decrease in events. If not the aforementioned, then probably the campus population is low on rainy days. The 'no overstay'

events at SIO could be attributed to the fact that most people avoid driving towards the seaside during rains if heavy downpour or high speed wind warnings were issued which is quite common along the La Jolla coast. Graduate and Family Housing shows some instances of large increase in overstay events.

The average decrease during rainfall hours, as shown in the Table 4.5 (calculated using values in Table 4.3), is found to be quite significant for the SIO Campus which shows a 42% decrease in occurrence of overstay events, followed by the Main Campus at 32% decrease and Medical Campus at 26% decrease. Graduate & Family Housing showed an increase in overstay events which could be the result of many students choosing to stay home those days and are avoiding walking to the plaza in order to unplug their EVs from the charging stations.

From this discussion, it can be concluded that there is a decrease in occurrence of overstay events on rainy days at all sub-campuses except GFH owing to the likelihood that these sub-campus populations on rainy days is lower than on non-rainy days. Figure 4.10 serves as an example of how plots were compared in order to arrive at values shown in Table 4.5. Refer Appendix Figures A24-A29 for plots of other rainy days.

Table 4.4: Cumulative average change in percentage of recorded overstay events on 'rainy days' when compared to year-round overstay events. Rainy days ordered from highest to lowest rainfall received. Cumulative averaging performed for days with multiple hours of rainfall. See caption of Appendix Figures A24 through A29 for hours of rainfall on each rainy day.

Rainy Day in 2019	***Cumulative Average % Change in Overstay during 'Rainfall Hours' on Rainy Day w.r.t. all days in 2019***			
	Main Campus	*SIO Campus*	*Medical Campus*	*Graduate & Family Housing*
12/4/2019	7	-20	19	55
2/4/2019	-12	4	1	22
1/6/2019	-41	-49	7	-6
2/2/2019	-49	-62	-20	21
1/31/2019	-36	-56	-21	16
2/14/2019	-33	-44	-15	18
11/20/2019	-31	-52	-13	1

Table 4.5: Average change in overstay occurrence at sub-campuses on 'rainy days' (refer Section 3.7 for method of calculation)

Sub-Campus	Main Campus	SIO Campus	Medical Campus	Graduate & Family Housing
Average % Change in Overstay Events during 'Rainfall Hours'	-32	-42	-26	13

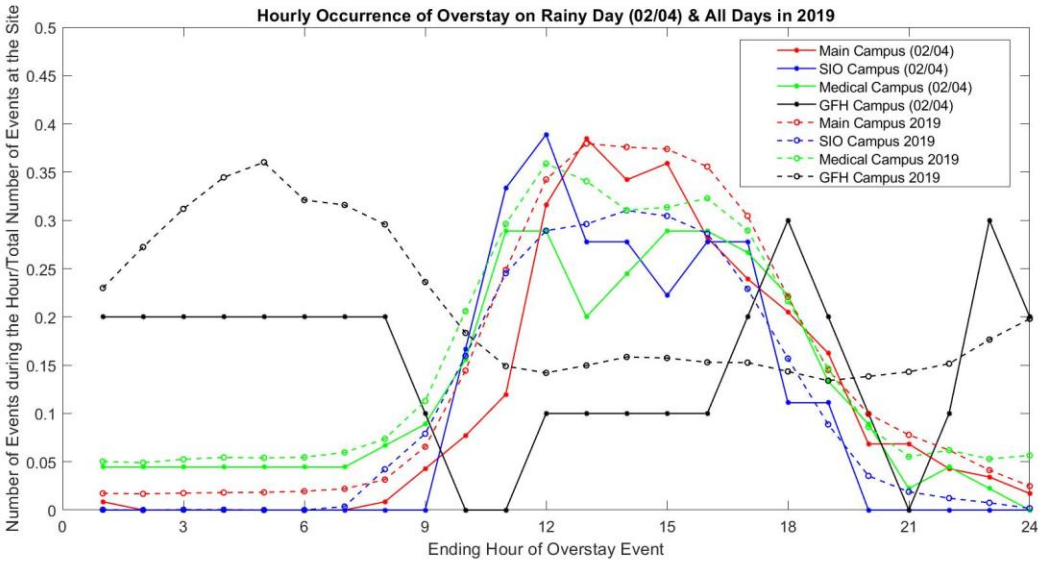

Figure 4.10: Hourly occurrence of normalized overstay events on each sub-campus on 'rainy days' and throughout 2019. Normalization for 'rainy days' done using values in Table A3 in the Appendix. The above plot for 02/04/2019 was one of many plots used to arrive at the percentage change of overstay events during hours of rainfall. Refer caption of Figure 4.2 for example on how to interpret the plots.

5. Conclusion and Future Work

EV user behavior is affected by meteorological and school/work scheduling which in turn affects overstay patterns at EV charging stations on UCSD campus. In 2019, it was found that most overstay events occurred on the Main and Medical campuses due to a direct correlation with a larger number of daily visitors to these sub-campuses. It was also observed that the fraction of charging events that are overstay events gradually increased between 9AM to 5PM indicating the possibility of some overstay events lasting for a few hours or most of the 9AM - 5PM time period. The higher number of overstay events and higher overstay rates (see Section 3.1 for definition) on school days (as defined by the University's academic calendar) across all sub-campuses imply that overstay occurrence is affected by the university's academic schedule. Thus, overstay occurrence is more likely on school days and during the conventional work/school hours 9AM – 5PM. High daytime temperatures during the hottest days in 2019 resulted in a small increase in overstay numbers at all sub-campuses except the SIO Campus implying that high daytime temperatures may contribute to an increase in overstay events. Rainfall, on the other hand, contributed to a significant decrease in overstay occurrences at all campuses except at Graduate & Family Housing. The conclusions derived from the analysis for effect of selected factors on overstay is as follows:

1. School/work schedules and the University's academic/administrative calendar seem to have a larger impact on the number of overstay events at UCSD.

2. High peak daytime temperatures on the hottest days of the year could contribute to a small increase in occurrence of overstay although more analysis results from previous years may be needed to clearly determine the effect.
3. Rainfall contributed to a significant decrease in overstay occurrence at the Main, SIO and Medical Campuses which was attributed to lower campus populations on those days. Thus, rainfall is more likely to affect overstay occurrence compared to high daytime temperatures.

With the UCSD campus population having grown since 2019, it is likely that there would be higher numbers of EV users in the UCSD community in the coming years which could lead to more demand for EV charging stations. Consequently, there may arise a need to keep check on overstay events in the future. With little to no expansion in the EV charging network and increased demand, long overstay duration at charging stations by some EV users will pose an inconvenience to those in need of charging stations. It is also highly probable that there are repeated overstayers at EV charging stations. Thus, imposing a time-based penalty fee on EV users for long overstay durations especially during work/school hours (7AM to 7PM) could help reduce the occurrence of such events. A charging system exception could be made for healthcare workers on long shifts by imposing a less strict penalty system or alternatively hiring a valet [13] to move EVs at selected Medical Campus plazas during peak working hours (9AM to 5PM).

The results of the analysis in this thesis could be useful for further detailed analysis such as correlating overstay occurrence and station availability under conditions similar to those used in this analysis. The results and conclusions discussed in this thesis may be conducive to future planning and expansion of the EV charging network at UCSD campus or other institutions.

Appendix

The appendix is structured as follows. Table A1 lists the plazas and their sub-campus groups with the number of stations, charging events and overstay events. Tables A2 and A3 show the number of overstay events at each sub-campus on ‘hot days’ and ‘rainy days’ respectively.

Figures A1 through A4 show the hourly overstay occurrence for all plazas. Figures A5 through A8 show the duration of overstay events for plazas across every sub-campus. Figures A9 through A12 show the distribution of station overstay events at plazas on school and non-school days. Figures A13 through A16 show plaza-wise normalized overstay occurrence on ‘hot days’ and Figures A17 through A23 show overstay occurrence for plazas of each sub-campus group on ‘hot days’. Figures A24 through A29 show overstay rates for plazas of each sub-campus group on ‘rainy days’.

Table A1: List of all plazas used in this analysis with corresponding sub-campus group, number of Level 2 charging stations and number of charging and overstay events in 2019. Each Level 2 station has two ports. 71779 charging events and 45,283 overstay events recorded from 112 charging stations were used in the analysis.

Plaza	Sub-campus	Stations	Charging Events	Overstay Events
Arbor	Medical	6	4214	2608
Athena	Medical	6	6389	3864
Bachman Canyon	Medical	3	818	547
Birch Aquarium	SIO	1	1059	280
Career Services Center	Main	1	1038	671
East Campus	Medical	1	1625	1114
Faculty Club P206	Main	1	1632	768
Gilman	Main	7	7874	4689
Hopkins	Main	5	4802	3380
Hubbs Hall	SIO	2	775	571
Keck Hall	SIO	1	787	587
Keeling Apartment	Main	1	1557	942
La Jolla Del Sol	GFH	9	113	44
Medical Center P751	Medical	1	142	97
Mesa	GFH	1	806	558
Mesom Hall	SIO	1	719	444
Nuevo West	GFH	11	360	204
Ola	GFH	5	2262	1205
One Miramar Street	GFH	1	1294	721
Osler	Main	13	9556	6840
Osler P610	Main	3	3512	2391
Pangea	Main	8	5868	3432
Rady	Main	4	4460	2738
Ritter Hall	SIO	1	218	133
School of Medicine	Medical	2	1867	1209
Scripps	SIO	3	91	69
SIO P001	SIO	2	2074	1256
Torrey Pines Center North	Main	2	1218	834
Torrey Pines Center South	Main	6	1559	1224
UCSD Extension	Main	2	1073	598
UCSD Warehouse	Main	1	135	65
West Campus	Medical	1	1882	1200
Total		**112**	**71779**	**45283**

Table A2: Number of overstay events at each sub-campus on hot days in 2019. Plotted values in Figure 4.5 (Top) normalized using the values in this table.

