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ABSTRACT

University campuses have unique characteristics that influence travel demand. They benefit from controlled planning frameworks, can influence almost all aspects of pricing and on-campus transportation infrastructure, benefit from simplified many-to-one travel patterns, and maintain extensive data on nearly the entire campus community. Campuses represent millions of trips daily, yet, little research has been conducted that focuses on developing tailored frameworks to assess transportation demand, target travel demand management strategies, and assess environmental or other impacts. This paper describes how two sets of commonly collected data can be leveraged to provide new insights into travel behavior, incentives, and environmental policy. Specifically, we illustrate the fusion of standard travel demand survey data with disaggregate and precise household address data to provide new inferences into appropriate strategies to improve transportation sustainability. We apply three use cases – carpool potential, walk and bike incentives, and mode shift to reduce greenhouse gas emissions – to the data from three universities, University of Tennessee, Cal Poly San Luis Obispo, and San Diego State University, respectively. We find that the richer dataset provides substantially better data resolution that allows for transportation strategies to be more precisely targeted and expand the potential impact of transportation demand management strategies.

INTRODUCTION

University campuses provide unique mixed land use, multimodal, and walkable environments to students, faculty, and staff. Often, these campuses are islands of sustainable transport within mostly auto-oriented cities. Campuses are often internally balanced, with most amenities needed by the campus community located within walking distance. Campus populations vary widely but can range from several thousand to tens of thousands, the size of a small town. Universities can also be the largest single employer in many urban areas, providing significant leverage when developing transportation planning strategies. Despite millions of university students and employees, little research has been conducted on best practices and unique methods of transportation and environmental analysis for these unique cases. Universities are increasingly developing comprehensive transportation and environmental plans with little guidance on best approaches that are catered to the unique features of university-related travel.

Universities have relatively unique many-to-one travel patterns and tend to have central control over transportation and land use policies (e.g., parking) for the campus community. Moreover, universities tend to keep some household data on all or most campus users (e.g., home address). These features make some traditional transportation and environmental planning and travel demand management strategies ill-fitting for campuses.

This paper presents a unique methodology with specific cases outlined for exploiting some of the data and travel behaviors that are available to universities. We focus on pairing specific origin (home location) data provided by universities with traditional travel and activity surveys to identify travel demands and opportunities for improved travel demand management. This is a novel contribution relative to mostly descriptive university-related travel research – allowing more precise policy interventions. We do this in the context of traditional travel demand management (TDM) plans and emerging campus greenhouse gas inventories and climate action plans.

The paper is organized as follows. First, we describe the existing work on campus transportation planning and identify gaps in the literature. Next, we propose a method that fuses precise spatial location information (e.g., home coordinates) with survey data and existing transportation infrastructure variables to identify campus transportation demand and greenhouse gas impacts. Last, we illustrate three use cases of such data to show the unique aspects of this work. The three case studies focus on carpool and ridesourcing potential, walk and bicycle potential, and parking and transit policy; applied at three universities (University of Tennessee, San Diego State University, and Cal Poly San Luis Obispo, respectively).

BACKGROUND AND LITERATURE

Universities are major activity generators requiring advanced travel demand management strategies (*1-2*). However, few studies have focused on methods to improve campus-planning outcomes. Considering a mix of using and housing concentrated within a short distance from campuses, along with compactness and density make them ideal for walking and bicycling, but the commute to university campuses often relies on car-commuting (*3*). An online survey has been used to study mode switching of an urban campus populations in places like, Virginia, Berkeley, and Perth (*4–9*). Most campus travel demand surveys mimic conventional travel surveys to aid planning, but tend not to leverage unique features of campuses to inform tactical transportation decisions. New spatial tools are being used in order to evaluate travel behavior including precise GIS methods to inform travel demand and environmental policies (*10*).

In recent years, environmental and climate plans have pushed campuses to more carefully consider transportation's role in GHG emissions and air pollution (*11*). In order to do so, systematic environmental management approach is needed to reduce negative impacts on environment with a particular focus on transportation (*12-13*).

Parking pricing is one of the powerful policies being used frequently by campuses (*14*). Universities rarely provide free parking. Moreover, some universities develop parking cash-out programs. For example, Stanford through its 'Clean Air Cash' program pays 2500 employees who do not purchase a parking permit during the year (*11*). Likewise, UC Boulder is using a recent fleet of small buses with an 'Ecopass' where employers buy passes for their employees and pass holders ride the buses for free with a valid ID. After this policy was enacted with the city of Boulder and the University of Colorado, total transit use in the last 5 years has increased by 400% (*15*). UC Berkeley's Class Pass has had similar success, providing deep discounts to students in exchange for unlimited marginally free transit rides (*16*).

Travel choice is tied both to market norms as well as social norms, and this is true in the campus environment. On campuses, travel behavior is related not only to personal health but to the environmental sustainability and social capital of communities. Sustainable transport can also result in substantially more economically resilient communities (*17-18*), but the practical reality is that this type of environment is not the case in many university campuses and communities across the US (*19*).

Built environment factors play a role in active travel behavior and policy and incentives play a key role in transportation decisions. Transportation choice is tied to financial and social factors as well as to public policies (*20-24*). Yet the interrelationship between these forces, particularly in the University context, remain under-explored, especially in the face of new technology and mobile proliferation. Policies and incentives can encourage or deter driving behaviors and influence auto ownership (*21-27*), (*16*). Some communities use a 'carrot' approach, offering incentives such as free transit passes, cash back ('cash-out') parking programs, or social media nudge tools (*28*) to reward alternatives to driving (*29*). Other communities prefer to use the 'stick' approach, with high prices for parking, tolls, or other usage fees. Universities have a unique opportunity to balance these approaches.

UNIQUE METHODS AND DATA

Universities tend to rely on campus travel surveys, in the tradition of conventional travel surveys that often inform travel demand modeling efforts. One of the main advantages of university travel survey deployment is that university employee and student databases tend to be comprehensive, allowing for 100% sampling rates. This could potentially remove some sampling bias (*30*). However, the survey could still suffer from response bias.

