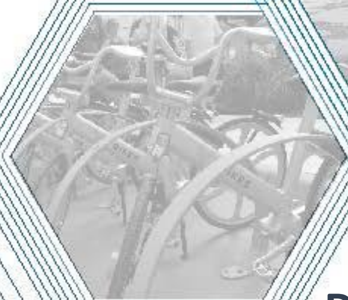

Distribution of Potential Benefits across Stakeholder Groups for Shared Electric Vehicles Serving Multi-University Commute Travel

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FINAL REPORT

Center for Transportation Equity, Decisions & Dollars

DISTRIBUTION OF POTENTIAL BENEFITS ACROSS STAKEHOLDER GROUPS FOR SHARED ELECTRIC VEHICLES SERVING MULTI-UNIVERSITY COMMUTE TRAVEL

FINAL PROJECT REPORT

By:

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Randall Guensler
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16. Abstract

Transit, shared mobility, and vehicle electrification serve as major enablers of transportation decarbonization. Several shared mobility has been offered in the US and abroad, with a major focus on implementation on university campuses and at airports. However, combined offerings of shared and electric vehicles providing on-demand service rather than route-based service are still forthcoming. In this project, we conducted a comparative study of greenhouse gas (GHG) reduction potential and potential equity impacts of the deployment of shared electric vehicles servicing student, faculty, and staff commute travel to and from three university campuses –Cal Poly, Georgia Tech, and UT Arlington.

This research project 1) identified the potential users and use cases of shared electric vehicles serving university commute travel; 2) estimated the potential for GHG reduction and other benefits for different technology deployment and policy scenarios; 3) assessed the distributional differences of the estimated benefits across stakeholder groups; and 4) recommended measures to remove barriers to adoption of shared electric vehicles and increase equitable shared electric fleet programs.

In this project, the three teams surveyed potential users of shared and electric fleets. To this end, all three campuses utilized the large-scale transportation survey data to obtain sociodemographic and travel behavior characteristics of the students, staff, and faculty.

17. Key Words

Shared mobility; Equity; Electrification; Adoption

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Abbreviations and Acronyms

API: Application Programming Interface

Ave.: Avenue

CH4: Methane

CO: Carbon Monoxide

CO2: Carbon Dioxide

CO2e: Carbon Dioxide Equivalent

CSV: Comma-Separated Values

DMP: Data Management Platform

Dr.: Drive

EMFAC: Emission Factors

EPA: Environmental Protection Agency

EV: Electric Vehicle

GGMAP: R package used to create maps

GHG: Greenhouse Gas

GWP: Global Warming Potential

Hr.: Hour

LDA: Passenger Cars

MCY: Motorcycles

MDHD: Medium Duty, Heavy Duty; in reference to Trucks

Mt.: Mount

MTCO2e: Metric Tons of Carbon Dioxide Equivalent

MVMT: Million Vehicle-Miles Traveled

N2O: Nitrous Oxide

NOx: Nitrogen Oxides

Rd.: Road

PC: Personal Computer

PCE: Passenger Car Equivalent

PM: Particulate Matter

PM2.5: Particulate Matter, diameter of 2.5 microns or less

PM10: Particulate Matter, diameter of 10 microns or less

PMBW: Brake Wear Particulate Matter Emissions

RUNEX: Running Exhaust Emissions

SLO: San Luis Obispo

SOx: Sulfur Oxides

U-BUS: Urban Buses

VMT: Vehicle-Miles Traveled

Executive Summary

This study observes and analyzes response data from a California Polytechnic State University San Luis Obispo campus-wide transportation survey conducted in the spring of 2022. In some instances (such as observing shifts in transportation mode usage and comparing differences in VMT, vehicle-miles traveled, and GHG, greenhouse gas, emissions), this study compares data from 2015 and/or 2018 with the data obtained from the 2022 survey. Additionally, this study seeks to document the methodology behind and obtain data regarding VMT and GHG emissions from survey response data. In calculating VMT and GHG emissions, external sources such as GGMAP were used for programming, and EMFAC and GWP were consulted in obtaining factors necessary for the calculation. Finally, this study also explored the methodology behind collecting traffic data at five road segments leading towards/away from campus and displays the resulting data.

Due to the COVID-19 pandemic, it is thought that mode usage shifted from shared modes such as buses and carpooling to more individual modes such as bicycling and driving alone. However, responses from the 2022 data shows that this is not necessarily the case, as only 11% of respondents indicated that they changed travel modes due to the pandemic. Additionally, overall, the number of individuals driving alone reduced, while the number of individuals bicycling, walking, and riding the bus (for students) increased between the years of 2018 and 2022.

Calculations of VMT for this 2022 survey display that the total estimated weighted yearly VMT is 46.8 million. The largest contribution to the VMT was from those who traveled by gas-powered cars. This is unsurprising, as driving alone and carpooling/vanpooling were reported to be used by those with the largest commute distances per the 2022 survey. Qualitative results were similar from the previous 2018 survey, although the numerical data differed (for example, the average commute distances increased between the 2018 and 2022 surveys). Significantly far behind in VMT contribution were electric vehicles (EVs) followed by buses and motorcycles, per the 2022 survey results.

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Chapter I: Survey Design

Participant Outreach

To bring awareness to the campus community regarding this survey, the team worked with university communications to send the survey link to all campus community members. Both an initial email introducing the survey and a reminder email were sent to the campus community. Figure # below displays the reminder email; this email is similar to the initial survey email.

Figure 1.1 Survey reminder email.

REMINDER: Cal Poly Campus Transportation Survey 2022

A team of Administration and Finance staff and Civil and Environmental Engineering faculty is conducting a comprehensive transportation survey that will help develop the Cal Poly Transportation Demand Management Plan in support of the Campus Master Plan and the California State University Climate Action Plan.

The information obtained through this survey will help us understand how you get to and from campus and whether you travel to the university every day or once a month, so we can better understand your transportation needs and the resulting emissions. It will also inform mitigation efforts to minimize environmental impacts.

The survey is now available and will be open until midnight on Friday, May 27th:

https://survey.alchemer.com/s3/6824576/CampusTransportationSurvey2022

It should take roughly 10 minutes to complete and is anonymous. Once submitted you will be entered into a raffle for prizes that include an e-bike, an iPad and gift vouchers.

If you have any questions or would like additional information, please contact: sustainability@calpoly.edu

Based on these outreach efforts, the survey team received 1,791 responses. The total campus community member count was 24,969 at the time of the survey, leading to a response rate of 11%. This response rate is similar to that of the most recent two transportation surveys. Table

1.1 below displays the campus member counts and survey response trends for the four most recent transportation surveys.

Survey year	Survey administration dates	Reference week	Total Campus population	Total Survey Respondents	Response Rate
2015	June 9 - June 15	NA	22,898	4,272	19%
2018	May 29 - June 8	May 20 - May 26	25,170	2,625	10%
2019	January 22 - February 1	Most recent 7 days	24,969	2,809	11%
2022	May 6 - May 27	Most recent 14 days	24,950	2,769	11%

Table 1.1 Survey timing and response rates.

The overall response rate can be further broken down into rates by respondent category; these rates are displayed in Table 1.2 below. There is a discrepancy in the sum of the number of responses in Table 1.2 and the total responses reported in above Table 1.1, as 113 respondent categories were marked as blank. As can be seen, the response rate was highest amongst full-time staff members, and lowest amongst part-time staff and undergraduates who are second years and older.

Respondent Category	Campus Population	Number of Responses	Response Rate
Faculty, Full-time	892	253	28%
Faculty, Part-time	518	65	13%
Staff, Full-time	1,292	574	44%
Staff, Part-time	226	16	7.1%
Undergraduate, 1st Year	3,866	402	10%
Undergraduate, 2nd Year and Above	17,227	1209	7.0%
Graduate	929	137	15%

Table 1.2. Response rates per respondent category.

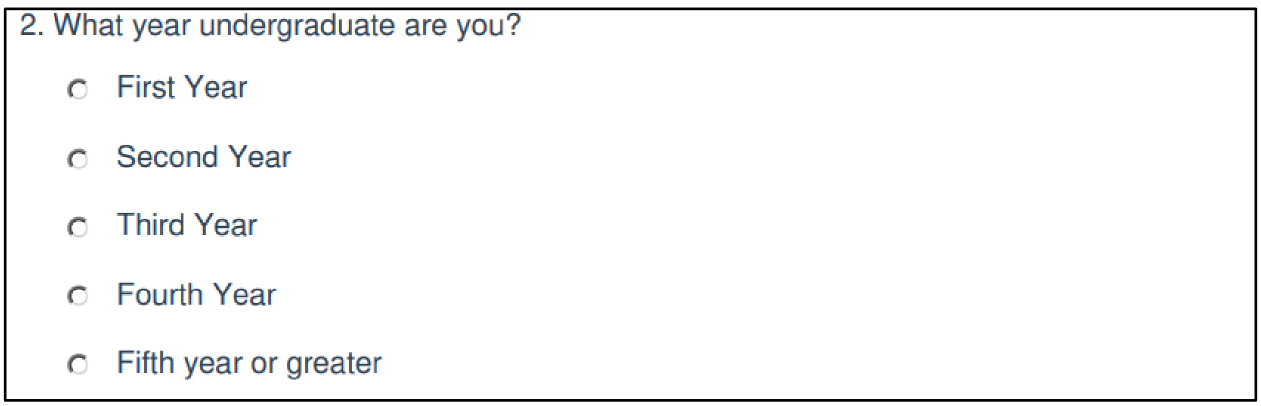
Modifications to 2022 Survey

There were a number of modifications made to the survey sent out in 2022 from the survey in 2018. This involved adding questions to the survey and altering the wording of particular questions. No questions were removed fully from the 2018 survey when composing the 2022 survey.

Questions Added to 2022 Survey

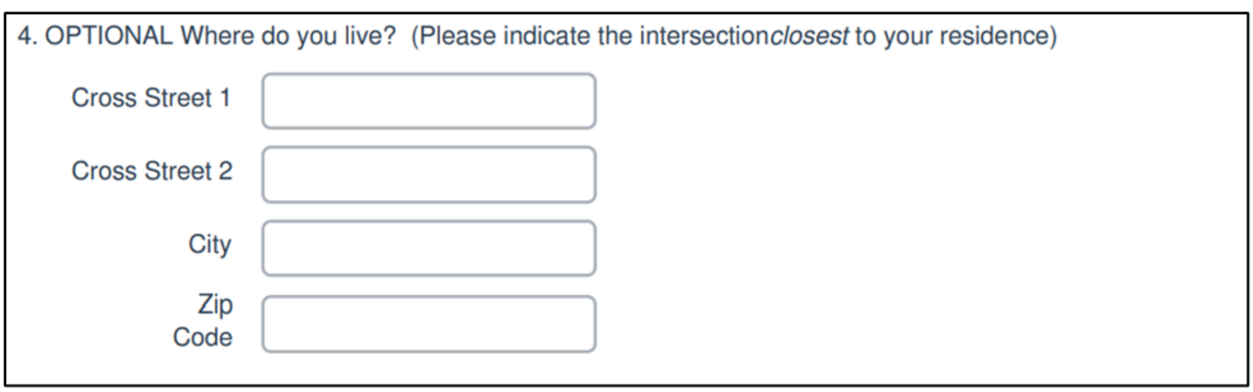
The following are questions that did not exist in the 2018 version but were added to the 2022 survey. The main goal of these added questions was to collect more detailed and comprehensive data regarding the survey respondents. A few questions were also added to collect information on how the COVID-19 pandemic (which was not present at the time of the 2018 survey) may have impacted travel patterns of survey respondents. For simplicity, the descriptions and reasoning behind each question addition are provided within the Figure label.

Figure 1.2. First question added to 2022 survey, used to further organize the student respondents and study patterns of commuting based on year in the university.


2. What year undergraduate are you?

- First Year
- Second Year
- Third Year
- Fourth Year
- Fifth year or greater

Figure 1.3. Second question added to 2022 survey, used to indicate more precisely where respondents are commuting to campus from and to be able to generate a heatmap (see "Results and Discussion" within the VMT methodology section) of this data.


4. OPTIONAL Where do you live? (Please indicate the intersection *closest* to your residence)

Cross Street 1

Cross Street 2

City

Zip Code

Figure 1.4. Third question added to 2022 survey, used to get an idea of which respondents are actively traveling to/from campus or are temporarily prevented from doing so due to the COVID-19 pandemic.

5. Have you been to campus in the past two weeks?*

- ○ Yes, have been to campus because my work/school is all in-person
- ○ Yes, I come to campus, but I also can work/do school remotely (telecommute)
- ○ No, I don't ever come to campus because all my work/school is remote (telecommute)
- ○ No, I have been sick/quarantining

Figure 1.5. Fourth and fifth questions added to 2022 survey, used to generate data specific to the COVID-19 pandemic.

9. Has the COVID-19 pandemic had an effect on which mode you chose/choose?*

- ○ No, COVID-19 has not affect my mode choice
- ○ Yes, I have switched modes due to the COVID-19 pandemic

10. If yes, how have your travel modes changed?

I switched from

Driving alone
Bus
Walking
Biking
Carpooling
Vanpool
Motorcycling/Motorized scooter
Ride-hailing app (Uber/Lyft)

to

Driving alone
Bus
Walking
Biking
Carpooling
Vanpool
Motorcycling/Motorized scooter
Ride-hailing app (Uber/Lyft)

Figure 1.6. Seventh, eighth, and ninth questions added to 2022 survey, to include information from respondents regarding EV ownership and habits.

20. Do you have an electric vehicle (EV), including plug-in hybrid or battery electric, that you currently use to commute to campus? *

- Yes
- No

21. Do you intend to begin commuting to campus in an EV?

- No
- Yes, within 1 year
- Yes, in 2-3 years
- Yes, in 3-5 years
- Yes, in 5+ years
- Do not know

22. How often do you charge your electric vehicle on campus?

- Never
- 1-2 days per week
- 3-4 days per week
- 5+ days per week

Figure 1.7. Tenth question added to the 2022 survey, and this textbox was originally part of another question in the 2018 survey but was presented as an individual question in the 2022 version.

27. Additional comments regarding alternative forms of transportation (other than a person vehicle) that you use to travel to and from campus?

Figure 1.8. Eleventh question added to the 2022 survey, to study in more detail the commuting patterns of respondents throughout the week.

28. In the past 7 days, check which, if any of the the following modes you used to travel to and from home and campus? (Leave blank transportation types and days not traveled)

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Drive Alone	☐	☐	☐	☐	☐	☐	☐
Telecommute/remote work	☐	☐	☐	☐	☐	☐	☐
Bus	☐	☐	☐	☐	☐	☐	☐
Walk	☐	☐	☐	☐	☐	☐	☐
Bike/scooter/skateboard	☐	☐	☐	☐	☐	☐	☐
Rideshare (carpool/vanpool/Uber or Lyft/dropped off)	☐	☐	☐	☐	☐	☐	☐

In addition to the above questions, the 2022 survey includes a series of self-identifying questions from the following list (all of which are optional for respondents):

- What gender do you most strongly identify with?
- Which racial/ethnic category do you most strongly identify with?
- In what year were you born?
- Not including yourself or roommates, how many people in each of the following age categories live in your household?
- What is your total household annual income?

Questions Altered between 2018 and 2022 Surveys

The following are a series of questions that were altered between the 2018 and 2022 surveys. Sequentially, within the following sets of figures, the 2018 version appears first and the 2022 version appears second.

Figures 1.9 and 1.10. The first set of altered questions, shortened in the 2022 survey to make it more user-friendly for respondents and to obtain a more concise set of response data from this question.

* 2. Do you live:

- On-campus, student in resident student housing (RAs should classify themselves as students)
- On-campus, faculty or staff in campus housing (RAs should classify themselves as students)
- Off-campus, within 1 mile of campus
- Off-campus, 1 to 1.9 miles from campus
- Off-campus, 2 to 2.9 miles from campus
- Off-campus, 3 to 4.9 miles from campus
- Off-campus, 5 to 9.9 miles from campus
- Off-campus, 10 to 14.9 miles from campus
- Off-campus, 15 to 19.9 miles from campus
- Off-campus, 20 to 29.9 miles from campus
- Off-campus, 30 to 39.9 miles from campus
- Off-campus, 40 to 49.9 miles from campus
- Off-campus, 50 or more miles from campus

3. Do you live: *

- On-campus, student in resident student housing (RAs should classify themselves as students)
- On-campus, faculty or staff in campus housing (RAs should classify themselves as students)
- Off-campus, within 1 mile of campus
- Off-campus, within 1 to 2.9 miles from campus
- Off-campus, within 3 to 9.9 miles from campus
- Off-campus, 10 or more miles from campus

Figure 1.11 and 1.12. Second set of altered questions, in which “Bicycling”, “Vanpooling”, and “Other” were added as responses, “Skateboarding/Longboarding” was removed, and “Public transportation” was replaced with “Bus”.

* 3. How do you most frequently travel to and from campus?

- Driving alone
- Carpooling
- Getting dropped off
- Motorcycling/scootering
- Public transportation
- Cycling
- Skateboarding/Longboarding
- Walking
- Ride-hailing app (e.g., Lyft or Uber)

6. How do you most frequently travel to and from campus? *

- ○ Driving alone
- ○ Bus
- ○ Walking
- ○ Bicycling
- ○ Carpooling
- ○ Vanpool
- ○ Dropped off
- ○ Motorcycling/Motorized scooter
- ○ Ride-hailing app (Uber/Lyft)
- ○ Other - Write In

Figure 1.13 and 1.14. Third set of altered questions, in which “Bicycling”, “Vanpooling”, and “Other” were added as responses, “Skateboarding/Longboarding” was removed, and “Public transportation” was replaced with “Bus”.

* 5. What other modes do you or have you ever used to get to and from campus? (Please choose all that apply.)

- ☐ Driving alone
- ☐ Carpooling
- ☐ Getting dropped off
- ☐ Motorcycling/scootering
- ☐ Public Transportation
- ☐ Cycling
- ☐ Walking
- ☐ Ride-hailing app (e.g., Lyft or Uber)
- ☐ None of these

8. What *other* modes do you or have you ever used to get to and from campus? (Please choose all that apply)

- ☐ Driving alone
- ☐ Bus
- ☐ Walking
- ☐ Bicycling
- ☐ Carpooling
- ☐ Vanpool
- ☐ Getting dropped off
- ☐ Motorcycling/Motorized scooter
- ☐ Ride-hailing app (e.g., Lyft or Uber)
- ☐ None of these
- ☐ Other - Write In

Figure 1.15 and 1.16. Fourth set of altered questions, in which the options of "Safety" and "The COVID-19 Pandemic" were added and the scale of importance was altered to be clearer and more comprehensive for survey respondents.

10. How important are the following factors in determining what mode of transportation (e.g., walk, bike, ride transit, drive, etc.) you use to travel to campus?

	Not at all important	Not very important	Somewhat important	Very important	N/A
Availability	○	○	○	○	○
Cost	○	○	○	○	○
Convenience	○	○	○	○	○
Environmental sustainability	○	○	○	○	○
Physical abilities or disabilities	○	○	○	○	○
Desire for exercise	○	○	○	○	○

16. How significant are the following factors in determining what mode of transportation (e.g., walk, bike, ride transit, drive, etc.) you use to travel to campus?

	Very significant	Somewhat significant	Neutral	Not very significant	Not at all significant	N/A
Availability	○	○	○	○	○	○
Cost	○	○	○	○	○	○
Convenience	○	○	○	○	○	○
Environmental sustainability	○	○	○	○	○	○
Safety	○	○	○	○	○	○
Physical abilities or disabilities	○	○	○	○	○	○
Desire for exercise	○	○	○	○	○	○
The COVID-19 pandemic	○	○	○	○	○	○

Figure 1.17 and 1.18. Fifth set of altered questions, in which the options of "Safety", "The COVID-19 Pandemic", and "Weather" were added to provide more comprehensive options for survey respondents to select.

11. Which one of these factors is most important to you?

- ○ Availability
- ○ Cost
- ○ Convenience
- ○ Environmental sustainability
- ○ Physical abilities or disabilities
- ○ Desire for exercise

17. Which one of these factors is most important to your transportation mode choice?

- ○ Availability
- ○ Cost
- ○ Convenience/time
- ○ Environmental sustainability
- ○ Safety
- ○ Physical abilities or disabilities
- ○ Desire for exercise
- ○ The COVID-19 pandemic
- ○ Weather

Figure 1.19 and 1.20. Sixth set of altered questions, in which the response options were re-ordered and the additional option of "Neutral" was added in order to provide a more comprehensive scale for survey respondents.

* 12. How much do you feel like your transportation choices impact Cal Poly's environmental sustainability?

Not at all	Somewhat	A lot	Not sure
○	○	○	○

18. How much do you feel like your transportation choices impact Cal Poly's environmental sustainability?*

A lot	Somewhat	Neutral	Not at all	Not sure
○	○	○	○	○

Figure 1.21 and 1.22. Seventh set of altered questions, in which additional, more detailed response options were provided to collect more comprehensive data.

* 14. Do you have a current Cal Poly parking permit?

- ○ Yes
- ○ No

23. Do you have a current Cal Poly parking permit?*

- ○ Yes, I have a pass for the academic school year
- ○ Yes, I have a monthly pass
- ○ No, I don't park on campus
- ○ No, I purchase daily/weekly permits or park at meters

Figure 1.23 and 1.24. Eighth set of altered questions, in which the commuter pass options had a specific number of cars and motorcycle, and evening permit options were added. The "None" options from the 2018 survey were removed, because, in the 2022 survey, the question prior is designed to have respondents skip this question if they do not have a permit.

15. What type of Cal Poly permit do you have?

Choices:

- Student Resident (campus housing)
- Student Commuter
- Student - None, I purchase daily or weekly permits
- Student - None, I don't park on campus
- Faculty/Staff permit
- Faculty/Staff - None, I purchase daily or weekly permits
- Faculty/Staff - None, I don't park on campus

24. What type of Cal Poly permit do you have?

Student Resident (campus housing)
Student Commuter (1 car)
Student Commuter (2+ cars/Carpool permit)
Faculty/Staff permit (1 car)
Faculty/Staff permit (2+ cars/Carpool permit)
Motorcycle permit
Evening permit

Figure 1.25 and 1./26. Ninth set of altered questions, in which the response options of "I don't have a vehicle" and "N/A (I did acquire a current parking permit" were removed because previous questions would have redirected a respondent who didn't have a vehicle or had a permit away from this question.

* 16. If you answered "no" to the question above, please tell us which reason below best represents why you have chosen not to acquire a permit?