Sub-campus	***Overstay Events***
Main	798
SIO	64
Medical	251
Graduate and Family Housing	79
Total Number of Overstay Events on Hot Days in 2019	***1192***

Table A3: Number of overstay events at each sub-campus on rainy days in 2019. Plotted values in Figures 4.6 (Top), A17-22) were normalized using values in this table. Total overstay events across all rainy days is 1116.

Rainy Day in 2019	***Overstay Events***			
	Main Campus	*SIO Campus*	*Medical Campus*	*Graduate & Family Housing*
1/6/2019	27	5	15	8
1/31/2019	120	17	39	14
2/2/2019	28	2	8	9
2/4/2019	142	18	45	10
2/14/2019	112	11	44	8
11/20/2019	155	10	36	9
12/4/2019	151	9	49	15
Total Number of Overstay Events on Rainy Days in 2019	***735***	***72***	***236***	***73***

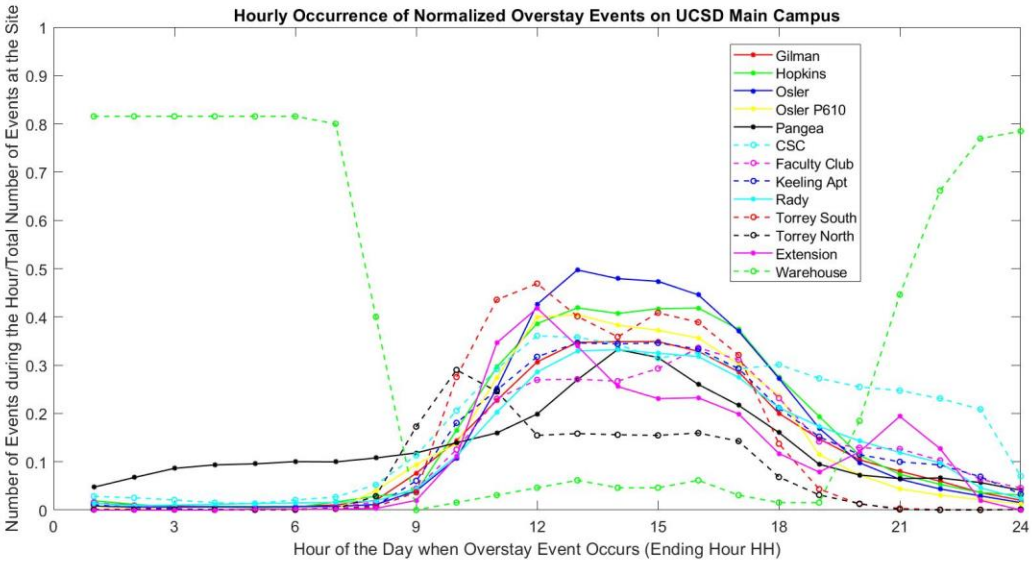

Figure A1: Hourly occurrence of normalized overstay events on Main Campus. Normalization was performed using values from Table A1. The results have been plotted using an hour-ending time stamp. All plazas except for the Warehouse and Torrey Pines North Center follow similar trends and akin to that of the Main Campus as shown in Figure 3.2 showing peak in overstay events from 11AM to 4PM.

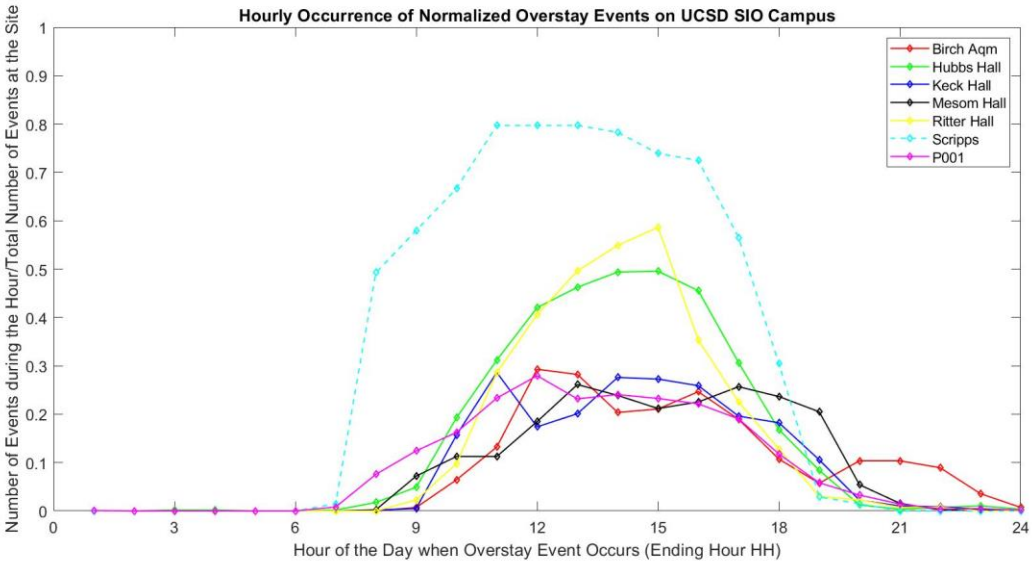

Figure A2: Hourly occurrence of normalized overstay events on SIO Campus. Normalization was performed using values from Table A1. Scripps plaza show highest overstay rates from 7AM to 6PM followed by Hubbs Hall and Ritter Hall plazas show higher overstay rates from 12PM to 4PM. These three plazas show steady increase and decrease in overstay rates compared to other SIO plazas.

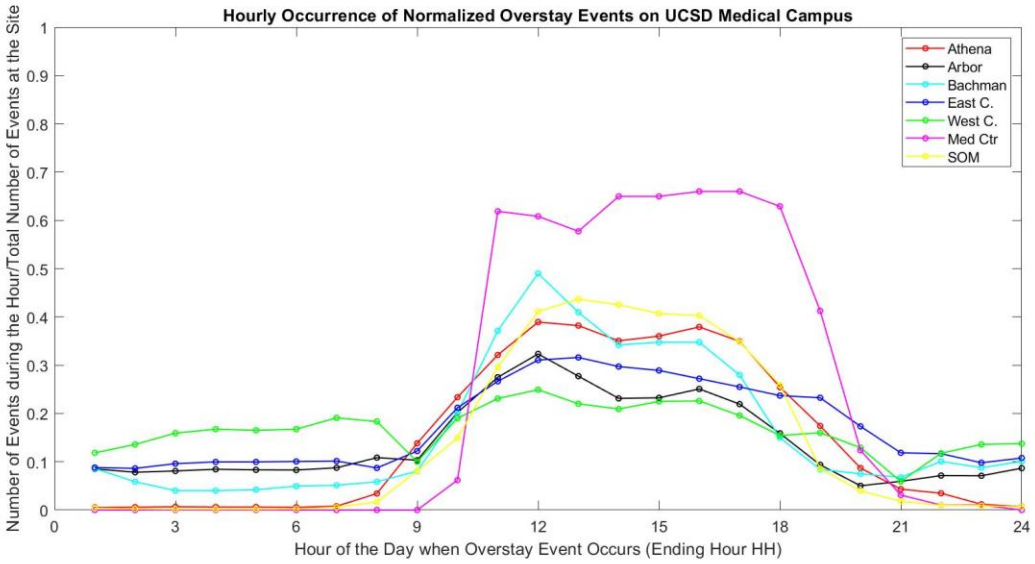

Figure A3: Hourly occurrence of normalized overstay events on Medical Campus. Normalization was performed using values from Table A1. Medical Center plaza shows highest overstay rates from 10AM to 7PM while other plazas show more or less similar peak overstay rates from 10AM to 4PM.

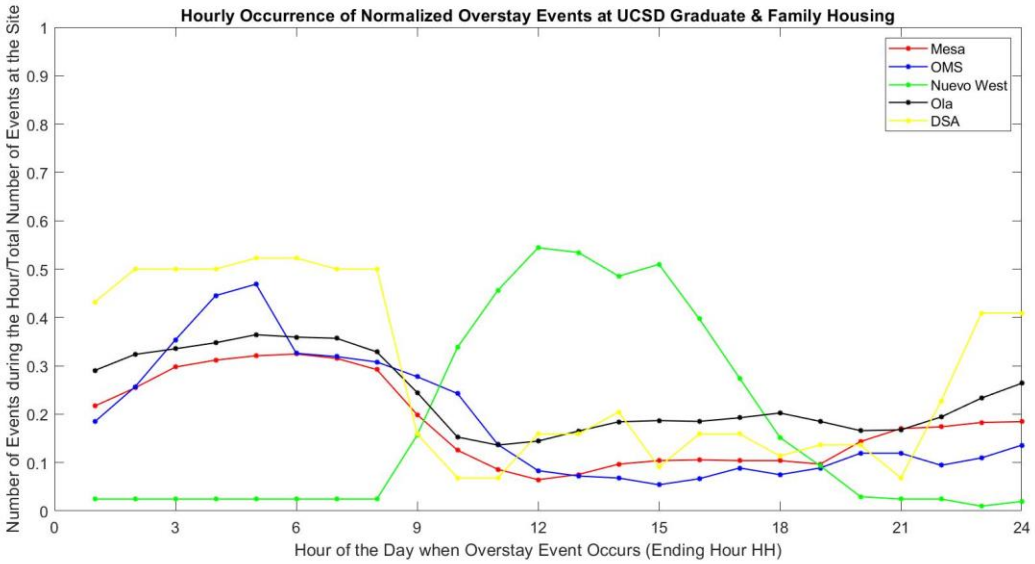

Figure A4: Hourly occurrence of normalized overstay events at GFH Community. Normalization was performed using values from Table A1. Nuevo West plaza deviates from the general GFH plaza trend showing a trend similar to that of the Main, SIO & Medical Campuses in Figure 4.2. This could be due to thee possibility of healthcare workers or off-campus resident medical students using this plaza since it is the largest GFH plaza and closest to the Medical Centers. The other plazas follow similar trends which is reflected in the cumulative overstay results for the GFH Community in Figure 4.2.