Here, we rely on three different travel surveys, developed for different purposes (i.e., transportation demand modeling and greenhouse gas inventories), but the three surveys include similar travel related data. Specifically, they include home location and trip-level mode choice questions (in standard travel diary format) relevant to this study, along with some attitudinal questions regarding travel demand strategies. All surveys were conducted online and the campus population was sampled using the university-provided email recruitment. The online surveys allowed branching and tailored surveys for different members of the campus communities (e.g., on-campus student residents, faculty, staff etc.).

In this aspect, these surveys are not just conventional travel surveys in a university context those which have been featured in publications by Khattak et al. (9), Riggs et al. (7), Wang et al. (8) and others. While in the three cases evaluated, these surveys are relatively standard, they offer new ways of modeling university communities as small microcosms with the capacity for more robust analysis than larger regional travel studies—perhaps the next frontier of travel studies, unique to universities. One key point of difference in the three cases presented is that the compact campuses are small relative to the distance between home and campus and in almost all cases, travel demand is generated at home (off campus) and destined for campus, creating a many-to-one travel pattern. This eliminates one of the key challenges in travel demand modeling, especially for college or corporate campuses with large employment or student bodies – developing defensible trip distribution patterns (i.e., origin and destination pairs). Here, we know that (almost) all respondents of our survey, for commute trips, travel from a home origin to a single campus destination. This leads to the main unique innovation for campus travel demand studies.

Beyond surveys of the campus community, which have a high sample rate, but generally a low response rate, Universities tend to have near-perfect and precise disaggregate data on home location for all members of the campus community. This campus population can number in the tens of thousands and the implications of this resolution of campus data has been scarcely studied. In the three cases described here, we have addresses for all students, faculty, and/or staff (FIGURE). This allows stratification of survey data to more closely represent true travel patterns of the campus community.

Moreover, with precise data on home locations, and a sample of mode choice and trip making behavior, we can, with some precision, estimate total commute travel, mode split, greenhouse gases and other travel metrics; for the entire campus community. These data can be used to develop targeted travel demand management interventions for specific subgroups (either spatially, or by employee/student classification) based on location and travel patterns nearby. These new datasets can inform many policies, as outlined below.

FIGURE 1 Population distribution at different campuses. All scales are the same. Top Left is poly-centric survey respondents from San Luis Obispo (Cal Poly), top right is all dense urban staff home locations in San Diego (SDSU), bottom is all faculty, staff, and students in sprawling Knoxville (UT).

POTENTIAL DATA APPLICATIONS

Pricing and TDM in the Campus Environment

Pricing is one of the key factors that conceals the social and environmental costs of driving decisions (*27, 31*) and keeping rates low potentially encourages the purchase of the annual permit, increasing the drive-alone rate and GHG emissions (*32*). Based on other decisions one can assume that the cost of parking in general ascribes an arbitrary coherence to the cost of other types of travel for example via walking and biking since the full costs are paid upfront usually on a monthly basis and it appears 'free' on a daily basis when compared to the cheaper (and healthier) options of walking, biking or taking transit – with people making what are effectively irrational decisions (22, *27, 31-34).*

GHG Estimation Methods

Mode shift, vehicle class and Vehicle Miles Traveled (VMT) can result in an estimation of reduction of greenhouse gases is possible by considering all the commuters and people willing to change their mode, housing location, or vehicle (*35*). Furthermore, survey data in our surveys includes make, model, and year of vehicle used to commute. Coupled with sampled household locations and paired with full population household locations and estimated fuel economy of vehicles, we can estimate, with some certainty, the amount of fuel and thus GHG emissions from single occupant vehicles.

Carpooling or app-based ridesourcing

There is abundant capacity in existing personal vehicles to accommodate a large portion of the campus community. University carpool programs can be very effective at reducing single occupant vehicles. At UC Santa Barbara, within four years of implementing a carpool program, carpooling rates increased by 30 percent for staff and increased by 25 percent with students (*36*). The primary barrier to carpooling is ride-matching (spatially and temporally). Universities can overcome these challenges with common-destinations and fewer work-schedule challenges. Moreover, the administrative ability to match co-workers is greater at Universities than distributed employers, with many successful examples. Transportation Network Companies (TNCs) aim to provide real-time ride matching with many-to-many trip distribution patterns. The University case is dramatically simplified by many-to-one trip distribution patterns, a feature that enables earlier non-technology enabled ridesharing like casual carpool or "slugging" (*37*).

Walk and bike access to campus with supportive infrastructure

With survey data alone, bike and walk trips could be underreported, and the total population that lives within bicycle or walking distance is unknown. Understanding the spatial distribution of actual bicycle and walk trips (from surveys) and campus populations (from home address data) allows targeted interventions, either through marketing or infrastructure, and allows policies that could expand those areas (e.g., promoting electric bikes).

Transit Access

Transit is among the most efficient users of road space, has low marginal emissions, and requires little parking or terminal space. Many universities offer transit benefits to employees (in addition to parking benefits). Again, strategic investment in transit infrastructure, incentives, and other policies is important for Universities. Here, the portions of the campus population that is inclined to use, or even within reach of transit service is important to understand. In the case of University of Tennessee, only 2/3 of students and 1/4 of staff and faculty are within walking distance to the urban transit system, discouraging broad-based programs like deep-discount fares (*16*) .

CASE STUDIES

Here we illustrate possible uses of these data with three case studies. These are small data use-cases that are not exhaustive, but show some of the possibilities of how such data could be used by campus transportation or environmental planners. The three case studies reflect slightly different types of data, collected for different purposes, with different spatial resolution. We start with the University of Tennessee-Knoxville, located in a medium-sized city. In Knoxville, we focus on ridesharing potential with a combination of household location data and survey data. Next, we discuss walk and bike potential at Cal Poly San Luis Obispo, whose campus is in a small city on California's central coast. Last, we to investigate policy at San Diego State University, located in the third-largest metropolitan area in California.