- I prefer commuting by bus, carpool, or other modes of transportation
- Other options are less expensive or free
- Campus parking locations are inconvenient
- Campus parking is too difficult to find
- Permits are too expensive
- Other (please specify)
- Campus parking is unsafe
- I prefer to take my chances that I won't get a ticket
- I don't have a vehicle
- N/A (I did acquire a current parking permit)

25. If you answered "no" to the question above, please tell us which reason below best represents why you have chosen not to acquire a permit? *

- I prefer commuting by bus, carpool, or other modes of transportation
- Other options are less expensive or free
- Campus parking locations are inconvenient
- Campus parking is too difficult to find
- Permits are too expensive
- Campus parking is unsafe
- I prefer to take my chances that I won't get a ticket
- Other - Write In (Required)

Figure 1.27 and 1.28. Tenth set of altered questions, in which the "Carpool" and "Vanpool" options were combined into one for simplicity. Additionally, the scaling values were modified to be more descriptive and comprehensive for survey responses. Finally, the "Additional comments?" textbox was removed for this question, and made as its own free-standing question in the 2022 survey.

* 26. How willing would you be to try each of the following alternative forms of transportation?

	Not at all willing	Somewhat willing	Very willing	I already use this mode at least sometimes	Not sure
Public Transit	○	○	○	○	○
Carpool	○	○	○	○	○
Vanpool	○	○	○	○	○
Walk	○	○	○	○	○
Bicycle	○	○	○	○	○

Additional comments?

26. How willing would you be to try each of the following alternative forms of transportation to travel to and from campus? *

	I already use this mode frequently	Very willing to use this mode	Sometimes willing to use this mode	Probably not willing to use this mode	Not at all willing	Never considered it	N/A
Public Transit	○	○	○	○	○	○	○
Carpool/Vanpool	○	○	○	○	○	○	○
Walking	○	○	○	○	○	○	○
Bicycling	○	○	○	○	○	○	○

Figure 1.29 and 1.30. Eleventh set of altered questions, in which “bikeshare” was generalized to “shared micro-mobility” to encompass more modes such as e-scooters. Additional response options of “I already own a powered micro-mobility device”, “I am interested but unsure of safety”, and “I am not interested” were included to gauge how many respondents would not participate in a shared mobility program.

27. Would you be interested in bikeshare bicycles for any of the following (check all that apply):

- ☐ Ride between campus destinations
- ☐ Ride for business-related errands
- ☐ Ride for personal errands
- ☐ Ride for exercise/recreation

29. Would you be interested in shared micro-mobility for any of the following (check all that apply):

Shared micro-mobility refers to any small, human or electric-powered transportation solution such as bikes, e-bikes, scooters, e-scooters or any other small, lightweight vehicle that is being used as a shared resource between multiple users.

- ☐ Ride between campus destinations
- ☐ Ride for business-related errands
- ☐ Ride for personal errands
- ☐ Ride for exercise/recreation
- ☐ I already own a powered micro-mobility device
- ☐ I am interested but unsure of safety
- ☐ I am not interested

Figures 1.31, 1.32, 1.33, and 1.34. Twelfth set of altered questions, with the first two being from 2018 and the second two being from 2022. Response options relevant to the COVID-19 pandemic were added to both questions to account for the potential impact of this factor on not using Zipcar.

29. I have heard of Zipcar and...

- ◯ I currently use it for University-related business (department paid)
- ◯ I currently use it for personal errands (individually paid)
- ◯ I currently use it for business and personal errands
- ◯ I do not currently use it, but am interested in doing so
- ◯ I am not interested in using it

30. I have not heard of Zipcar, but...

- ◯ I am interested in using it for University-related business (department paid)
- ◯ I am interested in using it for personal errands (individually paid)
- ◯ I am interested in using it for business and personal errands
- ◯ I am not interested in using it

31. I have heard of Zipcar and...

- I currently use it for University-related business (department paid)
- I currently use it for personal errands (individually paid)
- I currently use it for business and personal errands
- I do not currently use it, but am interested in doing so
- I do not currently use it for reasons related to the COVID-19 pandemic
- I am not interested in using it

32. I have not heard of Zipcar, but...

- I am interested in using it for University-related business (department paid)
- I am interested in using it for personal errands (individually paid)
- I am interested in using it for business and personal errands
- I am not interested in using it for reasons related to the COVID-19 pandemic
- I am not interested in using it

Figure 1.35 and 1.36. Thirteenth set of altered questions, in which an option regarding COVID-19 was added in order to account for its potential impact on respondents choosing not to carpool.

* 32. If you prefer not to carpool, or would not consider it as an option, which of the following best describes the reasons why? (Please select no more than <u>three</u> choices.)

- The cost of my commute, fuel, and parking are very reasonable
- I have responsibilities to a child or children and must be able to respond to their needs immediately
- I need to be able to respond to an emergency without inconveniencing anyone else
- I have frequent appointments off campus
- My work or class schedule is too irregular
- I cannot find anyone with whom to carpool
- Carpooling takes too much time
- I prefer to walk, cycle, or ride the bus/shuttle
- I prefer driving alone
- I feel uncomfortable not having my personal vehicle available to me
- N/A (I <u>would</u> consider carpooling)

34. If you prefer not to carpool, or would not consider it as an option, which of the following best describes the reasons why? (Please select no more than three choices.) *

- ☐ The cost of my commute, fuel, and parking are very reasonable
- ☐ I have responsibilities to a child or children and must be able to respond to their needs immediately
- ☐ I need to be able to respond to an emergency without inconveniencing anyone else
- ☐ I have frequent appointments off campus
- ☐ My work or class schedule is too irregular
- ☐ I cannot find anyone with whom to carpool
- ☐ Carpooling takes too much time
- ☐ I prefer to walk, cycle, or ride the bus/shuttle
- ☐ I prefer driving alone
- ☐ I feel uncomfortable not having my personal vehicle available to me
- ☐ I feel unsafe carpooling due to the COVID-19 pandemic
- ☐ N/A (I would consider carpooling)

Figure 1.37 and 1.38. Fourteenth set of altered questions, in which "iRideshare" was generalized to "rideshare" programs to include the programs of "Guaranteed Ride Home" and "Carpool parking permits".

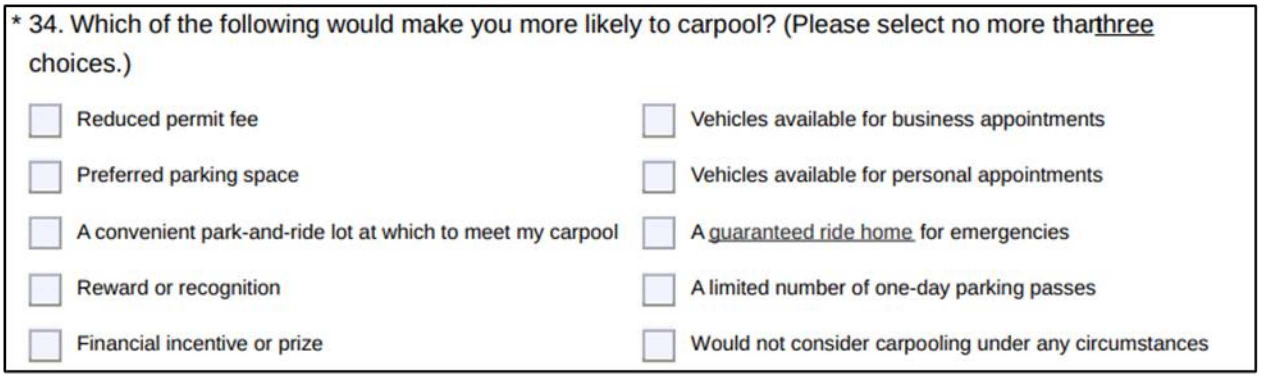
* 33. Are you familiar with the iRideshare, ridematching tool that can be used to help for carpools/vanpools?

- ○ Yes, and I have used it
- ○ Yes, but I have not used it
- ○ No

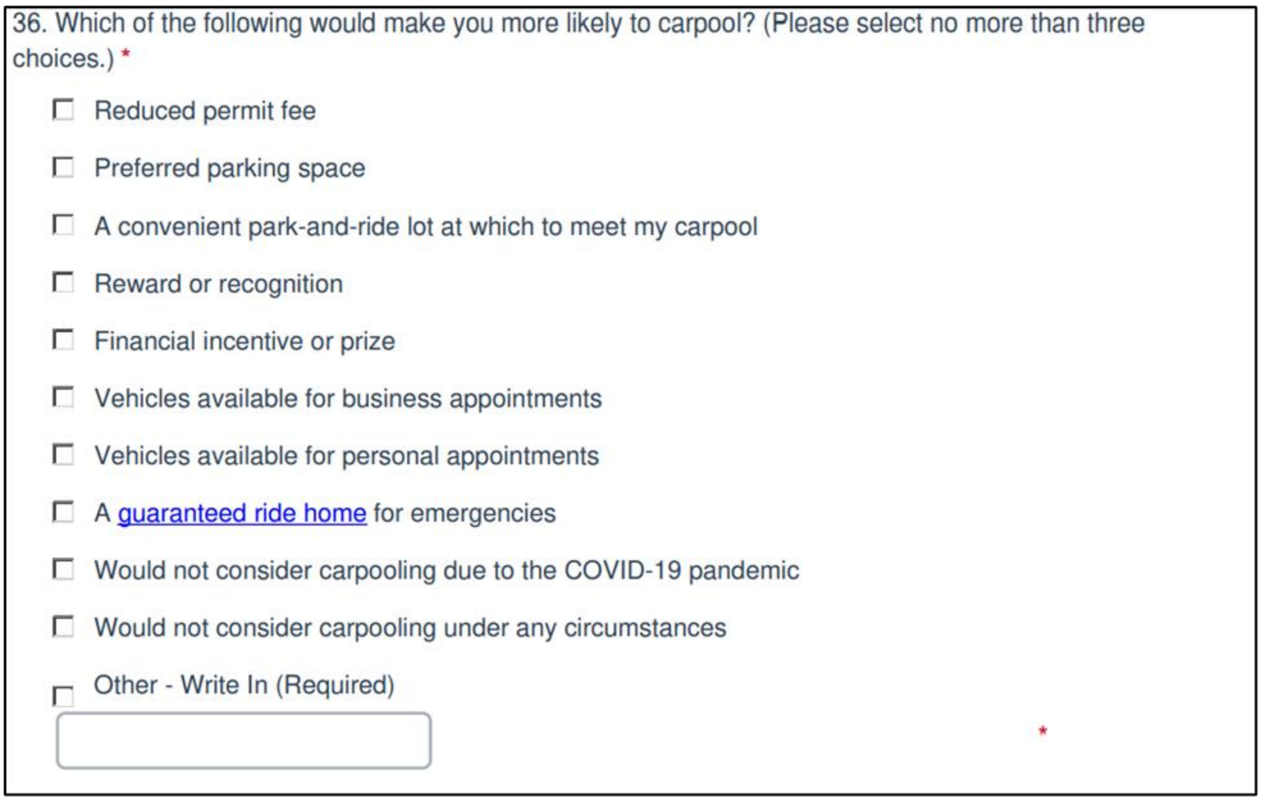
35. Are you familiar with Cal Poly's rideshare programs (Rideshare Network, Guaranteed Ride Home, or Carpool parking permits)? *

- ○ Yes, I have used it
- ○ Yes, but I have not used it
- ○ No

Figure 1.39 and 1.40. Fifteenth set of altered questions, in which the response of "A limited number of one-day parking passes" was removed and the responses of "Would not consider carpooling due to COVID-19 pandemic" and "Other/Write In" were added. This was to observe any potential impact of COVID on carpooling and provide a space for respondents to describe their unique circumstance if applicable.


* 34. Which of the following would make you more likely to carpool? (Please select no more thanthree choices.)

- ☐ Reduced permit fee
- ☐ Preferred parking space
- ☐ A convenient park-and-ride lot at which to meet my carpool
- ☐ Reward or recognition
- ☐ Financial incentive or prize
- ☐ Vehicles available for business appointments
- ☐ Vehicles available for personal appointments
- ☐ A guaranteed ride home for emergencies
- ☐ A limited number of one-day parking passes
- ☐ Would not consider carpooling under any circumstances


36. Which of the following would make you more likely to carpool? (Please select no more than three choices.) *

- ☐ Reduced permit fee
- ☐ Preferred parking space
- ☐ A convenient park-and-ride lot at which to meet my carpool
- ☐ Reward or recognition
- ☐ Financial incentive or prize
- ☐ Vehicles available for business appointments
- ☐ Vehicles available for personal appointments
- ☐ A guaranteed ride home for emergencies
- ☐ Would not consider carpooling due to the COVID-19 pandemic
- ☐ Would not consider carpooling under any circumstances
- ☐ Other - Write In (Required) *

Figure 1.41 and 1.42. Sixteenth set of altered questions, in which the responses of "Better COVID-19 safety measures", "I have no interest in riding the bus for reasons related to the COVID-19 pandemic", and "Other/Write In" were added. This was to account for any potential impact of COVID-19 on openness to travel via transit, as well as to provide respondents with an opportunity to type in a unique response if applicable.

37. Which of the following would make you more likely to use transit for your commute? (Please select no more than three options.)

- ☐ More frequent service
- ☐ More direct route
- ☐ A park and ride lot
- ☐ Vehicles available for business appointments
- ☐ Vehicles available for personal appointments
- ☐ A guaranteed ride home for emergencies
- ☐ A limited number of one-day parking passes
- ☐ More route and schedule information
- ☐ An app showing real-time bus locations
- ☐ WiFi on the buses
- ☐ I have no interest in riding the bus

39. Which of the following would make you most likely to use transit for your commute? (Please select no more than three options.)

- ☐ More frequent service
- ☐ More direct route
- ☐ A park and ride lot
- ☐ On demand vehicles available for business appointments
- ☐ On demand vehicles available for personal appointments
- ☐ A guaranteed ride home for emergencies
- ☐ A limited number of one-day parking passes
- ☐ More route and schedule information
- ☐ An app showing real-time bus locations
- ☐ WiFi on the buses
- ☐ Better COVID-19 safety measures
- ☐ I have no interest in riding the bus for reasons related to the COVID-19 pandemic
- ☐ I have no interest in riding the bus
- ☐ Other - Write In

Figure 1.43 and 1.44. Seventeenth set of altered questions, in which the response option "Safer bike routes on campus" was removed.

39. Which of the following would make you more likely to commute by bicycle? (Please select no more than three options.)

- ☐ Safer bike routes to campus
- ☐ Safer bike routes on campus
- ☐ More bike racks on campus
- ☐ Bike lockers scattered on campus
- ☐ A bike cage centrally located on campus
- ☐ Shower/changing facilities
- ☐ Bike repair facility on campus
- ☐ Cycling safety class on campus
- ☐ I have no interest in riding a bicycle
- ☐ I would rather drive to campus and use my bike to move between campus locations
- ☐ I would rather drive to campus and use a bikeshare bike to move between campus locations

41. Which of the following would improve your biking experience or make you more likely to commute by bicycle? (Please select no more than three options.)

- ☐ Safer bike routes to campus
- ☐ More bike racks on campus
- ☐ Bike lockers scattered on campus
- ☐ A bike cage centrally located on campus
- ☐ Shower/changing facilities
- ☐ Bike repair facility on campus
- ☐ Cycling safety class on campus
- ☐ I have no interest in riding a bicycle
- ☐ I would rather drive to campus and use my bike to move between campus locations
- ☐ I would rather drive to campus and use a bikeshare bike to move between campus locations

Survey Pilot

Before releasing the travel survey to the entire campus community, the team conducted pilot surveys with two individuals from each of the following categories: staff, faculty, and student. Some respondents tested the version of the report as having a parking permit, and some responded as not having a permit, depending on their individual circumstances. This was to test as many question pathways in the survey as possible.

The survey team and respondents observed aspects such as the order of the questions, the logical flow of the questions, and made sure that all the hyperlinks were operational and directed survey respondents to the appropriate web address. The survey team also recorded how long it took respondents to take the survey, in order to give an accurate time, estimate of how long the survey would take for the general campus community.

In addition to taking the survey, the test respondent provided feedback while participating in and after submitting the survey. Table 1.3 below displays a few key points that test respondents brought up while taking the survey and how this feedback was applied to the final survey.

Feedback	**Application**
The more user-friendly method of determining from where people are commuting to/from campus is via typing in cross-streets, as opposed to clicking the location on a heatmap.	The survey team was testing the heatmap as an option to replace the typing in of cross-streets but decided to keep the cross-street fill-in method based on user preference.
It should be clarified whether a "trip" to and from campus should be counted as 1 trip in the survey, or two trips.	The question "In the past 7 days, check which, if any of the following modes you used to travel to and from home and campus?" was changed to a matrix of checkboxes for days those individuals commuted to/from campus and what mode they used, as opposed to typing in the number of trips to and from campus.
It should be clarified whether owning or leasing an EV includes owning a hybrid vehicle.	The survey team adjusted the wording of questions involving reference to owning or using an EV such that it was clear to respondents that hybrid vehicles are included under the category of EV.
Adjust the "Try Alternatives?" ranking question of how willing one would be to try an alternative mode, such that the scale options are more consistent and comprehensive.	The survey team adjusted the wording of the question "How willing would you be to try each of the following alternative forms of transportation to travel to and from campus?" such that a consistent scale was used.

Table 1.3. Key feedback provided by test survey respondents and how the survey team applied them to the final draft.

The survey team received feedback on grammar and wording improvements of questions, which we considered while reviewing and editing the survey. Test respondents overall felt that the survey was user-friendly in its graphics and seemed to appreciate the logical order of the questions. Some test respondents decided to take the test survey on their cell phone, and some did so on their laptop – both versions were well-received as user-friendly.

Chapter II: Changes in Campus Travel Transportation Mode

Two overarching themes will be explored in this subsection: how the preferred modes of transportation have changed between the 2018 and 2022 surveys, and what factors within 2022 only impact respondents' transportation mode of choice.

2018 vs. 2022 Comparison

When comparing preferred transportation modes between 2018 and 2022, the survey team's analysis observed the percentage of students and faculty/staff that used each mode of transportation for each respective year. These percentages are displayed in Table 2.1 below. Among students and faculty/staff for both years, "Diving Alone" was consistently the most preferred mode of transportation, while the modes of "Motorcycling/Motorized Scooter", "Ride-Hailing app (Uber/Lyft)", and "Other" were least popular. Overall, for both years, students also largely preferred "Walking", while faculty/staff did not have a mode other than "Driving Alone" that came close in popularity. This is likely due to faculty/staff living farther away from campus than students, as is explored with the average one-way commute distances in Table 2.1 within the results section of "Estimating Vehicle Miles Traveled".

	2018 Students	2022 Students*	2018 Faculty/ staff	2022 Faculty/ staff*
Bicycling	14%	17%	8%	11%
Bus	10%	19%	4%	3%
Carpooling & Vanpooling	14%	5%	9%	9%
Driving Alone	33%	31%	74%	69%
Dropped Off	5%	2%	2%	1%
Motorcycling/Motorized scooter	1%	1%	1%	1%
Ride-Hailing app (Uber/Lyft)	1%	<1%	<1%	<1%
Walking	21%	24%	1%	2%
Other	1%	1%	1%	3%
All Modes	89%	53%	11%	47%

*off-campus trips only

Table 2.1. Mode use comparison between students and faculty/staff, and between 2018 and 2022.

As can be seen in comparing the 2018 and 2022 percentages in above Table 2.1, the number of individuals driving alone reduced, while the number of individuals bicycling, walking, and riding the bus (for students) increased. This indicates that individuals are selecting more eco-friendly commute modes in 2022.

Transportation Mode Choice in 2022

When exploring the factors that impact transportation mode choice within the year 2022, it is important to consider and provide a variety of options for individuals. Drawing from factors listed in the 2018 survey such as availability, cost, and desire for exercise, the 2022 survey team also added the factors of safety and the COVID-19 pandemic. The survey team also explored how willing respondents were to try particular modes of transportation. All of the following tables include a "blank" row and column, which represents the respondents that did not answer the question.

Table 2.2 below displays what factors led to respondents selecting certain transportation modes. The factor of convenience/time is what led to a large number of individuals selecting to drive alone, walk, or bicycle. This is reasonable, as these three modes of transportation are easily accessible to their users and do not depend on another individuals' participation (as opposed to a mode such as the bus, in which a driver is required). Similarly, the factor of availability leads to many individuals selecting to drive along, due to this mode being accessible. A promising trend is that those who bicycle are also considering environmental sustainability as the most important factor.

Table 2.2. Factors of why respondents choose particular commute modes.

Most Important Factor	Bicycling	Bus	Carpooling	Driving alone	Dropped off	Motorcycling/ Motorized scooter	Ride-hailing app (Uber/Lyft)	Vanpool	Walking	Other - Write In	(blank)	Grand Total
Availability	15	48	26	159	1	1	1	1	23	3	127	405
Convenience	1	0	0	1	0	0	0	0	0	0	0	2
Convenience/time	104	85	62	557	13	13	0	0	128	18	393	1373
Cost	59	49	14	48	3	4	0	9	44	7	92	329
Desire for exercise	15	0	0	0	0	1	0	0	11	0	17	44
Environmental sustainability	46	9	2	9	0	0	0	0	10	2	26	104
Physical abilities or disabilities	1	1	1	7	0	0	0	0	1	0	10	21
Safety	3	0	2	26	0	0	0	0	5	3	35	74
The COVID-19 pandemic	0	0	0	6	0	0	0	0	2	0	2	10
Weather	3	0	0	3	1	1	0	0	3	1	12	24
(blank)	10	13	4	60	2	1	1	0	24	0	268	383
Grand Total	257	205	111	876	20	21	2	10	251	34	982	2769

The willingness of individuals to try commute modes unique from the ones they currently use, and that are more environmentally friendly, was also explored in this survey. This report will explore the two particular alternative commute modes of public transit and biking. The following two Tables 2.3 and 2.4 show the willingness to try the alternative mode in comparison to what mode the respondents use most frequently to commute to campus. As Table 2.3 displays, more individuals are willing to try public transit than not; however, Table 2.4 displays that more people would rather not try biking as an alternative. The preference of trying public transit versus biking is likely due to bicycling requiring a perceived level of safety, bicycle ownership and access, and a level of physical ability and fitness. Riding the bus, on the other hand, does not require a level of fitness nor ownership of a vehicle, and it accommodates those who have disabilities more easily.

Table 2.3. Willingness of individuals to try public transit based on their current most frequently used mode of transportation.