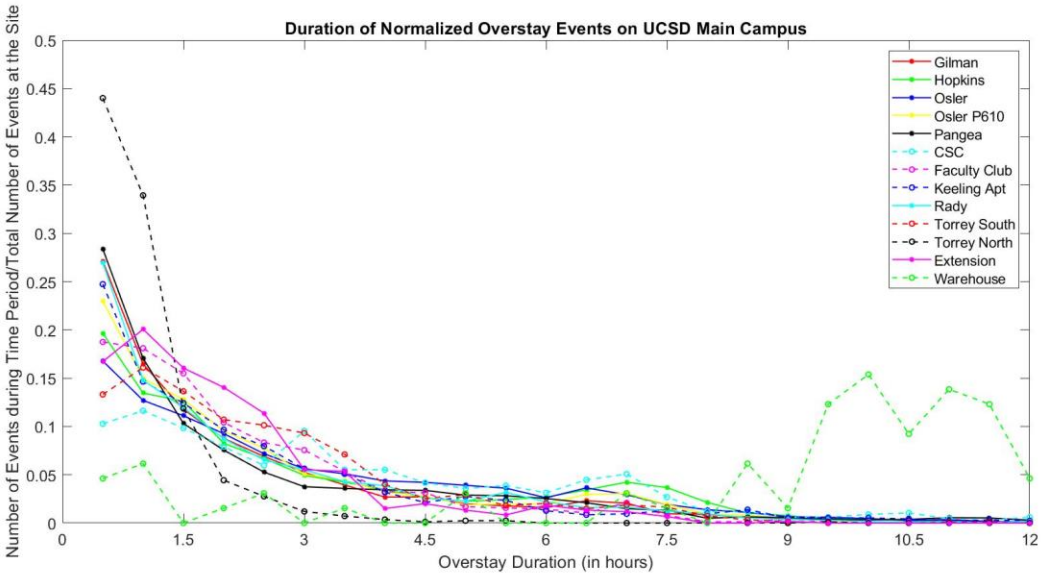

Figure A5: Duration of normalized overstay events on Main Campus. Normalization was performed using values in Table A1. The results have been plotted on an hour-ending time stamp. The x-axis represents duration periods of 30 minutes. All plazas follow similar trends except for the UCSD Warehouse.

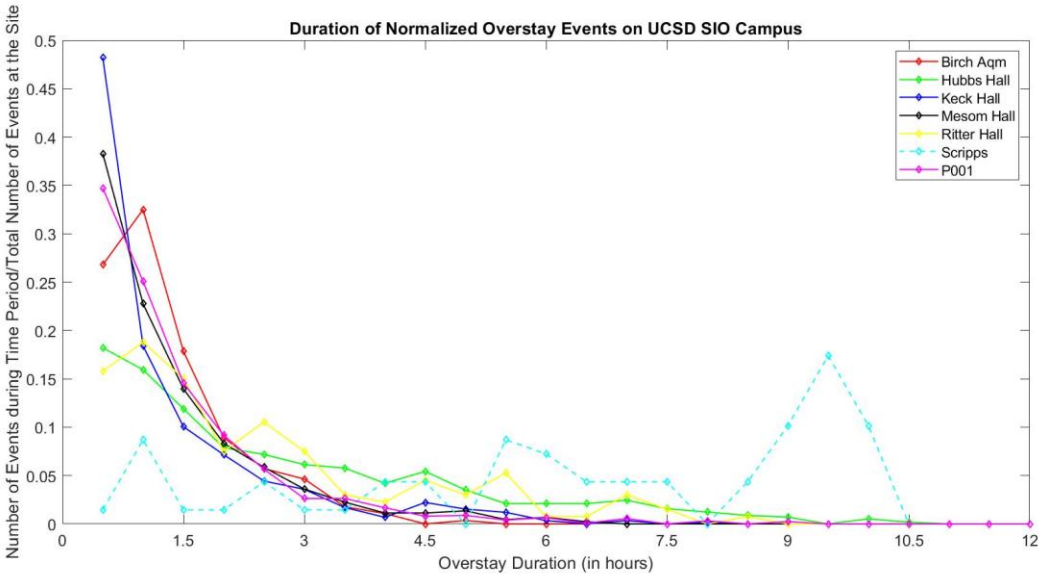

Figure A6: Duration of normalized overstay events on SIO Campus. Normalization was performed using values in Table A1. All plazas follow similar trend except for Scripps plaza which shows higher occurrence of events with overstay durations longer than 5 hours.

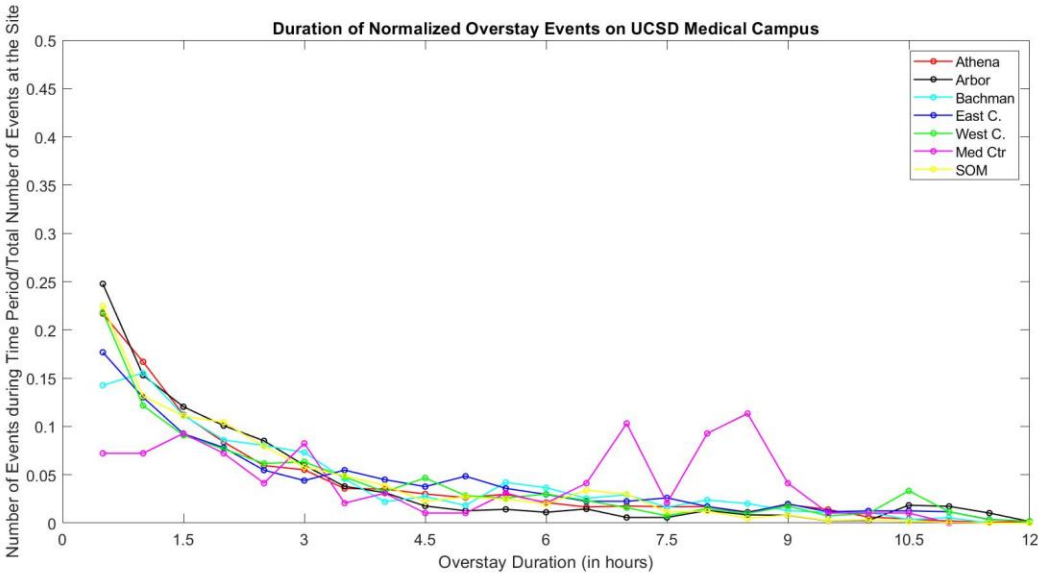

Figure A7: Duration of normalized overstay events on Medical Campus. Normalization was performed using values in Table A1. The Medical Center shows higher occurrence of events with overstay durations between 6.5 hours to 9 hours which could be attributed to healthcare workers leaving their vehicle plugged-in during long work shifts.

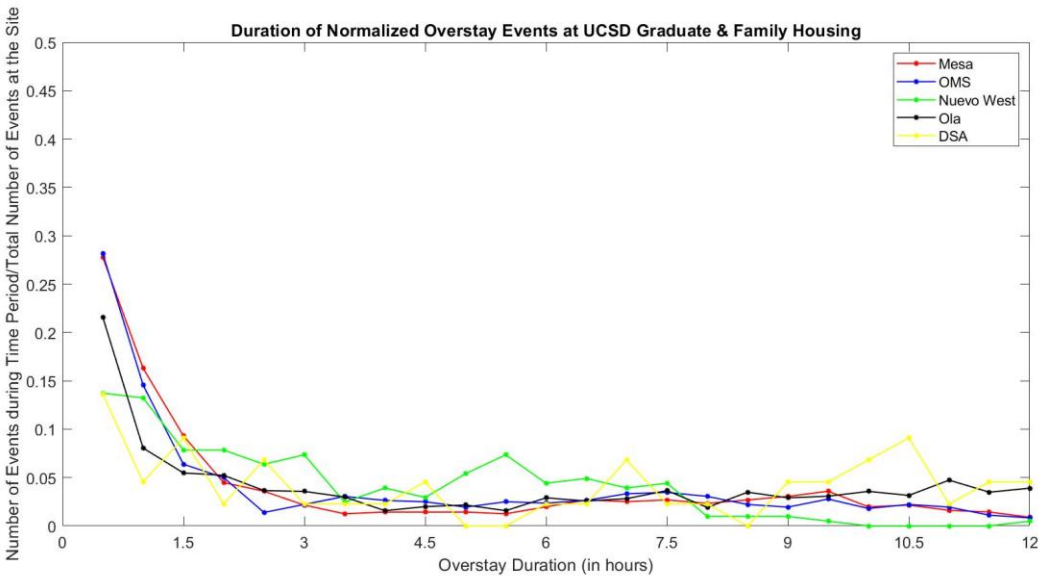

Figure A8: Duration of normalized overstay events at GFH Community. Normalization was performed using values in Table A1. All plazas follow similar trend. Del Sol Apartments (DSA) plaza showing higher occurrence of events with overstay durations longer than 9 hours.