University of Tennessee: Carshare and Ridesource Potential

The University of Tennessee (UT) is an urban campus built on a peninsula bounded by the Tennessee River and adjacent to downtown Knoxville. Fort Sanders neighborhood borders UT to the north, which is the most densely populated area in the city, with a population of over 15,000 living in approximately 3,100 residential units, in a 50-block 474-acre area (*32*). UT is at the crossroads of West-Knoxville's transit system (Knoxville Area Transit) and the University operates a circulator bus system that serves campus and surrounding neighborhoods. An important note is that the only fixed route transit system (KAT) that operates in the region only serves the limits of the City of Knoxville, and not the surrounding urbanized area, where a large portion of the campus community lives.

UT also has relatively good expressway access from all directions. The campus is well-served by off-road greenways and other bicycle infrastructure and the City of Knoxville has a League of American Bicyclist "Bronze" level rating. The UT student body is about 28,000 students (~3/4 undergraduate). UT also employs 9,800 faculty and staff and is the largest employer in Knoxville.

UT has developed a Climate Action Plan to achieve carbon neutrality by 2060 (*38*). Transportation is part of that goal and transportation sector emits 14 percent of total GHGs on the UTK campus (including commute and on-campus transportation). Of that 14 percent, 13 percent is attributed by single occupancy vehicles, or SOVs. Therefore, the Climate Action Plans at the University of Tennessee has set a intermediate goal of reducing SOV commuting miles per year to 25% below 2007 levels by 2020 (*39*).

Moreover, part of the UT Master Plan is to move most parking to the periphery of campus and use other modes of transportation such as transit, walking, or biking—making campus a more pedestrian and bicycle friendly area. This strategy could make driving less convenient, or at least diminish SOV's door-to-door advantage compared to other modes. These initiatives require more diverse travel patterns and this study investigated many travel demand management strategies to assess and reduce energy and GHG intense modes. Here we focus on rideshare and carpool approaches.

Methodology: Surveys, home location, and cluster analysis for targeted intervention

The University of Tennessee, Knoxville, like most other campuses, keeps household data on most of their campus users including the home addresses. This dataset is composed of identifiable and geocoded home addresses of students and faculty, and classification (e.g., graduate or undergraduate student), without any other characteristics or mode choice information. This information is initially collected for non-transportation purposes. To complement this information, a detailed revealed preference travel demand survey is conducted capturing the attributes that may be associated with transportation mode choice decisions of commuters and non-commuters.

The survey garnered 721 respondents, 103 non-commuters (living on campus) and 618 commuters. Commuters include faculty, staff and students living outside campus. Of off-campus commuters 85% of the respondents travelled by car and the rest walked, biked and used transit. Most non-commuters (55) walked to campus although 70% have a vehicle and 10% have a bike on campus. The unique aspect of this application is that student and staff address data (collected for other purposes) were merged with conventional travel data to identify opportunities for spatially nuanced travel demand management strategies. Administrative units on campus do not suffer from privacy concerns of the conventional private sector or public sector datasets, since the data are generated and analyzed within the institution.

In this research, the addresses of the campus users were mapped using ArcGIS Pro's online address geocoding engine. A network for Knoxville was developed using network analyst extension using public data for roads, counties and zip codes (from data.gov). Network analyst was used to determine trips from each location to campus. The average home-to-campus trip distance for students' trips is 6.1 miles, for faculty is 9.5 miles, and for staff is 10.6 miles.

Using network analyst in GIS, we mapped the zones that were within walking and biking distance to campus and within walking distance to transit stops. A one mile distance was considered walkable to campus, two miles considered bikable, and quarter mile for walk to transit. We added one more zone with half-mile distance from bus stops as bike to transit zones. Collectively all these zones were identified as transport alternative zone as shown in FIGURE About 62% students, 32% faculty, and 29% staff lived in that zone. The black dots outside of the green buffer are those who are effectively out of reach of transit or other alternative modes. Our survey responses indicate almost 100% drive alone or carpool in those areas. Absent major expansions in the transit system, or significant land use changes and movement to the urban core, inducing a shift toward alternative modes is unfeasible for nearly half about the campus population. As such, we focus (in this illustration) on carpool and rideshare options for car-dependent suburbs. Knowing specific home locations enables precise analysis of transit or other non-motorized modes, where conventional traffic analysis zones do not provide the precision needed to assess short trips.

FIGURE 2 **Campus Population Overlaid on transportation zones. Darkest zone is walk distance, grey zone is bicycle distance, and green zone is transit distance. Black dots represent home locations of students, faculty, and staff. This map is scaled about five times larger than the map in Figure 1.**

Rideshare or Carpool as a Travel Demand Strategy

Segregated zoning and dispersion of population away from commercial corridors results in most population living outside zones with alternative modes of transportation. Here, we focus on those areas outside of transit's reach. We visualize the population dispersion to search for clusters, mapping density for of home locations. The population clusters were completed separately for students, faculty, and staff since employees have a relatively fixed schedule. The FIGURE shows the population clusters for each population.

FIGURE 3 Cluster zones for faculty (top left), students (top right), and staff (bottom left) and overall (bottom right)

Campus user's population outside of alternatives mode zones were given priority in consideration for carpool, though some of the densest clusters of the campus population have transit access, which is promising (and could be a target for transit-oriented incentives). The travel demand survey asked about mode choice of commute trips for the past week. During weekdays, around 7% of the respondents car-pooled while 70% drove alone. Of those carpooling, 36% were from zip codes 37920 and 37909. While relative close to campus, those areas have low transit access. This strengthened our belief that that population outside of transit accessibility zone would benefit from carpool.

Carpooling can be proposed in two different ways, either as a point-to-point park and ride model or by picking up persons along a route. The latter would be more feasible in terms of capital cost of facilities and ease for commuters, and is enabled by some of the corridor-oriented residential distributions in Knoxville. There are already many websites and forums (Tennessee Carpool Center, RTA Carpool ride match, Knoxville Smart Trips, Carpool World, etc.) connecting many carpoolers to plan and share their rides. An app can be developed to further connect the riders or other apps, mimicking ridesourcing apps that provide carpool service (e.g., UberPool and LyftLine).