Willingness to Try Public Transit	Bicycling	Bus	Carpooling	Driving alone	Dropped off	Motorcycling/ Motorized scooter	Ride-hailing app (Uber/Lyft)	Vanpool	Walking	Other - Write In	(blank)	Grand Total
I already use this mode frequently	20	179	12	5	5	1	0	1	37	5	164	429
Very willing to use this mode	49	6	11	114	4	3	0	0	40	5	191	423
Sometimes willing to use this mode	88	1	29	202	3	7	0	0	77	10	216	633
I am sometimes willing to use this mode	1	0	0	1	0	0	0	0	0	0	0	2
Probably not willing to use this mode	50	0	28	239	4	5	0	4	34	4	64	432
Not at all willing	14	0	16	176	1	3	0	3	13	7	24	257
Never considered it	14	0	5	43	1	1	0	1	12	1	15	93
N/A	5	1	6	25	0	0	1	1	6	1	11	57
(blank)	16	18	4	71	2	1	1	0	32	1	297	443
Grand Total	257	205	111	876	20	21	2	10	251	34	982	2769

Willingness to Try Biking	Bicycling	Bus	Carpooling	Driving alone	Dropped off	Motorcycling/ Motorized scooter	Other - Write In	Ride-hailing app (Uber/Lyft)	Vanpool	Walking	(blank)	Grand Total
I already use this mode frequently	228	27	7	23	3	1	5	0	0	32	146	472
I am very willing to use this mode	2	0	0	0	0	0	0	0	0	0	0	2
I want to use this mode	0	0	0	1	0	0	0	0	0	0	0	1
N/A	1	16	12	111	1	0	3	0	4	7	34	189
Never considered it	0	12	6	64	1	0	2	0	2	11	26	124
Not at all willing	0	20	28	266	3	4	11	1	4	15	47	399
Probably not willing to use this mode	0	46	19	118	4	3	4	0	0	35	109	338
Sometimes willing to use this mode	1	40	22	129	3	10	4	0	0	63	148	420
Very willing to use this mode	9	26	13	93	3	2	4	0	0	56	176	382
(blank)	16	18	4	71	2	1	1	1	0	32	296	442
Grand Total	257	205	111	876	20	21	34	2	10	251	982	2769

Table 2.4. Willingness of individuals to try bicycling based on their current most frequently used mode of transportation.

COVID-19 Pandemic

One of the many factors that makes this 2022 survey unique from previous ones is the potential impact of the COVID-19 pandemic on the travel patterns of survey respondents. To explore the impact of COVID-19, some questions that were already existing were altered to include response options related to COVID-19, as described within the "Questions Altered between 2018 and 2022 Surveys" section. Additionally, the 2022 survey contains particular questions that targeted information regarding travel and COVID-19 as follows:

- Has the COVID-19 pandemic had an effect on which mode you chose/choose?
- If yes, how have your travel modes changed?

In total, 191 off-campus respondents (or 11%) indicate that they switched modes due to the COVID-19 pandemic. A full breakdown of the responses as to how COVID-19 impacted respondents' commute mode is displayed in Table 2.5 below.

Respondent Category	No, COVID-19 does not affect my mode choice	No, COVID-19 has not affected my mode choice	Yes, I have switched modes due to the COVID-19 pandemic	Blank/No Response
Faculty, Full-time	2	202	29	3
Faculty, Part-time	0	49	11	1
Staff, Full-time	0	450	67	6
Staff, Part-time	0	9	3	1
Undergraduate, 1st Year	0	12	0	1
Undergraduate, 2nd Year and Above	1	727	66	35
Graduate	0	96	15	5

Table 2.5. Responses to the question "Has the COVID-19 pandemic had an effect on which mode you chose/choose?

The results of how travel modes have changed are shown below in Figure 2.1, with the rows being what the respondent's original transportation mode was and the columns being the mode that the respondent switched to due to COVID-19. There is a discrepancy in the total value of those who switched modes (sum of the "Yes" column in above Table 2.6), as some respondents selected switching within the same mode (ex: From Biking to Biking) and some left the question blank. As can be seen in Figure 2.1, a large number of individuals switched from commuting by Bus and Carpooling to Driving alone; this is reasonable, as there is concern that COVID can spread amongst individuals sharing a confined space.

Figure 2.1. Responses for switching from one mode to another.

	To								
From	Biking	Bus	Carpooling	Driving alone	Motorcycling/ Motorized scooter	Ride-hailing app	Telecommuting (remote work/ school)	Vanpool	Walking
Biking		1	1	5	0	0	0	1	1
Bus	13		8	59	2	1	4	0	16
Carpooling	1	1		20	0	1	0	0	1
Driving alone	6	3	4		2	0	9	0	3
Motorcycling/Motorized scooter	0	0	0	0		0	0	0	0
Ride-hailing app (Uber/Lyft)	0	0	0	0	0		0	0	0
Telecommuting (remote work/school)	1	0	0	1	0	0		0	1
Vanpool	0	0	3	6	0	0	0		0
Walking	2	0	1	2	0	0	2	0	

Telecommuting

A potential impact of the COVID-19 pandemic was telecommuting, in which students, faculty and staff had (and, in some cases still have) the opportunity to dial into classes remotely. From virtual planning meetings to virtual classes, telecommuting became the expected mode of instruction at the University during the height of the pandemic; now that restrictions have eased, many have returned to in-person instruction and meetings, and some have chosen to remain virtual. At the time of this survey, the pandemic restrictions had been significantly reduced, which is reflected in the low percentages of 4.38% for employees and 0.67% for students telecommuting as shown in Tables 2.6.

Primary Commuting Mode	Percent Employees	Percent Students
Driving alone	63.38%	16.68%
Other - Write In	2.63%	0.56%
Bicycling	9.98%	9.29%
Bus	2.85%	10.02%
Carpooling	7.35%	2.46%
Dropped off	1.10%	0.56%
Motorcycling/Motorized scooter	0.88%	0.73%
Vanpooling	1.10%	0.11%
Walking	2.08%	12.98%
On-Campus	1.86%	45.94%
Telecommuting	4.38%	0.67%
Total	**100.00%**	**100.00%**

Table 2.6. Percentages of employees and students using particular commute modes.

Within the respondent category of employees, one can also observe the number of days they telecommute per week. As can be seen in the below Table 2.7, the majority of employees do not telecommute or telecommute for only one or two days out of the week. Also evident in the below table is that approximately 60% of employees do not telecommute in an average week.

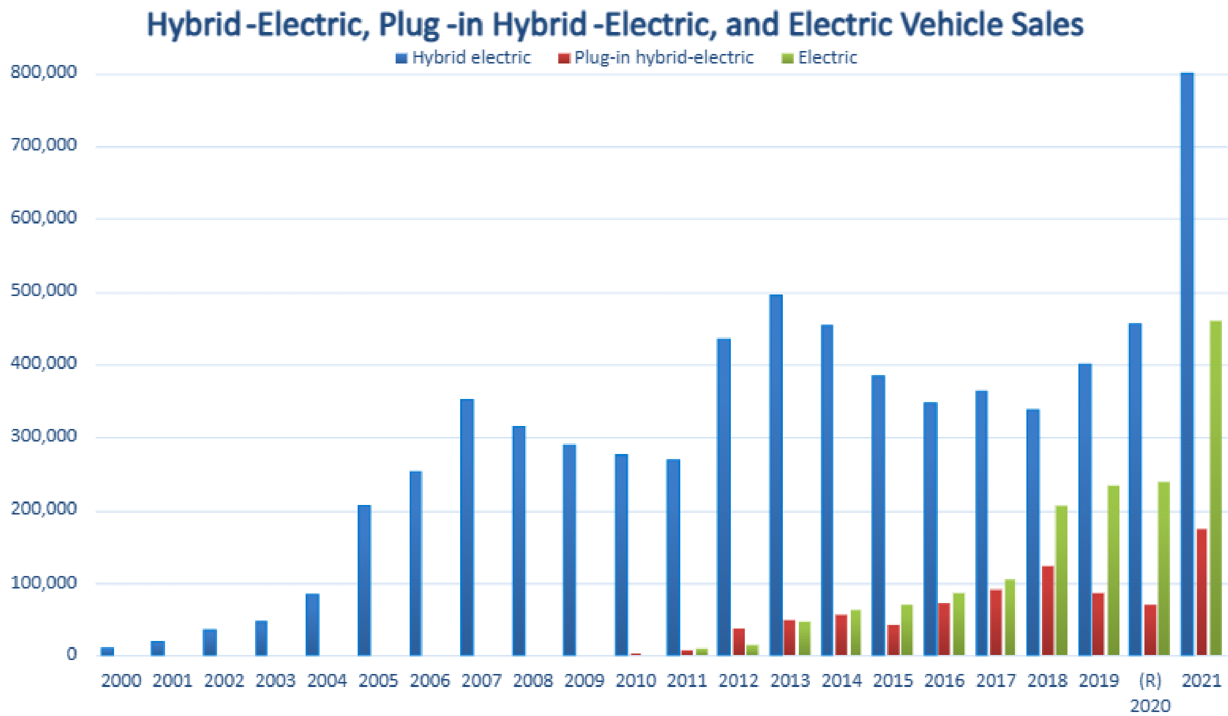
Days Telecommuted per Week	Number of Employees	Percentage of Employees
N/A	39	4.28%
Exclusive	40	4.39%
0	546	59.87%
1	93	10.20%
2	92	10.09%
3	49	5.37%
4	24	2.63%
5	21	2.30%
6	2	0.22%
7	6	0.66%
Total	**912**	**100%**

Table 2.7. Number of employees telecommuting for a certain number of days per week. "NA" refers to employee respondents who left this question blank.

Electric Vehicles

With more focus on reducing humans' impact on the environment, the popularity of EVs has increased in more recent years. As Figure 2.2 shows, the nationwide sale of hybrid-electric, plug-in hybrid-electric, and electric vehicles combined has been steadily increasing since the year 2000, and even approximately doubled between the most recent two years of 2020 and 2021 (*Hybrid-Electric, Plug-in Hybrid Electric*, 2022). This shows that the popularity of purchasing and owning EVs is ever-increasing, with the potential to continue this upward trend in the near future.

Figure 2.2. Sale of three types of EVs for the past twenty-one years in the United States. (Chart by U.S. Department of Energy, Energy Vehicle Technologies Office, Oak Ridge National Laboratory, *Transportation Energy Data Book, Edition 40,* table 6.2, available at https://tedb.ornl.gov/data/ as of Jun. 21, 2022.)



Due to this upward trend in EV ownership nationwide, it is important for the campus to be prepared for an increase in EVs in the near future. This can partially be predicted by individuals indicating interest in bringing to campus and charging EVs. The 2022 survey asks a series of questions to explore the campus community's interest in EVs as follows:

- Do you have an electric vehicle (EV), including plug-in hybrid or battery electric that you currently use to commute to campus?
- Do you intend to begin commuting to campus in an EV?
- How often do you charge your electric vehicle on campus?

Table 2.8 below displays how many individuals from each respondent category currently commute to campus via their EV. As can be seen, approximately 10% of those who responded to this question (or, 150 respondents) indicated that they currently commute via their EV.

Respondent Category	Yes	No
Faculty, Full-time	50	170
Faculty, Part-time	9	45
Staff, Full-time	55	433
Staff, Part-time	4	6
Undergraduate, 1st Year	0	7

Undergraduate, 2nd Year and Above	26	544
Graduate	6	83
Total	150	1288

Table 2.8. Responses to "Do you have an electric vehicle (EV), including plug-in hybrid or battery electric, that you currently use to commute to campus?".

With EV ownership comes the unique responsibility of charging the vehicle for proper operation. According to the University website, there are currently 21 ChargePoint spaces to charge an EV (*Electric Vehicles,* n.d.). However, this website also indicates that there was a planned expansion of these spaces in 2022, so this number is likely larger than 21 at the time of the writing of this report (*Electric Vehicles,* n.d.). Table 2.9 displays the number of days per week that individuals within each respondent category charge their EV on campus. It is important to note that this question was only visible to those who indicated "Yes" to the previous survey question of "Do you have an electric vehicle (EV)...that you currently use to commute to campus?"

Respondent Category	1-2 days per week	3-4 days per week	5+ days per week	Never
Faculty, Full-time	15	4	3	28
Faculty, Part-time	5	1	0	3
Staff, Full-time	10	4	4	37
Staff, Part-time	0	0	1	3
Undergraduate, 1st Year	0	0	0	0
Undergraduate, 2nd Year and Above	3	3	1	19
Graduate	3	1	0	2
Total	36	13	9	92

Table 2.9. Responses to "How often do you charge your electric vehicle on campus?".

As Table 2.9 displays of those who commute via their EV, most individuals do not charge their EV on-campus; the next-greatest frequency of vehicle charging is 1-2 days per week, and the least popular charging frequency is 5 or more days per week. This could indicate that individuals cannot easily find an available space to charge their EV, or that individuals simply choose not to charge many days of the week. In order to properly form a conclusion, these individuals would need to address an additional question of "Why do you charge your EV fewer days of the week or never on campus?".

Looking into the future of EV ownership, the 2022 survey sought to collect data on how many individuals intend to begin commuting to campus in an EV and in what time frame. The below Table # displays the response counts collected for this question. Naturally, this question was only visible to those who answered "No" to the question "Do you have an electric vehicle (EV), including plug-in hybrid or battery electric, that you currently use to commute to campus?".

As Table 2.10 below displays, the most respondents I indicated that they do not plan to or do not know if they will commute via an EV. This can be due to a variety of factors, such as limited EV charging spaces, insufficient infrastructure at home to charge an EV, or insufficient funds to purchase an EV and/or its at-home charging infrastructure. However, the table also displays a number of individuals who plan to commute via EV, with most stating that they plan to do so in the next 2-3 and 3-5 years. The total number of individuals who indicated that they have a plan to commute via EV in the future is 265. This indicates that the campus should expect an increased usage of EVs in the near future and consider expanding its charging capabilities.

Respondent Category	Yes, within 1 year	Yes, in 2-3 years	Yes, in 3-5 years	Yes, in 5+ years	No	Do not know
Faculty, Full-time	10	22	17	20	71	30
Faculty, Part-time	1	9	6	4	18	7
Staff, Full-time	22	47	41	31	190	102
Staff, Part-time	0	1	0	0	2	3
Undergraduate, 1st Year	0	2	0	0	3	2
Undergraduate, 2nd Year and Above	11	7	3	5	440	77
Graduate	3	0	3	0	64	13
Total	47	88	70	60	788	234

Table 2.10. Responses to "Do you intend to begin commuting to campus in an EV?".

Chapter III: Estimation of Vehicle Miles Traveled

Vehicle miles traveled (VMT) refers to total miles traveled by motorized vehicle modes. This includes modes such as buses, cars, motorcycles, and alternative fueled vehicles. VMT does not include non-motorized modes such as walking and bicycling. Across the United States and in California the trend of VMT per year has generally been an upward increase (*California VMT Data*, n.d.). There are a variety of factors that influence the number of VMTs produced by a community. These range from factors such as the unemployment rate and median income of a community, to fuel prices and the number of licensed individuals (Hymel, 2014).

In this chapter, the methodology used to calculate VMT from the survey response data will be described. Additionally, the results from these analyses will be presented and discussed. For the VMT calculation, origin/destination locations as reported by respondents and factors based on average occupancy of transportation modes were utilized.

Methods and Data

The following section explores the methodology used to determine VMT. It follows a set-by-step sequence, summarized by section titles and described more thoroughly underneath each title. Additionally, select data is displayed via figures and tables to support the methodology.

Determining Average Commute Distances

Average commute trip distances for the travelers were determined using the self-reported cross street locations. We used the 'Geocode' function in the GGMAP library in programming language R to find the latitude and longitude of the cross street location. The input value for the cross street location included Street 1 Name, Street 2 Name, City, State, and Zip Code. The 'Geocode' function finds the latitude and longitude of a location using the Google Geocoding API. To use Google's Geocoding API, we first enabled the API in the Google Cloud Platform Console. The cost of using the Geocoding API was 0.005 USD per each (5.00 USD per 1000) query.

Next, distances from the geocoded locations were calculated from the Cal Poly campus. The following latitude and longitude location was used as the center of Cal Poly campus.

35.302622, -120.662970

Using the 'mapdist' function from the GGMAP library in R, we calculated the shortest driving distance between the geocoded address location to the aforementioned coordinate in Cal Poly campus.

Furthermore, we estimated the trip distance for respondents that did not complete a cross-street location in their survey. We used the answer to the following question to impute their trip distance. The imputed average trip distance values are included in the captions of Figures 3.1 - 3.4.

Where do you live?

A. On-campus, faculty or staff in campus housing (RAs should classify themselves as students)
B. On-campus, student in resident student housing (RAs should classify themselves as students)
C. Off-campus, within 1 mile of campus
D. Off-campus, within 1 to 2.9 miles from campus
E. Off-campus, within 3 to 9.9 miles from campus
F. Off-campus, 10 or more miles from campus

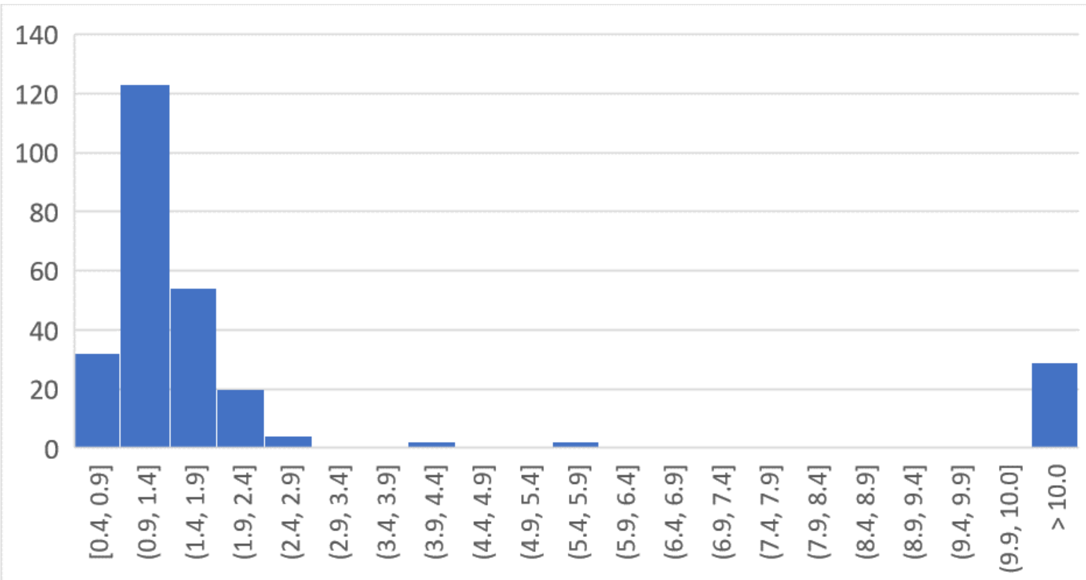


Figure 3.1. Self-reported distance for trips within 1 mile of campus (average = 1.36 miles for trips less than 5 miles)

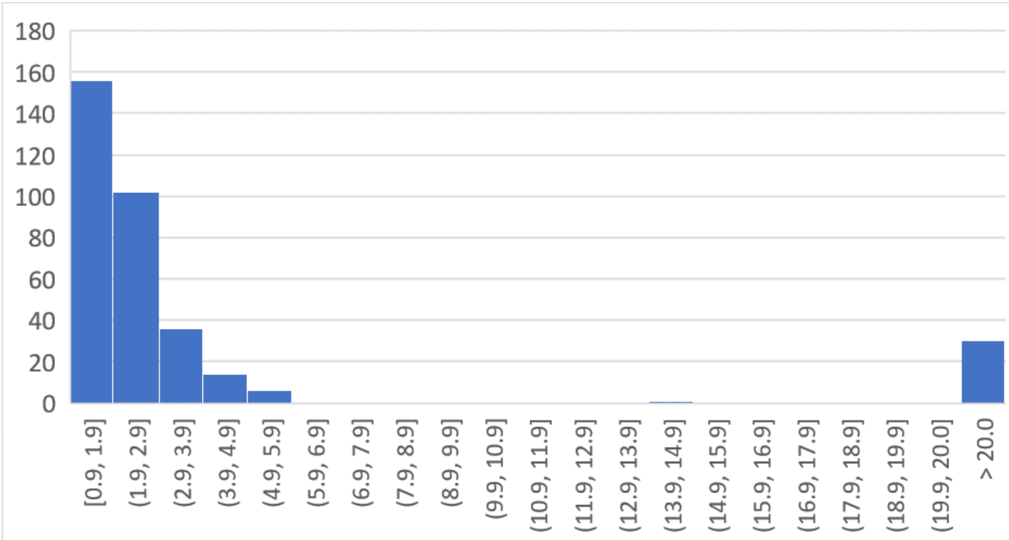


Figure 3.2. Self-reported distance for trips within 1 to 2.9 miles from campus (average = 2.13 miles for trips less than 10 miles)

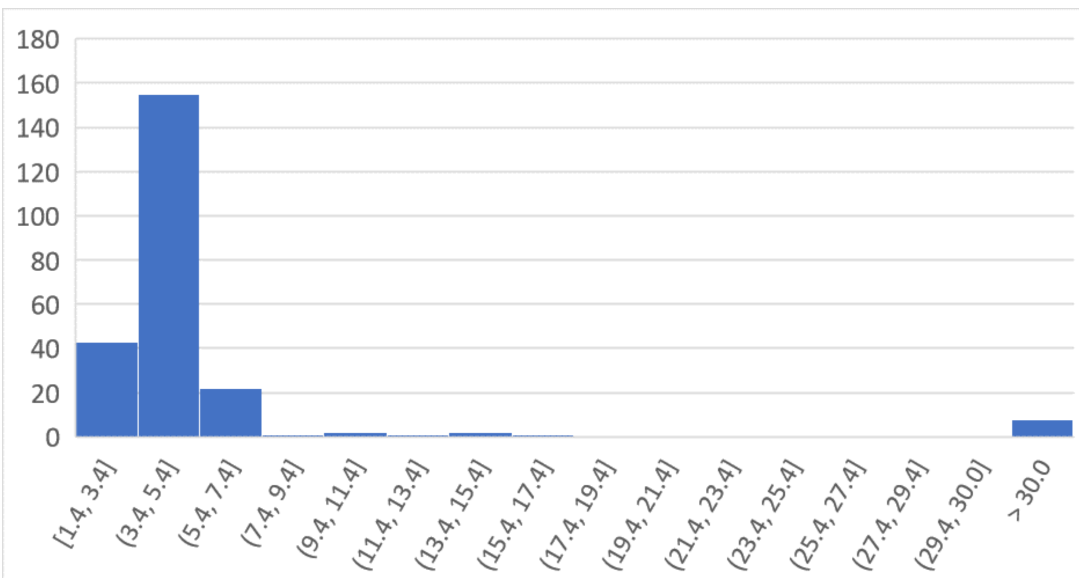


Figure 3.3. Self-reported distance for trips within within 3 to 9.9 miles from campus (average = 4.47 miles for trips less than 25 miles)

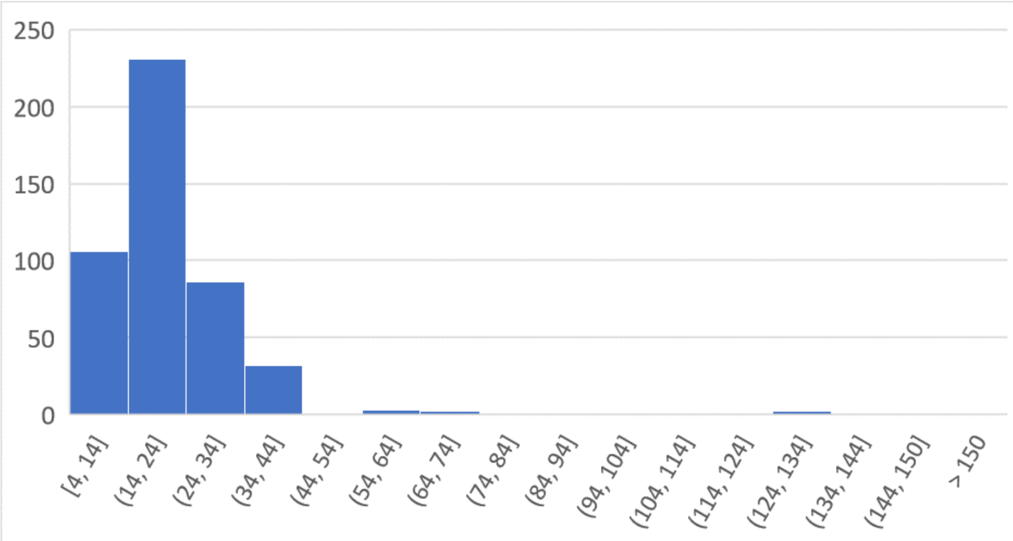


Figure 3.4. Self-reported distance for trips 10 or more miles from campus (average = 22.43 miles for trips less than 150 miles)

Estimating Unweighted Weekly VMT

Next, we determined the number of days per week that an individual respondent travels to and from campus. This was achieved through asking off-campus respondents to select which days they travel to/from campus. This value was used in subsequent steps of the VMT estimation.