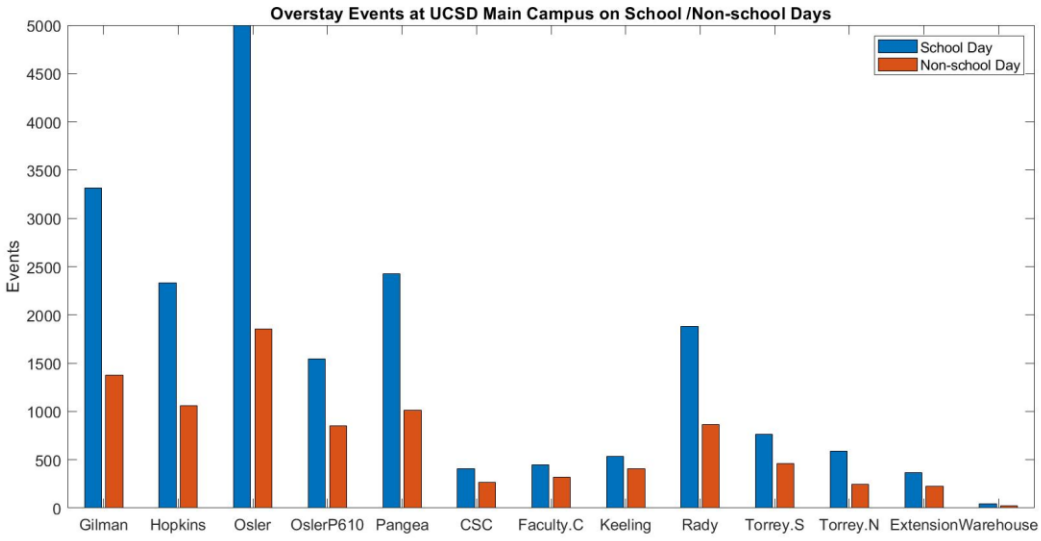

Figure A9: Overstay events on Main Campus on school and non-school days as defined by the University's academic calendar. Osler and Gilman plazas constitute close to 50% of overstay events that occur at Main Campus plazas on school days. The significantly high numbers for Gilman, Hopkins, Osler, Pangea and Rady were expected since these plazas are the largest on Main Campus and house many charging stations.

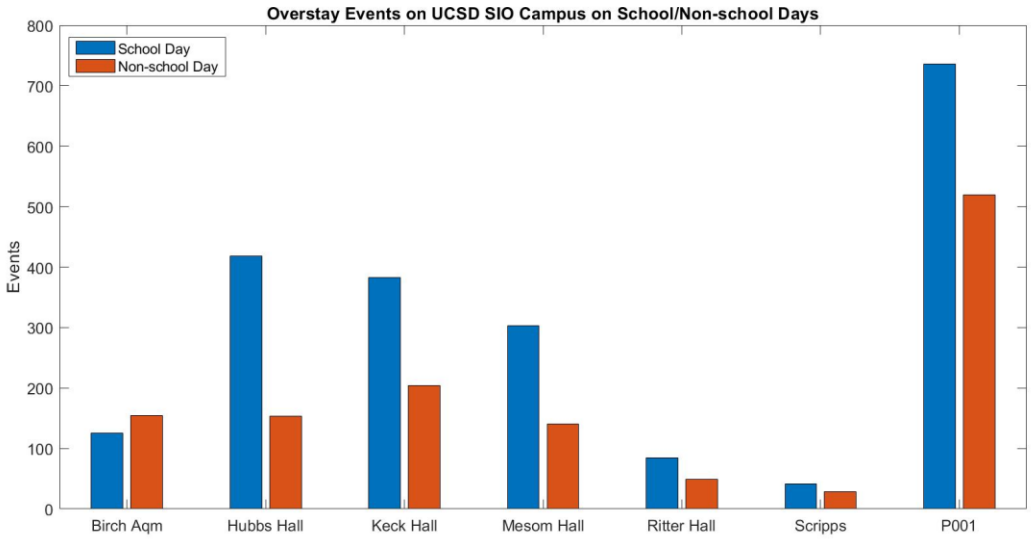

Figure A10: Overstay events on SIO Campus on school and non-school days as defined by the University's academic calendar. P001 plaza has highest overstay occurrence on school and non-school days when compared to other plazas. Birch Aquarium plaza is the only one to have higher overstay events on non-school days and this could be attributed to higher number of visitors and volunteers/employees during holidays and the summer.

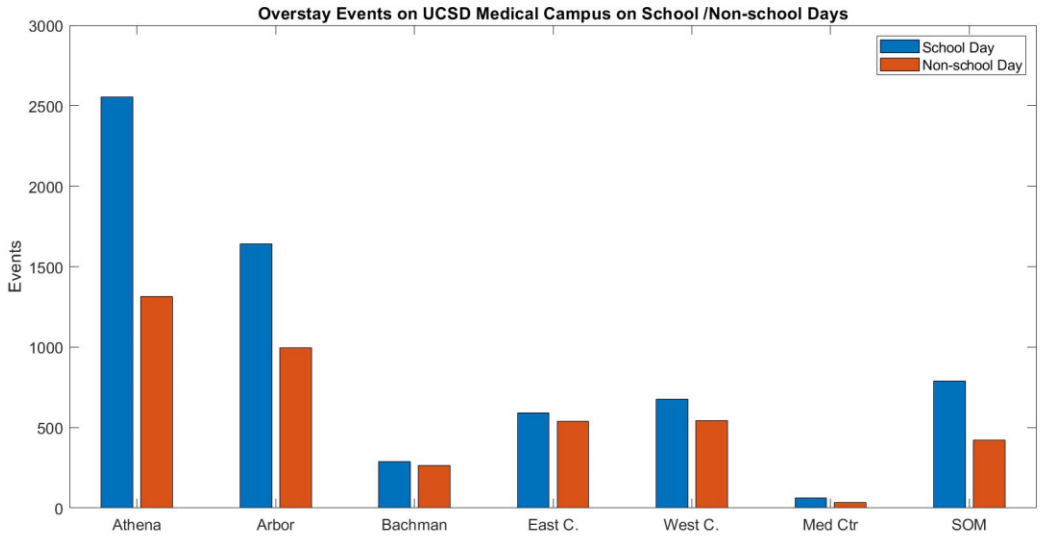

Figure A11: Overstay events on Medical Campus on school and non-school days as defined by the University's academic calendar. Athena and Arbor (Hillcrest) plazas constitute for more than 50% of overstay events recorded on both school and non-school days. This is expected as these two plazas are the largest for the La Jolla and Hillcrest medical campuses respectively. The other plazas show almost similar numbers and this can be attributed to the fact that most of the users at these plazas must be healthcare workers who work year-round while higher numbers at Athena and Arbor plazas on school days could likely be due to use of stations by students.

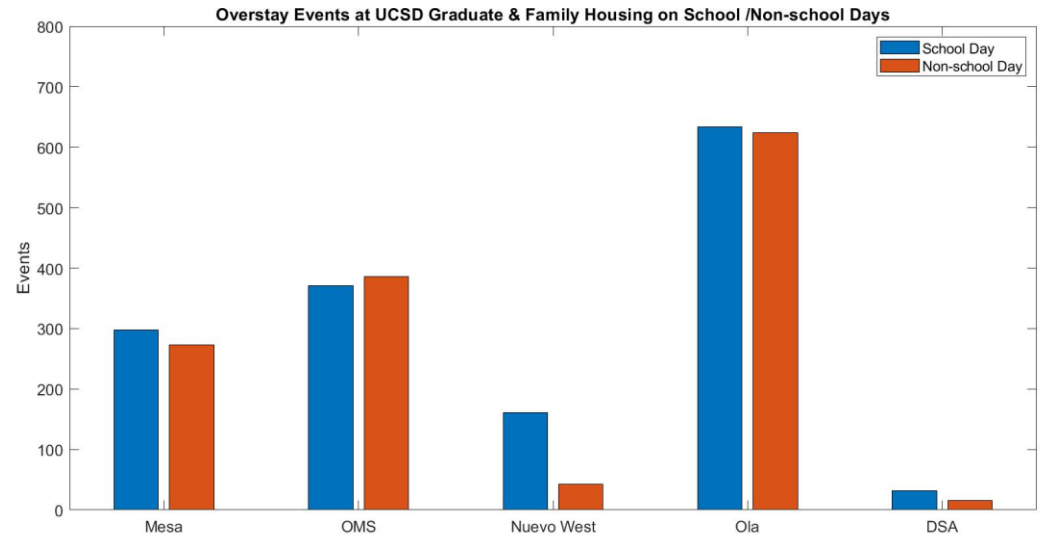

Figure A12: Overstay events at GFH Community on school and non-school days as defined by the University's academic calendar. Nuevo West shows significantly higher overstay occurrence and probably for reasons similar to those stated for the anomaly in Figure A4.