In order to promote this practice, UT can further incentivize the riders or partner with service providers. Like other university, the incentive can provide free and convenient parking for carpoolers, or designated lots for carpool cars. The university would benefit from this program, as this would reduce the demand for parking on campus, reducing capital expenses to support their current structured parking initiatives. The western part of Knoxville has larger population of students, staff and faculty, and based on that, we selected a test corridor in this general vicinity to demonstrate the applicability of a carpool strategy. In all, 23 faculty, 75 staff, and 146 students live within 2.5 miles from this location. We found each rider choosing to carpool would save about 15.6 miles each way. Furthermore we looked at a route running through a higher density suburban area. On this corridor, 55 faculty, 60 staff, and 151 students are within a ¼ mile buffer from this street. A driver agreeing to carpool would not have to make a significant detour to pick other riders. Like stated before, an app or website could enable trip matching and incentives could be tested to generate sufficient demand.

This case study aims to showcase a specific application of using an internal database (enrollment and human resource records) to inform specific travel demand management strategies and tactics. The home-location data was paired with a conventional survey-based travel demand analysis to target specific strategies to reduce SOV travel to campus. Prior to this, like many campuses, travel demand management strategies were not targeted to populations (e.g., transit benefits for all). This study shows how, using a spatially rich dataset, transportation administrators could target and directly market different TDM incentives to individuals based on their home location. This could, if well executed, be more cost effective than blanket incentives, marketing, and education campaigns.

CalPoly San Luis Obispo: Encouraging biking and walking
CalPoly is the largest employer in its respective county and occupies a large share of the urban center. As such, it could be likened to either a small town or a large corporate campus, and transportation plays a large role in the campus' functionality – both in terms of trips generated, as well as facilitating accessibility and the interactions that make it a vibrant place of intellectual exchange and innovation. At the same time, it poses land use, sustainability, and costs challenges, especially as the campus is an urban environment with constraints on space and budgets.

The CalPoly campus has ample surface parking that in the past limited the need for more aggressive alternative transportation programs. The monthly permit system requires payment up-front for monthly parking priced below market rates. Based on this, demand is high, and the daily decision on commute alternatives is embedded into the parking permit decision. The low cost of parking has impacted demand and increased circling for oversubscribed spaces and spillover into residential neighborhoods and on-street spaces. Due to these challenges related to housing, traffic, and the environment issues, the campus has chosen to experiment with pricing and behavioral strategies.

In terms of travel choices, many students walk to campus. Walking accounts for 41% of the students' commutes *(40)*. Eight percent (8%) of faculty and 19% of staff walk to campus. Ten percent (10%) of students commute by public transit, and around 5% of staff and faculty. Despite this, the average round trip commute length to campus is 17.4 vehicle miles traveled (VMT) per day per commuter, because many students live far away from the campus—on average, further from campus than faculty. While some may find this trend counterintuitive, since many students do in-fact live close to campus, in actuality the second largest share of both students (and of staff) live greater than 10 miles from the campus.

Transportation currently accounts for 50% of the GHG emissions at Cal Poly. This sector consists of automobiles, public transportation, bicycles, and walking. The major contributor to GHG emissions within this sector is single automobile commute. Only 24% of students commute by this method, as well as 68% of faculty and staff, however many of the students that commute by car have longer commutes than faculty and staff. This makes for a total of 38% of commuters driving alone to campus.

TABLE 1. Distance by Cohort

Methodology: Surveying with a focus on incentives
In this context, the campus engaged in a Climate Action Plan and Travel Survey in 2015 with recognition that travel behavior is complex. Researchers recognized that knowledge about and attitudes toward transit and driving, self-image, and travel choices all play a role in transportation behavior. Prior experience and habit have also been found to enter into transportation mode choice decisions and to shape what alternatives are considered, as well as how alternatives are assessed.

The planning process began with a survey issued to all campus constituents. The survey received a total of 3,961 responses, 17% of the entire campus population of roughly 23,000. Unsurprisingly, the majority of respondents were students, totaling 68.6%, while the rest were made up of faculty, staff, and visitors. Respondents answered questions about the closest intersection to their home and travel patterns. Like UT efforts, these address locations were mapped using the ArcGIS online geocoding engine and network analyst was used to trip location and distance.

Focus on Biking, Walking and Housing

In additional to establishing the modal split breakdown presented earlier, the Cal Poly survey focused on testing incentives to bike or walk, asking a segment of respondents to answer a series of structured questions about how they might behave when presented an incentive to walk or bike. This included randomly assigned incentives: A) a $5 monetary incentive; B) a free cup of coffee or juice; C) a free cup of coffee or juice, with a specified value of $2; D) a social request to give up their parking pass for altruistic reasons; in this case benefit to the environment.

The rationale for this was to encourage a culture of biking and walking and to test a new TDM approach focused on behavioral economics. This focus was rational given the temperate climate of the city and the active bicycling community that already exists. The City received a Gold Award by the League of American Bicyclists. The City, other local agencies, and cycling advocates regularly host workshops, lessons, school assemblies, and community events to continue to promote cycling.

As a result a pilot of both financial and social incentives was conducted finding that social incentives that tapped in to altruistic tendencies had a strong pull on campus travel habits. The program found that such incentives were much more effective than financial incentives at influencing individuals living beyond the 10-mile threshold to explore transit, carpooling and cycling (*22*). This provides impetus for the campus to explore transport-related social programs including things like: a social application that allows for group connections; a commute club where campus travelers and entitled to a free cup of coffee or juice when they travel via walking or biking; or a free monthly gym membership to allow for shower before work and support a holistic healthy lifestyle / workplace.

The survey also revealed a glaring housing issue for students and that by increasing the number of housing units on campus, the university could begin to decrease the percentage of students who live in off-campus housing and subsequently commute using single occupancy vehicles. As a result, the Climate Action plan suggested increasing the number of housing units for students by an average of 500 units every 5 years for students, faculty and staff.