Another necessary component of this calculation was to determine the VMT factor based on the estimated occupancy of the mode type, such that the calculation accounts for modes such as bus and vanpool that carry more than one passenger. A summary of the VMT factors and the reasoning behind each factor is provided in Table 3.1. This table includes VMT factors for all motorized mode types, as all non-motorized modes (i.e. biking, walking) were assumed to have a VMT factor of zero.

Table 3.1. VMT factors for motorized mode types and the reasonings behind these factors.

Mode	**Assumed Number of Occupants (X)***	**VMT Factor (1/X)**	**Reasoning**
Driving Alone	1	1	Assumed that students are driving by themselves if they select “Car” as the mode instead of “Carpool”
Motorcycle/ Motorized Scooter	1	1	Motorcycles and motorized scooters are typically designed for and/or ridden by a single individual
Dropped Off	1	1	Assumed this value is 1, as there is a significant amount of variability in being “dropped off”. For example, the person could be just returning to their original destination, going to work after dropping off their child, etc. that would lead to multiple occupants or a single occupant at any given time.
Uber/Lyft	1.35	0.741	The estimated occupancy is between 1.2-1.5 persons according to Tirachini and Gomez-Lobo (2020), therefore the middle value of 1.35 was assumed.
Bus	10.5	0.095	The document “Average Vehicle Occupancy Factors for Computing Travel Time Reliability Measures and Total Peak Hour Excessive Delay Metrics” was used to average bus occupancies amongst the reported cities in California (FHWA, 2018). The resulting average was 10.5 occupants.
Carpool	2.25	0.444	The value of 2.25 persons was determined by a CalTrans HOV lane study (Caltrans, n.d.)
Vanpool	10	0.100	San Luis Obispo Rideshare reports vanpools as having an estimated occupancy range between 5 and 15 individuals. Therefore, the middle value of 10 occupants was assumed. (*Vanpool - San Luis Obispo County*, n.d.)

VMT factors included in Table 3.1 were multiplied by the estimated distances from the Google maps calculations in accordance with the associated mode type, which were in turn multiplied by the number of days that the respondent reported traveling to/from campus. This value gave an estimate of the weekly VMT per survey respondent. Via a pivot-table in excel, the average number of days commuted and the average weekly VMT per person per respondent category (see Table 3.2 for clarification on what the respondent categories include) were determined. Then, the unweighted total weekly VMT was determined by multiplying this average weekly VMT per person within the respondent category by the actual off-campus population of the respondent category. This "actual off-campus population" refers to the number of individuals within the campus community subtracted by the number of on-campus residents within the category, and not only the count of those off-campus respondents to the survey, that fall within a particular respondent category. This data is as of Fall 2022 and was provided by the University and is presented alongside the number of survey respondents per respondent category in Table 3.2.

Table 3.2. Number of survey respondents and number of university community members per respondent category.

Respondent Category	**Number of Off-Campus Survey Respondents**	**Number of Total Individuals in the Campus Community**	**Number of Total On-Campus Individuals**	**Number of Total Off-Campus Individuals**
Faculty, Full-time	236	892	6	886
Faculty, Part-time	61	518	0	518
Staff, Full-time	523	1292	21	1271
Staff, Part-time	13	226	0	226
Undergraduate, 1st Year	13	3866	3703	163
Undergraduate, 2nd Year and Above	829	17227	4709	12518
Graduate	116	929	50	879
Total	1791	24950	8489	16461

Weighting

To transform the unweighted total weekly VMT per respondent category into weighted VMT values, the weighting value of each response was determined. These values are unique to each respondent category and represent the portion of the category within the campus community that participated in the survey. The weighting process accounts for the fact that the relative amount of participation is different among varying categories and attempts to correct for this by the weighting factor (see Kalton and Flore-Cervantes, 2003, and Pew Research Center, 2018, for further information regarding weighting). A larger weighting factor value indicates a lower response rate.

The weighting factors (WF) were determined by using the following Equation 3.1, whereby the values of Number of Off-Campus Survey Respondents and Total Off-Campus Population are derived from Table 3.3. To compare apples to apples, the survey team used the number of off-campus survey respondents and off-campus population (as opposed to total survey respondents and total campus population). A summary of the resulting weighting factors for each category are provided in Table 3.3.

$$WF = \frac{Total\ off\ campus\ population}{Numbers\ of\ off\ campus\ survey\ respondents} \quad (3.1)$$

Table 3.3. Response weighting factors (WF) based on respondent category.

Respondent Category	**Weighting Factor (WF)**
Faculty, Full-time	3.75
Faculty, Part-time	8.49
Staff, Full-time	2.43
Staff, Part-time	17.4
Undergraduate, 1st Year	12.5
Undergraduate, 2nd Year	15.1
Graduate	7.58

Finding Total Weighted Yearly VMT

The respective above weighting factors were then multiplied by the unweighted average weekly VMT values per respondent category to determine the weighted weekly VMT value per respondent. Then, to determine the weighted yearly VMT value per respondent category, each respondent group was assigned an assumed number of weeks per year that they traveled to/from campus. All faculty were assigned 40 weeks, all staff 46 weeks, and all students 38 weeks. The week value for students was determined according to how many weeks the University is in session; the value for faculty was determined by assuming a yearly faculty employment period is nine months; and the value for staff was determined by subtracting vacation and holiday time from total weeks in a year. The weighted yearly VMT per category value was calculated by multiplying the weighted weekly VMT value by the number of weeks the respondent category is expected to report to campus per year. Finally, the total weighted yearly VMT value was determined by summing together the weighted yearly VMTs for respondent categories.

Results and Discussion

Based on the cross-street locations that survey respondents entered, a heatmap was generated to observe patterns. This better visualizes the "hotspots" of where respondents were traveling to and from. Figure 3.5 shows the responses for all survey takers, while Figure 3.6 displays the locations broken down by respondent type.

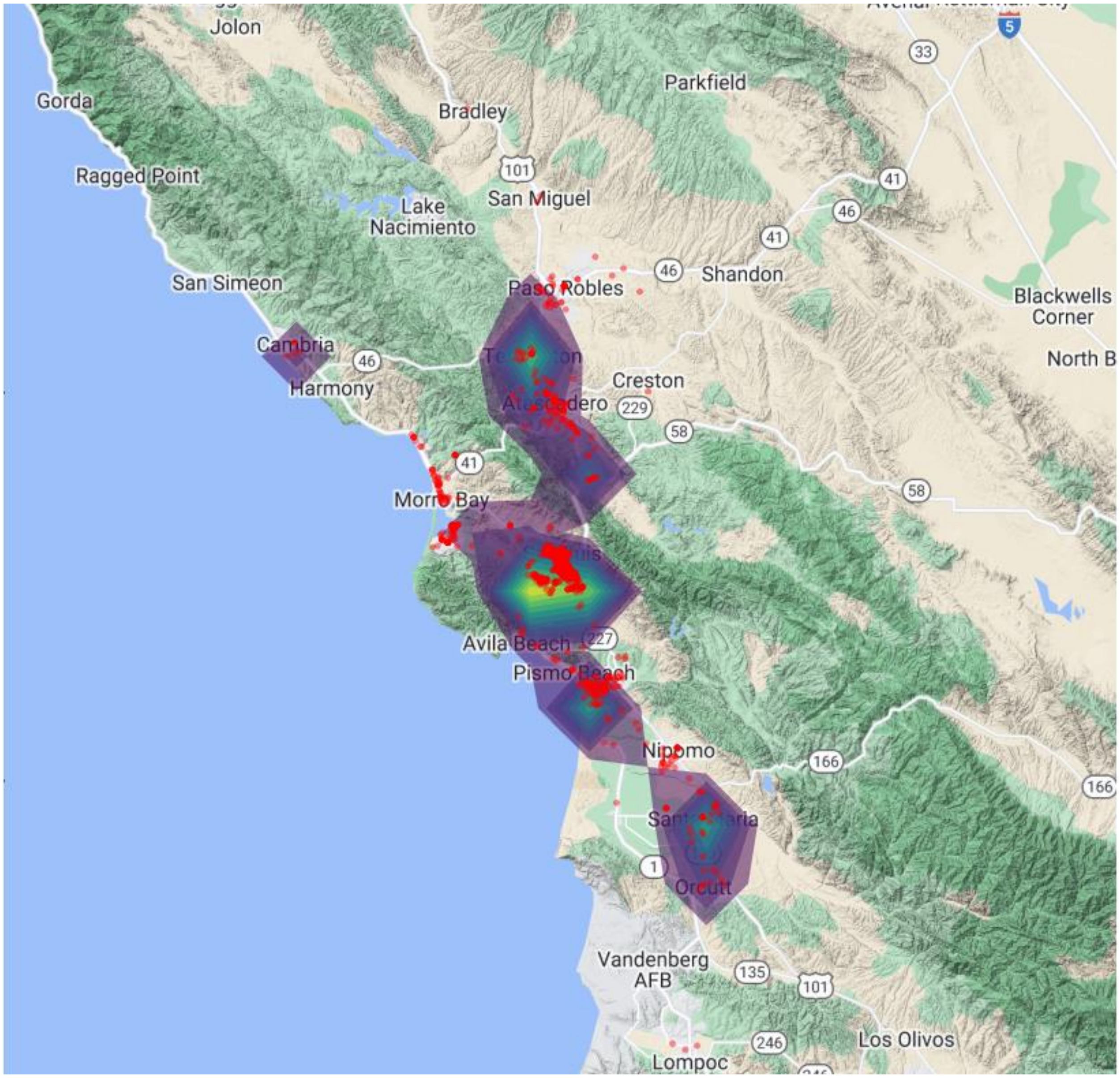


Figure 3.5 Heatmap of Survey Respondent Commute Start Points

As can be seen in Figure 3.5, the majority of respondents travel to campus from within San Luis Obispo, and a significant portion of respondents travel from Santa Maria, Arroyo Grande/Pismo Beach Area, and Atascadero/Paso Robles. Additionally, a smaller portion of individuals travel to/from campus and Cambria.

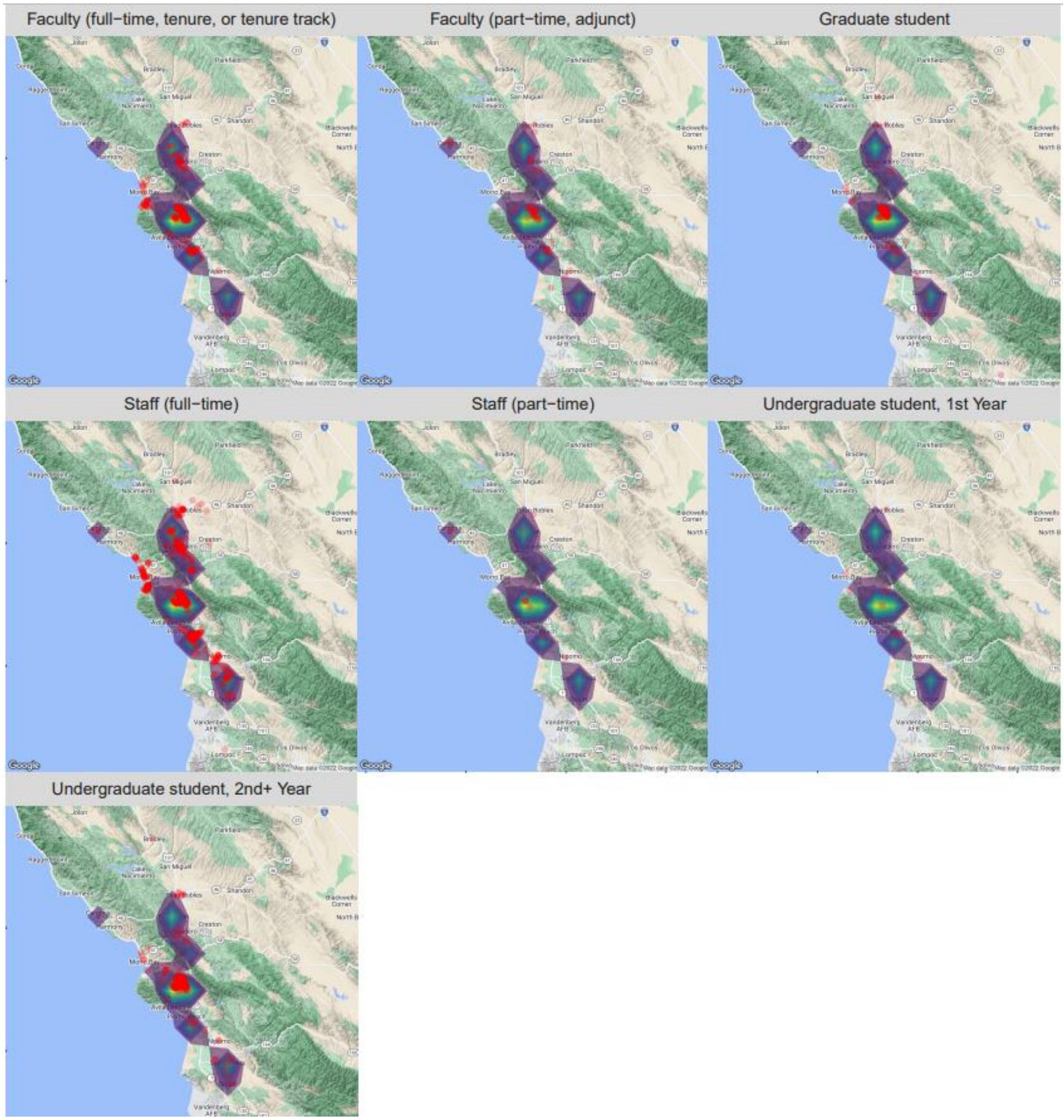


Figure 3.6. Heatmap of Survey Respondent Commute Start Points by their Campus Roles

As can be seen in Figure 3.6, the average one-way commute distance in miles for each mode was also determined, and Table 3.4 displays these distances as total values and broken down among faculty/staff and students. All values of zero in Table 3.4 indicate that no responses were recorded for the particular set of characteristics. The farthest commute distance for all respondents is by traveling via vanpool, for students is "other", and for faculty/staff is vanpooling. Ignoring all values of zero, the shortest commute distance across the board is experienced by those whose mode is walking. This indicates that individuals who live farther from campus are selecting to travel as a larger group to get to campus, likely to save gasoline which directly reduces the carbon footprint. Given this, it was surprising that the carpool and vanpool mileages were not closer in value; perhaps this is attributed to vanpool being a company-based service, while carpool is a less official gathering of individuals.

Table 3.4. Average one-way commute distance (miles) by mode and role, 2022 (off-campus trips only)

	Students	Faculty /staff	Total
Bicycling	1.9	3.5	2.5
Bus	3.3	12.7	4.5
Carpooling	6.1	15.3	11.7
Driving Alone	8.8	15.5	13.2
Dropped Off	3.0	10.4	6.7
Motorcycling/Motorized scooter	1.7	12.5	5.8
Ride-Hailing app (Uber/Lyft)	3.6	0.0	3.6
Vanpool	0.0	40.6	40.6
Walking	1.5	2.0	1.5
Other	17.1	16.6	16.8
All Modes	4.6	14.0	9.0

Table 3.5 compares the one-way commute distance values in Table 3.4 for 2022 with the distance values obtained in the 2018 survey. The average total trip length for all modes increased between 2018 to 2022 by 56%.

Table 3.5. Average one-way commute distance (miles) by mode and role, 2018 vs. 2022 *off-campus trips only

	2018 Students	2022 Students*	2018 Faculty/ staff	2022 Faculty/ staff*	2018 Total	2022 Total*
Bicycling	1.8	1.9	2.8	3.5	1.9	2.5
Bus	2.7	3.3	12.4	12.7	3.1	4.5
Carpooling & Vanpooling	3.0	6.1	16.1	18.6	4.4	14.0
Driving Alone	6.5	8.8	13.2	15.5	8.0	13.2
Dropped Off	2.3	3.0	13.4	10.4	2.9	6.7
Motorcycling/Motorized scooter	3.1	1.7	15.0	12.5	4.5	5.8
Ride-Hailing app (Uber/Lyft)	2.4	3.6	4.0	0.0	2.4	3.6
Walking	1.1	1.5	1.1	2.0	1.1	1.5
Other	1.9	17.1	6.0	16.6	3.1	16.8
All Modes	3.5	4.6	12.3	14.0	4.6	9.0

Table 3.6 displays a numerical process of the calculation of total VMT which was described in the previous section. The total weighted weekly VMT was calculated to be 1.12 million miles, and the total weighted yearly VMT was 46.8 million miles.

Table 3.6. Weekly & Annual VMT calculation process off-campus population only.

Strata	Number of Responses	Average Travel Distance (miles)	Average No of Days Commuted	Average Weekly VMT/ person	Response Weight	# of Weeks Traveled to Campus/ Year	Actual Population	Unweigted Total Weekly VMT
Faculty (full-time, tenure, or tenure track)	236	11.4	4.3	78.2	3.8	40	886	69,263
Faculty (part-time, adjunct)	61	13.0	3.1	73.6	8.5	40	518	38,119
Staff (full-time)	523	15.4	4.1	107.6	2.4	46	1,271	136,787
Staff (part-time)	13	13.5	3.9	92.6	17.4	46	226	20,926
Undergraduate student, 1st Year	13	15.1	4.5	90.7	12.5	38	163	14,777
Undergraduate student, 2nd+ Year	829	4.1	4.7	21.8	15.1	38	12,518	272,569
Graduate student	116	7.1	4.2	43.9	7.6	38	879	38,597
Grand Total	**1791**	-	-	-	-	-	**16,461**	**591,038**

Average Weighted Weekly VMT per Capita	**68**
Average Weighted Yearly VMT per Capita	**2,841**
Total Weighted Weekly VMT	**1,122,528**
Total Weighted Yearly VMT	**46,768,158**

From this overall VMT value, the weekly weighted VMT per mode class can be calculated. These values are displayed in Table 3.7. The mode class of car comprises the largest portion at 89 percent, with all other modes comprising less than 10 ten percent of total VMT respectively.

Table 3.7. VMT Per Mode Class (off-campus population only)

Mode Class	Number of Responses	Total Weekly VMT per Mode	Percentage of Total VMT Per Mode Class
Bus	207	913	1%
Car	957	93,249	89%
Electric Vehicle	87	9,633	9%
Motorcycle	21	955	1%
Non-Motorized Mode	519	-	0%
Grand Total	**1791**	**104,751**	**100%**

Chapter III: Estimation of Greenhouse Gas Emissions

The greenhouse gas (GHG) emission quantities were determined after calculating the VMT, as they are dependent on the distances traveled by transportation modes. According to the United States Environmental Protection Agency, in 2020, the transportation sector contributed the largest percentage (27%) of GHGs than any other sector in the US (*Fast Facts*, 2022). At Cal Poly, just over half (52%) of GHG emissions are produced from transportation, and 97% of these transportation emissions result from commuter traffic (Greve et al., 2017). This illustrates the need for a campus-wide survey amongst commuters and campus community members, in order to determine the greatest sources of emissions amongst commuter traffic and how to reduce these emission sources.

In this chapter, the methodology used to calculate GHG will be described. Additionally, the results from these analyses will be presented and discussed. For the GHG calculation, VMT values, as well as factors based on emission type and transportation mode determined via an online generator were utilized.

Methods and Data

The GHG calculation is dependent on the total weighted yearly VMT as calculated in the previous section. In the previous section, transport types (i.e. walking, biking, driving alone, etc) were referred to as "mode"; however, for the calculation of GHG emissions, it was more efficient to categorize these modes into five overarching "mode classes". Table 4.1 displays these mode classes, as well as which modes fall within each mode class category.

Table 4.1. Mode classes and the modes contained within.

Mode(s)	**Mode Class**
Bus	Bus
Carpooling, Driving alone (partial*), Dropped off, Ride-hailing app, Vanpool	Car
Driving alone (partial*)	EV
Motorcycling/Motorized scooter	Motorcycle
Bicycling, Walking	Non-Motorized Mode

*"Driving alone" responses were individually assigned to the "Car" and "EV" mode class, based on these respondents' answer to the survey question of whether they commuted to campus with an EV.

For the calculation, it was first necessary to convert this total VMT value into the VMT per mode class by using a ratio. This ratio was determined by dividing the weekly VMT for a particular mode class by the overall weekly VMT value. The weighted yearly VMT was then multiplied by the ratio for each respective mode class, leading to the individual VMT per mode class.

Before deriving the greenhouse gas quantities, it was also necessary to determine the corresponding EMFAC (emission factor) values. The "Emissions" tab on the EMFAC website (arb.ca.gov/emfac/) was used. It is important to note that two separate factor generations were performed, one that encompassed the modes of Cars, Motorcycles, and Buses (referred to as "LDA", "MCY", and "U-BUS"), and one that encompassed EVs. It was necessary to conduct these reports separately due to the nature of the EMFAC value generator and how it interpreted the fuel-type input.

Table 4.2 displays the EMFAC values that were derived from this generator and were used in the subsequent calculation steps. The particulate matter (PM)2.5 and PM10 factors for all mode classes were each determined by summing together the running exhaust emissions (RUNEX) and Brake Wear Particulate Matter Emissions (PMBW) values respectively. These values are combined because they are two different sources of emissions and particulate matter specifically is generated from both the running engine as well as the vehicle tires. For the EV mode class, only the PM2.5 and PM10 values were considered, and all other emissions were assumed to be zero. This is because the EV produces PM via its tire treads and exhaust, but it does burn gasoline and therefore would not emit the remaining emission types. Naturally, all non-motorized EMFAC values were assumed to be zero as they do not run on gasoline and assumedly do not produce significant PM. All other factors were transcribed directly from the RUNEX columns.

Table 4.2. EMFAC factors utilized in the GHG emissions calculations, all in units of grams/mile.