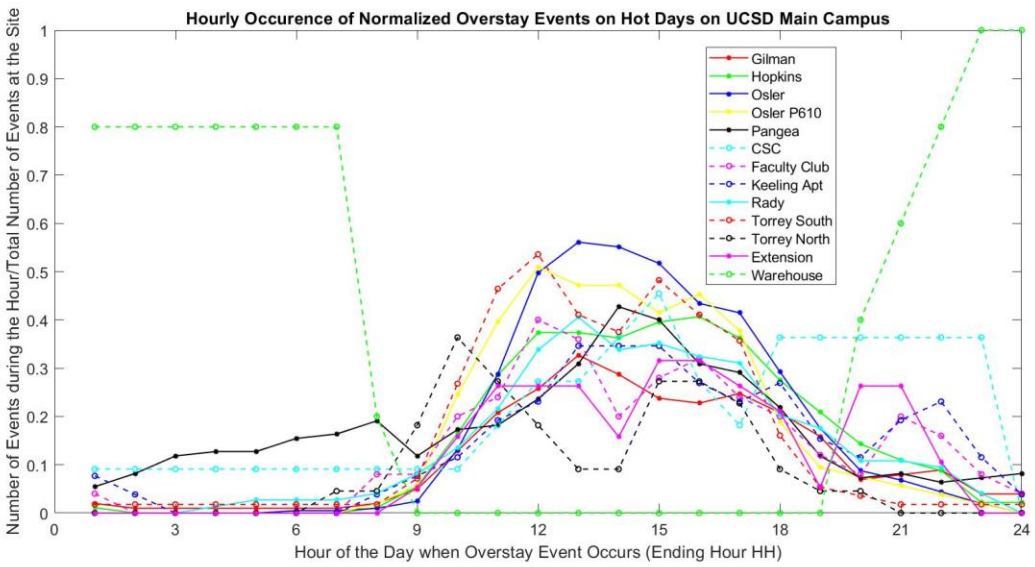

Figure A13: Hourly occurrence of normalized overstay events on Main Campus on days with high daytime temperatures. Pangea, Torrey Pines Center South, Osler and Osler P610 show a small but considerable increase in overstay occurrence on hot days when compared to other days in 2019 while several plazas show a significantly reduced overstay rate between 12 PM and 4PM (selected time window for comparison) on hot days.

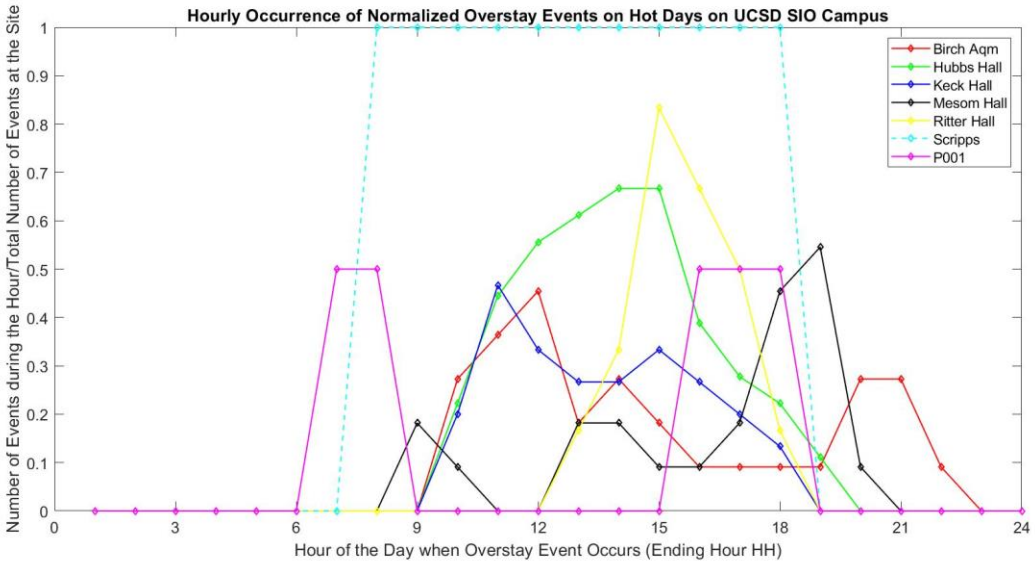

Figure A14: Hourly occurrence of overstay on SIO Campus on hot days. Hubbs, Ritter, Mesom plazas show 15-20% increase in occurrence of overstay during midday on hot days when compared with Figure A2. These plazas seem to have significant effect on overall overstay shown in Figure 4.5. Plaza P001 shows lowest recorded overstay numbers while Scripps shows the highest for the 12PM – 4PM time window which is due to very low number of overstay events on those days.

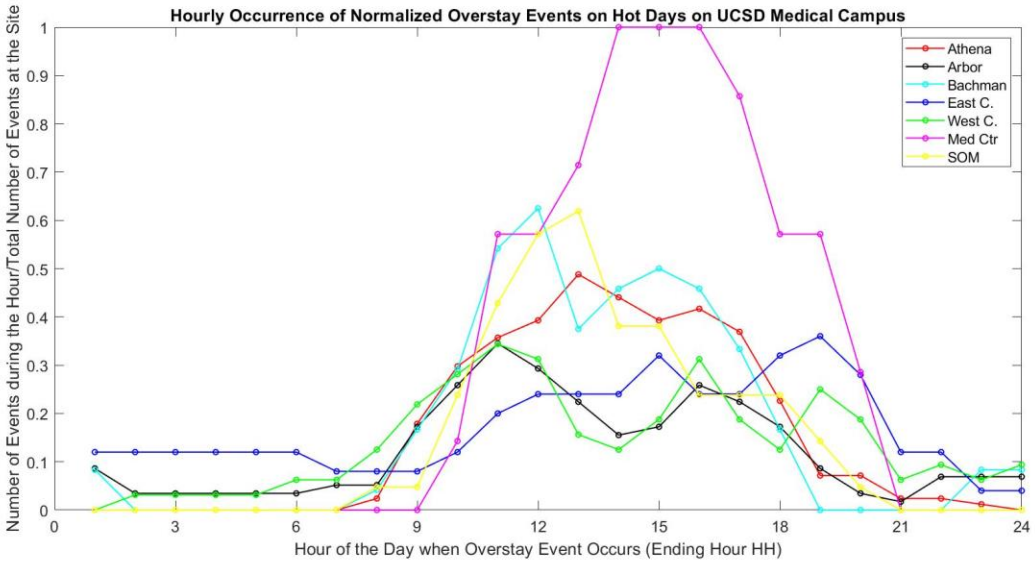

Figure A15: Hourly occurrence of overstay on Medical Campus on hot days. Overstay rate on hot days is higher by around 5-10% compared with that in Figure A3 during 12PM – 4PM time window for Bachman, SOM, Athena plazas whereas other plazas show slightly higher/similar rates of overstay on hot days than on other days. The Medical Center plaza shows a 30-35% increase (highest) in overstay occurrence on hot days when compared with Figure A3.

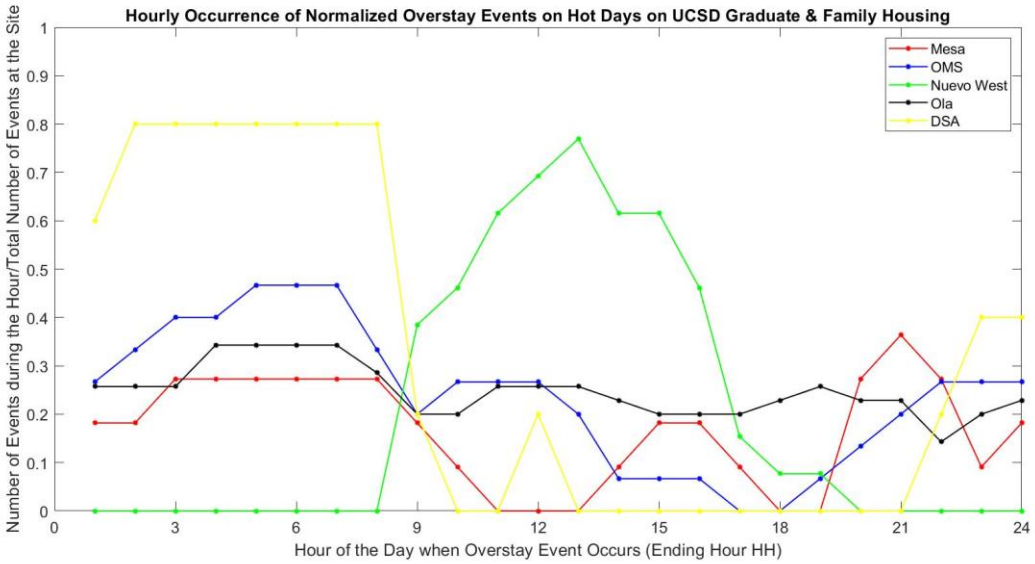

Figure A16: Hourly occurrence of overstay at GFH Community on hot days. Overstay events at Nuevo West plaza seem to have a significant effect on cumulative GFH overstay rate on hot days (refer Figure 4.5) from 12PM to 4PM. Mesa and DSA show very few overstay events during peak sunshine hours. Comparing with Figure A4, overstay during midday on hot days at GFH seems to be higher by approximately 10% for Nuevo West and lower or almost equal for other plazas.