San Diego State University (SDSU): Commute Mode Sheds

SDSU Commute/Policy Catchment Zones and the Standard Deviation Ellipse

In 2014 and 2015, as SDSU began to explore emissions reduction strategies commuting was expected to be a large portion of emissions A comprehensive online travel demand survey was done, gathering information regarding various aspects of university transportation behaviors. The survey was deployed via email to faculty, staff, and auxiliaries in Fall of 2015 and students in Spring of 2016 *(42)*. The results of the survey help understand travel behavior and incentives necessary for creating a significant mode shift. 2801 survey responses were gathered, representing 7.55% sampling rate, with 2122 student responses, 202 faculty responses, and 477 staff responses. The survey revealed that 80% of staff and 63% of students drive to campus. These responses were then geocoded in ArcGIS. The data were made non-identifiable for privacy reasons and ArcGIS was used to find determine trip distance. The resulting map provided the spatial distribution of campus population and to create to create commute/policy sheds for each mode using the Standard Deviation Ellipse function as shown in Figure 4.

The survey respondents were divided on the basis of mode chosen—similar to both UT and Cal Poly cross tabulation methods. The points for each mode were used in Standard ellipse function in ArcGIS to find the commute zone for each mode as shown in Figure 4. The inclination of the zones explains the distribution of each mode. Most people walking and biking live close to campus, especially towards east and west of campus. About 41% of the student population from registrar data was found to be living in the Biking zone. The first transit zone contained 32% of the population, and walking zone contained 6% of student data. These data can be used to identify which modes are viable for each population group, based on the mode choice of their neighbors.

FIGURE 4: SDSU standard deviation ellipse commute zones for walk, bike, bus, and car trips

Emissions Calculations

The trip distance calculated by network analyst was used to calculate the student emissions in each zone. Overall, 29,845.6 MTCO2e (94.76%) of total student emissions were distributed throughout five catchment zones. The other 5% of emissions are created from students who reside outside of the catchment zones. 53.03% (15,828 MTCO2e) of student emissions were found to be attributed to transit zone 2. 7,340.9 MTCO2e, or 24.6%, of emissions came from transit zone 1. Another 18.93% (5,649 MTCO2e) were produced within the car zone. Only 325.4 MTCO2e and 702.3 MTCO2e were produced in the walk and bike zones, respectively. The biking zone contained 40.92% of the student data but contributed only 702.3 MTCO2e in emissions. Given this a strategic policy was proposed that focused on providing incentives to 1) shift students to the biking zones closer to campus through housing, or 2) expand the biking zone through better infrastructure or improved technology (e.g. e-bikes).

Policy Strategy 1: Changes in Student Housing

This policy scenario is based on the possibility of SDSU realizing a total of 10,000 beds on campus by 2030, as indicated on 2007 SDSU Master Plan. Currently over 4,385 students live in on-campus housing. Leaving over 30,000 commuting students. Expanding the on-campus population by 5,615 would reduce commuting related emission by approximately 6,392.8 MTCO2e a year (16.4%) by 2030 from the projected business as usual scenario. Highlighting the importance of university housing policy and land use planning in the reduction of campus carbon footprint and expanding multimodal transport.

Policy Strategy 2: Encourage more Bicycling and Walking

Another proposed strategic policy was to promote better walking and biking infrastructure, instead of parking facilities. This focuses on car-free commuting and has the potential to reduce emissions by 1027.7 MTCO2e, or 2.71% from the baseline scenario. Given the terrain surrounding SDSU, these findings suggested the benefits from not only improving bike lanes, but also making student e-bike subsidies available.

CONCLUSION

This study is meant to highlight more advanced approaches to use data that is often generated by universities, sometimes for alternate reasons, that can inform travel demand studies. In short, universities can develop like small cities – those with large captive populations, top-down planning processes, and in many cases significant power to develop campuses in very sustainable ways. As summarized in Table 2, our cases provide lessons for many growing corporate and technology campuses that are producing increasingly regional trips and impacts. Both university and corporate campus typologies have developed as progressive mixed-use developments with relatively low auto-reliance and highly walkable and livable spaces, often in the middle of car-centric cities. This presents significant opportunities for campus transportation- and environmental-planners as they seek to address commute-related issues.

As is summarized in the table, a key lesson is that each campus used a sophisticated data approach, starting with a survey and then moving to GIS and more robust statistical modeling. This is important because universities have the ability to harness specific high-resolution data for their entire campus population, to assess current conditions and target populations for interventions. This is unprecedented in conventional public sector transportation planning methods—unique over other more traditional jurisdictional boundaries. To leverage this advantage, we argue that university transportation planners and administrators should be well-versed in more advanced data sciences and economics to induce more sustainable behavior. As can be shown in our examples, every campus used an advanced modeling method. Some of this expertise can be developed through interactions with faculty and students in those areas.

Moreover, as integrated data provides more opportunities for improving campus operations, improvement in communication between campus units can allow better analysis. In these cases, campus transportation, sustainability, enrollment, and human resources departments can share data to improve specific transportation applications. Improved data transparency between campus units can enable these opportunities. This provides a key recommendation for further study—that common GHG and sustainability metrics begin to be applied across campuses, allowing for better benchmarking and comparisons.

TABLE 2. Summary of Cases

Further, while the opportunities and outcomes at each campus varied slightly each had the similarity in that policy was directed at nudging individual behavior away from driving through hyper-targeted (and data enabled) marketing and incentives, and parking pricing. This policy highlights an inherent power campuses have that is important to harness—that they control almost all parking and even some transit to their entire community, which often is all destined to one location (many origins to one destination). This allows significant control over economic or other incentives to push behavior.

While these provide important lessons for other campuses they also highlight on-going research and study should continue on this topic. In that light, the following items also warrant more analysis in the future.

- Research should evaluate how and if the lessons from campus planning apply to many growing corporate and technology campuses.
- Evaluation should be done to judge the efficacy of policy and transportation demand management measures developed to address GHG emissions and if they are having longitudinal impacts on reductions.
- As all campuses used climate solutions that involved student housing, the land use – transportation connection should be investigated with greater purpose to demonstrate the reduction in trips from changes in land use at these locations.