Mode Class	NOx Factor	PM2.5 Factor	PM10 Factor	CO2 Factor	CO Factor	SOx Factor	CH4 Factor	N2O Factor
Bus	0.087598	0.032581	0.097057	1187.81	0.494894	0.011743	0.002531	0.008695
Car	0.061909	0.003392	0.007442	292.7773	0.841272	0.002894	0.003244	0.005929
EV	0	0.001529	0.004369	0	0	0	0	0
Motorcycle	0.773122	0.006106	0.014024	198.9956	18.26294	0.001967	0.220964	0.0483
Non-Motorized Mode	0	0	0	0	0	0	0	0

The factors from Table 4.2 were multiplied by the mode-specific weighted yearly VMT value in order to determine the quantity of emissions in grams. The CO_2 equivalent (CO_{2e}) values for each mode class were determined by using the following Equation 4.1. In this equation, the VMT_{mode} refers to the weighted yearly VMT value previously derived, the EMFAC factors are from Table 4.2, and the Global Warming Potentials (GWPs) are from standards decided by the UN Framework Convention on Climate Change in 2007 (*Global Warming Potential*, 2022).

-

The total CO_{2e} value was then determined by summing together the CO_{2e} values from each mode class. To determine CO_{2e} per mile, this total CO_{2e} value was divided by the total weighted yearly VMT. Finally, the metric ton CO2e ($MTCO_{2e}$) value was derived by dividing the CO_{2e} value by one million.

Results and Discussion

Using the emission factors from EMFAC listed in Table 4.2 in the previous section, Table 4.3 displays the resulting emission types in kilograms per mode class. The largest total emission is from CO_{2e} and CO_2, while the smallest emission values are from PM2.5 and PM10.

Table 4.3. Emissions (in kilograms) Per Mode Class (off-campus population only)

Mode Class	VMT	NOx	PM2.5	PM10	CO2	CO	SOx	CO2e
Bus	407.75	35.7	14.1	39.6	484,334	202	4.8	485,416
Car	41,633.11	2,577.5	141.2	309.8	12,189,229	35,024.8	120.5	12,275,436
Electric Vehicle	4,300.83	-	6.6	18.8	-	-	-	-
Motorcycle	426.47	329.7	2.6	6.0	84,865	7,788.5	0.8	93,359
Grand Total	**46,768**	**2,943**	**165**	**374**	**12,758,428**	**43,015**	**126113.3**	**12,854,211**

As described in the previous section, it was necessary to calculate mode class ratios to determine the weekly VMT to be allocated to each mode class. Table 4.4 below displays these mode class ratios. The "2018 vs 2022 Comparison" section shows the mode use percentages among students and faculty/staff members; connecting that table with Table 4.4, it can be seen that the highest mode class ratio is associated with the largest percentage of use amongst campus members.

Table 4.4. Mode class ratios

Mode Class	Mode Class Ratio
Bus	0.008718621
Car	0.890201969
Electric Vehicle	0.09196068
Motorcycle	0.00911873
Non-Motorized Mode	0

The total GHG emissions calculated were highest for the "Car" mode class at 12275.4 $MTCO_{2e}$, and lowest for the "Motorcycle" mode class at 93.4 $MTCO_{2e}$ (not including EVs, as they resulted in $MTCO_{2e}$). Table 4.5 below displays the total million vehicle miles traveled (MVMT), emissions rates, and total emissions for each mode class. This does not include the mode class of "Non-Motorized Mode", as this class evidently does not produce emissions of any kind.

Table 4.5. Annual greenhouse gas emissions (MTCO2e) by mode class, 2022 (off-campus trips only)

	Total MVMT	Emissions rate (CO2e per mile)	Total emissions (MTCO2e)
Bus	0.4	1190.5	485.4
Car	41.6	294.8	12275.4
Electric Vehicle	4.3	0.0	0.0
Motorcycle	0.4	218.9	93.4
Grand Total	**46.8**	**272.8**	**12854.2**

The overall total estimated MTCO2e value is 12854.2, as displayed in Table 4.5. This is a two percent reduction from the 2018 MTCO2e value. The total emissions rate reduced by four percent between 2018 and 2022, while the average trip length increased by 56%. This indicates that more individuals are traveling farther from campus but are likely finding methods to do so that are more beneficial to the environment (such as carpooling and commuting via EVs). Table 4.6 shows a comparison of the aforementioned values, as well as number of students and staff, between the years of 2015 & 2018 and the years of 2018 & 2022. The previous Table 4.5 only considered off-campus trips, while Table 4.6 includes responses from the on-campus population – this is why values such as the total emission rate (CO2e/mile) may differ from the previous tables.

Table 4.6. Changes in factors influencing campus-generated GHG emissions, 2015-2022 (including on-campus population)

	2015	2018	Percent change	2018	2022	Percent change
Number of students	20,944	22,188	6%	22,188	22,022	-1%
Number of faculty/staff	3,015	3,088	2%	3,088	2,928	-5%
Share of trips by single-occupancy vehicle	29%	39%	34%	39%	36%	-8%
Average trip length (miles)	3.7	4.6	24%	4.6	7.2	56%
Emission rate (CO2e/mile)	305.9	285.1	-7%	285.1	274.85	-4%
Total commute-generated emission (MTCO2e)	**9,325**	**13,179**	**41%**	**13,179**	**12,854**	**-2%**

Chapter IV: Traffic Count Data

Background

Figure 5.1. Map of California Polytechnic State University, San Luis Obispo.

Above is a general map of the campus of California Polytechnic State University, SLO. The entrances, exits, streets, and main buildings are highlighted in this drawing. Though there are many entrances to the campuses, the main two, which were included in this research data collection, are through California and Grand. The main transportation modes on campus are buses, bicycles, heavy and light duty vehicles (i.e., cars), and motorcycles. Hence, this research paper focuses mainly on the data and numbers associated with these modes of transportation depending on both time and site.

Below is a description of each site from the location coordinates with attached images showing the streets where the data was taken. For the following five locations, A->B (direction 1) is towards campus and B->A (direction 2) is away from campus.

Locations

Site 1: (Grand Ave.)

Location coordinates:

Latitude: 35' 17.8743 North	Location Accuracy
Longitude: 120' 39.9381 West	High

Where: Direction 1 is towards N. Perimeter (towards campus) and Direction 2 is towards Deer Rd. (away from campus)

Site 2: (Longview Lane)

Location coordinates:

Latitude: 35' 17.8645 North	Location Accuracy
Longitude: 120' 39.5261 West	Low

Where: Direction 1 is towards Hathway Ave (towards campus) and Direction 2 is towards S. Perimeter (away from campus)

Site 3: (California Blvd.)

Location Coordinates:

Latitude: 35' 18.0052 North	Location Accuracy
Longitude: 120' 39.9628 West	High

Where: Direction 1 is towards N. Perimeter (towards campus) and Direction 2 is towards Foothill (away from campus)

Site 4: (Highland Dr)

Location Coordinates:

Latitude: 35' 18.1464 North	Location Accuracy
Longitude: 120' 40.0818 West	High

Where: Direction 1 is towards Mt. Bishop Rd (towards campus) and Direction 2 is towards W. Creek Rd (away from campus)

Site 5: (Campus Way)

Location Coordinates:

Latitude: 35' 17.8020 North	Location Accuracy
Longitude: 120' 39.8593 West	Low

Where: Direction 1 is towards College Ave. (towards campus) and Direction 2 is towards W. Creek Rd (away from campus)

Data Processing and Filtering Methodology

Next, we begin describing the overall data processing that took place to ultimately create the informative tables and graphs located in this report from a software called Trax pro. Note: this was done and repeated for all five sites and bicycles were the only model type counted for Site 2.

The software used to actually open the original files (due to the original files being in .DMP format) was called Trax pro, a transportation data processing software. One must open the software, select open file, and click on the desired .dmp file located on the PC. From there, the PROCESS button must be selected, and a file name is chosen. The correct times/dates are selected, which have to be verified by comparing the data to the day on which it was taken (i.e., a weekday would have higher counts than a weekend). Then, 'Modified Scheme F with Bikes' needs to be chosen for the most accurate and detailed data. Save and process is chosen, and a new tab is brought up in the software. Here, the user must select 'Class' next to 'Across the Top' and change 60 minutes to 15 minutes for the 'Interval Length & Options.' The next step was to verify the directions and which direction (Direction 1 or 2) was towards or away campus, and which specific street these directions were towards. This was done through Google Maps by searching the exact location coordinates given also in Trax pro. Once the directions could be identified (ex. Site 1: Direction 1 towards N. Perimeter (toward campus) and Direction 2 towards Deer Rd. (away campus), one must manually change the direction name under the 'Directions' tab. Finally, the green checkmark 'Process' is clicked and all the raw data counts, based on direction and time of day, is presented in a table. From here, these were exported to an Excel spreadsheet and further analysis and data organization could take place.

The spreadsheets in Excel were first done for each specific site. The tabs were arranged from left to right in order of directional raw data (direction 1 then direction 2), and then data only based on the day of the week and the PCE counts. These were then combined under one excel file spreadsheet corresponding to two main themes: weekday PCE data and model vehicle types.

One of the first steps taken was to verify the dates for which the data was taken for each site. This was crucial because all of the data would then be processed based on date and day from then on. To do this, the original videos of the transportation data being taken aided the process but only for a couple of sites, in which the date can be seen. This could only do so much so next a new method had to be used. This was comparing the date listed in the Trax pro software with what the number counts actually turned out to be to see if a set day matched with the expected corresponding number of vehicle counts. For instance, as was mentioned earlier, a weekday would have higher counts than a weekend. If the counts made sense, the dates for the data were taken from the software and adjusted for 2022. This was the case, thankfully, for all the sites.

The initial calculations of PCE were one of the first steps taken when making meaning out of the raw data. This would be needed for the pivot charts created for each site and direction and the weekday plots and bar graphs. PCE, Passenger Car Equivalent, is a useful way to interpret the counts and the trends for based on time of day for the flow of transportation-related activities across campus. To make the PCE calculation, a new column in excel was created solely for this, and the calculation was as follows: all of the numbers across the row for its set time and model types were added but with different scales and ratios. Cars and two-axle trucks were counted as 1.0, motorcycles were 0.5, and buses and bigger trucks were 3.0. (Note: these model types will be described more specifically later on in the report)

The next calculation that needed to be done to organize the data and create tables and graphs after PCE was the number of trips (#trips). A similar procedure was followed but this time with different scales based on established standardized numbers associated with each model type from an online resource. The scales were as such: 1.7 for Cars & Trailers and 2 Axle Long, 9.5 for Buses, and 1.0 for all remaining model types. Below is the link used as a resource for these scales:

https://www.fhwa.dot.gov/tpm/guidance/avo_factors.pdf

The next step in the data organization process was to create weekday specific data for each site. Each site was also categorized by two directions, in and out. This was done by copy pasting the pivot chart data using two main categories: PCE and the number of trips (see above for how PCE and #trips were calculated). The PCE data is distributed under the column labels 'weekday' from Sunday to Saturday and the row labels 'time in decimal.' The same was done with the number of trips. Finally, an adjusted PCE total was done to account for the 15-minute intervals and the number of lanes (where PCE value was divided by 4 to get into 15-minute intervals and multiplied by the number of lanes) and then averages were taken from these adjusted totals for just Tuesday-Thursday and the Weekend for each direction. The plots could finally be made. First was a pivot line chart for the Flow Rate (PCE/hr./lane) for Sunday through Saturday. The second was a bar chart for Total Directional Volume (PCE/day) on the y-axis and combined averages for each direction, in and out, for Tuesday-Thursday and the weekend.

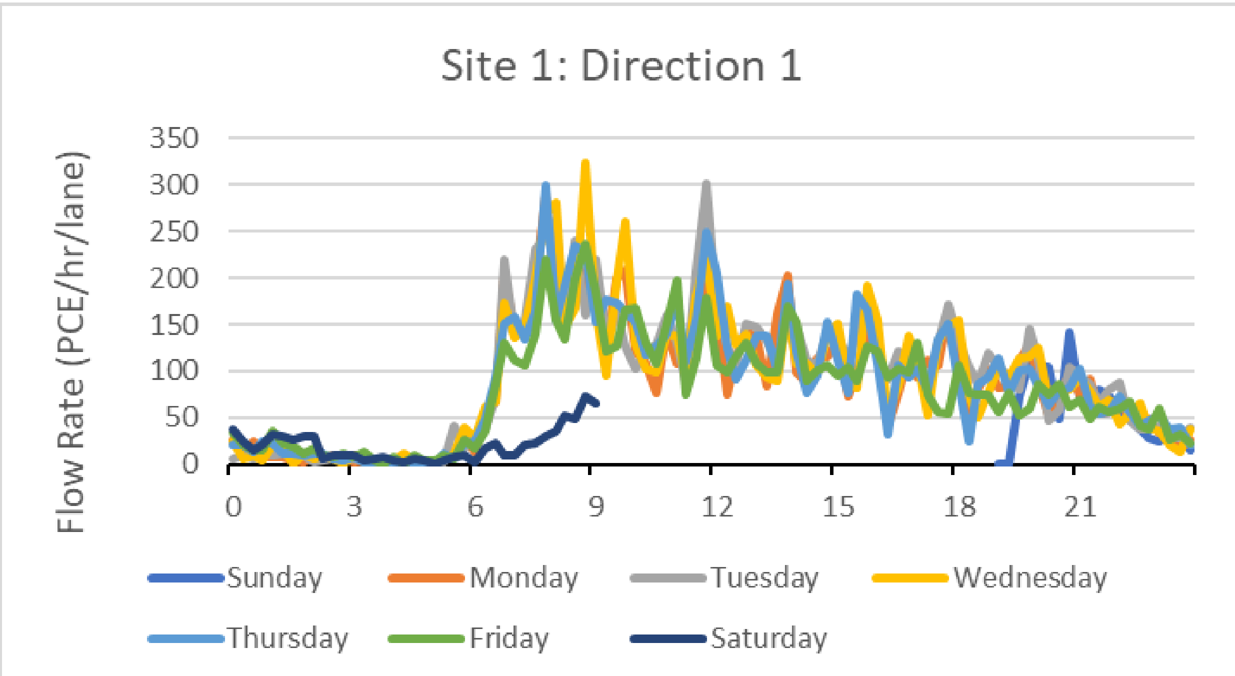
The last arrangement of data was done depending on model vehicle type. To begin, the different model types listed on Trax pro were grouped under set categories to make the data easier to organize: bicycles, motorcycles, light-duty (which included Cars and Trailers), light-duty trucks (which included 2 axle long and 2 axle 6 tire), buses, and MDHD trucks (which included the rest of the vehicle categories). The sums based on direction were totaled and the data was organized in the following way for each site: model type as the column header (with Site 2 including bicycles only—see earlier note above about Site 2) and the date/weekday as the row label. It is worth noting each model type had totals summed for both the in and out directions.

Results

We now proceed to further detail and present the tables and plots made from the above descriptions of data.

Flow Rates per Day of the Week

The next set of graphs created were the pivot charts for the weekday data for each direction and each site. The flow rate is in terms of PCE/hr./lane and is the measured variable dependent on the time in decimal-the independent variable. The different weekdays are color coded to help



separate the trends between each day.

Figure 5.2. Site 1, Direction 1 Flow Rates

We can see from above that in general, the flow rate is at its highest from about 7 AM-12 PM, which makes sense with the general flow of traffic seen on campus.

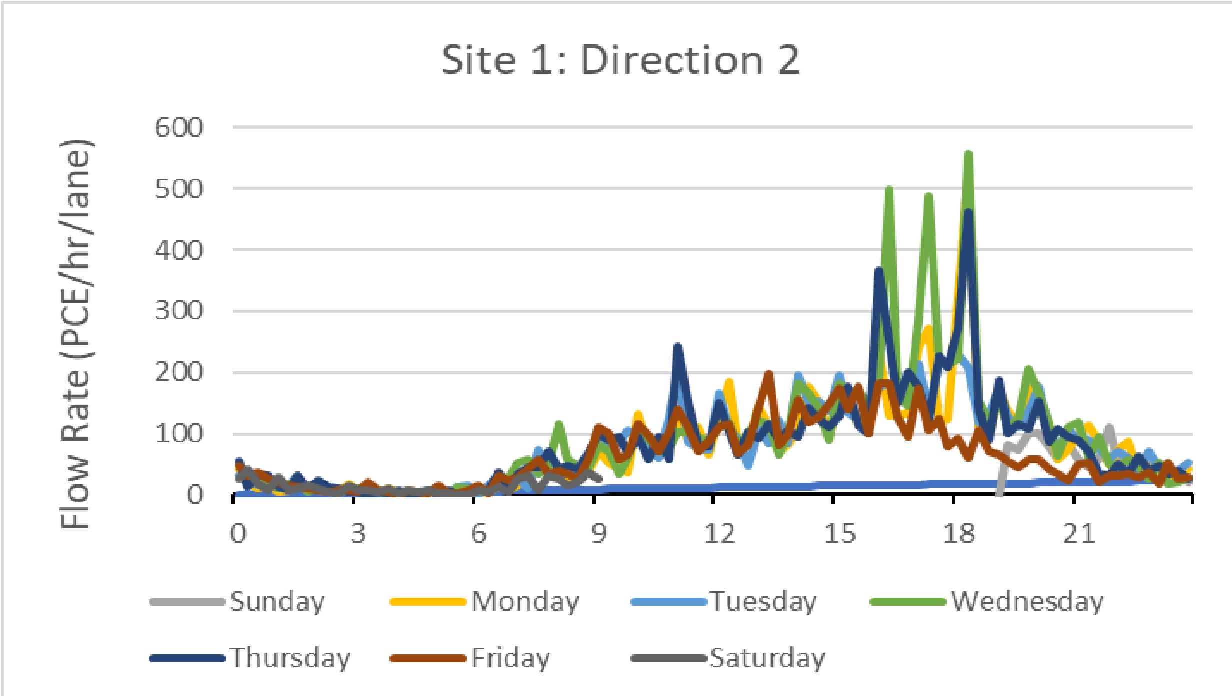


Figure 5.3. Site 1, Direction 2 Flow Rates

Above, we see there are major changes and peaks towards the end of the day around 3 PM-6:30 PM. This is consistent with the direction as direction 2 is always away from campus and the route taken when leaving campus.

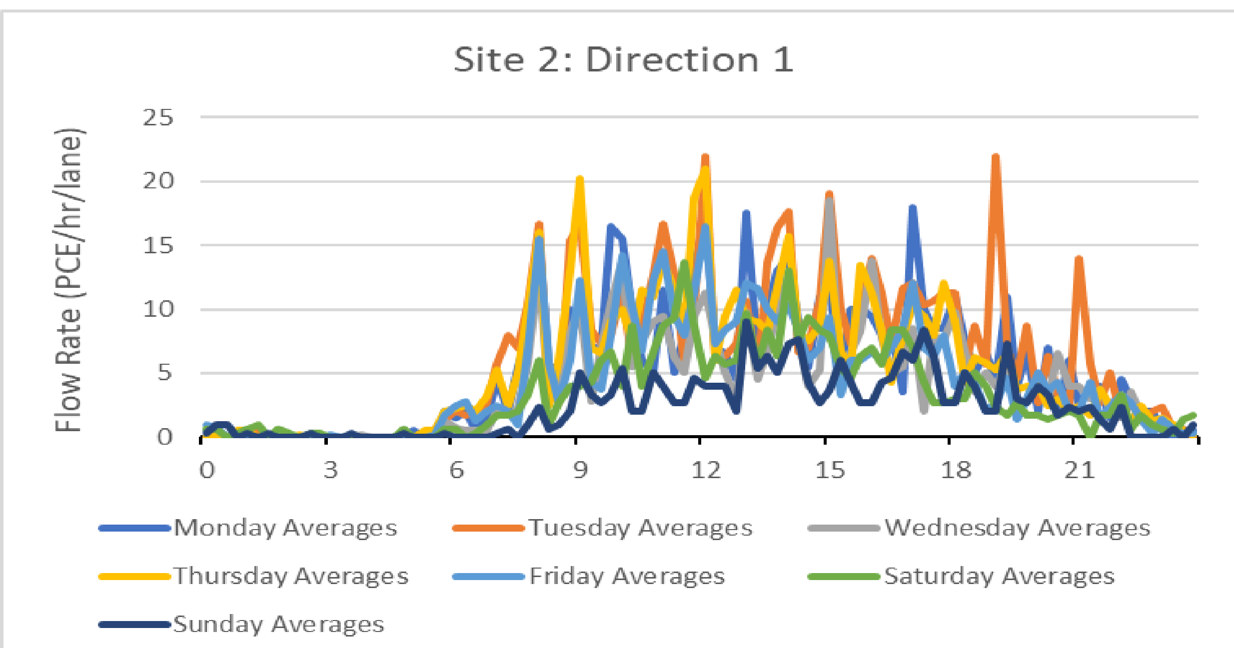


Figure 5.4. Site 2, Direction 1 Flow Rates

Apart from the different peak heights for the different weekdays, we see a consistent trend where the flow rate is nearly zero until 6 AM, where after that is an alternation between an increase then decrease (back and forth) for the rest of the day.