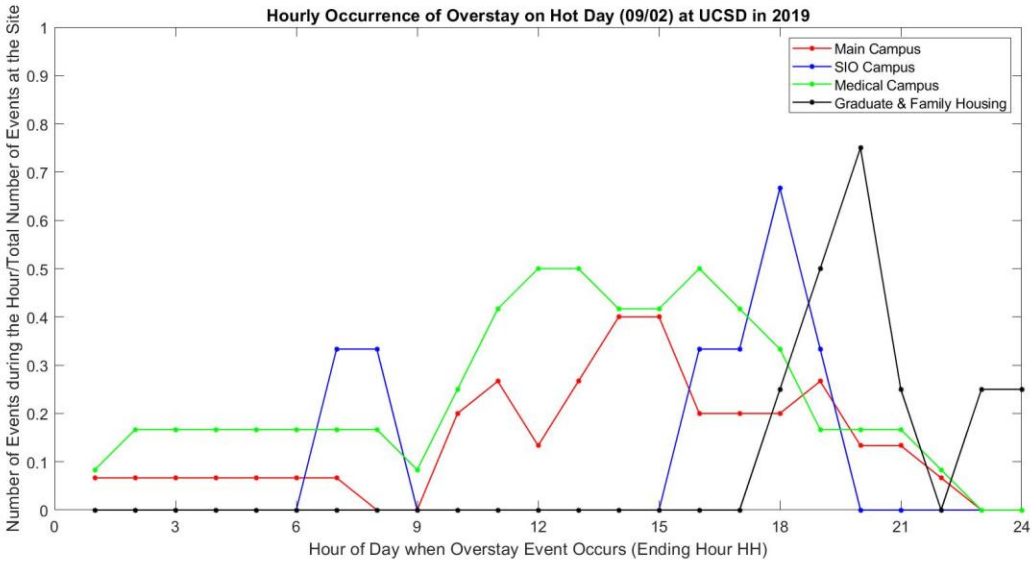

Figure A17: Hourly occurrence of overstay on each sub-campus on hot day – 09/02/2019. Time period chosen: 12PM – 4PM

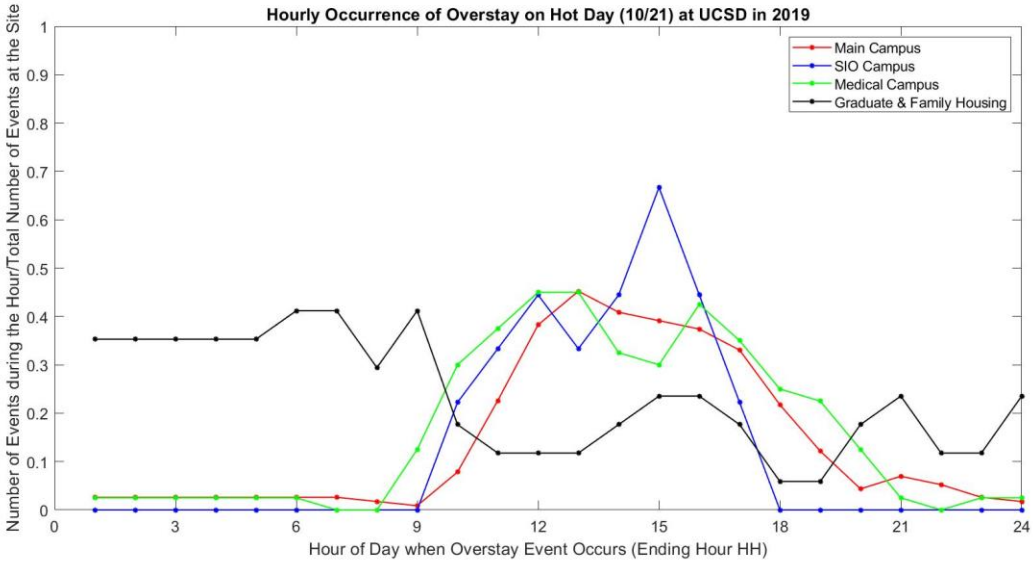

Figure A18: Hourly occurrence of overstay on each sub-campus on hot day – 10/21/2019. Time period chosen: 12PM – 4PM

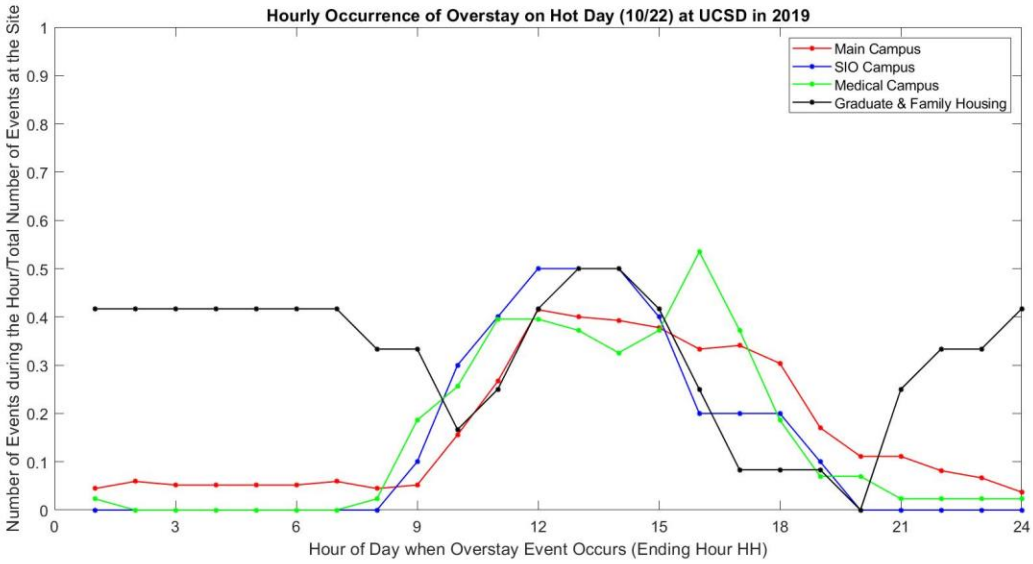

Figure A19: Hourly occurrence of overstay on each sub-campus on hot day – 10/22/2019. Time period chosen: 12PM – 4PM

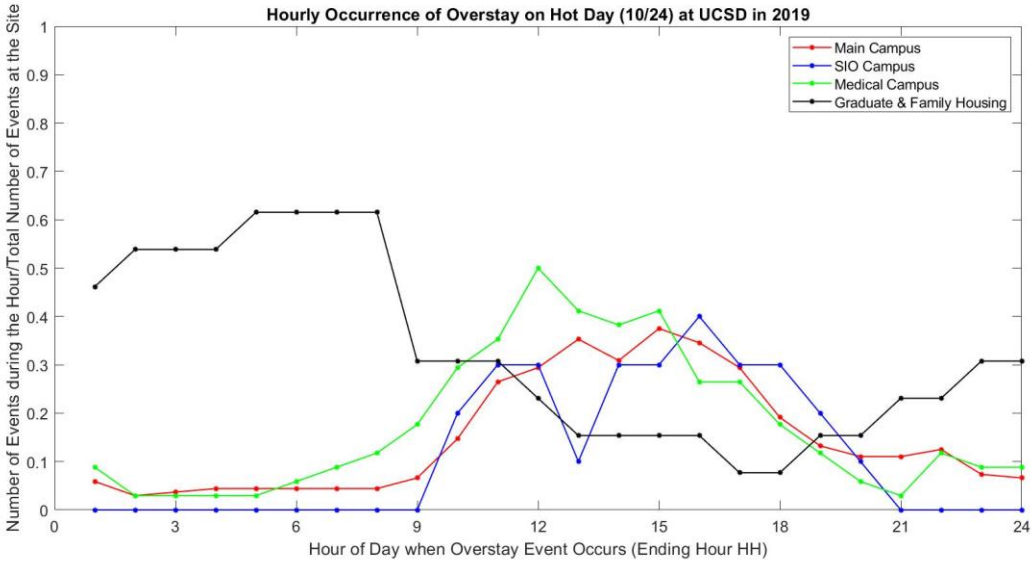

Figure A20: Hourly occurrence of overstay on each sub-campus on hot day – 10/24/2019. Time period chosen: 12PM – 4PM

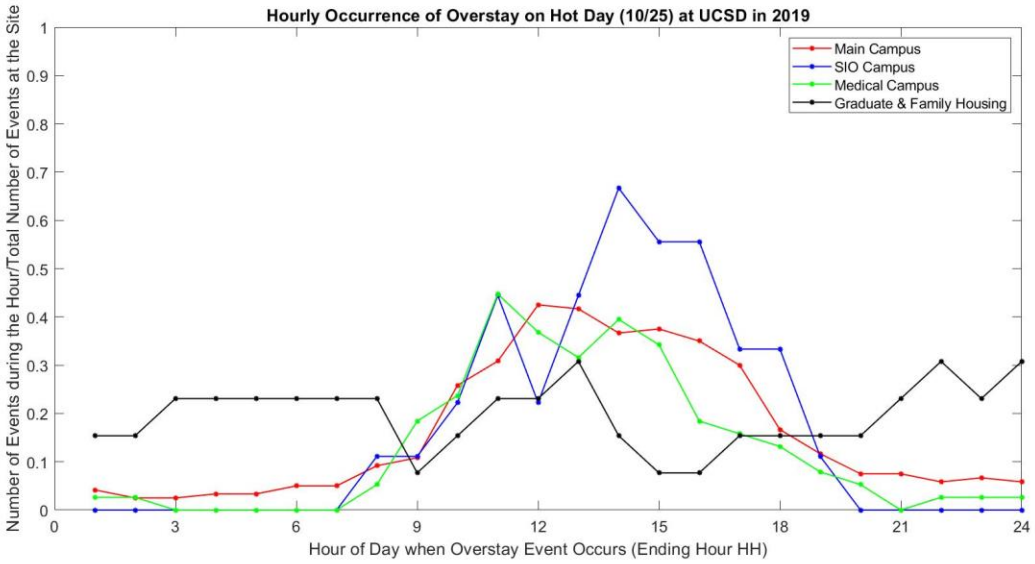

Figure A21: Hourly occurrence of overstay on each sub-campus on hot day – 10/25/2019. Time period chosen: 12PM – 4PM