To conclude, this paper highlights a few examples of how data can be used to target policies or develop scenarios that can shift behavior to reduce parking demand, reduce the adverse effects of drive-alone traffic, or reduce the environmental footprint of the University. The applications of such data are broad and this paper only highlights a few of the applications we applied, specifically focused on carpool or rideshare strategies, targeted bike and walk incentives, and mode shift to reduce greenhouse gas emissions. While not a comprehensive view of how these datasets can be applied or even a comprehensive view of all data sources that can be mined and fused from Universities for transportation purposes—this does illustrate how data can be gathered and applied in novel, new ways to address complicated issues of campus commute and climate-related emissions.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: Cherry, Riggs, Appleyard; data collection: Cherry, Riggs, Appleyard, Dhakal, Frost, Jeffers; analysis and interpretation of results: Cherry, Riggs, Appleyard, Dhakal, Frost, Jeffers; draft manuscript preparation: Cherry, Riggs, Appleyard. All authors reviewed the results and approved the final version of the manuscript.

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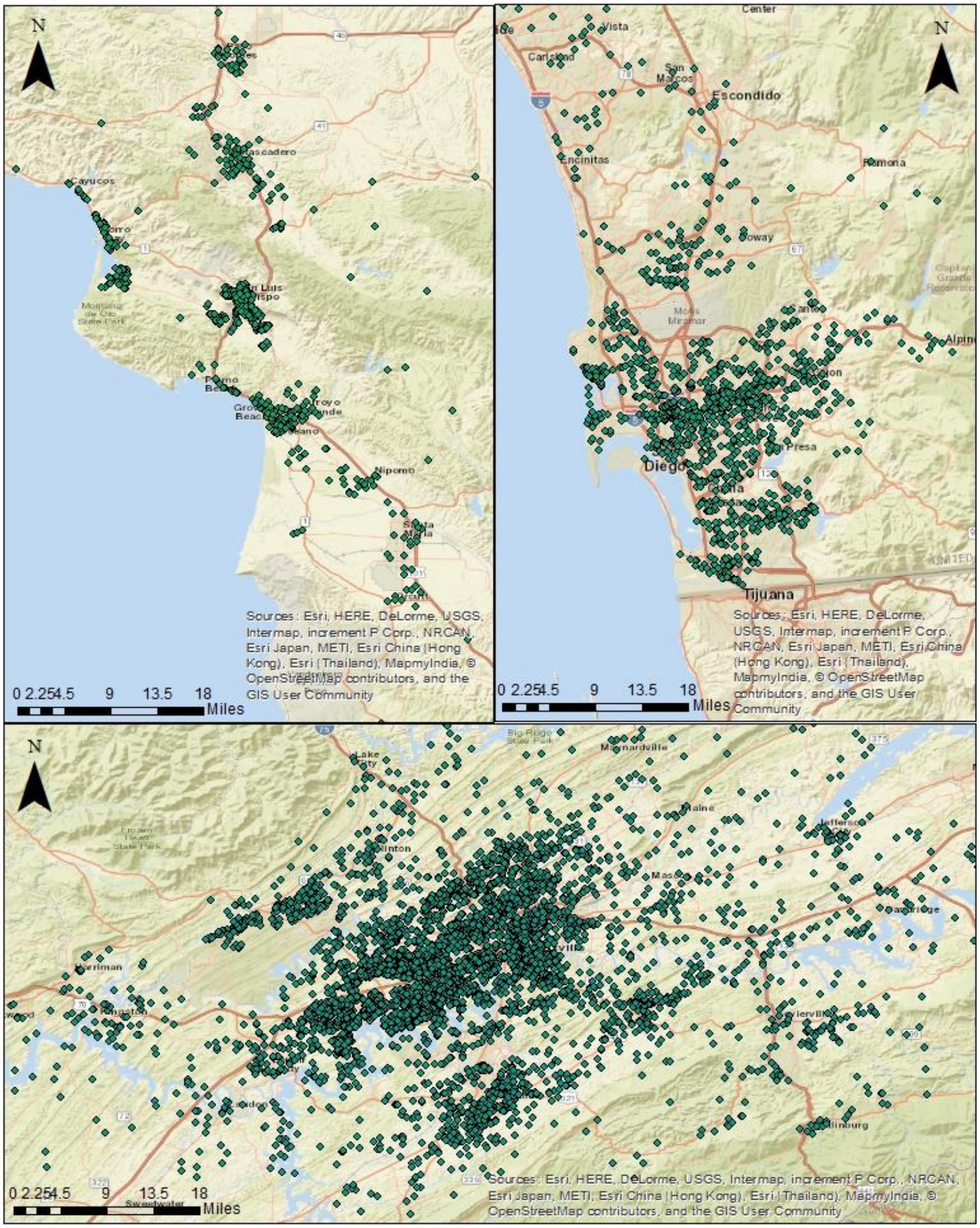

FIGURE 1 Population distribution at different campuses. All scales are the same. Top Left is poly-centric survey respondents from San Luis Obispo (Cal Poly), top right is all dense urban staff home locations in San Diego (SDSU), bottom is all faculty, staff, and students in sprawling Knoxville (UT).