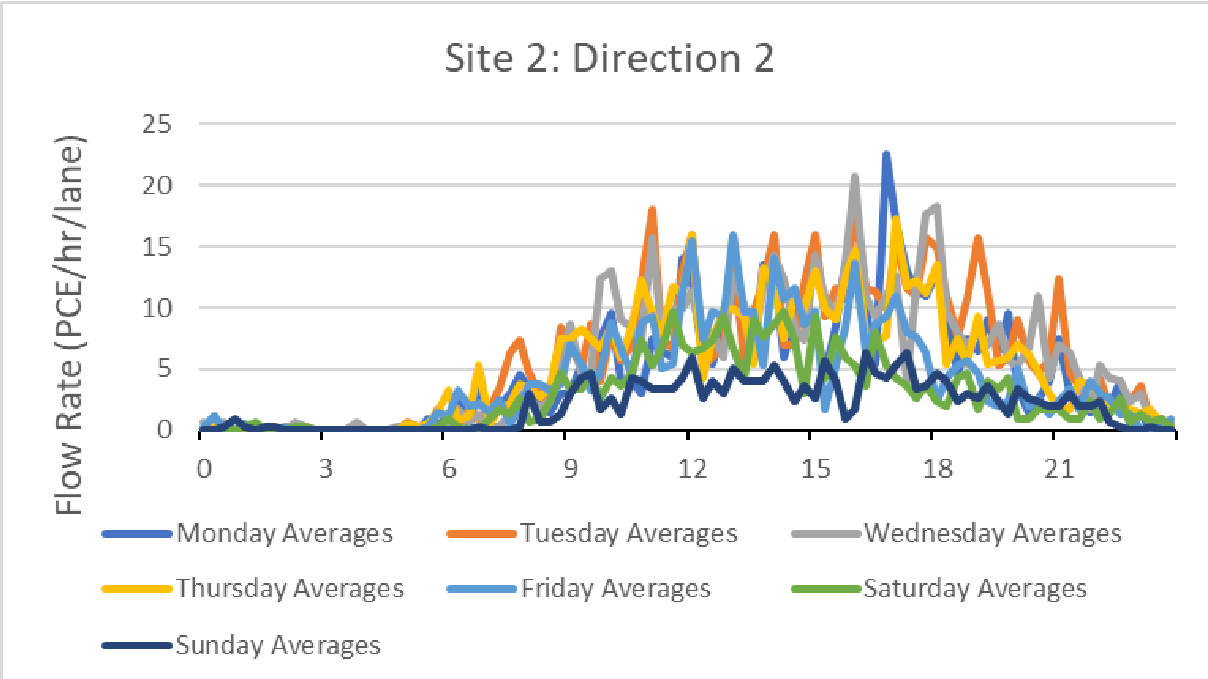


Figure 5.5. Site 2, Direction 2 Flow Rates

Here, the major peaks occur towards the end of the day—expected for direction 2

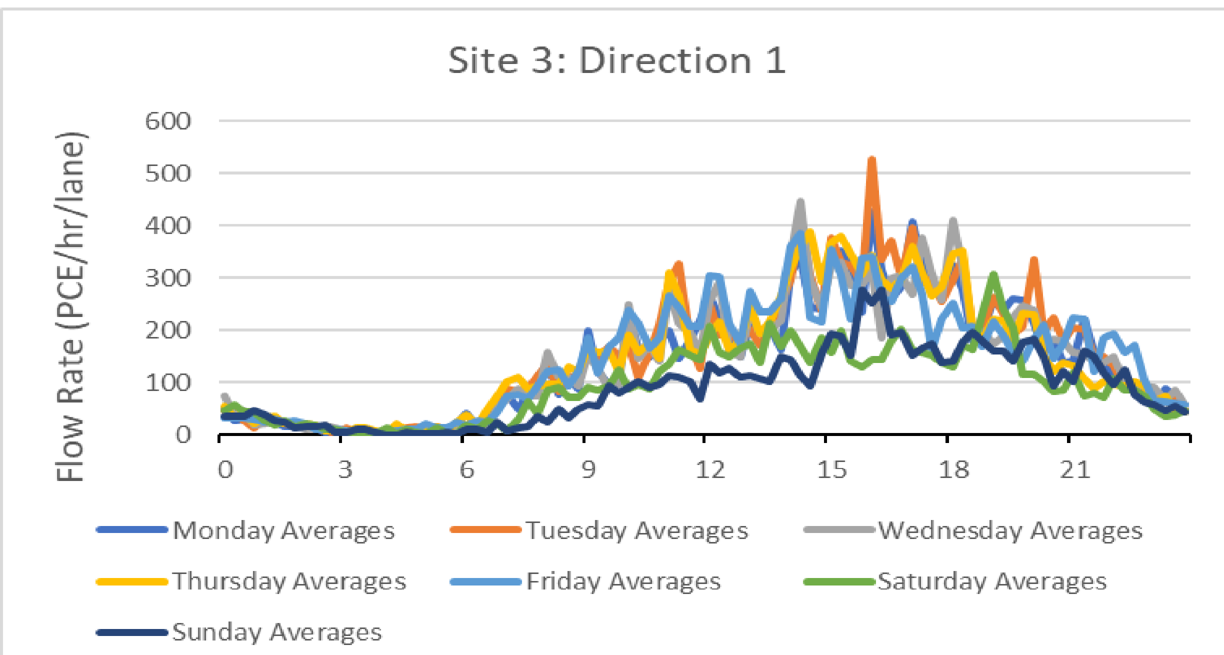


Figure 5.6. Site 3, Direction 1 Flow Rates

Figure 5.6 does not match expectations or predictions as we see the major maximums taking place later in the day relative to other direction 1 graphs towards the campus. This may be a site dependent finding or a source of error.

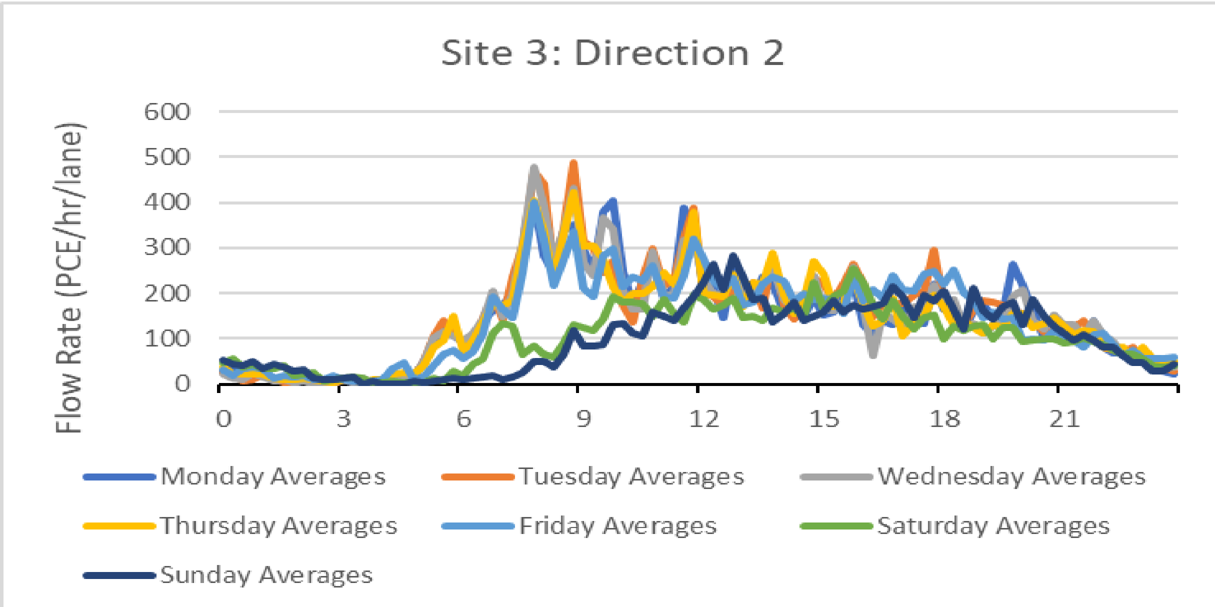


Figure 5.7. Site 3, Direction 2 Flow Rates

This graph further shows a disconnect from expectations as the major maximums are early in the day relative to other direction 2 graphs away from campus. This may be a site dependent finding or a source of error.

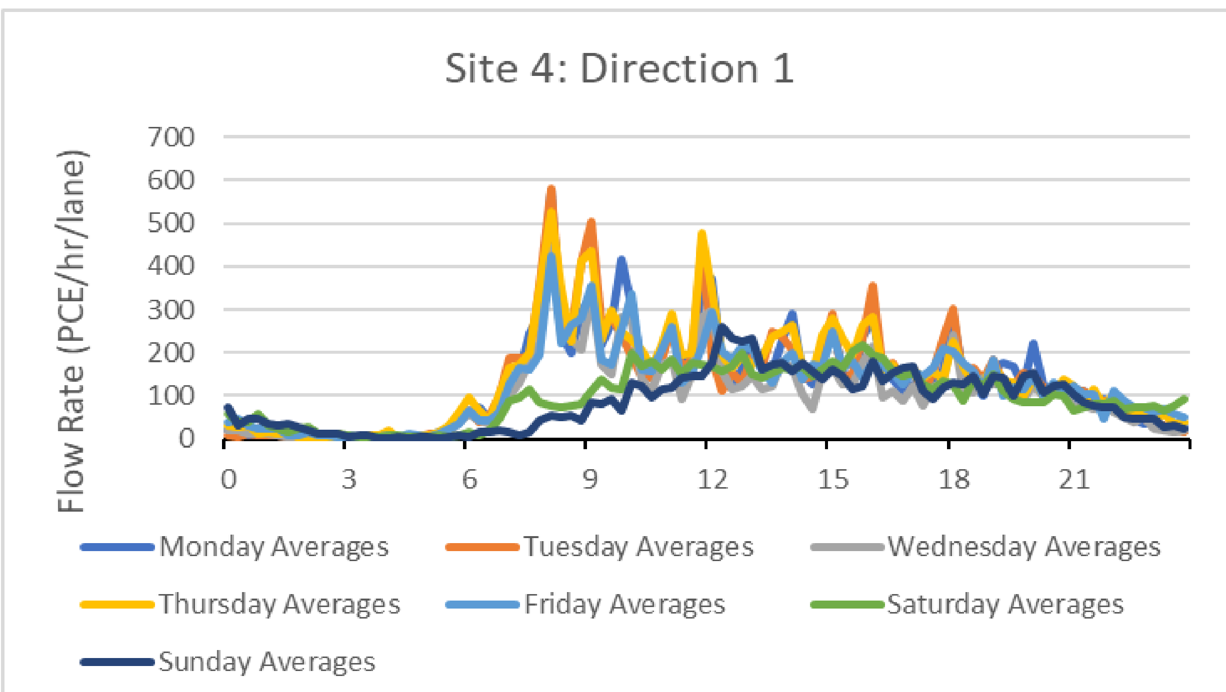


Figure 5.8. Site 4, Direction 1 Flow Rates

This set of data closely mirrors that of Site 1: Direction 1, with a sudden increase at around 6 AM and then on average decreasing for the rest of the day with occasional relative maximum peaks.

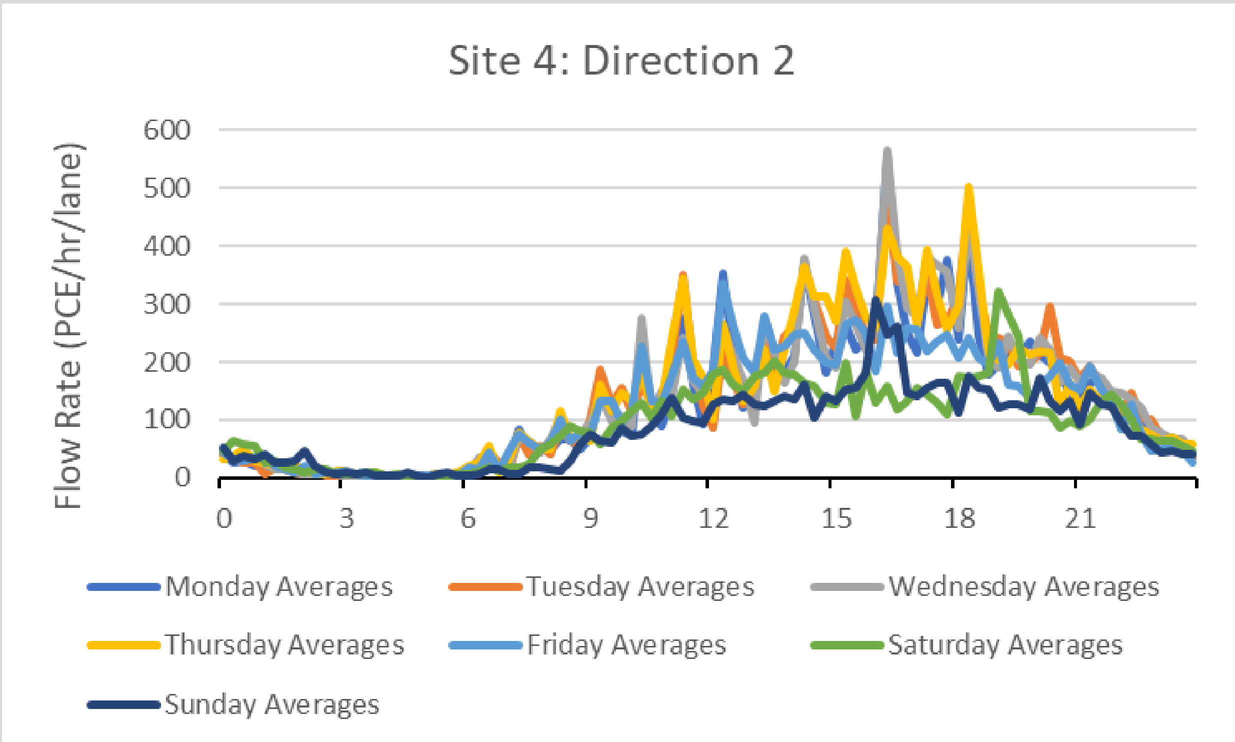


Figure 5.9. Site 4, Direction 2 Flow Rates

Here expected directional data is depicted with major increases taking place at the end of the day way from campus.

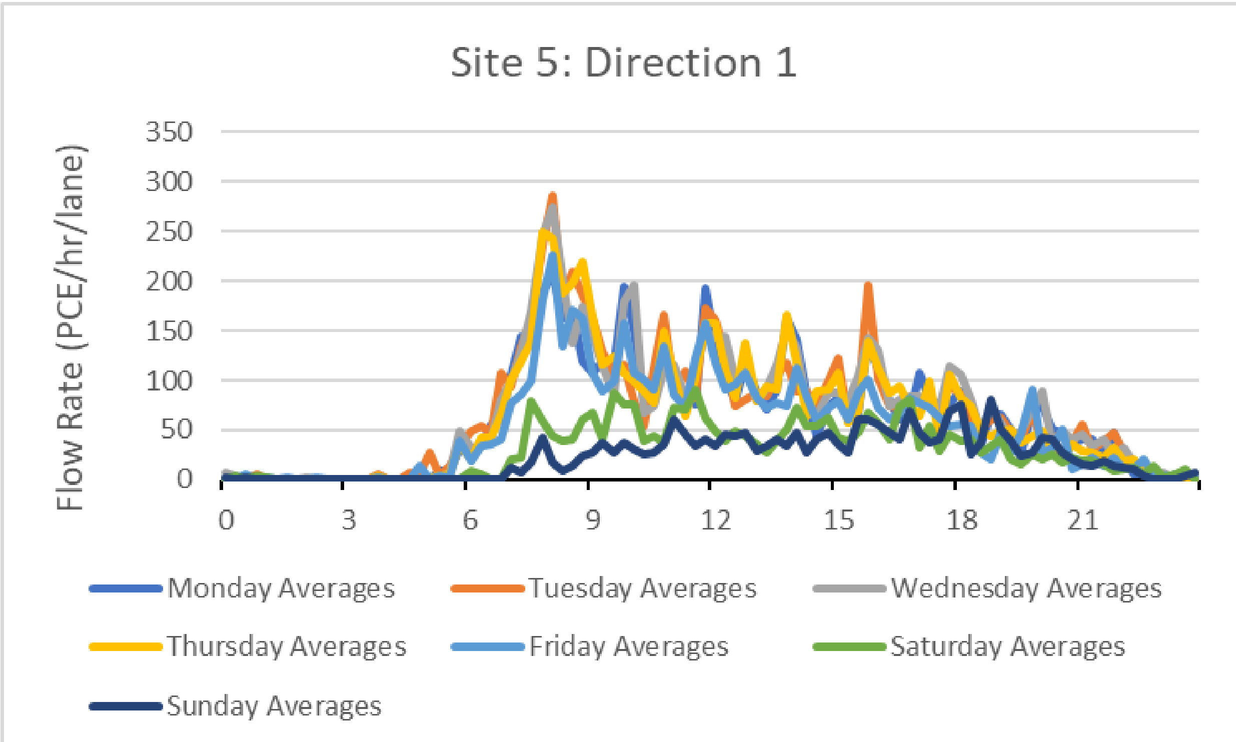


Figure 5.10. Site 5, Direction 1 Flow Rates

Above is a consistent trend with what one would expect for a flow rate towards campus.

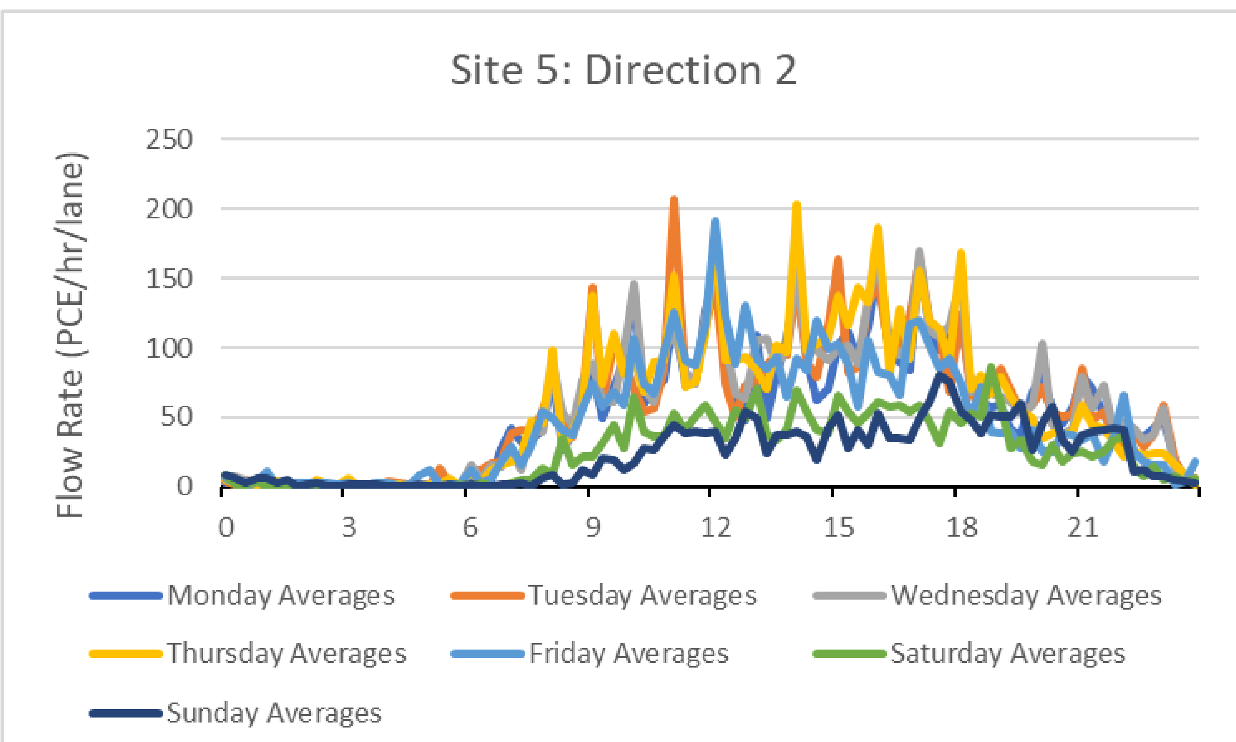


Figure 5.11. Site 5, Direction 2 Flow Rates

Most days above alternate between similar maximums and minimums from 9 AM to 6 PM, then decrease on average from then on.

Trip Counts

Next, we proceed to present tabular data for the number of trips calculated in excel. The number of trips was the standard used to compare the newest 2022 data with that of 2019. It is only for Monday-Friday, is site-dependent, and separated based on direction. The average of both directions was taken to compare with the data from 2019 for the relevant sites with data available from 2019.

Year	Grand	California	Highland	Campus Way
2019	6998	5487	5412	N/A
2022 (toward)	6516	5295	5360	2358
2022 (away)	5669	5648	5530	2206
2022 avg.	6093	5472	5445	2282

Table 5.1. Monday Counts

	Grand	California	Highland	Campus Way
2019	7367	5864	5667	N/A
2022 (toward)	7096	5682	5481	2503
2022 (away)	6078	5913	5812	2340
2022 avg.	6587	5798	5647	2422

Table 5.2. Tuesday Counts

Year	Grand	California	Highland	Campus Way
2019	7965	5532	5946	N/A
2022 (toward)	6927	4811	5590	2529
2022 (away)	5966	5668	5851	2339
2022 avg.	6447	5240	5721	2434

Table 5.3. Wednesday Counts

Year	Grand	California	Highland	Campus Way
2019	8582	5546	5998	N/A
2022 (toward)	6769	5412	5753	2395
2022 (away)	5706	5652	5899	2349
2022 avg.	6238	5532	5826	2372

Table 5.4. Thursday counts:

Year	Grand	California	Highland	Campus Way
2019	8525	4889	4800	N/A
2022 (toward)	5998	4415	3703	1360
2022 (away)	5132	4878	3744	1271
2022 avg.	5565	4647	3724	1316

Table 5.5. Friday Counts:

Note: the most important takeaway is while numbers are consistent and can be comparable with the 2019 data with an on average <10% difference, we see some major changes between the years in for all the data for Grand and one for Highland in the Friday counts. While Highland can be excused due to this abnormality occurring in just one weekday, one cannot ignore the large and consistent difference for Grand. One possible explanation for this margin of error is the effects of the pandemic on public transportation and the routes previously taken on Grand. 2019 was pre-pandemic and 2022 was post-pandemic.

Total Directional Volume

The next set of plots were bar graphs for Monday-Thursday averages and then weekend averages marking total directional volume for PCE per day. The main takeaway is as follows: the bar heights corresponding to Monday-Thursday were always higher than that for the weekend for all sites, a finding one should not find surprising for a college campus.