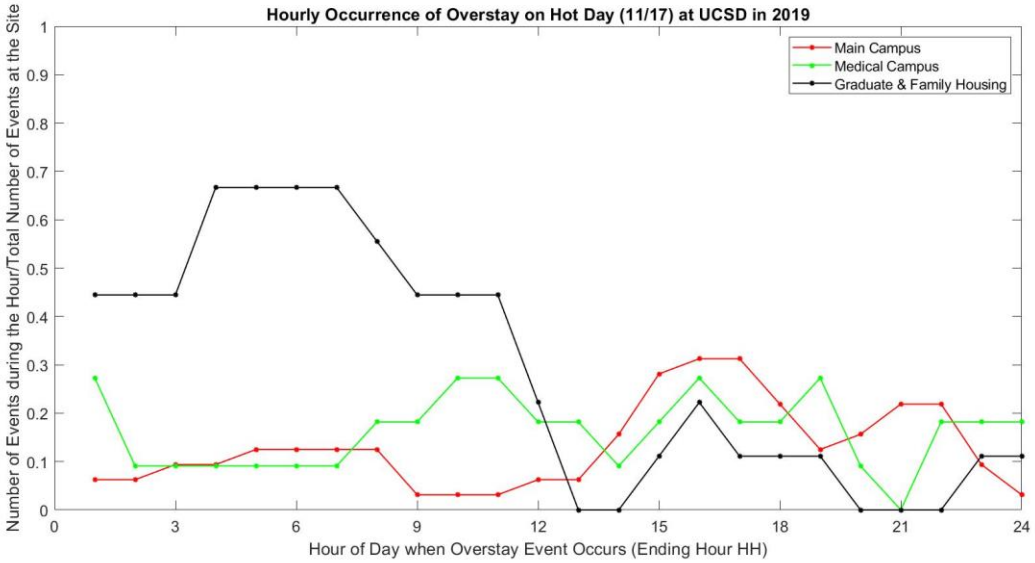

Figure A22: Hourly occurrence of overstay on each sub-campus on hot day – 11/17/2019. Time period chosen: 12PM – 4PM

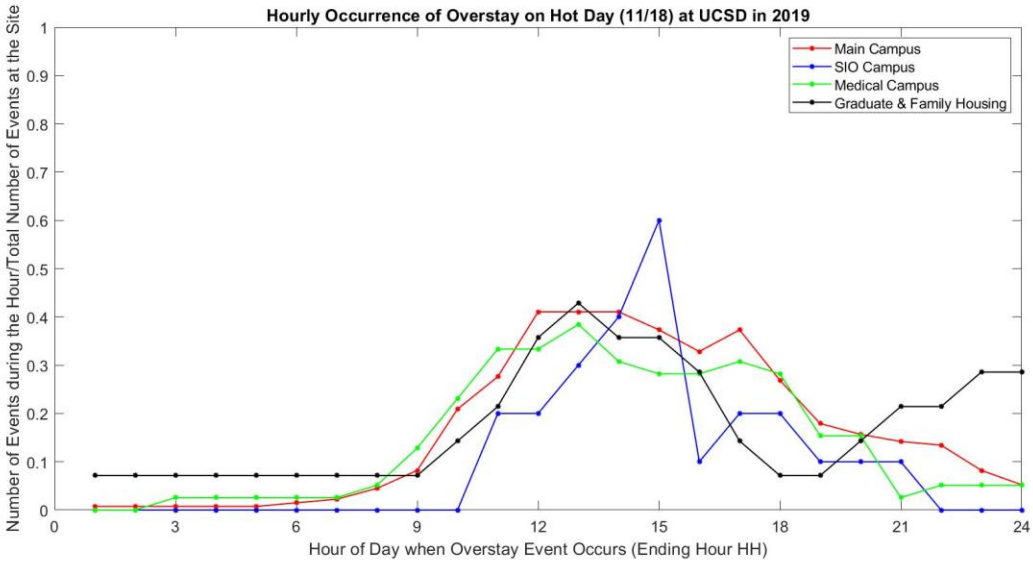

Figure A23: Hourly occurrence of overstay on each sub-campus on hot day – 11/18/2019. Time period chosen: 12PM – 4PM

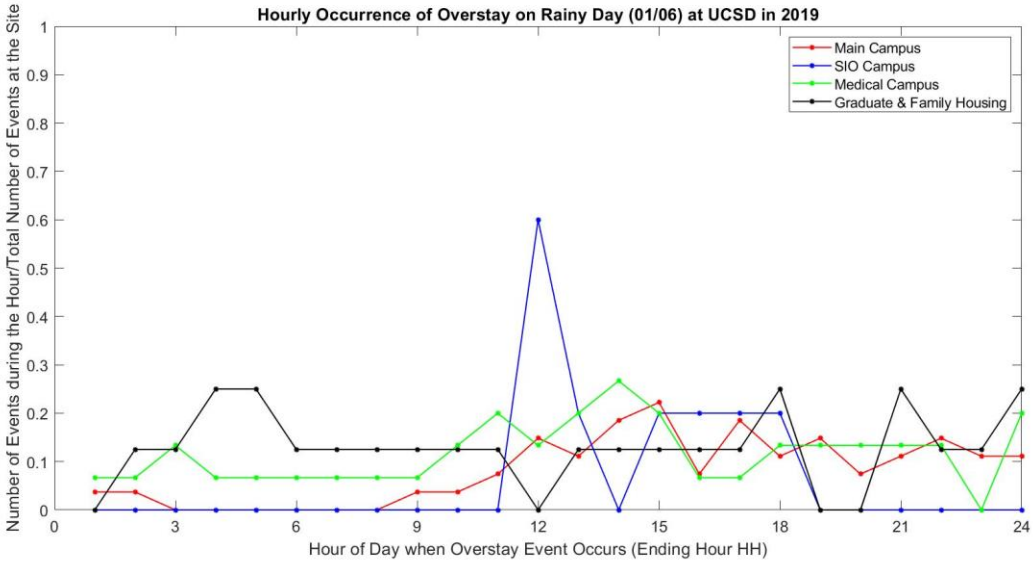

Figure A24: Hourly occurrence of overstay on each sub-campus on rainy day – 01/06/2019. Hours of rainfall: 5AM – 7AM

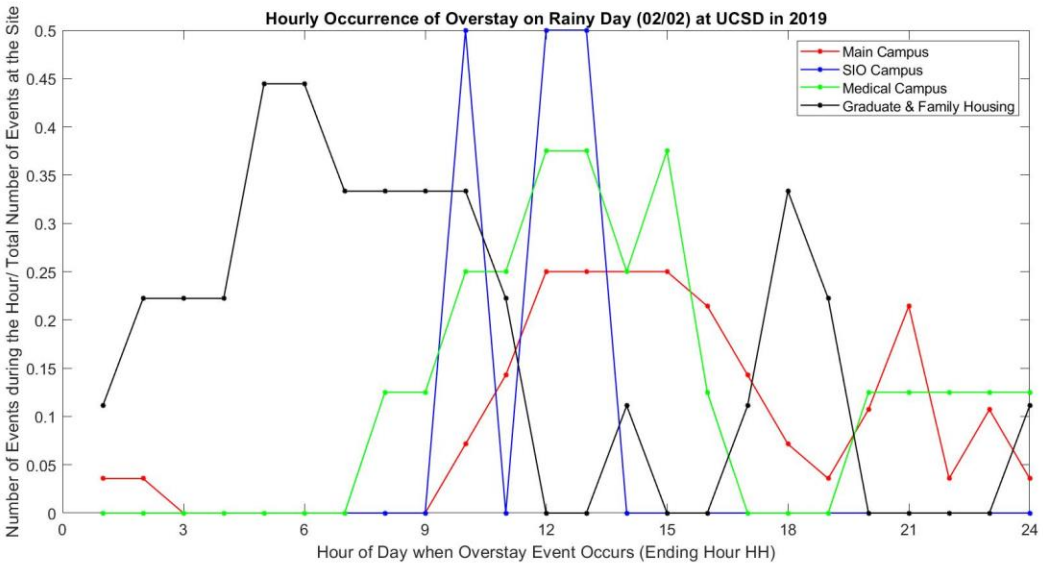

Figure A25: Hourly occurrence of overstay on each sub-campus on rainy day – 02/02/2019. Hours of rainfall: 5PM – 7PM

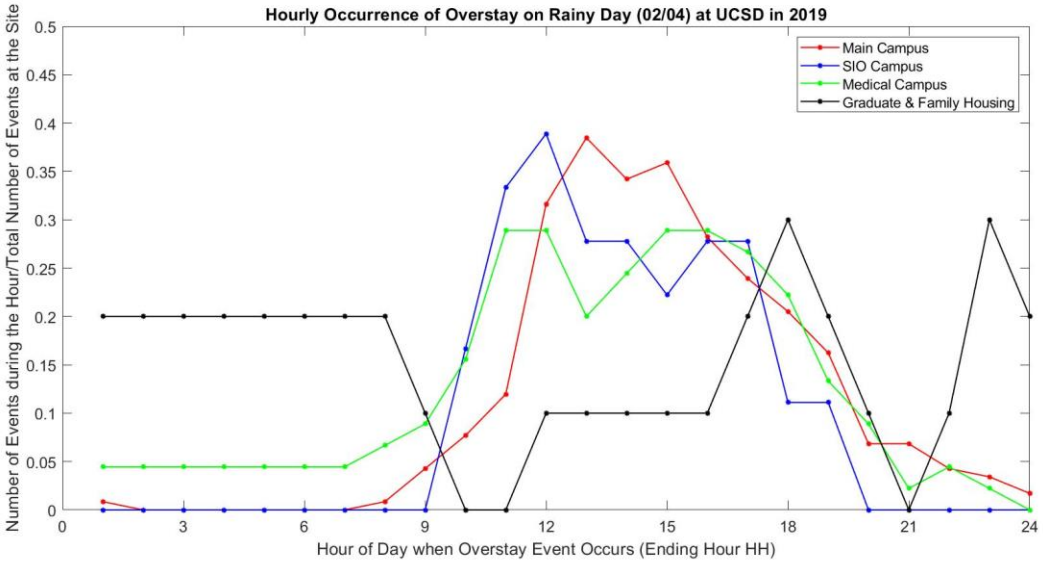

Figure A26 Hourly occurrence of overstay on each sub-campus on rainy day – 02/04/2019. Hours of rainfall: 7AM – 9AM, 1PM – 2PM, 6PM – 7PM