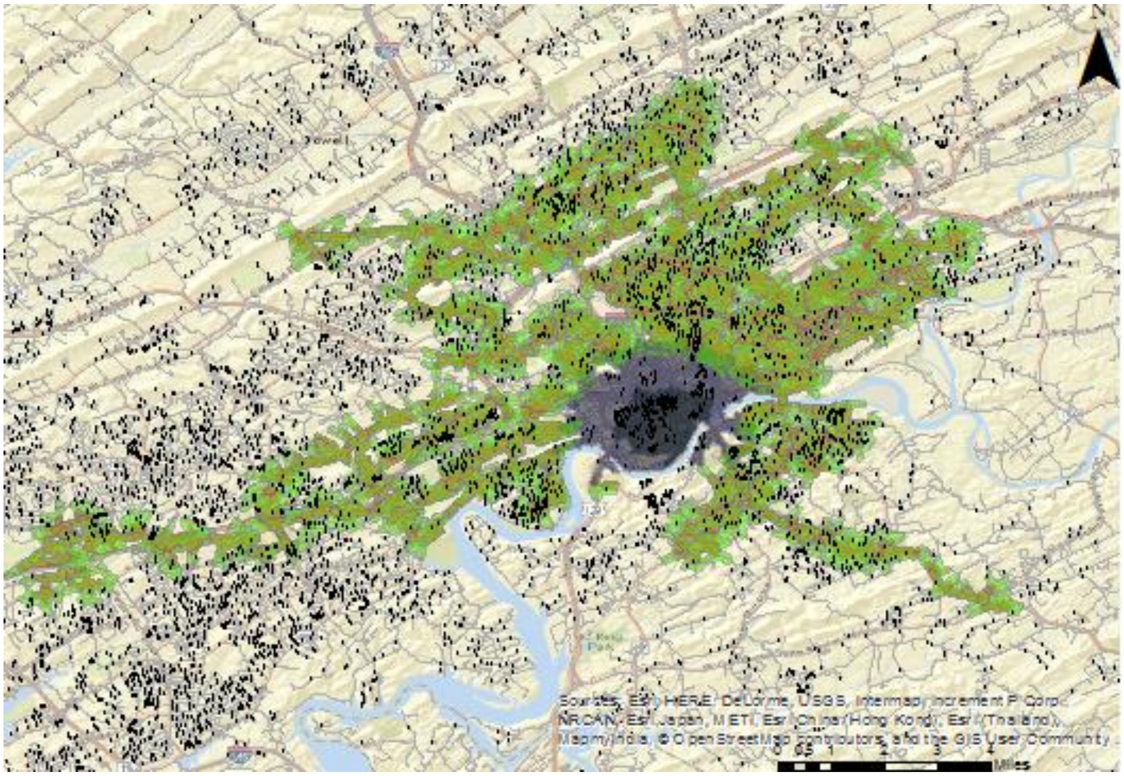

FIGURE 2 **Campus Population Overlaid on transportation zones. Darkest zone is walk distance, grey zone is bicycle distance, and green zone is transit distance. Black dots represent home locations of students, faculty, and staff. This map is scaled about five times larger than the map in Figure 1.**

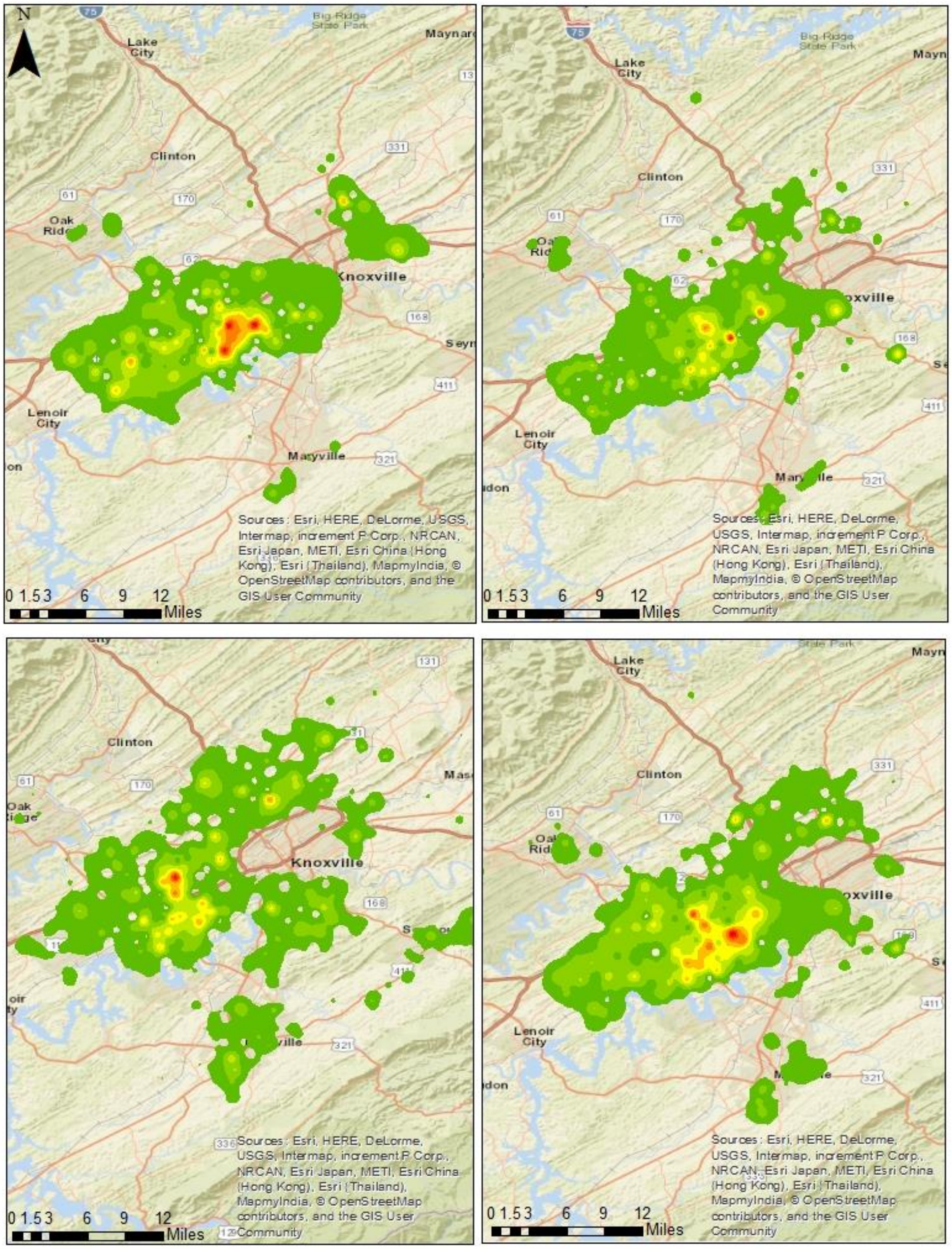

FIGURE 3 Cluster zones for faculty (top left), students (top right), and staff (bottom left) and overall (bottom right)