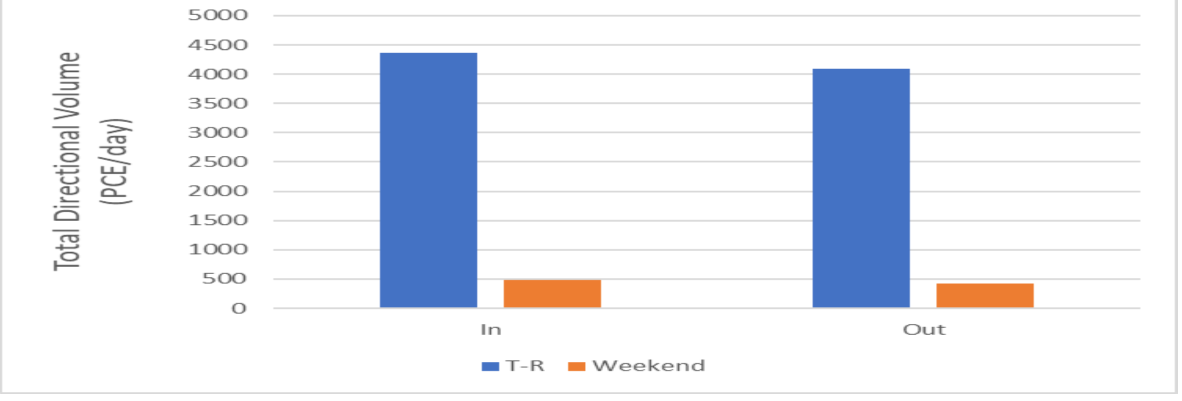


Figure 5.11. Site 1 Total Directional Volume

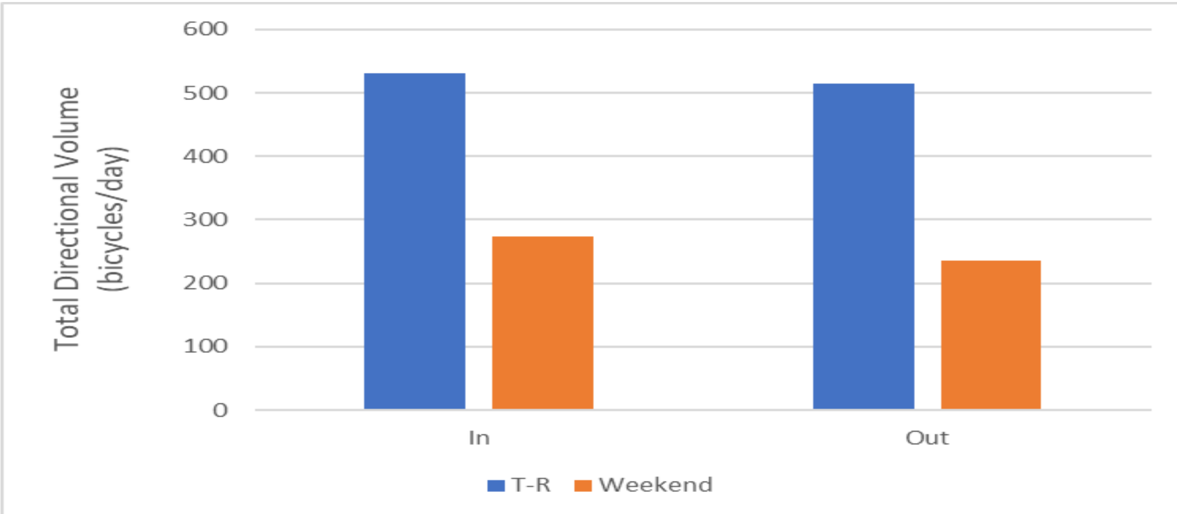


Figure 5.12. Site 2 Total Directional Volume

Figure 5.13. Site 3 Total Directional Volume

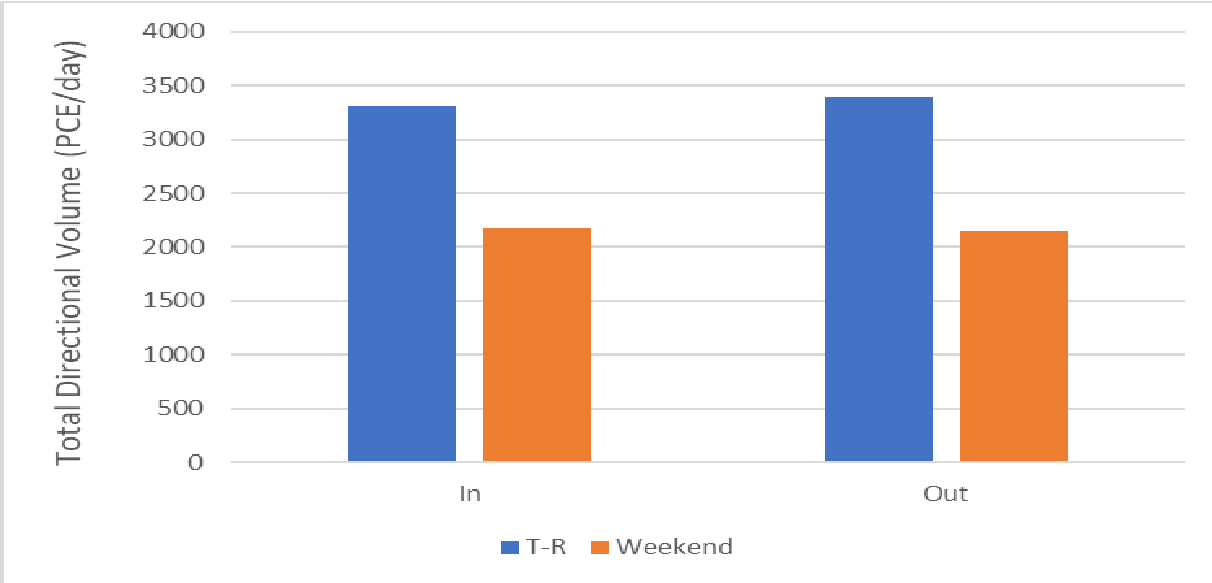


Figure 5.14. Site 4 Total Directional Volume

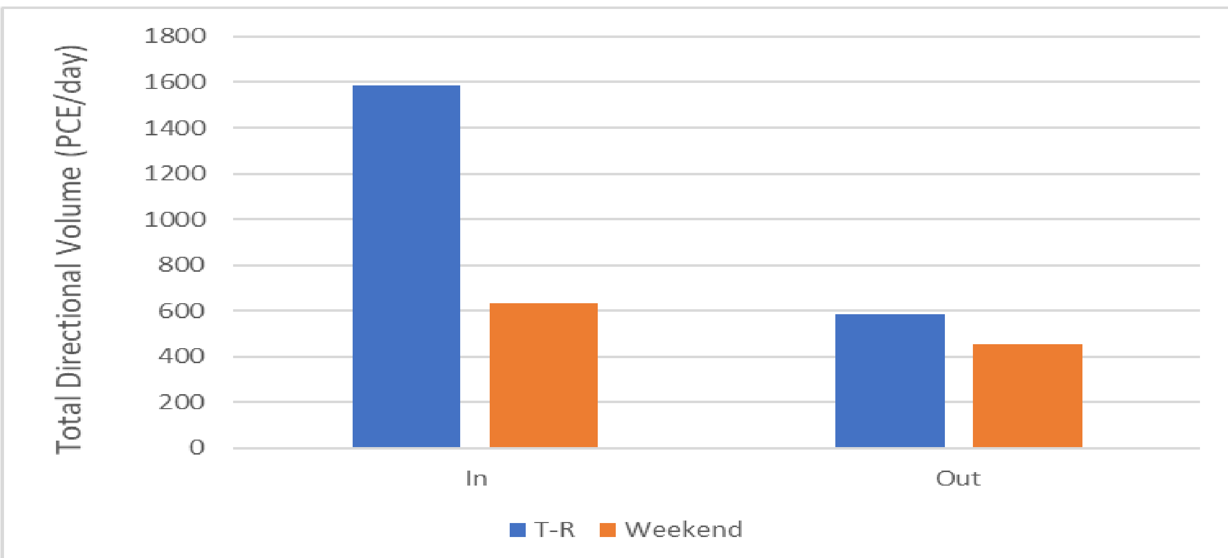


Figure 5.15. Site 5 Total Directional Volume

Margin of Error

The last set of graphs were created using a programming language called RStudio. Here, the data from excel was automatically inserted into the program and then boxplots with margins of error relating to each model type, site, and applicable counts. To begin, it is worth presenting the tabular data relating to each model type for both directions and for each site.

Date	Day	Bicycle in/out	Motorcycle in/out	Light Duty In/out	Light Duty Truck In/out	Buses In/out	MDHD In/out
5/1	Sun	5/29	5/6	542/533	75/164	2/2	6/8
5/2	Mon	304/437	26/47	2879/2181	192/226	36/31	60/114
5/3	Tues	350/359	24/50	3039/2374	778/900	39/29	52/59
5/4	Wed	296/629	32/54	3006/2092	645/858	47/40	66/84
5/5	Thurs	258/462	17/33	2942/2051	711/916	42/31	50/90
5/6	Fri	167/210	23/40	2667/1906	588/849	57/33	58/84
5/7	Sat	7/14	1/2	285/186	51/69	2/2	6/8

Table 5.6. Site 1 trips in/out per mode

Date	Day	Bicycle
4/27	Wed	278/300
4/28	Thurs	509/449
4/29	Fri	431/397
4/30	Sat	369/308

5/1	Sun	238/194
5/2	Mon	535/543
5/3	Tues	631/592
5/4	Wed	571/534
5/5	Thurs	503/508
5/6	Fri	447/403
5/7	Sat	255/255
5/8	Sun	202/185
5/9	Mon	520/471
5/10	Tues	531/521
5/11	Wed	483/519
5/12	Thurs	523/491
5/13	Fri	441/402
5/14	Sat	343/272
5/15	Sun	236/200
5/16	Mon	499/451
5/17	Tues	624/579

5/18	Wed	570/568
5/19	Thurs	563/547
5/20	Fri	169/124

Table 5.7. Site 2 trips in/out for bicycles

Date	Day	Bicycle In/out	Motorcycle In/out	Light Duty In/out	Light Duty Truck	Buses In/out	MDHD in/out
4/27	Wed	159/66	14/5	1399/1008	294/146	36/12	49/9
4/28	Thurs	278/287	32/25	2175/2435	645/471	15/26	67/36
4/29	Fri	204/207	34/22	2261/2656	671/516	12/15	54/30
4/30	Sat	92/75	13/10	1557/1989	429/332	28/25	19/7
5/1	Sun	105/100	20/5	1614/2086	395/351	26/29	8/11
5/2	Mon	223/284	29/23	2052/2449	561/503	29/26	18/32
5/3	Tues	272/264	25/24	2245/2608	627/533	23/28	27/32
5/4	Wed	272/284	32/23	2078/2498	621/528	22/18	27/23
5/5	Thurs	274/274	35/23	2202/2588	611/531	27/26	23/28
5/6	Fri	186/216	37/29	2148/2517	714/512	35/32	39/31
5/7	Sat	84/104	25/12	1452/1879	565/464	17/15	8/10

5/8	Sun	73/70	8/5	1294/1786	332/276	14/11	2/4
5/9	Mon	232/284	33/26	2166/2557	559/431	27/28	43/46
5/10	Tues	265/325	27/18	2285/2592	667/518	28/26	49/73
5/11	Wed	255/314	27/24	2171/2581	556/482	26/15	67/72
5/12	Thurs	299/299	28/26	2207/2536	543/444	21/25	54/62
5/13	Fri	199/193	28/23	2172/2456	510/421	28/29	24/20
5/14	Sat	76/86	12/19	1435/1764	269/248	17/13	6/4
5/15	Sun	108/114	10/12	1562/1878	292/273	10/14	12/10
5/16	Mon	253/290	29/26	2313/2649	544/464	33/25	30/39
5/17	Tues	286/264	26/25	2476/2761	573/481	31/30	27/37
5/18	Wed	293/289	32/32	2305/2581	540/509	27/28	25/19
5/19	Thurs	246/296	26/30	2382/2556	583/491	31/24	19/36
5/20	Fri	61/136	11/12	565/1149	197/232	14/17	12/11

Table 5.8. Site 3 trips in/out per mode

Date	Day	Bicycle In/out	Light Duty In/out	Light Duty Truck	Buses In/out	MDHD in/out
4/29	Fri	44/176	1305/1798	204/311	19/7	20/12

4/30	Sat	55/88	1933/1870	275/337	2/1	8/6
5/1	Sun	50/79	1821/1855	265/277	16/0	14/8
5/2	Mon	274/338	2339/2504	393/391	37/22	60/10
5/3	Tues	267/288	2455/2633	406/417	26/22	32/14
5/4	Wed	300/367	2468/2597	444/417	24/21	32/22
5/5	Thurs	247/308	2482/2608	410/415	30/22	48/30
5/6	Fri	173/217	2251/2357	425/449	35/25	52/20
5/7	Sat	53/80	1684/1801	502/458	20/1	20/18
5/8	Sun	44/61	1486/1492	209/208	16/0	12/6
5/9	Mon	284/320	2252/2403	365/340	29/29	34/18
5/10	Tues	237/301	2467/2625	404/452	25/21	50/46
5/11	Wed	257/323	2505/2646	406/405	32/18	44/38
5/12	Thurs	250/287	2735/2836	384/396	34/23	58/42
5/13	Fri	180/210	2220/2246	292/298	34/24	42/20
5/14	Sat	62/86	1583/1715	188/202	12/0	6/4
5/15	Sun	64/85	1709/1723	188/217	16/0	2/2
5/16	Mon	272/307	2497/2599	399/375	23/22	28/12

5/17	Tues	258/326	2488/2641	363/391	26/16	16/22
5/18	Wed	258/315	2497/2615	384/410	25/22	70/82
5/19	Thurs	261/314	2524/2609	416/397	32/22	80/66
5/20	Fri	115/35	783/347	155/85	12/13	34/38

Table 5.9. Site 4 trips in/out per mode

Date	Day	Bicycle In/out	Light Duty In/out	Light Duty Truck	Buses In/out	MDHD in/out
4/29	Fri	21/79	240/344	47/63	3/4	18/0
4/30	Sat	37/77	469/487	145/107	3/2	32/2
5/1	Sun	28/39	469/481	60/78	0/0	12/0
5/2	Mon	164/251	905/895	227/214	2/3	90/32
5/3	Tues	166/233	1022/980	247/221	3/3	74/16
5/4	Wed	165/249	1066/996	242/226	1/1	70/24
5/5	Thurs	166/249	1009/970	221/213	4/6	62/24
5/6	Fri	116/167	860/772	206/208	4/4	42/14
5/7	Sat	33/49	389/406	123/146	1/1	6/0
5/8	Sun	20/29	398/410	48/51	0/0	2/0

5/9	Mon	146/248	989/951	198/180	2/4	38/6
5/10	Tues	154/249	1060/1030	250/221	1/1	62/12
5/11	Wed	174/233	1085/1047	231/212	3/5	66/10
5/12	Thurs	161/240	1018/1025	219/230	3/3	72/26
5/13	Fri	104/169	877/861	201/204	2/4	34/6
5/14	Sat	29/43	508/490	87/97	0/0	16/2
5/15	Sun	26/33	543/524	60/73	0/0	8/0
5/16	Mon	164/237	1030/969	228/213	5/2	56/14
5/17	Tues	168/246	1064/1003	227/221	2/3	44/12
5/18	Wed	164/241	1023/980	260/224	4/4	40/16
5/19	Thurs	154/235	1022/1007	221/217	2/5	42/14
5/20	Fri	57/32	323/186	107/51	0/0	26/2

Table 5.10. Site 5 trips in/out per mode

From this, the boxplots were created for these model types but also for both PCE and the number of trips calculations mentioned earlier.