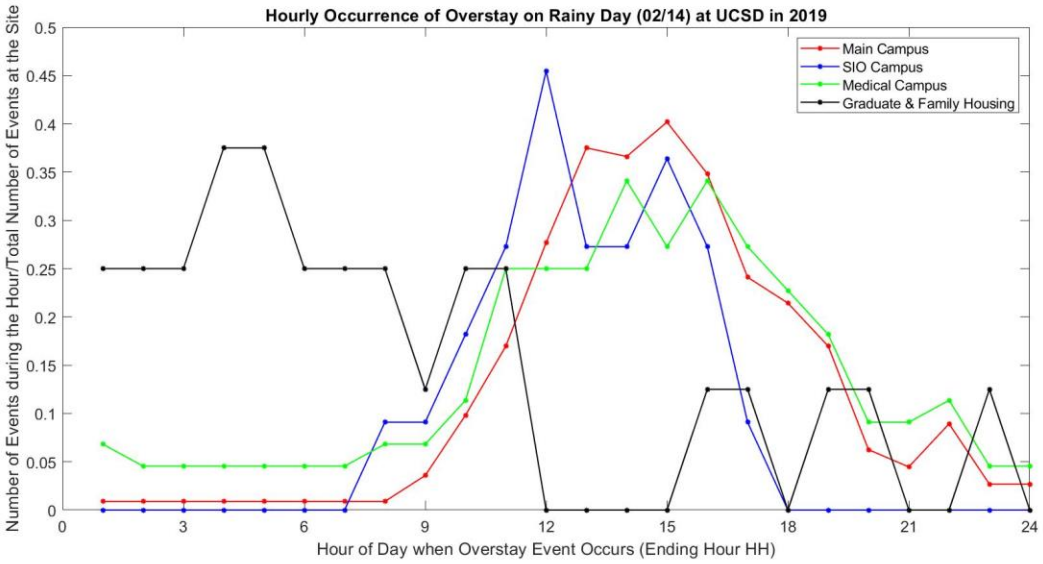

Figure A27: Hourly occurrence of overstay on each sub-campus on rainy day – 02/14/2019. Hours of rainfall: 10AM – 11AM, 2PM – 3PM

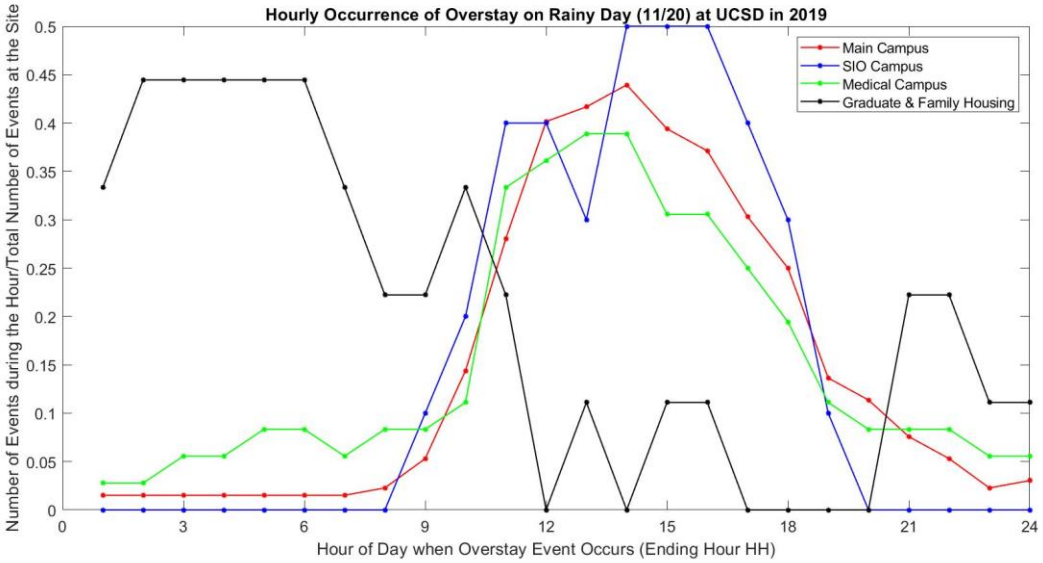

Figure A28: Hourly occurrence of overstay on each sub-campus on rainy day – 11/20/2019. Hours of rainfall: 7PM – 8PM

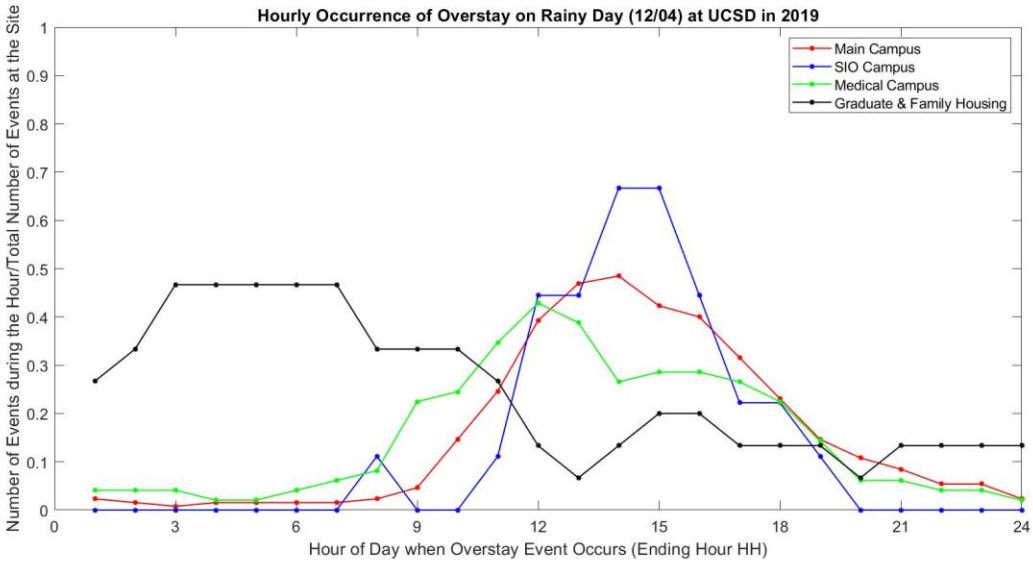

Figure A29: Hourly occurrence of overstay on each sub-campus on rainy day – 12/04/2019. Hours of rainfall: 9AM – 12PM

Bibliography

[1] Veloz. “EV Market Report.” Veloz, 14 Aug. 2021, www.veloz.org/sales-dashboard.

[2] California Energy Commission (2021). “California Energy Commission Zero Emission Vehicle and Infrastructure Statistics.” Data last updated [June 30, 2021]. Retrieved [August 12, 2021] from http://www.energy.ca.gov/zevstats.

[3] Christine Clark and Lily Chen. “UC San Diego’s EV Charging Program Awarded for Modeling ‘Energy System of the Future.’” UC San Diego News Center, 20 June 2018, ucsdnews.ucsd.edu/pressrelease/uc_san_diegos_ev_charging_program_awarded_for_modeling_energy_system_of_the.

[4] Graham McClone, Jan Kleissl, Byron Washom and Sushil Silwal. “Impact of the Coronavirus Pandemic on Electric Vehicle Workplace Charging.” Journal of Renewable and Sustainable Energy, vol. 13, no. 2, 2021, p. 025701. doi:10.1063/5.0038641.

[5] Ioana Patringenaru. “We Need to Build More EV Fast-Charging Stations, Researchers Say.” UC San Diego Jacobs School of Engineering, 5 May 2021, jacobsschool.ucsd.edu/news/release/3275.

[6] Arias, Mariz B., and Sungwoo Bae. “Electric Vehicle Charging Demand Forecasting Model Based on Big Data Technologies.” Applied Energy, vol. 183, 2016, pp. 327–39. doi:10.1016/j.apenergy.2016.08.080.

[7] UC San Diego. “Strategic Energy Initiatives.” Resource Management and Planning, 2021, rmp.ucsd.edu/strategic-energy/index.html.

[8] UC San Diego. “EV Charging Stations.” Transportation Services, 2021, transportation.ucsd.edu/commute/ev-stations.html.

[9] “5 Ways to Master EV Etiquette.” ChargePoint, 2018, www.chargepoint.com/blog/5-ways-master-ev-etiquette/#:%7E:text=The%20ChargePoint%20app%20will%20let,them%20from%20getting%20a%20charge.

[10] UC San Diego. “Academic and Administrative Calendar.” Blink, 2021, blink.ucsd.edu/instructors/resources/academic/calendars.

[11] National Centers for Environmental Information (NCEI). “Search | Climate Data Online (CDO) | National Climatic Data Center (NCDC).” National Oceanic and Atmospheric Administration (NOAA), 2021, www.ncdc.noaa.gov/cdo-web/search.

[12] Weather Underground. “Local Weather Forecast, News and Conditions.” Weather Underground, 2019, www.wunderground.com.

[13] S. Bae, T. Zeng, B. Travacca and S. Moura, "Inducing Human Behavior to Alleviate Overstay at PEV Charging Station," 2020 American Control Conference (ACC), 2020, pp. 2388-2394, doi: 10.23919/ACC45564.2020.9147587.