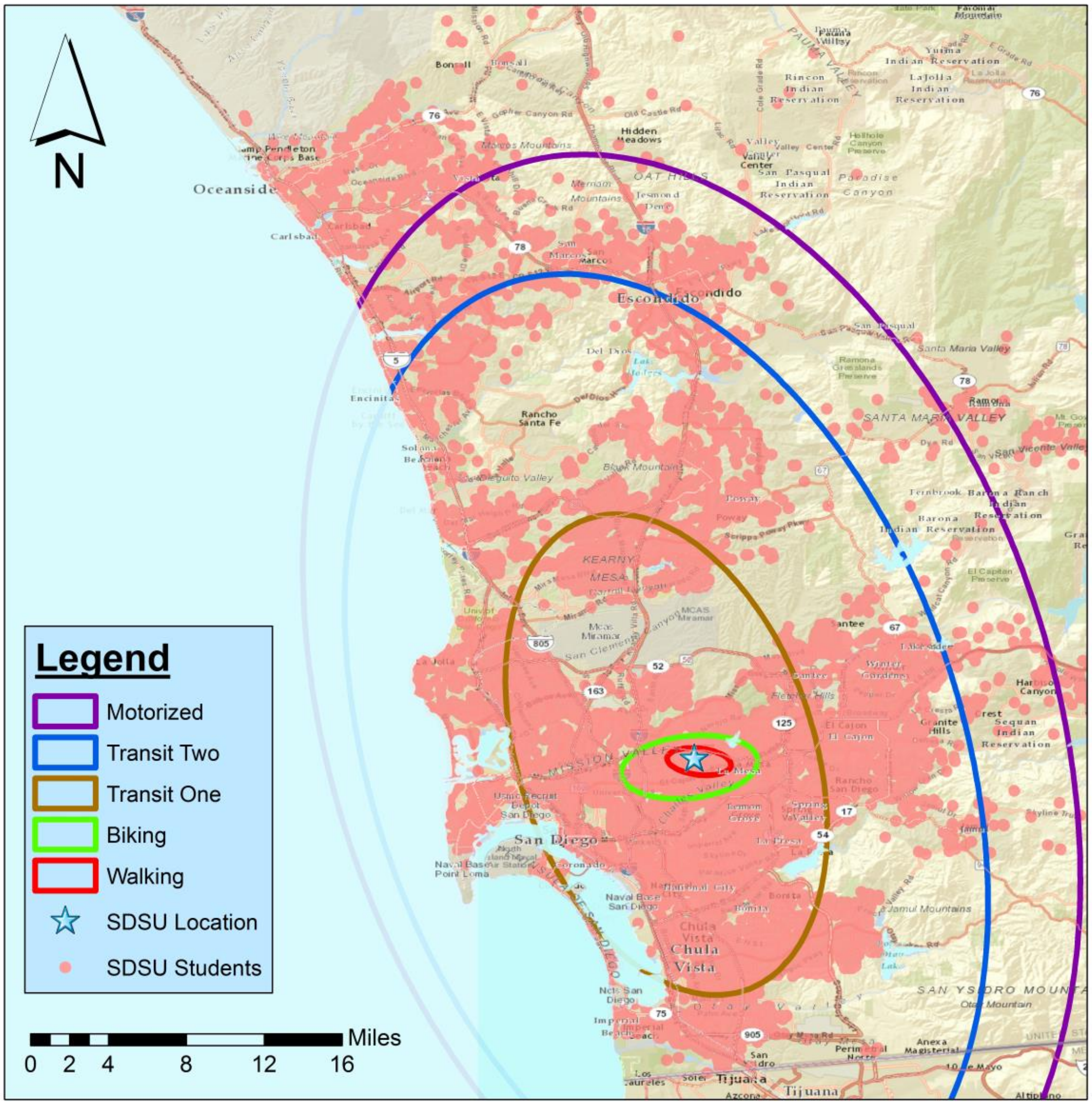

FIGURE 4: SDSU standard deviation ellipse commute zones for walk, bike, bus, and car trips

TABLE 3. Distance by Cohort

		Less than 1.5 Mile	1.5 to 5 Mile	5 to 10 Mile	Great than 10 Mile	
Student	Count	357	805	17	453	1632
	% within User Type	22%	49%	1%	28%	100%
	% within Distance Cohorts	70%	72%	68%	71%	71%
	% of Total	16%	35%	1%	20%	71%
Faculty	Count	63	105	2	59	229
	% within User Type	28%	46%	1%	26%	100%
	% within Distance Cohorts	12%	9%	8%	9%	10%
	% of Total	3%	5%	0%	3%	10%
Staff / Other	Count	94	209	6	127	436
	% within User Type	22%	48%	1%	29%	100%
	% within Distance Cohorts	18%	19%	24%	20%	19%
	% of Total	4%	9%	0%	6%	19%
Total	Count	514	1119	25	639	2297
	% within User Type	22%	49%	1%	28%	100%
	% within Distance Cohorts	100%	100%	100%	100%	100%
	% of Total	22%	49%	1%	28%	100%

TABLE 4. Summary of Cases

Location	Method	Policy Recommendations	Opportunities & Outcomes
University of Tennessee, Knoxville	• Surveys • GIS / Location • Cluster Analysis	Rideshare / carpool as a TDM Strategy	Pricing for parking Opportunity to target (primarily carpool) interventions using specialized location-based matching
Cal Poly, San Luis Obispo	• Surveys • GIS / Location • Regression and Segment Analysis	Focus on social norms to encourage biking & walking	Decision to address parking pricing Opportunity to target campus patrons by individual social characteristics Parallel decision to institute more on-campus housing
San Diego State University	• Surveys • GIS / Location • Zonal Analysis	Strategies to incentivize housing on campus and biking / walking	Pricing for parking Decision / commitment to construct 10,000 beds on the campus. Zone / location-based incentives to encourage biking and walking