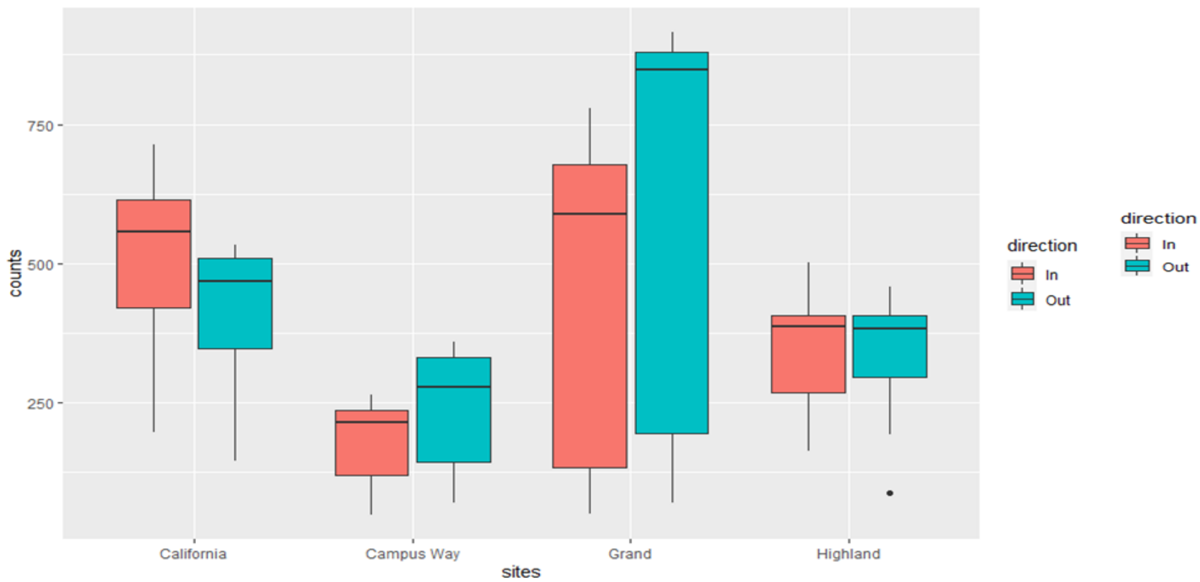


Figure 5.16. Bicycles

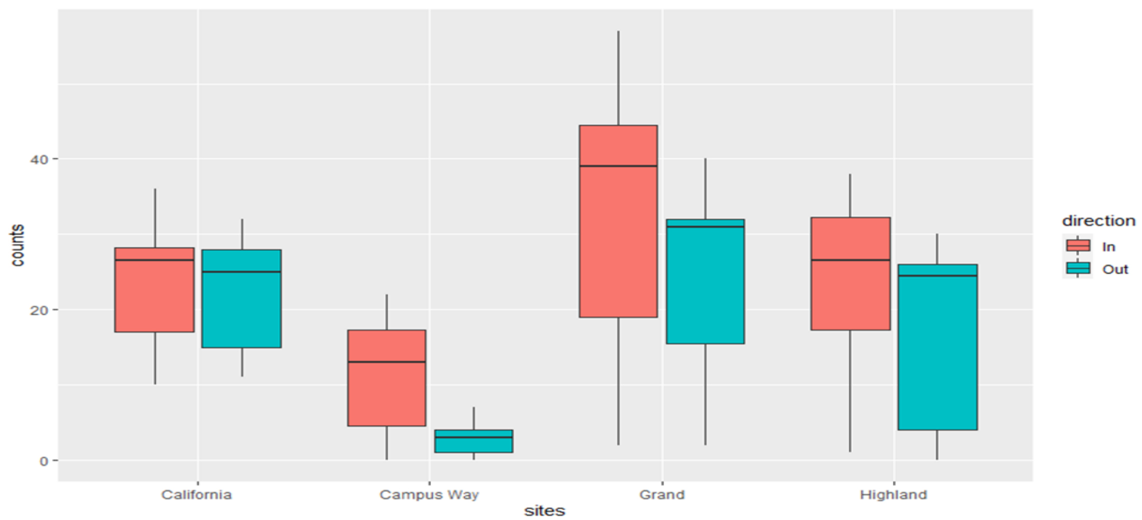


Figure 5.17. Buses

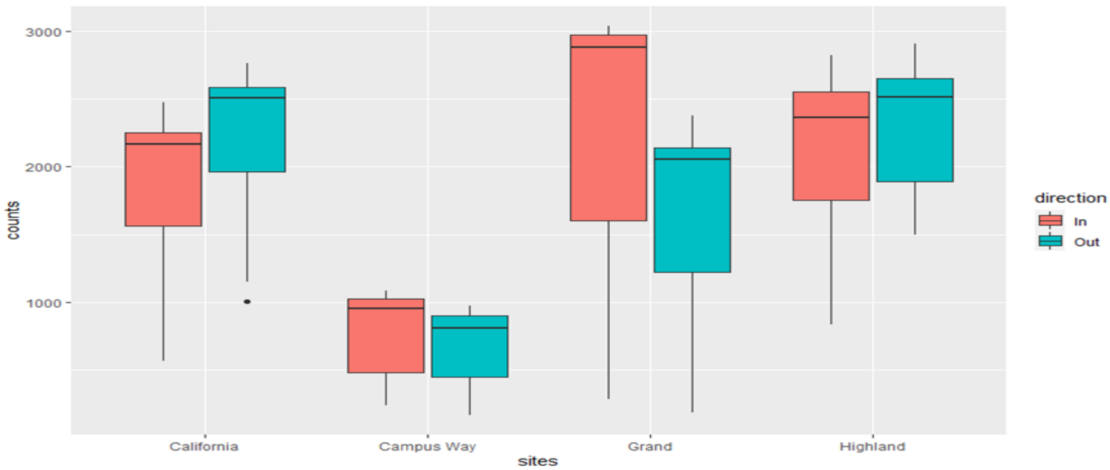


Figure 5.18. Light Duty Vehicles

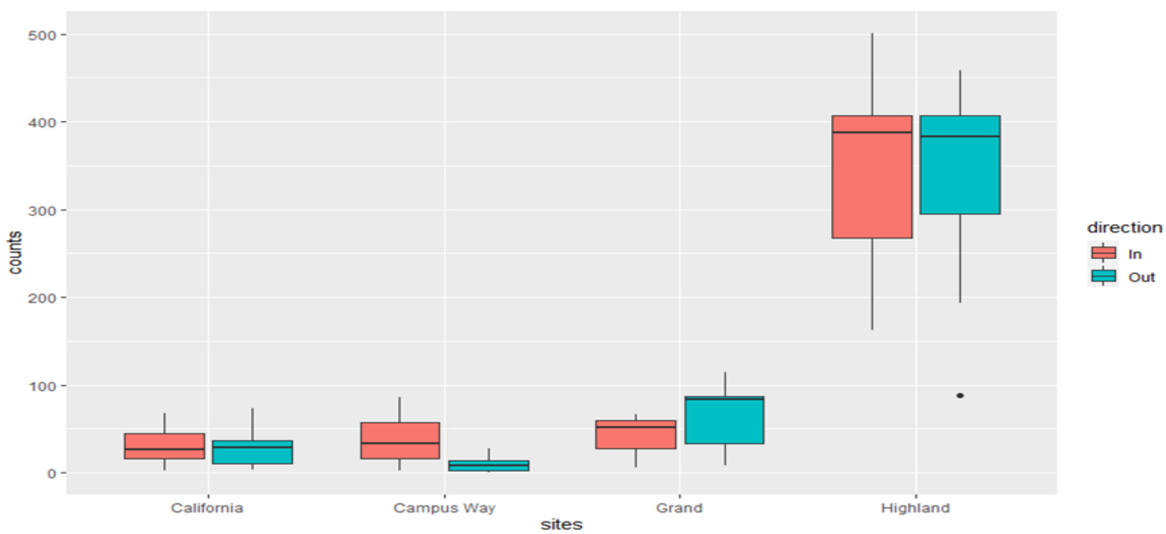


Figure 5.19. Light Duty Trucks

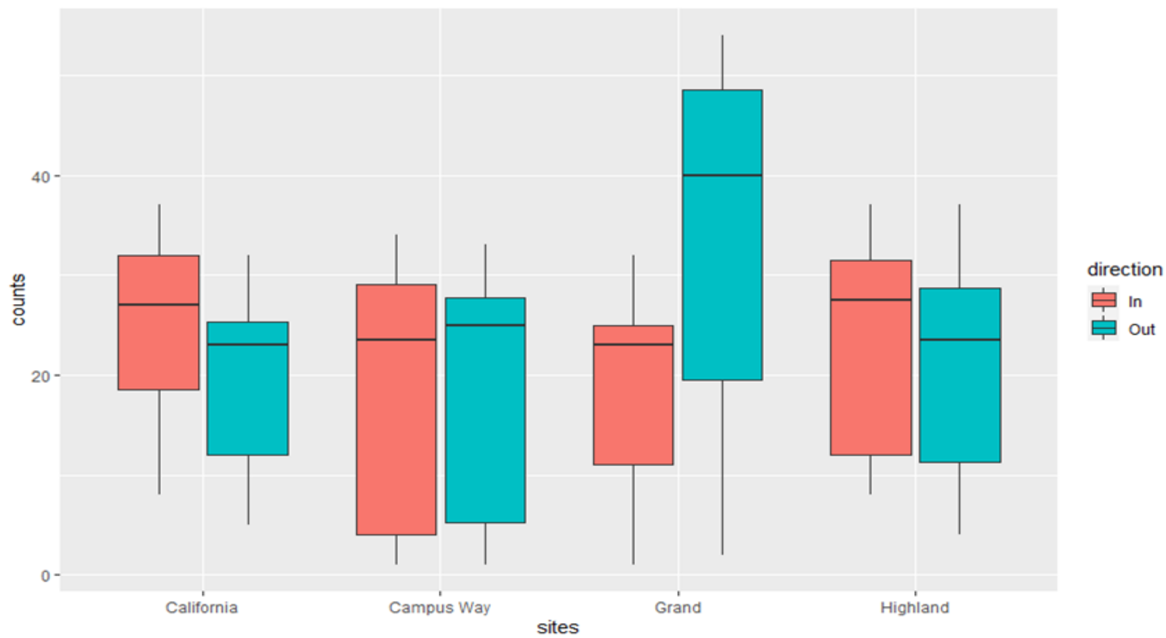


Figure 5.20. MDHD

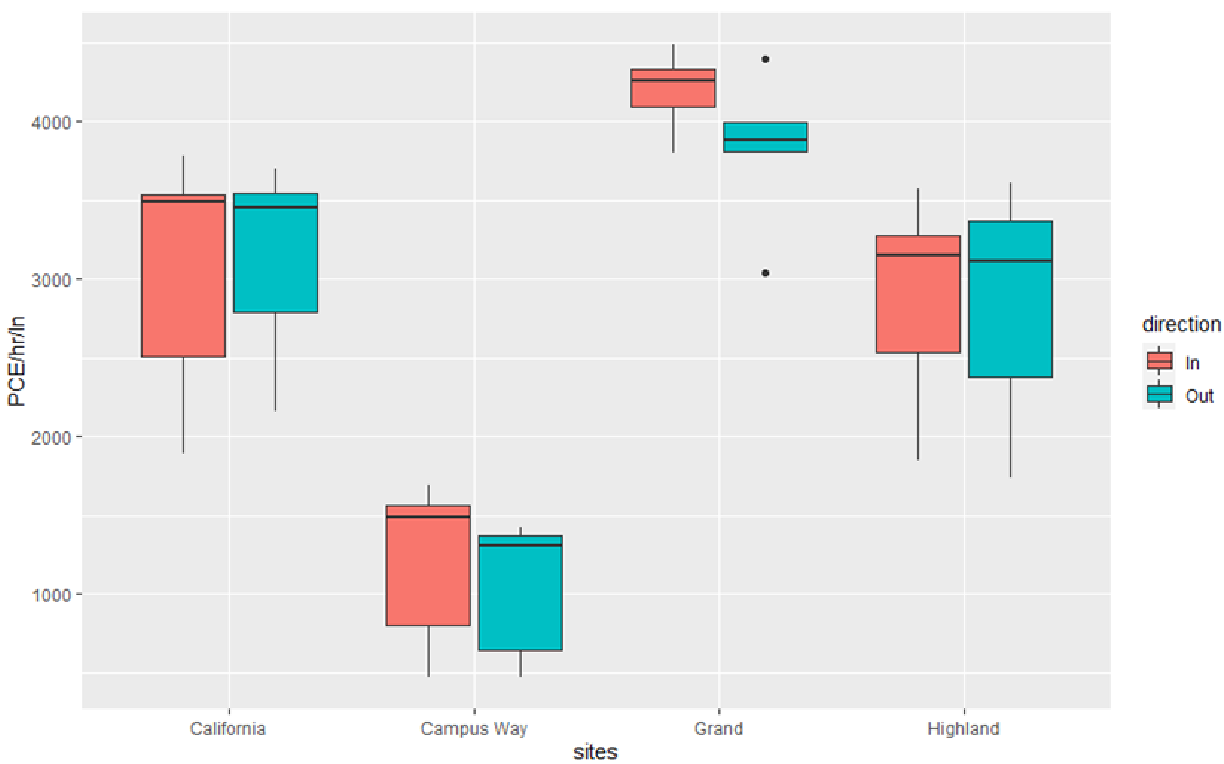


Figure 5.21. PCE

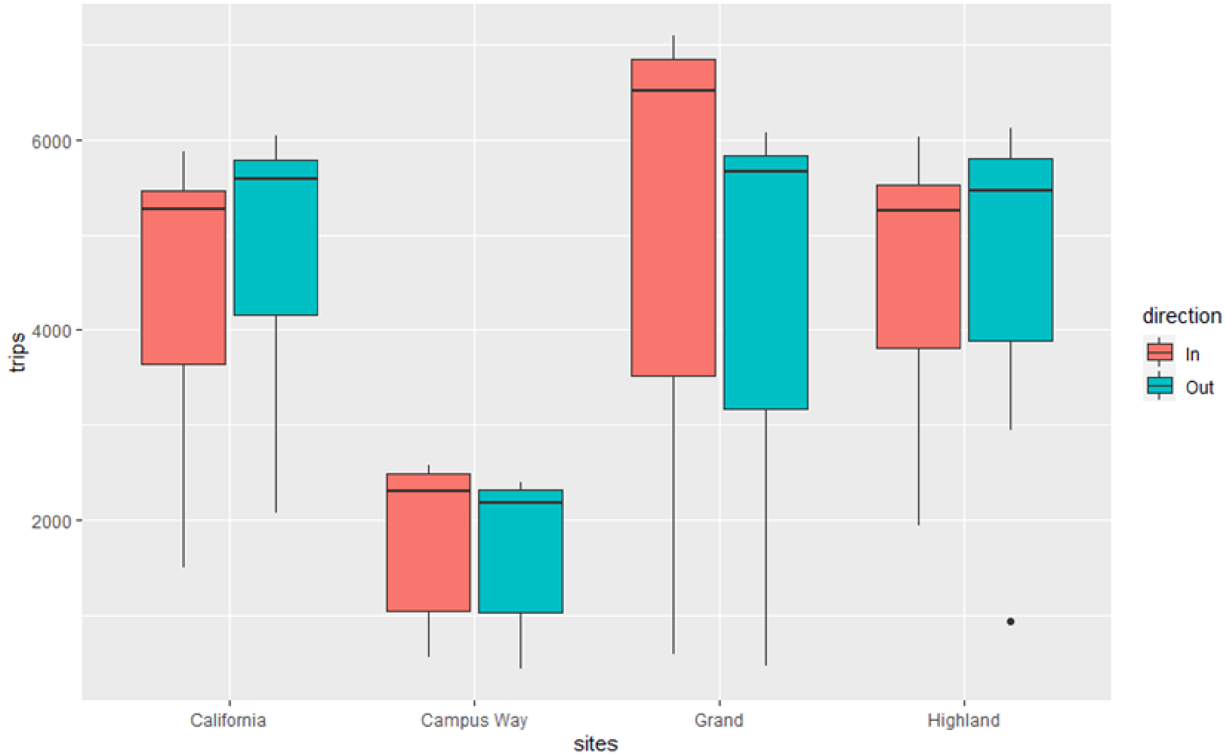


Figure 5.22. Number of Trips

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Appendix A: Literature Review

INTRODUCTION

Automobility was once one of humankind's greatest promises, providing mobility opportunities at an accessible cost for many people, particularly in industrialized nations. In these nations, the vehicle has come to prominence and is enmeshed in a system of automobility-oriented infrastructures and lifestyles (Burghard and Dutschke 2018, Sanguesa et al. 2021).

Unfortunately, the traditional automobile, which runs on fossil fuels, is a major factor in many of the pressing problems of the present day, including global warming, poor air quality, and resource scarcity (Bergman et al. 2017). Unnecessary greenhouse gas (GHG) emissions from the combustion of fossil fuels now have exceeded a dangerous level that requires prompt attention of control by enacting eco-friendly climate policies. The global population is anticipated to reach 9.8 billion in 2050; accordingly, there will be around 2 billion automobile son the road (Ghosh 2020). Even though these developments have helped a great number of people, they have also caused issues, such as increasing traffic congestion and ecological degradation in metropolitan areas. They have directly contributed to the dispersed growth patterns in rural and suburban areas, making public transportation service more challenging(Ferenchak and Katirai 2017, Lloyd et al. 2017). According to Pojani and Stead (2017), urban sprawl, rapid motorization, insufficient public transportation networks, disordered traffic patterns with a high use of automobiles, and inadequate infrastructure for cyclists and pedestrians are prevalent in many cities around the world. Consequently, the problems are exacerbated by the fact that more people prefer to acquire and utilize private vehicles (Enoch 2012). This cycle highlights why the transport sector is amongst the most difficult areas for public policy in the present, particularly about the negative transport externalities, and the environmental, social, and economic consequences of these issues. To effect a systemic change, policymakers, academics, and businesses are all actively researching alternative modes of transportation (Machado et al.2018).

Shared mobility and vehicle electrification are two major developments in the evolution of transport systems because they have the ability to enhance several facets: traffic congestion by reducing the number of single-occupant automobile trips, GHG emissions, accessibility, and mobility flexibility (Rycerski et al., 2016; Lio and Correia 2022; Etminani-Ghasrodashti et al.2022a, Patel et al. 2022). Instead of needing vehicle ownership, shared mobility is the temporary use of shared automobiles based on the user's needs and preferences (Shaheen et al. 2016). This phenomenon results from demographic and cultural developments, shifting social views toward the ownership of things (particularly in industrialized nations), and improvements in digital technology. Globally, the principle of sharing is fast developing and becoming more prevalent. It permits a reduction in the number of personal vehicles per household and develops a new mindset in which customers forego owning a vehicle in favor of shared mobility alternatives(Vine et al. 2014).

Electric vehicles (EVs) that release no GHGs are a promising strategy for addressing global warming and other environmental pollution issues. Between 1832 and 1839, Robert Anderson invented the first electric vehicle with non-rechargeable primary batteries (Guarnieri 2011, Thielet al. 2020). Eventually, several models were created but failed because they needed a suitable rechargeable battery and an efficient electric motor. EVs were popular up to 1918, but the presence of gasoline caused their popularity to decline. Due to their inadequate speed and costly internal combustion engine (ICE), the number of EVs had dropped to zero by 1933 (Ghosh2020). ICE vehicles release carbon dioxide (CO2), carbon monoxide (CO), hydrocarbon, and nitrogen oxides (N2O), resulting in global warming via GHGs effects and pollution that is detrimental to the environment and individuals. As a pollution-prevention technique, zero-emission vehicles (ZEV) are necessary. ZEV incorporates fuel cells and electric vehicles (Ghosh2020, Sanguesa 2021).The need to understand how to incorporate shared mobility and car electrification into urban transportation networks and make them more socially, environmentally, and economically efficient has increased over the past few decades. In the future years, EVs and shared mobility will play a crucial role in smart cities. Consequently, the purpose of this research is to perform a literature analysis to evaluate each trend in detail and assess the possibilities of combining them. This study's findings can be utilized in the long-term planning of shared electric programs.

METHODLGY

An extensive literature review was conducted for this research. First, we identified the keywords for running the query for the literature review. Next, a search query was submitted using the identified keywords in research databases such as Google Scholar, Scopus, Web of Science, and Science Direct. Recently published research papers and government reports were obtained to collectively compile the existing research on electric vehicles and shared mobility. The literature review was conducted using the snowball approach. The most relevant research articles that examine electric vehicles and shared mobility were studied extensively toconduct this research. These research articles uncovered more research articles through citations.

SHARED MOBILITY

Different Forms of Shared Mobility

Shared mobility is the shared use of a vehicle, bicycle, or other mode that provides on-demand access to transportation options (Shaheen et al. 2016, Machado 2018). In a broader sense it can be described as travel replacements that strive to optimize the utilization of mobility resources that a society can feasibly afford by decoupling their use from their ownership. The goal is to provide a variety of mobility options, hence enhancing multimodality and minimizing transportation costs. Due to technological improvements, economic shifts, and environmental and social concerns associated with vehicle ownership and urban living, shared mobility services have recently gained popularity (Shaheen et al. 2017, Vecchio 2018; Khan et al. 2023).Carsharing, micromobility, ridesharing, ridesourcing, and microtransit are the most prevalent types of shared mobility (EPA 2022).

Carsharing

Carsharing is the temporary use of a shared vehicle. Carsharing enables users to experience the advantages of personal vehicle use without the associated fees and obligations. Instead of possessing an own vehicle, the consumer will have an on-demand access to a fleet of shared automobiles. 95% of the time, private vehicles are estimated to remain idle; therefore, carsharing can boost the effectiveness of automotive use (Fraiberger & Sundararajan 2015). There are multiple carsharing forms, with the roundtrip model being the oldest. Recent years have seen the emergence of many carsharing forms, including one-way and peer-to-peer carsharing (Jorge et al. 2015, Lage et al. 2018).

Micromobility

Micromobility refers to modes of transportation smaller than cars, such as bicycles and e - scooters. Like carsharing, bikesharing is a temporary rental service, often for less than an hour.

Free-floating services allow the user to park the bicycle anywhere that is legal and safe. Docked bikesharing services require the user to pick up and return a bicycle to a designated station. Generally, shared scooters operate in the same way and are free-floating (Raux et al. 2017, Liand Kamargianni 2018, and Zhang et al. 2018; Etminani-Ghasrodashti et al. 2022b).

Ridesharing

Ridesharing enables riders and drivers with the same origin-destination combinations to share rides. Carpooling and vanpooling have been in existence for many years. The US Federal Highway Administration (FHWA) defines vanpooling as a group of 7 to 15 people travelling together in one van, whereas carpooling involves fewer than 7 people travelling together in one car. The modal proportion of ridesharing in the United States has decreased from 20.4% in 1970to 9% in 2016. However, it remains the second most popular means of transportation in the United States after driving alone (Jia et al. 2017, Vecchio 2018; Khan et al. 2022).

Ridesourcing

Ridesourcing, sometimes known as ride hailing, is among the most prevalent forms of sharing transit. In this approach, customers book a ride online, generally a mobile application, which matches them with a driver. Charges and reviews are also processed online. These service providers are known as transportation network businesses. Ridesourcing may also involve ridesplitting, wherein individuals may share their trip with other passengers in the similar direction for a lower fare. Typically, drivers use their own automobiles; however, some businesses provide rental vehicles for drivers. Few taxi businesses also offer ride-hailing applications. Ridesourcing debuted in San Francisco, California, in the summer of 2012, and has since rapidly spread around the United States and the world, with both support and opposition (Alemi et al. 2017, Shaheen et al. 2017).

Microtransit

Microtransit is an on-demand transit service incorporating variable routing, flexible scheduling, or both. Trips are shared with other customers in SUVs, or vans and they might have either stationary routes and schedules or flexible, dynamic itineraries. Microtransit's smartphone technology eschews conventional and expensive means of reserving trips, such as call centers and booking websites. Utilizing advanced technology can reduce operating expenses for programs aimed at populations, such as the disabled, elderly, and low-income individuals. Such trips are typically restricted to a predetermined service region. Even with adaptable routes, you may be compelled to walk a short distance to a close pickup place and from the destination to your destination. Vanpools and these services are similar, although vanpool participants often share driving responsibilities, whereas microtransit vehicles employ drivers. These services are more similar to public transit and may pose more direct competition because of their more rigid nature (defined routes and times) (Vine et al. 2014, Jorge et al. 2015).

Benefits of Shared Mobility

A growing body of empirical research suggests that shared mobility offers significant transportation, land usage, environment, and social benefits. While substantial studies have been performed on the impacts of roundtrip carsharing, more is needed about the effects of ridesharing and the more recent service model of ridesourcing (Fraiberger & Sundararajan 2015). Each carsharing vehicle eliminates nine to thirteen vehicles from the road (delayed and sold). Most of this change in vehicle ownership is due to one-car households becoming car-free (Ballus et al.2014). The most recent research and member survey findings issued by carsharing companies in the United States and Canada indicate that 16 to 35% of carsharing members sold their vehicles and that 25 to 71% of members refrained from purchasing a vehicle due to carsharing. In addition, reductions in auto ownership are frequently connected with an increase in walking, carpooling, and cycling, as well as a decrease in parking demand and vehicle miles travelled. In addition to reducing VMT and automobile possession, carsharing also reduce GHGs. The observed impact was a 34 to 41% reduction in GHG emissions per home per year. Lastly, carsharing has additional positive societal effects, such as improved mobility made possible by one-way service models and vehicle accessibility for students and low-income communities. The precise amount of ridesharing's transportation, infrastructure, and environmental implications have yet to be discovered. Ridesharing participants individually enjoy pooled travel expenses, trip time savings from high occupancy car lanes, reduced commuting anxiety, and frequently preferred parking and other perks (Jia et al. 2017, Vecchio 2018).

ELECTRIC VEHICLES

Different Types of EVs

ICE-powered traditional vehicles are unsustainable and emit a significant amount of greenhouse gases. Alternate Energy Vehicles include EVs, bio-fuel vehicles, fuel cell vehicles, compressed natural gas vehicles, and more. Electric vehicles are propelled entirely or partially by electricity. EVs provide various advantages over conventional vehicles, such as zero emissions, convenience, reliability, affordability, convenience efficiency, and connectivity (Albatayneh2020). However, electric vehicles face significant battery-related challenges, including driving range, recharging time, and battery pricing (Berjoza and Jurgena 2019). EVs are classified intothree types based on the technology of their engines.

Hybrid EV and Plug-In Hybrid EV

The hybrid electric vehicle (HEV) is propelled by an electric motor and a conventional ICE, with the electric motor only contributing to the vehicle's starting and propulsion. The slowing or braking of a HEV charges its battery. Due to their lack of grid energy use, HEVs are alleged to be half as polluting and double efficient as traditional gasoline-powered vehicles (Ghosh 2020,Sanguesa et al. 2021). In a plug-in hybrid electric vehicle (PHEV), fuel cell storage may be charged via the electrical utility grid (Shamshirband et al. 2018). They typically have a highly efficient internal combustion engine and a battery pack with a massive capacity. The PHEV has charge-depleting and charge-sustaining operating modes (Yong et al. 2015, Sanguesa et al.2021)

Battery Electric Vehicles

Battery electric vehicles (BEVs) replace the ICE and gas storage with an electric battery powered engine. BEVs frequently employ enormous battery packs to achieve acceptable autonomy. When the BEV is not in use, it is connected to a charging station. The BEV removes conventional engines, gas tanks, and tailpipes, as well as the potential to generate electricity onboard (Wang et al. 2020, Zhou et al. 2020). Some BEVs have a range of up to 300 miles per charge. A BEV's typical range is between 100 and 150 miles (Kwon et al. 2020, Li et al. 2020).The BEV may charge overnight utilizing low-cost electricity provided by any power plant, renewable or not. In addition, the BEV has enough propulsion. Unfortunately, slow charging time, and costly energy storage prevent the broad use of these model (Fernandez 2018; Andwari 2017).

Environmental Impact of Electric Vehicles

Although numerous environmental concerns, such as effects on air quality, water usage, urban sprawl, and diversity, are worthy of consideration, we limit our environmental impact evaluation to particulate matter and GHG emissions in this article. Traditional diesel and gasoline-powered automobiles or ICE vehicles emit greenhouse gas pollutants, including CO2,CO, N2O, and particulates (Yong et al. 2015, Sanguesa et al. 2021). The primary benefit of the EV is that it emits no pollutants from its tailpipe. The potential for EVs to reduce greenhouse gas emissions can range from 10% to 60%, depending on the type of EV and geographic area. Consequently, it is believed that an electric vehicle with a grid-powered battery can contribute to environmental preservation .

Conventional petroleum and diesel fuel automobiles or ICE vehicles emit both greenhouse gases and particulate matter (PM). PM10 denotes particles with an aerodynamic diameter of less than 10 micro meter, whereas PM2.5 denotes particles with an aerodynamic diameter of less than 2.5 micro meter. Analysis of PM emissions from road traffic reveals that 70% of particles are PM1 type. PM2.5 andPM10 are associated with lung disease, chronic and acute pneumonia, breathing problems, respiratory issues, and lung cancer risk. The World Health Organization suggests that the PM2.5concentration should be 10 g/m3. Because there are no tailpipe emissions, the BEV does not emit PM from exhaust sources (Albatayneh 2020).

Potential Electric Vehicle and Car Sharing Synergy

Electric vehicles could enhance shared mobility services such as car sharing. In recent years, an increasing number of carsharing companies have incorporated electric vehicles (EVs) into their fleets or developed completely electric carsharing programs. Electric carsharing (ECS)provides certain benefits over the private purchase since carsharing automobiles get a greater yearly mileage than private ones (Meyer and Shaheen 2017, Burghard and Dutschke 2018), the accounting rate of return of EVs is shorter, and the service life evaluation is more favorable(Plotz et al. 2014). In station-based systems, it is easier to offer charging stations than it is for individual customers. However, the maintenance of an ECS is more expensive due to limited vehicle utilization and installation costs for charging stations. From the user's perspective, the existing shortcomings of EVs manifest in carsharing fleets and diminish the assumed autonomy(Hinkeldein et al. 2015). However, the normal carsharing journey is very short, so the low range should not often present any issues (Wappelhorst et al. 2014).Considering that the collaboration between electric vehicles and shared mobility is still in its infancy, there is a dearth of literature in this field. According to Burghard and Dutschke (2018),ECS have the possibility to alleviate the ecological impacts of personal vehicle travel. Based on the actual data of carsharing's known effects on lowering parking requirements, ownership, VMT, and greenhouse gas emissions, ECS can enhance these effects. The other possibly significant synergies exist between EVs and shared vehicles (Ampudia al. 2020). Furthermore, ECS is more appealing to consumers than privately owned EVs, as ECS will travel several times further annually than private EVs. In addition, the capacity to deploy these cars based on the passenger occupancy requirements of each journey might significantly reduce energy usage and, consequently, greenhouse gas emissions (Kwon et al. 2020). In conjunction with the greater inherent efficiency of BEVs and the lower GHG intensity of electricity compared to gasoline, the life cycle GHG emissions per mile of an ECS vehicle might decrease by almost 90 percent compared to the average passenger vehicle of today. Together, these characteristics would likely make ECS more affordable than owning a normal car, with nearly all of the conventional vehicle's benefits, plus the convenience of AVs and substantial GHG savings (Yong et al 2015).

CONCLUSION

This study reviewed the most relevant published research articles and government reports over the last few years to compile the research on shared mobility and electric vehicles. Shared Mobility and electric vehicles are two major developments in transportation evolution. Shared mobility services such as carsharing, ridesharing, ridesourcing, and microtransit have recently gained popularity due to mobile internet advancements. The environmental and social concerns associated with vehicle ownership have also boosted the use of shared mobility services in recent years. The traditional ICE vehicles account for a large number of greenhouse gas emissions. However, electric vehicles are stated to have multiple advantages over ICE vehicles in the form of low carbon emissions, convenience, connectivity, efficiency, affordability, and reliability. Recently, car-sharing companies have started integrating EVs into their services. However, there is very little literature in this field as the integration of electric vehicles with shared mobility is still an emerging market. Electric carsharing can provide major benefits over privately owned vehicles in terms of shorter accounting rates of return and greater service life than ICE vehicles. Electric car sharing has the potential to reduce parking requirements, VMT, and GHG emissions. The synergy between electric vehicles and shared mobility can be more economical and environmentally friendly than privately owned vehicles.

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